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FRENCH GEOLOGICAL SURVEY **2023 ANNUAL REPORT**

Geoscience for a sustainable Earth
brgm

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

BRGM is responsible for groundwater monitoring. Underground river of Malaval (Lozère, France).

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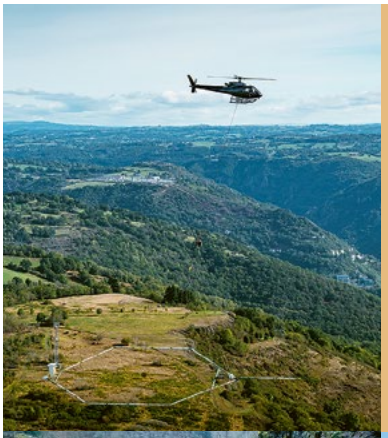

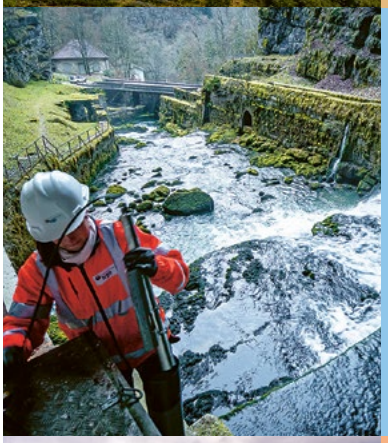

ORGANISATION

The augmented digital version of the annual report is available on our website

www.brgm.eu

CATHERINE LAGNEAU
Chair and CEO

"BRGM plays a pivotal role in current affairs and national priorities on the major issues of our century."

In 2023, BRGM played a leading role in current events and the shaping of national priorities on the major issues of our century: adapting to climate change and the need for energy and industrial sovereignty.
Our commitment has proven its worth in France, of course, but also internationally, on all fronts:

• Risks, exacerbated by climate change, have been a major preoccupation, with many regional and local authorities asking us for advice, particularly on coastal hazards and the shrinkage and swelling of clay formations;
• Water: short-, medium- and long-term forecasting tools have been developed and we have widened our research to anticipate the consequences of climate change on water resources, while promoting ways of adapting, such as those based on nature; the groundwater bulletin is now issued monthly, and was even published fortnightly during the drought crisis;
• The potential of the subsurface for the energy transition: we have taken on the task of characterizing geothermal potential as part of the national plan. The national inventory of CO_2 storage potential in France has begun.
• Mineral resources to support the ecological and digital transitions, and our country's sovereignty: the French President has announced the undertaking of a new inventory of mineral resources as part of our country's ecological planning; the French Observatory of Mineral Resources for Industrial Sectors (OFREMI) has started work and proved its relevance.
Internationally, with more than €7m in contracts signed this year, our partnership with AFD makes us an effective contributor to French development aid, particularly concerning water. Furthermore we are increasingly involved in supporting mineral resources diplomacy.
BRGM has also worked in the digital field, a key element of our future, by helping to develop the France Green-Nation roadmap.

BRGM's strengths were highlighted in 2023, and we shall continue to consolidate them in 2024:
• We have signed a remarkably ambitious 'objectives, resources and performance' contract for 2023-2027. The French government has committed to providing new resources for BRGM's development, which is a real sign of confidence from our supervising ministries;
• Our priority research and equipment programmes (PEPRs), the key elements of the national research programme in the framework of 'France 2030', have been launched. By co-leading three of them (OneWater - on water, IRiMa - on risks, SOUSSOL - on subsurface potential) and being involved in a fourth (RECYCLING), we are helping to unite the national scientific community around major strategic challenges that will shape our country. The excellence

Former underground tufa quarry. (Indre, France, 2023).
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of our interdisciplinary research, which is resolutely focused on providing reliable input for public policy, has thus been recognised;
• We have consolidated our high-level, independent and impartial research and expertise, which is recognised and appreciated but also exposes us to critical review and possibly controversy.

The year 2023 was also marked by a major industrial action to secure higher wages commensurate with our commitments and the challenges we face. Despite this campaign, in 2023 contracts were signed covering two years of business ahead of us, so that we have once again achieved a positive net result, with the hiring of 60 new employees. Throughout the movement, the women and men at BRGM remained constantly mobilised to deal with this growth, which clearly reflects the accelerated impact of climate change. Their commitment and expertise are highlighted in this annual report, which demonstrates the need for science, our usefulness, and more than ever, recognition, which is our principal *raison d'être*.

In 2024, BRGM will be facing increasing demands, concerning all the societal issues it covers and will be helping to implement the State's climate strategy. We need to develop rapidly, supported by our objectives, resources and performance contract. Together, we shall light the way for science in the service of society. ●

2023 highlights

1 JANUARY
BRGM TAKES OVER THE CHAIR OF EUROGEOSURVEYS

On 1 January 2023, Christophe Poinssot, Deputy Managing Director of BRGM, took over the chair of EuroGeoSurveys for two years. BRGM is a driving force behind the European construction industry in the field of Earth Sciences and took part in establishing EuroGeoSurveys (EGS), the association of European geological surveys (with 37 members), which has just celebrated its 50th anniversary. Founded in Orléans, EuroGeoSurveys is now based in Brussels, close to the European Commission.

2 FEBRUARY
BRGM IS POISED TO ADDRESS THE CHALLENGES OF THE GEOTHERMAL ACTION PLAN

As part of the renewable energy acceleration plan, the Energy Transition Minister, Agnès Pannier-Runacher, presented the Government's action plan to speed up the deployment of geothermal energy, alongside François Bayrou, the High Commissioner for the Plan. In particular, BRGM will contribute to the following:
- Finalising the regional mapping of small-scale regulatory geothermal energy zones;
- Regulatory adjustments for a number of surface geothermal systems;
- Continuing to collect, analyse and disseminate the available subsurface data, in particular through the development of a decision-making tool for vertical geothermal heat exchangers;
- Improving subsurface knowledge to encourage the initiation of deep geothermal projects.

8 FEBRUARY
RENEWAL OF THE BRGM – SUEZ PARTNERSHIP

Under the agreement signed between Suez and BRGM, the two organisations will complement each other's capacities in the areas of water and the environment. This reflects the wishes of both organisations to strengthen and sustain their existing long-term cooperation. The agreement covers eight major themes: groundwater resources, materials recycling, metrology, emerging pollutants and isotopes, geothermal energy, carbon capture, usage and storage (CO_2, CCUS, H_2), contaminated soils and sediments and their rehabilitation, the mining environment and rehabilitation of mining sites.

13 FEBRUARY

LAUNCH OF A VAST RESEARCH PROGRAMME FOR THE SUSTAINABLE USE OF THE SUBSURFACE IN FRANCE

This priority research and equipment programme (PEPR), called "The Subsurface: a common good" was launched on 13 February and will last seven years. It is managed by BRGM and CNRS, with the involvement of 35 public organisations and laboratories. It aims to identify and anticipate possible future uses of the subsurface in France and provide a more exhaustive assessment of the potential. Five priority uses of the subsurface have been identified: mineral resources, deep geothermal energy, the storage of various gases such as CO_2, hydrogen or methane, research on native hydrogen and urban infrastructures. And five specific study sites have been targeted: the centre of the Paris Basin (for urban subsurface management), French Guiana (for conflicts of use in regional development), the "Rhine Graben" (for its deep geothermal potential), the Aquitaine basin (for the storage of emerging geo-resources and energy uses), and the Massif Central (for its mineral and geothermal potential). For each of these uses, scientists will analyse the potential and model future national demand, as well as the conditions and impacts of possible exploitation. The programme should also help develop new exploration and exploitation technologies, better integrate environmental constraints and take greater account of social and economic issues, while promoting the development of governance and legal instruments.

10 MARCH

PARTNERSHIP AGREEMENT BETWEEN BRGM AND THE GEOLOGICAL SURVEY OF THE DEMOCRATIC REPUBLIC OF CONGO

On the occasion of the State visit of the French President to the Democratic Republic of Congo (DRC), Christophe Poinssot – Deputy Managing Director of BRGM – and Professor Kampata Dona – Managing Director of the DRC's Geological Survey (SGN-C) – signed a bilateral partnership agreement on 4 March 2023. This new agreement will help SGN-C to deploy an efficient geological data management system, improve knowledge of the DRC's subsurface and prepare responsible-mining pilot projects for the energy transition.

21 MARCH

BGR AND BRGM SIGN A NEW AGREEMENT TO REINFORCE THEIR PARTNERSHIP

Ralph Watzel – President of Germany's Federal Institute for Geosciences and Natural Resources (BGR) – and Christophe Poinssot – Deputy Managing Director of BRGM – signed a new partnership agreement at the 54th EuroGeoSurveys General Meeting in Dublin (Ireland). BGR and BRGM notably intend to further develop their partnership concerning critical raw materials and reinforce the exchange of data and expertise between DERA, the German Mineral Resources Agency, and the French Observatory of Mineral Resources for Industrial Sectors (OFREMI).

24 MARCH
INAUGURATION OF MIMAROC

At the Orléans science centre, BRGM inaugurated MIMAROC, a new 4D tomography platform. MIMAROC creates images of the evolution of geo-materials on a nanometric scale under conditions representative of those existing underground. MIMAROC can be used to observe the behaviour of geological samples subjected to different heat, hydrological, mechanical and chemical conditions, in particular to reproduce the conditions generated by technologies that use the subsurface. The tests will be carried out in 4D (including the time dimension). The models produced can then be used to predict the development of underground energy or waste storage, for example, or the re-injection of geothermal fluids into a reservoir.

31 MARCH
SIGNING OF THE NEW OBJECTIVES, RESOURCES AND PERFORMANCE CONTRACT (COMP) FOR 2023-2027 BETWEEN THE STATE AND BRGM

On 31 March 2023, BRGM signed its new objectives, resources and performance contract for 2023–2027 with the French government. The new COMP was signed by BRGM's four supervisory ministries in the presence of: Sylvie Retailleau, Minister for Higher Education and Research; Roland Lescure, Minister Delegate for Industry, representing the Minister for the Economy, Finance and Industrial and Digital Sovereignty; Cédric Bourillet, Director of the Directorate General for Risk Prevention, representing the Minister for Ecological Transition and Territorial Cohesion and the Minister for Energy Transition. The main lines of the 2023–2027 COMP are an ambitious scientific policy designed to improve subsurface contributions to societal needs, the development of BRGM's impact on society through innovation and expertise, and management to support the ecological and energy transition. With one substantial change: a commitment of resources from the State, which strongly reaffirms the roles entrusted to the organisation.

4 APRIL
SOCIÉTÉ DU GRAND PARIS (SGP) AND BRGM STRENGTHEN THEIR PARTNERSHIP

BRGM and Société du Grand Paris (SGP), responsible for the future Grand Paris Express metro, have strengthened their scientific partnership established in 2020 by signing a new agreement. Its aim is to use collected subsurface data to improve understanding of the ground and subsurface with a view to responding to a range of development and management issues in the Ile-de-France region, such as the drinking water supply, flood risk management, water quality, geothermal energy, geotechnics, etc. Two agreements have been signed: the first concerns the provision of Grand Paris Express data, in particular access to the SGP's SONGE database and its core sample collection. The second concerns the inclusion of borehole data from the SONGE database in BRGM's Subsurface Data Bank (BSS).

12 APRIL

SOCIAL NETWORKS: BRGM WINS A TOP COM D'OR AWARD

Along with the agency Néologis, BRGM was awarded a prize for its "Ambassadors on social networks" programme at the "Top Com Grands Prix Corporate Business 2023" awards. Since 2019, around one hundred employees, either scientists or support staff, have been receiving training and assistance from BRGM's Communication team concerning the use of social networks. The aim is to give these non-specialists in the field of communication certain key tools to help them improve the way they communicate on social networks and encourage them to post about their work. Participation in this initiative is on a volunteer basis. The programme raises awareness about the scientific projects carried out by BRGM, and the major societal issues in which it is involved. The Ambassadors programme also responds to a demand from employees, more and more of whom publish posts on social networks about professional topics.

22 MAY

LAUNCH OF THE "IRIMA" PEPR

The IRiMa research programme (Integrated Risk Management for more resilient societies in an era of climate change) was launched on 22 May 2023 at the *Cité des Sciences et de l'Industrie* in Paris. Jointly led by BRGM, CNRS and Grenoble-Alpes University, this eight-year exploratory priority research and equipment programme (PEPR) brings together over 30 partner organisations and laboratories. The IRiMa programme aims to formally define a new "science of risk" in order to help build a strategy for managing risks and disasters and their impacts, against a backdrop of global changes. To achieve this, the programme has implemented a series of research projects and expert studies to speed up the transition to a society capable of dealing with a whole series of new threats by adapting and becoming more resilient and sustainable. It aims to provide analyses and develop innovative tools that will help detect, understand, quantify, anticipate and manage risks and disasters.

22 JUNE

GROUND MOVEMENTS OF KARSTIC ORIGIN: A METHODOLOGICAL GUIDEBOOK

BRGM and Cerema published a guidebook for assessing and mapping the risks of karst-related ground movements. It is intended for authorities and companies involved in spatial planning and construction. Created for the Directorate General for Risk Prevention (DGPR) at the French Ministry of Ecological Transition and Territorial Cohesion, the guidebook is divided into three parts:

- A state-of-the art review of the description of karst systems (literature review).
- A presentation of ground movements that can occur on the surface and the main factors (or criteria) that cause them.
- A hazard-assessment methodology, with a presentation of the data required for this work.

21 SEPTEMBER

PUBLICATION OF GEOSCIENCES NO. 27: "ENERGY TRANSITION, SUBSURFACE SOLUTIONS"

Issue 27 of BRGM's Géosciences magazine investigates subsurface solutions: geothermal energy (the government's geothermal energy plan, geothermal energy in urban areas), CO_2 storage, heat storage and a mix of these different solutions with other sources of renewable energy (solar, biomass, wind, etc.). It also looks at access to mineral resources, which will be vital to the success of the energy transition. Lastly, this issue looks at the conditions for developing the use of the subsurface as part of the energy transition, with particular emphasis on the need to involve the public in decision making.

FROM 10 TO 13 OCTOBER

POLLUTEC TRADE FAIR 2023

Pollutec is a key event for environmental professionals as well as a showcase of environmental solutions for industry, cities and regions. BRGM presented its expertise on its stand and as part of several conferences. It was able to present its solutions for water resource management, the energy transition, climate-related risks and adaptation to climate change, waste management, the circular economy and remediation of polluted sites.

12 OCTOBER

AGREEMENT BETWEEN MONGOLIA'S GEOLOGICAL SURVEY AND BRGM

During the State visit to France by the Mongolian President from 10 to 13 October 2023, BRGM signed a partnership agreement with the Mongolian Geological Survey at the Élysée Palace, in the presence of Ambassador Ulambayar Nyamkhuu and the two Heads of State, Ukhnaa Khutelsukh and Emmanuel Macron. The purpose of this agreement is to undertake various projects of common interest that will enable Mongolia to better determine and exploit its critical metal resources.

13 OCTOBER

NOUVELLE-AQUITAINE: NEW AGREEMENT SIGNED FOR THE PERIOD 2022-2027 TO MONITOR CHANGES TO THE COASTLINE

The French government, the Regional Council of Nouvelle-Aquitaine and their partners renewed their support for the *Observatoire de la Côte de Nouvelle-Aquitaine* through a partnership agreement covering the period 2022–2027. As co-funder of the observatory with joint responsibility for technical issues alongside the ONF, BRGM will be involved in a number of strategic objectives: implement and optimise monitoring and surveillance of coastal change; provide expertise and assistance to all those involved in coastal management; strengthen the regional resource centre on coastal dynamics and make data more readily available; share knowledge, using it in communicating with different audiences; consolidate flexible and appropriate organisational and operational processes.

20 OCTOBER

ADAPTING TO CLIMATE CHANGE: AN AGREEMENT BETWEEN BRGM AND THE MINISTRY OF THE ARMED FORCES

The collaboration between BRGM and the Defence infrastructure department (SID) has been renewed for five years. Initiated in 2017, the agreement between the SID and BRGM structures scientific cooperation between the two organisations in terms of research and development in a number of areas, including: improving pyrotechnic diagnostics, managing and recovering used sand from firing ranges, and the resilience of infrastructures to climate change. In this way, BRGM is drawing upon its expertise to boost the resilience of the French armed forces.

2 NOVEMBER

KAZAKHSTAN AND UZBEKISTAN: COOPERATION ON STRATEGIC MINERALS

Catherine Lagneau, BRGM Chair, accompanied the French President on his State visit to Kazakhstan and Uzbekistan. A declaration of intent was signed to strengthen bilateral cooperation in the field of strategic minerals to support the energy transition. BRGM will contribute to strengthening exchanges and cooperation in the field of strategic minerals. The aim is to build resilient, well balanced and diversified supply chains for strategic minerals, in compliance with rigorous social, environmental and governance standards.

INNOVATION

Industrialisation as a new target

In line with the continuous and natural progression of the development cycle for innovative projects, introduced by the new Objectives Contract (COMP), BRGM has made industrialisation a new target in its activities. Alongside the implementation of this proactive policy, which is now guiding the work of the innovation division, BRGM also opened its doors more widely in 2023 to the start-up ecosystem in France, with an acceleration in the pace of new projects.

VICTOR LIGER
Head of Innovation, Development and Knowledge Transfer, Department of Innovation, Commercial and International Activities (DIC)

It has become clear in recent years that BRGM needs to focus on the practical application of the geoscience research carried out by researchers and engineers. Innovation is at the heart of what we do. It's in our genes.

In this way, BRGM has clearly defined its main areas of work. As well as nurturing an internal culture of innovation and entrepreneurship, and seeking to protect and promote its intellectual heritage, BRGM is also focusing on project development and industrialisation, and opening its doors more widely to innovation ecosystems. All of these factors are key to innovation. Following the creation of the Innovation Division, 2023 saw a drive to industrialise innovations and open up more widely to start-ups.

From development to industrialisation

The development of innovative concepts with economic potential is now up to cruising speed, with 37 projects under way. Through a process of continuous evolution, this project development cycle leads naturally to industrialisation. To reinforce these efforts, BRGM is pursuing a proactive policy to industrialise innovations, and steer its innovation division towards closer collaboration with industry.

This focus on industrialisation can be summed up in a few words: it involves finding the means to bring an innovation to market by scaling it up with the support of industry. This is a process that began five years ago and has now reached its logical conclusion. Formally defined for each project, it is led by the development team and steered by the innovation team.

Five projects are now at the industrialisation phase, four of which went through in 2023, with objectives exceeding those set out in the COMP for 2023-2027. These include the CO_2 Dissolved project with SLB (see "CO_2-Dissolved: towards industrial and commercial deployment" on page 59), and materials traceability with the Trace group.

Developing innovations with industry also involves joint innovation or shared R&D projects, with BRGM contributing through its capacity for applied research (see projects on page 11).

"Five projects are now at the industrialisation phase, of which four initiated in 2023, with objectives exceeding those set out in the objectives, resources and performance contract for 2023–2027."

inneauv

In partnership with the French Geographic Institute (IGN), BRGM launched the INNEAUV call for applications in 2023. The theme was the use of data to develop innovations for addressing water-related challenges. The aim is to protect water resources, improve water information and knowledge and prevent and manage water-related risks. 40 applications were received and the results will be announced in April 2024.

Bati-SimulaTerre

In the field of prevention and remediation of the effect of clay soil shrinkage and swelling (RGA) on buildings, BRGM has developed the Bati-SimulaTerre project together with Addactis and NamR. The aim of this project is to raise awareness of the RGA risk among property owners and provide them with guidelines for action. Any risk to their property is identified remotely and appropriate prevention and protection measures are proposed. This solution, in the form of a platform distributed on a white label basis to insurers and other players, is intended to "reveal any real risk as early as possible in order to trigger action".

45-8 energy

This player in the ecological transition has set itself the task of developing local helium and natural hydrogen resources. The innovative nature of its business has led 45–8 ENERGY to carry out R&D work with research teams, in particular with BRGM since 2020. This programme focuses on making data in relation to the geometry of subsurface geological architectures consistent with data from surveys that use geophysical tools in a 3D model. The purpose is to prove the existence of the resource and characterise a geological context that is favourable to gas trapping in the *Avant-Monts du Jura* area (Doubs).

Increasing collaboration with start-ups

The second focus for innovation in 2023 involves closer links with the start-up ecosystem. The aim is to speed up collaboration with start-ups in sectors linked to the Earth sciences. For this purpose we look for external start-ups through competitions such as INNEAUV, organised with the National Geographic Institute (IGN) (see box).

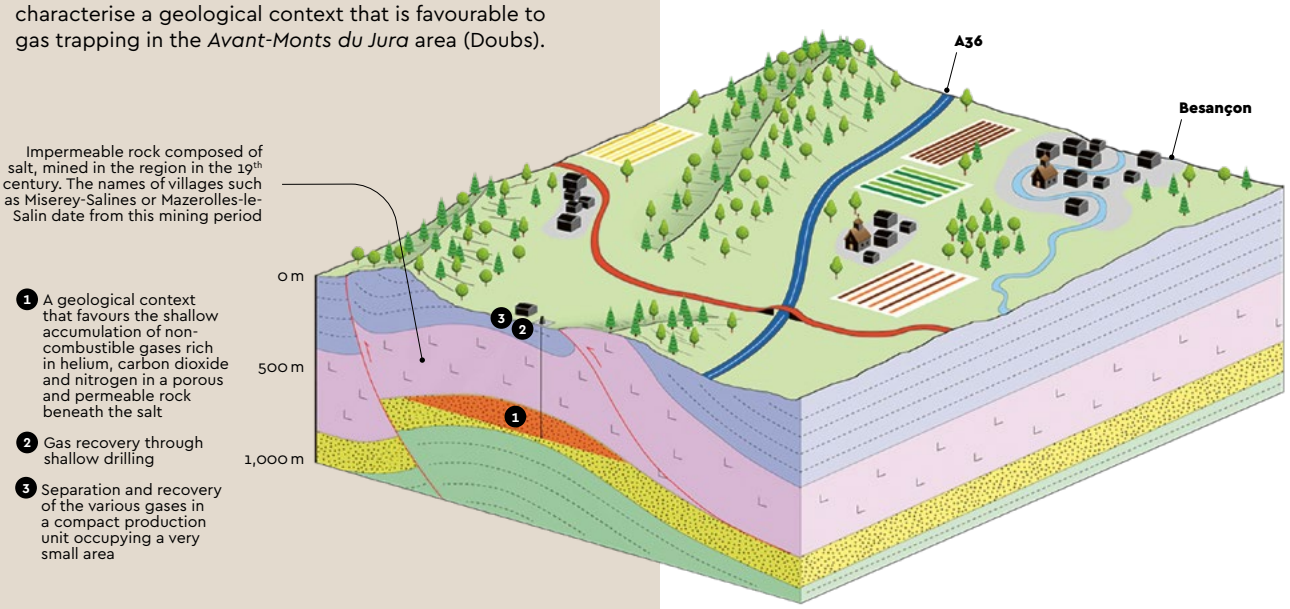
In this respect, external collaboration was structured and the reception of start-ups increased in 2023. The main sectors include satellite imaging applied to various risks or to water, for example, where the techniques are suited to BRGM's expertise.

For their part, start-ups are interested not only in using BRGM data, but also in working with our researchers on joint R&D projects, as is the case with NamR (see box).

All these activities are aimed at fulfilling BRGM's application role by facilitating the transfer of BRGM's expertise and innovative concepts to the socio-economic sphere. ●

PROJECT TO RECOVER HELIUM-RICH GAS FROM THE AVANT-MONTS AREA

Source: 45–8 ENERGY corporate website



INVENTORY OF MINERAL RESOURCES

Launch of the programme to update the National Inventory of France's Subsurface Mineral Resources

In order to address national and European sovereignty issues linked to the supply of critical mineral resources, the French President decided it was necessary to update the strategic inventory of French subsurface mineral resources. BRGM was placed in charge of this mission. Regional areas of interest have already been identified and will be covered by data acquisition campaigns. The project, which will last for an initial period of five years, will be financed by France 2030 and the French National Research Agency (ANR).

CHRISTOPHE POINSSOT
Deputy Managing Director and Head of the Scientific Division

BLANDINE GOURCEROL
Research engineer in metallogeny

On the occasion of the Ecological Planning Council in September 2023, the French President announced that the Inventory of France's Subsurface Mineral Resources (IRM) would be updated. This decision was taken following the adoption of the CRM Act in Europe in December 2023, and was in line with the political impetus provided by the conclusions of the "Varin Report" in France. This initiative aims to identify areas that might have mineral resources of interest, with a view to reducing our dependence on imports of primary and secondary materials. This updating process is also designed to guarantee France's security and sovereignty in terms of the supply of mineral resources, while promoting more efficient and sustainable use of these resources, which will help to strengthen the resilience of our economy.

The benchmark national mining inventory was carried out between 1970 and 1995 and is now obsolete for a number of reasons:

• More than 30% of the "areas of potential interest" (bedrock domains and their Mesozoic boundaries) were not studied during the previous campaign (Cassard et al., 2012; Bertrand et al., 2016) due to the existence of exclusive research permits (PER) held by private operators in these areas at the time.

• Mineral exploration techniques have improved considerably in recent years, taking advantage of the major technological advances that have emerged since the 1980s (e.g. large-scale geophysical surveys, geochemical analytical techniques).

• The inventory carried out in the 1980s focused on certain substances that corresponded to the priorities of the time. Many other substances, which are now regarded as critical and strategic, were neither searched for nor analysed (lithium, tantalum, caesium, gallium, germanium, hafnium, etc.), or their detection limits were far too high to enable geochemical anomalies to be identified. The new inventory will correct this major bias. With this in mind, the main objective of the IRM project is to focus specifically on strategic exploration phases aimed at identifying the most favourable areas for the presence of mineral resources.

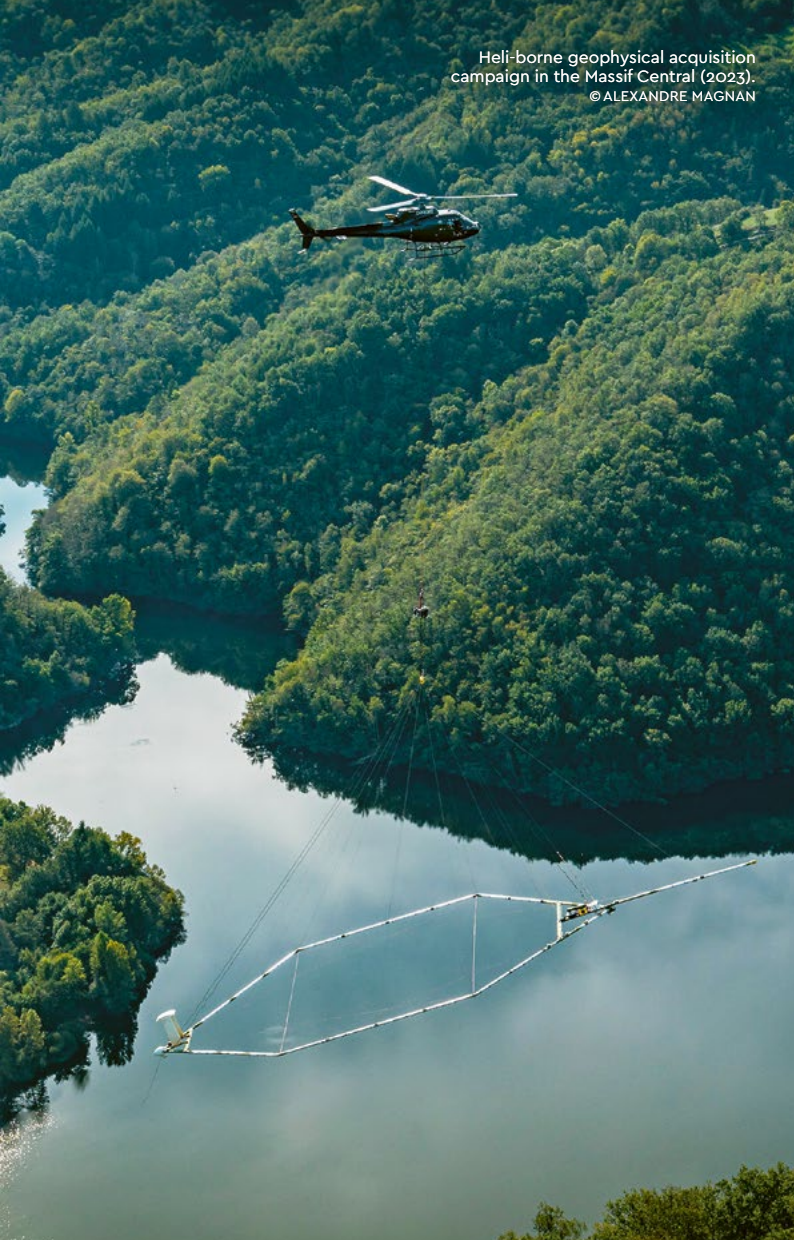
The challenges to be met

The success of this new nationwide inventory will require meeting a number of challenges:

• The logistic challenge of deploying significant ground and airborne acquisition campaigns across the country.

• Mobilising and coordinating a French ecosystem that has become fragmented, due to a lack of regular activity in France over the last thirty years.

• Creating added value and cutting-edge innovation with a dynamic approach, which is open to the creation of partnerships.



Heli-borne geophysical acquisition campaign in the Massif Central (2023).
© ALEXANDRE MAGNAN

"The updating of the national inventory of mineral resources is designed to guarantee France's security and sovereignty in terms of the supply of mineral resources, while promoting more efficient and sustainable use of these resources."

• Rolling out an effective communication campaign and appropriate scientific mediation process to explain the political, economic and societal motivation behind the work, as well as the technical details of the action undertaken.

The organisation

BRGM worked on the preliminary design of the IRM in collaboration with the French Inter-ministerial delegation for the supply of strategic minerals and metals (DIAMMS), the General Directorate for Spatial Planning, Housing and the Natural Environment (DGALN) and the General Secretariat for investment (SGPI). The IRM's technical programme was decided on the basis of multidisciplinary criteria, incorporating both scientific and public policy priorities. The resulting programme is designed to maximise the identification of areas of interest while ensuring consistency with regional policies.

The various working methods (e.g. geochemistry, geophysics, geology) should make it possible to identify deposits that are "hidden under a cover" (and therefore not detectable on the surface) and have never been identified in the past, or deep-sitting extensions of previously identified deposits. Consequently, the project has been designed to take account of the following parameters:

• Rapid operational implementation, starting at the end of 2024 and taking five years to complete.

• Regular publication of results/deliverables throughout the process.

• The use of the most effective and innovative approaches and technologies in order to optimise the quality of the results, particularly in the field of artificial intelligence and data sciences.

• Close collaboration with the French research ecosystem and innovative companies, as well as with the international network of Geological Surveys.

• The organisational agility required to ensure sufficient responsiveness to complete the project. BRGM will be the sole leader of the programme.

To carry out all this work, it will draw on the services of various subcontractors, notably including a subsidiary called BRGM EXPLORE, which will be responsible for the operational implementation of the technical programme, with BRGM handling the administrative, financial and scientific management (innovation, interpretation, dissemination).

As regards the operational implementation, BRGM EXPLORE will also be able to call on specialist subcontractors, in particular for airborne-campaign flights, the collection of sediment samples and multi-element laboratory analyses. ●

STRATEGY

France 2030: BRGM is fully committed to the joint management of three national research programmes

BRGM is now jointly managing three of these programmes: one relating to the subsurface and its uses (SOUS-SOL), one concerning water management in the context of climate change (OneWater) and the other working on risk science (IRiMa). These projects account for more than €175m in support for the national scientific community over seven to ten years. BRGM is also a partner in the national recycling programme.

BRGM is now jointly managing three large-scale national research programmes supported by France 2030. It is also a partner in the recycling PEPR (priority research programmes and equipment) in its strategic focus on critical metals. The launch of these major research programmes underlines the growing recognition by the French government and society of the need to better manage the subsurface, its uses, its resources and the corresponding risks.

The year 2023 saw the operational launch of these three programmes. This represents a major undertaking involving dozens of research laboratories across the country, national research bodies and universities. These research programmes are funded by France 2030 to the tune of €175m over seven to ten years. Each of these programmes is made up of a series of projects which were finalised and contracted out during the year.

For BRGM, these programmes support much of its scientific work, such as knowledge of the subsurface in France, energy uses, mineral resources, natural risk management and, of course, groundwater management.

They were selected by an international jury in a call open to all scientific sectors. This demonstrates the extent to which the issues addressed by BRGM are at the core of current challenges in society and constitute research topics at the highest scientific level.

CHRISTOPHE POINSSOT
Deputy Managing Director, Scientific Director

PHILIPPE FREYSSINET
Director of Research, Scientific Programming and Communication

SUBSURFACE programme: a common good

The subsurface from 1m to 5km below the surface is where the solid Earth interacts with human activities. This physical environment accommodates numerous human infrastructures and all our exploitable natural resources. The subsurface is essential to the energy transition: the search for new mineral resources essential to low-carbon technologies, the use of underground geothermal potential to replace gas heating and the geological storage of heat, cold and gases (CO_2, hydrogen, etc.). In addition, the increase in urbanisation density requires improved consideration of the subsurface in development strategies.

Jointly managed with CNRS, this programme targets several regions, including the Massif Central and French Guiana for their mineral resources, the Paris Basin for planning issues, the Aquitaine Basin for subsurface storage and Alsace for its geothermal resources. Researchers from different disciplines will be working together on a number of major areas of interest in the region in order to improve our knowledge of the subsurface. They will work with various stakeholders to develop scenarios for its use and model their impact.

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Image 1 — Launch of the PEPR "SUBSURFACE: a common good", on 18 January 2023, led by BRGM and CNRS with the participation of 35 institutions and laboratories over seven years. © BRGM - P. VASSAL

Image 2 — The IRiMa research programme (Integrated Risk Management for more resilient societies in an era of climate change) was launched on 22 May 2023 at the *Cité des Sciences et de l'Industrie* in Paris. The programme is co-led by BRGM, CNRS and the University of Grenoble-Alps. © BRGM - P. VASSAL

The IRiMa (Integrated risk management) programme

Climate change, other natural hazards, and technological risks are highly cross-disciplinary fields of research. Yet they remain little explored, even though they are essential to modern society. The IRiMa programme was set up to develop "risk science" in France. It aims to develop new concepts for risk and disaster management and their impact, particularly against the backdrop of climate change. The programme sets out to integrate knowledge from the fields of geoscience, engineering, digital technology and social sciences to take a systemic approach to the management of natural and technological risks. It will propose new innovative tools to better detect, understand, quantify, anticipate and manage risks and disasters. It will focus in particular on the issue of cascade effects combining natural, environmental, technological, health and biological hazards. Co-led by BRGM, CNRS and the University of Grenoble-Alps, the eight-year, €52m programme is built around a national consortium of leading universities and national reference organisations working in the field of natural, technological and environmental risks.

The OneWater programme

France was one of the first countries in the world to set up water governance at the catchment basin level, but the assumption that everything could be resolved at the basin level is no longer considered to be true. Global climate change has increased natural and anthropogenic pressures on water resources, creating a major challenge for our societies in the 21st century: it is urgent to act now and at all levels. Global phenomena are overtaking local conditions and new issues are emerging. These challenges need to be addressed through more integrated, systemic, multi-actor approaches to co-construct solutions that are adapted to a range of different realities. The OneWater programme has funding of €53 million over 10 years, and is co-led by BRGM, CNRS and INRAE. The aim is to change the paradigm by having water recognised as a common good, a central element of socio-ecosystems that are subject to climatic and anthropic forcing.

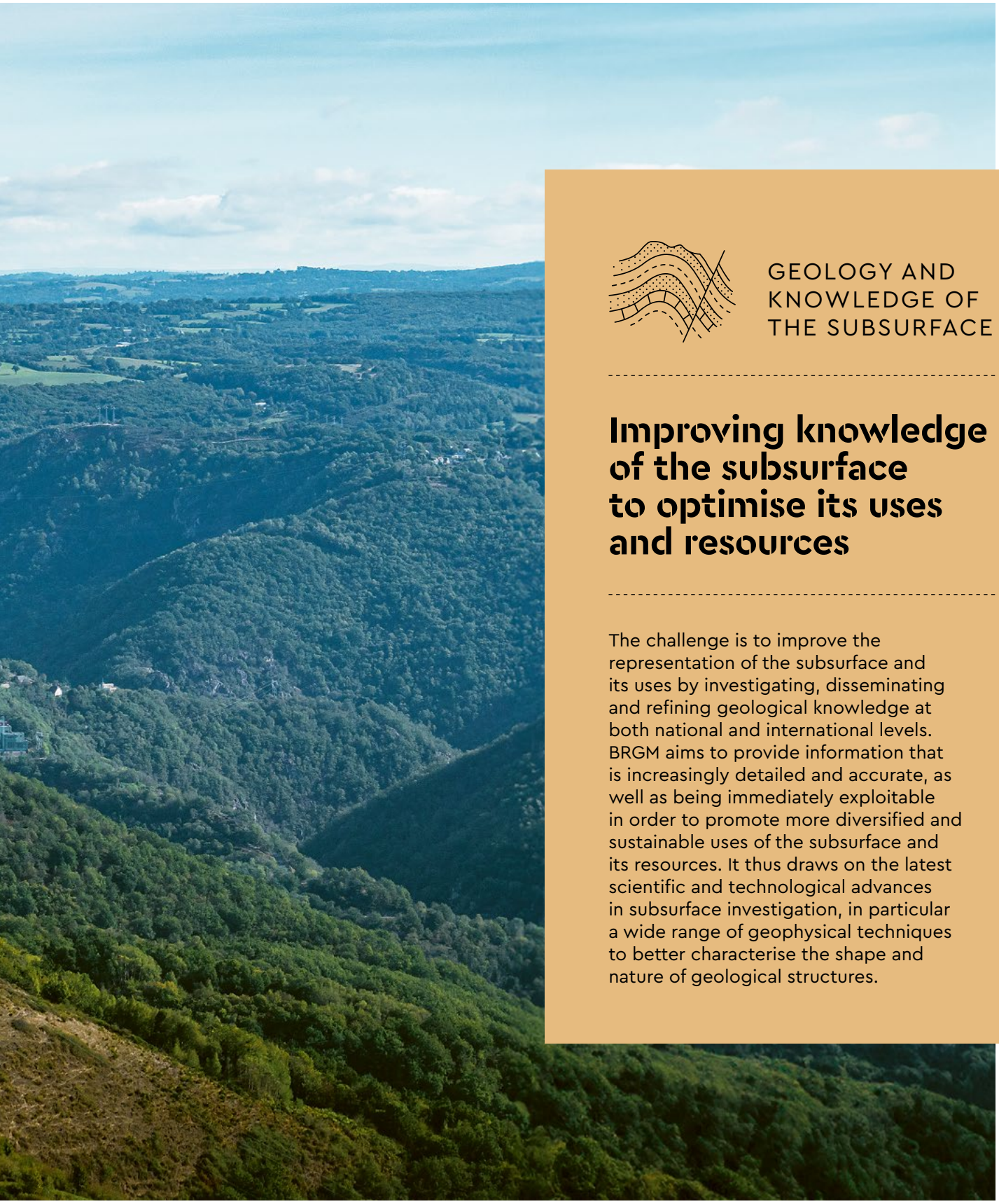
The Recyclability, Recycling and Reincorporation of Recycled Materials programme

This programme aims to address a number of ecological, economic and technological challenges in the transition to a more circular and environmentally-friendly economy. BRGM is responsible for the strategic metals strand of this €40 million programme coordinated by CNRS. ●

THE PEPRs

The Priority Research and Equipment programmes (PEPRs) were drawn up as part of the France 2030 plan, designed to accelerate and structure research and innovation and consolidate French leadership. The PEPRs target scientific and technological sectors that are considered to be emerging, for which the French government would like to structure the research community. Each exploratory PEPR has been selected by an international jury as part of a call issued by the French National Research Agency (ANR).

Airborne electromagnetic acquisition for the Ministry of Ecological Transition (MTE) in the Massif Central.
© Alexandre MAGNAN



GEOLOGY AND KNOWLEDGE OF THE SUBSURFACE

Improving knowledge of the subsurface to optimise its uses and resources

The challenge is to improve the representation of the subsurface and its uses by investigating, disseminating and refining geological knowledge at both national and international levels. BRGM aims to provide information that is increasingly detailed and accurate, as well as being immediately exploitable in order to promote more diversified and sustainable uses of the subsurface and its resources. It thus draws on the latest scientific and technological advances in subsurface investigation, in particular a wide range of geophysical techniques to better characterise the shape and nature of geological structures.

OUTSTANDING RESULT

The continental shelf, an area to be re-investigated in the face of growing challenges

As a specialist in subsurface knowledge, BRGM's expertise also extends to maritime areas close to land. Having a better geological understanding of these high-potential areas helps to provide answers and information to support decision-making concerning projects linked to spatial planning, risk prevention, the energy transition, decarbonisation and mineral resources.

What is the 'continental shelf'? In the morphological sense, the term refers to the geological area that extends from the coastline and out below the sea to a depth of around 200 metres. This area is concerned with various assets and activities: fishing, transport, tourism, the growing population in coastal areas, as well as with the energy transition, notably the development of marine renewable energies (MRE) and decarbonisation projects involving the geological storage of CO_2, not forgetting marine aggregates for a variety of uses.

Within this context, continuously improving our geological knowledge of the continental shelf is vital for several reasons: to ensure sustainable spatial planning and limit its impact on the natural environment as much as possible, to define and manage hazards and risks (earthquakes, submersion, tsunamis, salt-water intrusion, coastal erosion) that could affect the population and infrastructures, to manage the use of material resources (e.g. beach sand replenishment) and to effectively exploit the CO_2 storage or geothermal capacities of the subsurface. "Our aim is to be able to respond as effectively as possible to the growing number of questions on these issues from public authorities, industrial companies, academics and the general public, by building a knowledge base and expertise. This geological knowledge of the continental shelf and the land-sea continuum will also enable us to provide our colleagues at BRGM with data and parameters for more applied studies," explains Isabelle Thinon, a Geologist and Geophysicist.

ISABELLE THINON
Researcher, Geologist-Geophysicist

FABIEN PAQUET
Researcher, Geologist

Acquiring new data

Surveys – financed with the BRGM's own funds – are being conducted to acquire and exploit new geophysical and geological data. "We are essentially targeting areas that have not been investigated much until now, but which we suspect will be of interest in the future," says Isabelle Thinon. In recent years, surveys have therefore been conducted in certain French overseas territories (French Guiana, Mayotte) and around mainland France, notably the Bay de Seine and off the coast of Charente-Maritime. "In this area, our work identified tectonic structures (major faults, folds) and their characteristics (age of last movement, type of fault, etc.) off the *Île de Ré* and *Île d'Oléron*. It also highlighted the significant spatial heterogeneity of the bedrock geological formations." This information has been used to analyse regional land-sea seismicity and for spatial development projects. To obtain high quality data about the maritime subsurface, the teams needed maritime equipment and facilities, high-performance tools and favourable weather conditions. The campaigns carried out at sea in recent years have, among other things, enabled the teams to acquire marine seismic-reflection data which, after processing and

End of the acquisition of a high-resolution seismic-reflection profile. Recovery of the sparker seismic source (comb) by our team. © BRGM

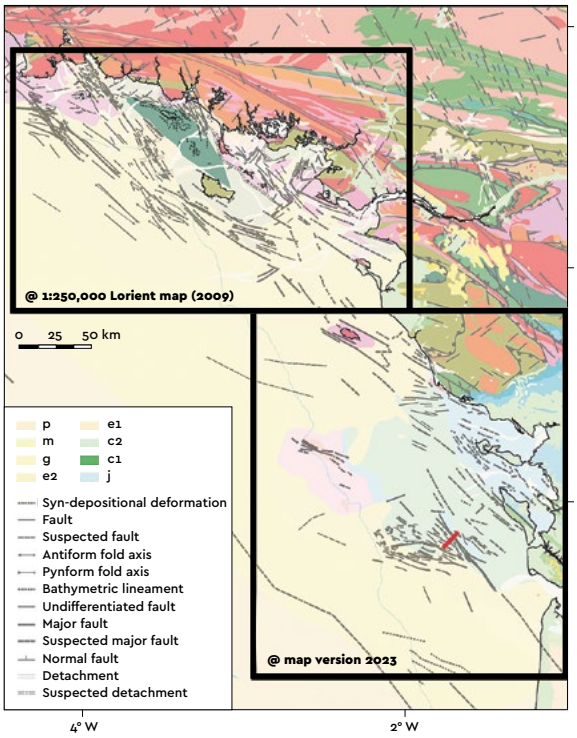


Image 1 — Summary map of tectonic structures (version 2023) identified on the Atlantic-seaboard continental shelf, primarily based on the interpretation of seismic-reflection profiles. The structural diagram for southern Brittany is taken from the 1:250,000 geological map (Lorient sheet) produced in 2008. The diagram concerning the area off the Charentes coast is currently being produced. © BRGM

Image 2 — Example of a high-resolution seismic reflection profile interpretation (in time) from the GIROPAL campaign (2018, https://doi.org/10.17600/18000525), showing the architecture of the subsurface beneath the seabed of the continental shelf off the Île d'Oléron. Note the presence of major faults with apparent multi-metre vertical discharges (black lines) that displace the sedimentary cover formations on either side (coloured seismic horizons). © BRGM

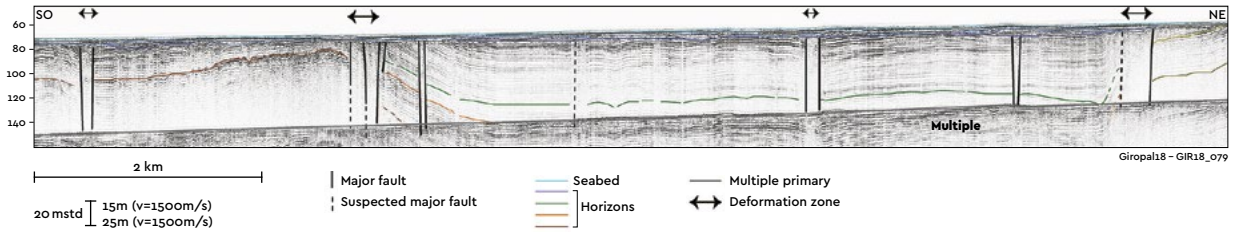
"Our aim is to be able to respond as effectively as possible to the growing number of questions about the continental shelf from public authorities, industrial companies, academics and the general public, by building a knowledge base and expertise."

interpretation, provide the geometry of the subsurface formations beneath the seabed. "To test and validate the interpretations of this geophysical data, we try to sample rocks by coring or dredging, whenever possible," explains the geologist Fabien Paquet. "More often than not, we use geological records from boreholes drilled by third parties (oil companies, etc.) as part of applied studies, as well as our geological knowledge concerning the coastal land area above water." "We are interested in getting all the existing data we can to help consolidate our observations and propose geological maps that are as up-to-date and accurate as possible," adds Isabelle Thinon. For this reason, BRGM has developed many different technical and scientific partnerships with academics, research institutes, industry and government departments.

A diverse range of support missions

The geological knowledge about the continental shelf is made available in the form of regional land-sea geological maps. A 1:250,000-scale geological map of Charente-Maritime is currently being produced, following on from the map of the southern Brittany shelf (Lorient sheet) published in 2008. In the same collection, the map of the Bay de Seine is being revised for publication, the map of Corsica is already available in vector format and the *Golfe du Lion-Provence* map is being finalised.

In recent years, BRGM has provided its geological knowledge and expertise concerning potential hazards for various purposes: upstream studies for offshore wind farms, the analysis of geothermal potential, assessing CO_2 storage capacities and the seismicity of certain areas, as well as in the field of crisis management (e.g. the seismic crisis in Mayotte). In 2023, BRGM also signed two agreements with the French government under which it will contribute its geological expertise in the fields of marine renewable energies (MRE) and marine aggregates.



— PARTNER INTERVIEW

MARION DECAMPS
Head of the capitalisation and transversal activities department (CAT) of the Engineering Division for the Offshore Grid and Interconnections (DIIREM) for the French Electricity Nework (RTE)

"In order to minimise the risks in connecting offshore wind farms on the continental shelf, we need to understand the related subsurface risk. BRGM's knowledge is indispensable to us, and its public library of subsurface data is an exceptional asset for RTE."

What scientific problems are you encountering on the continental shelf?

MARION DECAMPS — The continental shelf, which extends along the coastline to a depth of around 200 metres, has been the focus of offshore renewable energy development for more than ten years. It is against this backdrop that RTE, the national electricity transmission system operator and project developer for the connection of all French offshore wind farms, operates. DIIREM, the Offshore Grid and Interconnection Engineering Division, manages development projects, including the various studies required to minimise risks on the sites where our facilities are to be installed, right through to commissioning. This risk mitigation is multifaceted and extremely complex. In all our connection studies, we need to know the geology of the continental shelf and its hazards.

What expertise are you looking for at BRGM?

M.D. — Risk mitigation and the choice of infrastructure for the connection of offshore wind farms require in-depth mapping of the layers of the continental shelf to better understand the ground-related risk. BRGM's knowledge, which we already use for our land-based projects, is now just as indispensable to us in the maritime sector.

What is the practical benefit for your projects?

M.D. — The main benefit is in sharing valid and confirmed risk analysis data with a recognised scientific body such as BRGM. For this purpose we organise regular meetings with their teams. But we are also discussing new avenues for collaboration, for example in relation to the study of coastline erosion phenomena, or our future offshore electricity substations, which could enable the embedded installation of seismic sensors in areas of interest to BRGM in order to refine its knowledge of the subject. The collected data would be transmitted as open data via the fibre optic network in our cables and would benefit everyone. A public library of pooled, accurate and up-to-date data on subsurface knowledge such as that held by BRGM is an exceptional asset for RTE and will remain so for a long time to come.

Field survey in the Boghen metamorphic unit (New Caledonia).
© BRGM – L. ALIZERT

THE FUTURE GEOLOGICAL REFERENCE SYSTEM FOR NEW CALEDONIA, AN INVESTMENT IN THE FUTURE

BRGM has signed an agreement with the New Caledonian Geology Service (SGNC) to provide support for the development of the New Caledonian geological repository (RGC). BRGM will apply the know-how acquired through the geological reference system in France in terms of tools and methods. In this way, it will help the SGNC to streamline its knowledge of the New Caledonian subsurface and put it to use through the ongoing integration of old and new geological acquisitions. This will provide reliable, up-to-date and relevant data for the entire country.

GEOLOGICAL RISK ASSESSMENT IN THE NORTHERN REGION OF FRENCH GUIANA

In September 2023, BRGM supervised an airborne geophysical campaign in the Cayenne, Roura, Cacao and Macouria areas of French Guiana on behalf of government services. The magnetic and electromagnetic data acquired during these flights is now being used to produce three-dimensional images of the subsurface at depths of up to 300 metres. By improving our knowledge of the geological structure of the northern region of French Guiana, we will be able to better assess the risk of landslides and support the development of the coastline, which is highly changeable.

A CICO PROJECT TO SUPPORT THE "AVANT-MONTS" PER PROJECT IN THE FRANC-COMTOIS REGION

Following on from the Fonts-Bouillants PER (exclusive research permit) project, the Avant-Monts PER project in the Franc-Comtois region was launched in the spring of 2023. For this project, BRGM and 45–8 Energy, a company specialising in helium and hydrogen exploration and production, signed a tax credit contract for research partnerships (CICo). This type of contract is particularly advantageous for companies, which can recoup between 40 and 50% of eligible expenditure in the form of tax credits for projects with a research focus. The project involves a series of ground and airborne geophysical acquisitions that will be used to create a 3D geological model of the area covered by the PER, based on existing data. The goal is to integrate geophysical knowledge into this model and, as part of an iterative process, to oversee and maintain the coherence and integrity of the two approaches. The purpose of the programme is to provide a detailed understanding of the structures (faults and reservoirs) and petrophysical properties of the subsurface, enabling 45–8 Energy to identify locations for its drilling programme in 2024.

Operators measuring gravimetric points and GPS points.
© BRGM

WHERE DOES THE RADON DETECTED IN CARBONATE AREAS COME FROM?

While historical mapping of radon-222 in France has identified high levels of the gas in crystalline environments, it has been detected in similar proportions in the soil of certain carbonate areas. To better understand the source of these atypical concentrations, BRGM and IRSN (*Institut de Radioprotection et de Sûreté Nucléaire* – Institute for Radiation Protection and Nuclear Safety) conducted a study in the Fourbanne and Grands Causses areas. The results showed that it is actually sources outside these areas that contain radioactive elements. The content of carbonate rocks and their alterations is very low. In the Grands Causses area, bauxite is the main source of the radon222-radium226-uranium 238 triptych in the soil. This result is corroborated by the post-depositional history of these carbonate massifs, where alteration under cover led to karstification and the subsequent sinking of the allochthonous sedimentary cover within the carbonate massif. The same mechanisms were identified in Fourbanne, where radioactive elements also appear to stem from detrital fracture, which is rich in heavy minerals, whose source is still unknown.

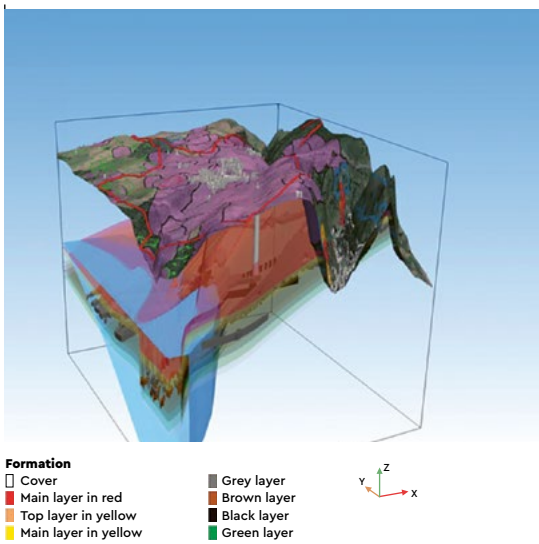
Doline on the *Causse de Sauveterre*, where the furrowed soil was formed mainly from bauxitic deposits.
© BRGM – E. HUSSON

A BETTER UNDERSTANDING OF THE KARSTIFICATION OF THE RESERVOIRS IN THE PARENTIS BASIN

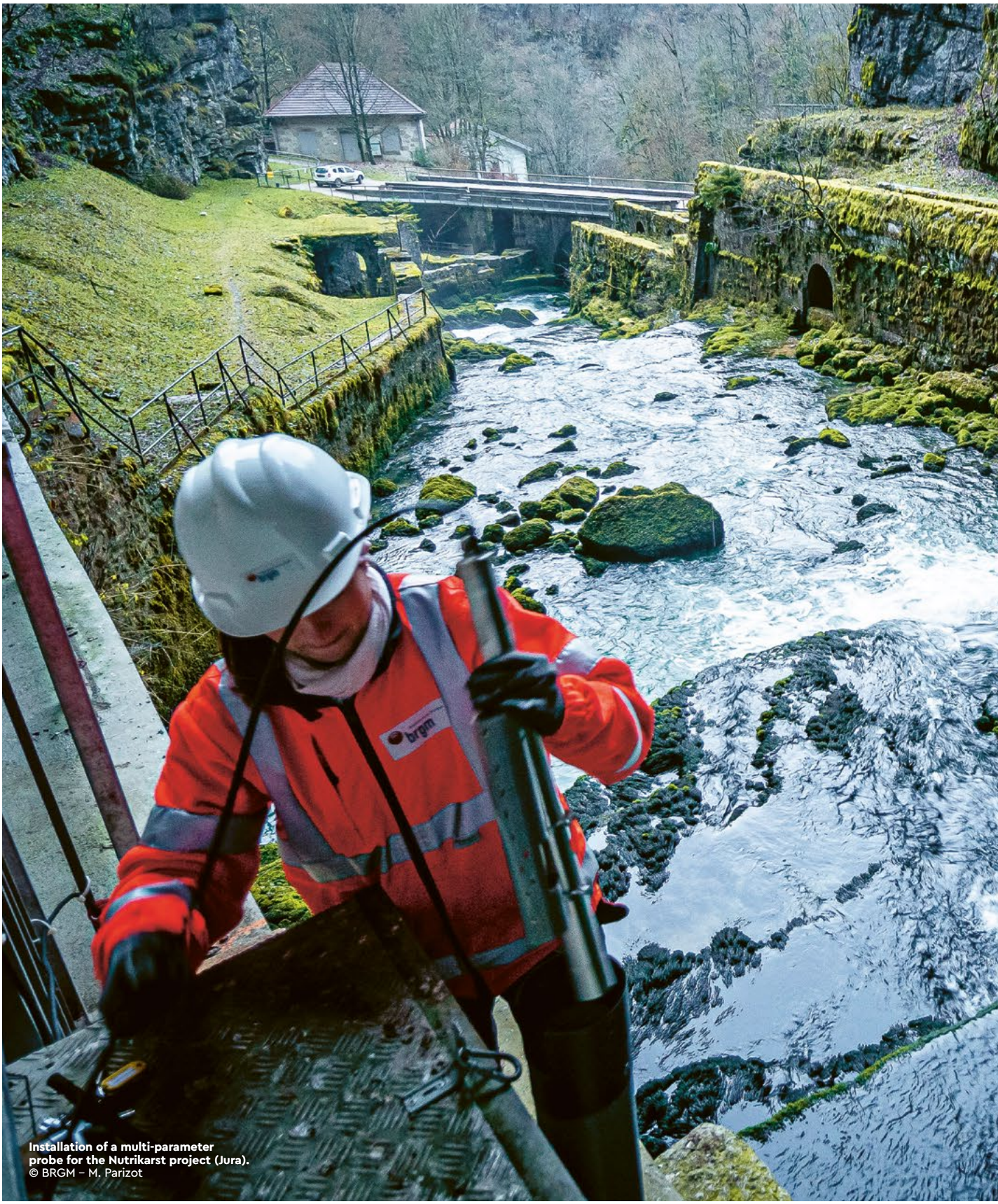
The Parentis basin contains the largest oil deposit in France, at a depth of over 2,000 metres. The Vermilion company plans to conduct a study to characterise the carbonate levels known to be faulted, diagenetised and karstified, and which contain the bulk of these residual reserves. BRGM is taking part in the project to gain a better understanding of karstogenesis phenomena and the geometry associated with karstification. Based on a multidisciplinary approach, this research and development project draws upon the latest methods and concepts to provide a better understanding of the karstification of these reservoirs and thus to improve geological models and their use for predictive purposes.

FORGEO FOR A NEW MODULAR MODELLING TOOL

BRGM has been producing geological models for forty years using specialised tools, sometimes developed in-house. As part of the ForGEO project, it is working on merging GDM Multilayer (multi-layer modelling of geological formations) and GeoModeller (modelling of complex structures) into a single environment. Software bricks have been redeveloped to provide an operational alternative to legacy tools, but also to create a modular, scalable environment that can be reconfigured according to production needs. Adapted to modern computing resources, this environment could also serve as an incubator for research projects.



3D model of the subsurface of the municipality of Angevillers, eastern France, showing the topography, the iron-bearing geological horizons (roofs and volumes) and the mining zones (homogeneous mined areas). The surfaces modelled are taken from a model generated and displayed using ForGEO tools.
© BRGM



Installation of a multi-parameter probe for the Nutrikarst project (Jura).
© BRGM – M. Parizot

GROUNDWATER MANAGEMENT

Managing groundwater to adapt to climate change

Global warming of +3°C by the end of the century is becoming increasingly probable, which will significantly affect the water cycle. For BRGM, these changes mean that the impacts and corresponding risks need to be assessed, and solutions proposed for monitoring and optimising aquifer recharge and use. In this context, groundwater quality is also a priority. BRGM is thus conducting research into the processes underlying aquifer resilience in the face of climate change and studying the impact of nature-based solutions, to support sustainable regional water resource management policies.

OUTSTANDING RESULT

Nature-based solutions: a toolbox for sustainable groundwater management

Global changes (climate, pollution, soil sealing) represent a major challenge and threaten the sustainable management of groundwater and biodiversity. Within this context, we present an overview of the work carried out by BRGM on nature-based solutions (NBS).

GÉRALDINE PICOT
PhD
Hydrogeologist

CÉCILE HÉRIVAUX
Environmental Economist

BRGM is developing a catalogue of nature-based solutions for sustainable groundwater management through two projects, JPI Water EVIBAN and SFNGest'ESO.

Whether new or already known (but re-adapted, or used in an original way), nature-based solutions are, by definition and above all, "natural". They can be applied in both rural and urban environments and are in line with key objectives in the fight against climate change, notably as regards addressing the increasing scarcity and deterioration of water resources, and the need to protect biodiversity in aquatic environments.

The use of NBSs in the fight against climate change

Nature-based solutions bypass the limits of conventional means used until now. Indeed, over the last few decades, conventional civil engineering solutions have shown their limits in mitigating the effects of climate change. Episodes of extreme rainfall or drought have challenged conventional management methods. For example, storm-water basins, which retain excess rainwater produced during a storm, were designed to deal with known rainfall patterns. But in the face of accelerating climate change, these basins are no longer suitable.

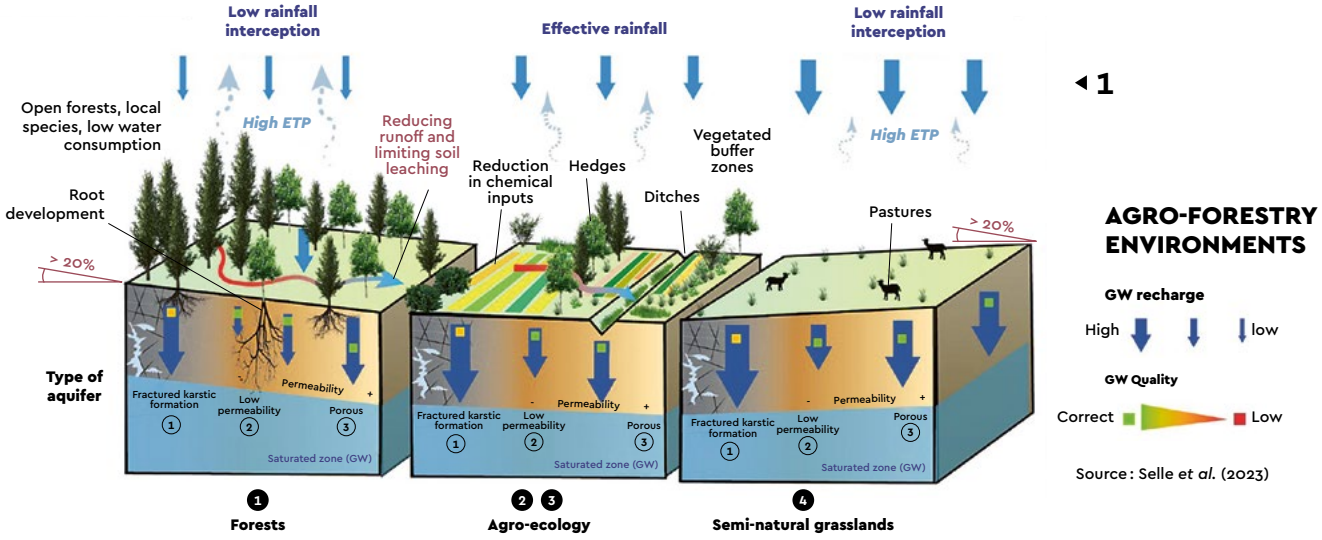
The artificialisation of land combined with increasingly dense urban development (housing) has also increased the risk of flooding due to soil sealing. In this context, heavy rainfall can cause drainage and sewerage networks to flood, and affect the operation of treatment plants, resulting in the risk of environmental pollution due to the discharges from waste-water treatment plants (affecting rivers, lakes, sea, subsurface and groundwater). BRGM is therefore working on all these different issues.

JPI Water EVIBAN: an experimental site for controlled aquifer recharge which eliminates micro-pollutants

This European programme, which ended in 2023, concerned a French pilot site located in Normandy. The programme confirmed that a system involving the collection and treatment of waste water in a traditional treatment plant combined with infiltration through the soil and through the coastal dune aquifer (already in use for 30 years) can provide additional water treatment to eliminate micro-pollutants, which are not yet monitored within the regulatory framework of this controlled aquifer-recharge system.

The dune aquifer acts as a natural filter. BRGM, which worked with the municipal council and the water-management operator Saur on this programme, analysed the water and was able to model and reproduce the behaviour of flows and certain micro-pollutants. While such practices go back a long way, reed beds were added to the infiltration basins on this pilot project to make the system more sustainable and adapted to the natural site of this coastal area.

GPS referencing of a piezometer (instrumentation for monitoring and analysing water quality) located in the infiltration basin of the controlled aquifer-recharge system.
© BRGM – G. Picot



Source : Selle *et al.* (2023)

◂ 1

The JPI Water EVIBAN programme carried out on this site had a significant impact; notably, it raised the awareness of the local population about these systems and changed the way they are perceived, since local people realised that the waste-water treatment plant could pollute the coastal waters. Thanks to the experimental monitoring and the model developed for this pilot project, local stakeholders are now interested in deploying these solutions to reduce the environmental risk at other coastal waste-water treatment plants in Normandy.

SFN-Gest'ESO: studying the effects of NBSs at aquifer level

Managed by BRGM in partnership with AERMC (Rhône-Mediterranean-Corsica Water Agency), this programme aims to examine the direct effect of NBSs on groundwater. While the solutions concerned are often well known, using them as a means to achieve sustainable groundwater management is a new approach.

Three areas, each being representative of a different environment, were studied using a multidisciplinary approach combining hydrogeological tools, interviews with local stakeholders and surveys among the general public.

In the Drugeon catchment basin (Doubs), the rewilding of the watercourse and the rehabilitation of peat bogs – implemented to restore aquatic biodiversity – have helped to mitigate the effects of climate change on aquifers while reducing greenhouse gas emissions.

In the Vistrenque-Costières area (Gard), an ecological compensation programme based on semi-natural grasslands has helped to restore the quality of the aquifer used to supply drinking water. In eastern Lyon, alternative storm-water management solutions based on "soil unsealing" can be used to increase aquifer recharge and improve the catchment basin's capacity to mitigate the effects of climate change.

Based on these promising results, greater consideration needs to be given to groundwater when designing NBSs, in order to strengthen the coherence between public policies and enable local regions to improve their resilience to global change.

> "Using NBSs to achieve more sustainable groundwater management (*Solutions Fondées sur la Nature pour une gestion durable des Eaux Souterraines [SFN-ESO]*) can help make regions more resilient to global change."

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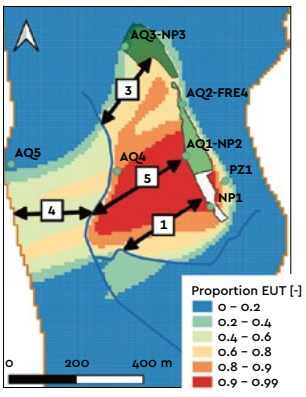


Image 1 — Hydrogeological processes associated with the use of NBSs in agro-forestry environments. © BRGM

Image 2 — Proportions of treated waste water (TWW) in the coastal dune groundwater at Agon-Coutainville and main behavioural patterns of recharged TWW in the aquifer (direction, flow velocity and TWW proportion) simulated by the hydrodynamic model. © GUILLEMOTO *ET AL.* 2023

PARTNER INTERVIEW

STÉPHANE ROUMEAU

Director of the Thau Bassin Water Authority

"We launched a five-year project to study the basin's water resources, and commissioned BRGM to manage the project. Today, the fact that the local council is better informed and more aware about the issue of water-resource management is really thanks to BRGM's detailed, in-depth expertise and input."

Why did you decide to call on the services of BRGM?

STÉPHANE ROUMEAU — The Thau Basin is a seawater lagoon in the south of France, located near the town of Sète (Hérault). It is the largest body of water in the Occitanie region. The Thau Basin Water Authority is a Public Regional Basin Authority (EPTB [*Établissement Public Territorial de Bassin*]), whose role is to manage water resources for a particular catchment basin or aquifer. Here, we cover 25 municipalities and, in addition to simply managing the water resources, we are also responsible for regional spatial planning and the regional coherence plan (SCOT). We are the only water authority in France with that remit. Obviously, one of the issues we have to deal with is water salinity. We have problems with water shortages, linked to the state of our aquifer. Another key aspect that we pay particular attention to is water quality, since the lagoon alone accounts for 10% of France's shellfish production. These are just some of the reasons why we call on the services of BRGM. Today, our management approach also needs to take climate-change mitigation strategies into consideration.

Could you briefly describe the projects conducted?

S.R. — We already had a long-standing partnership with BRGM concerning the management of the coastline, which notably involved the development of support programmes for spatial planning, which helped to stabilise the coastline in the 2000s. So, when we launched the DEM'Eaux Thau project, which lasted for five years, we commissioned BRGM to manage the project. The project involved studying the local water resources, in order to have a better understanding of the structure and operation of the complex karst hydrosystem in the basin area. In particular, the project studied the system of La Vise and its underwater spring, which is affected by a reverse-flow (*inversac*) phenomenon, resulting in temporary intrusions of brackish water into the aquifer. BRGM set up a web platform to observe the aquifer and the spring, along with a 3D hydrogeological model and an aquifer management tool.

How would you assess this partnership?

S.R. — Today, one of the main reasons that the local council is better informed and more aware about the issue of water-resource management is really thanks to BRGM's detailed, in-depth expertise and input. I was particularly struck by how interested the local councillors were in the scientific results. Incidentally, this partnership enabled us to discover the underwater source of the thermal-water deposit of Balaruc-les-Bains, France's leading spa. This added an extra bit of 'magic' to the work. I should point out that when the project ended, BRGM did not simply leave us on our own with our data and results; they provided further support, notably concerning the *inversac* phenomenon, for which they put in place an experimental programme on regulating the underwater spring in question.

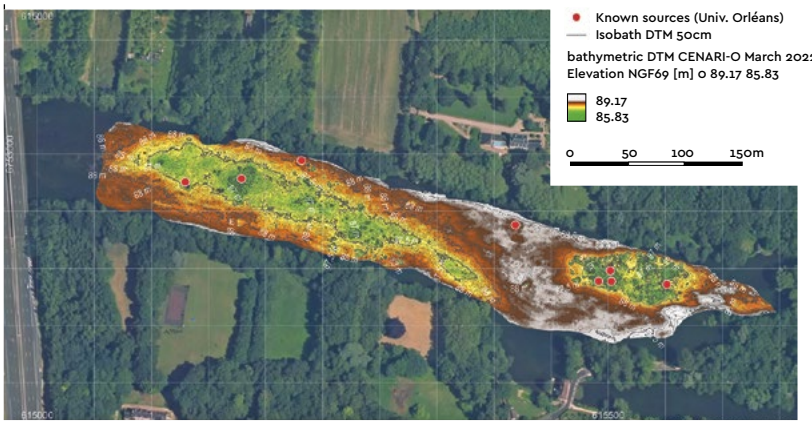
AQUAREF: TECHNICAL SUPPORT FOR THE REGULATORY MONITORING OF WATER BODIES

As part of AQUAREF, the national reference laboratory for monitoring aquatic environments, BRGM manages the operations aimed at defining the national analytical benchmarks (quantification limits) for the regulatory monitoring of groundwater and surface water bodies. This mission involves managing a database of over 1,000 elements of performance-related data corresponding to the same number of "parameter/matrix" pairs. This involves taking into account the environmental requirements (toxic or eco-toxic effect values) as well as the capacities of the laboratories. Moreover, in order to produce more reliable and usable monitoring data on phytosanitary products, BRGM launched a specific project which aims to establish a link between the active substances sold on the market and the chemical forms analysed by the laboratories. This project will continue until 2026. It is sometimes difficult to establish this link, which therefore makes it difficult to assess the environmental impact of these substances (via the ADES or Naïades databases, for example).

Sampling water to assess its quality and detect potential pollutants, Pontcharra, Isère.
© BRGM

UNDERSTANDING EXCHANGES BETWEEN AQUIFERS AND RIVERS WITH THE CENARI-O PROJECT

CENARI-O, a research project being conducted in the Centre-Val de Loire region, draws on a multi-criteria method to characterise aquifer-river exchanges. This innovative, integrated, multi-scale approach has been used to study the Loiret river and has enabled us to understand the exchanges and mixtures between the two bodies from a spatial perspective, from the source to the Loire-Loiret confluence, as well as from a time-based perspective during high-water and low-water periods.

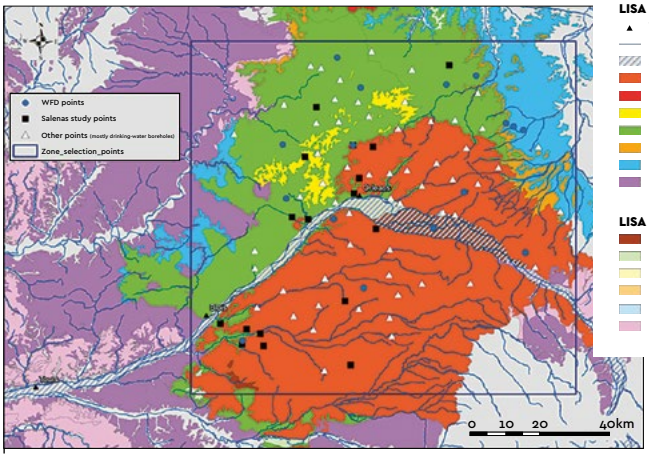


Location of low-lying areas in the Tacreniers basin, on the Loiret river.
© BRGM – T. DEWEZ

CENARI-O regional project – Bathymetric DTM of the Loiret, SubseaTech 22–23 measures March 2022 – processing T. Dewez BRGM Background from BD-Ortho IGN

IMPACT OF HUMAN ACTIVITIES ON WATER AND NUTRIENT TRANSFERS

The NUTRI-Karst project (in Franche-Comté) aims to understand the impact of human activities (agriculture, domestic waste) on the pollution of water by nutrients. The project looks at different scales, from the karst-based spring and the catchment basin (La Loue) to the region (Jura massif) as a whole. The initial results show that excess nitrogen transferred by the water account for an average of 20% of the quantities brought into the catchment basins, the origin of which is mainly agricultural, linked to dairy farming. Even though extensive agriculture is predominant in the area, the chronic deterioration in water quality illustrates the vulnerability of karst basins.



LISA DATABASE ORDER 1 (at outcrops)
- Towns
- Watercourses
- Alluvial deposits of the Loire – Entity 930DA
- Sand and clay formations of Sologne – 104AE03
- Pliocene sand and clay formations – 104AA04
- Marl and clay formations in the Orléans region – 104AE05
- Limestone formations in Pithiviers (free) – 107AA01/02/03/05/07
- Molasse formations in the Gâtinais region_107AE01
- Stampian limestone formations (free) – 107 AF01
- Clay-with-flint formations – 119AE01 – 119AE05

LISA DATABASE ORDER 2 to 5
- Sand and clay formations of Sologne – 104AE03
- Limestone formations in Pithiviers (captive) – 107AA01 /02/03/05/07
- Marl and clay formations in the Orléans region – 104AE05
- Molasse formations in the Gâtinais region – 107 AE01
- Stampian limestone formations (captive) – 107 AF01
- Clay-with-flint formations – 119AE01 – 119AE05

Location of sampling points on the BD LISA map background.
© BRGM – N. DEVAU

"BIODIVEAU" PROJECT AT THE SERVICE OF MICRO-BIODIVERSITY

The aim of the BIODIVEAU project is to assess the potential of tools for characterising the microbiological components in water bodies to reflect the state of water resources. Since little work has been done to date on assessing the microbial biodiversity of groundwater, BRGM can take a leading position on this very broad subject. As part of the project, sixty catchment points in the Beauce aquifer were sampled and analysed. Various microbiological signatures associated with hydro-geochemical signatures were identified. This is the first step towards establishing a reference base of the microbiological state of water.

VULNERABILITY OF WATER-CATCHMENT POINTS TO CLIMATE CHANGE

How can we help Water Authorities anticipate the impacts of climate change on the boreholes they operate? BRGM carried out an R&D project for the Water Authority of the Aube *Département* to rank boreholes according to their degree of vulnerability to climate change, using a multi-criteria approach that cross-examined the main factors of exposure and sensitivity. The project looked at the most relevant factors for this scope of study.

THE "CARE-PEAT" PROJECT LOOKS AFTER OUR PEAT BOGS

The aim of the Interreg NWE Care-Peat project was to study greenhouse-gas emissions from peat bogs. When these ecosystems become degraded, they release CO_2 and CH_4 (methane) into the atmosphere. BRGM worked on peat-bog rehabilitation on seven pilot sites in six countries. A decision-making tool was developed to assess the carbon flows before rehabilitation and propose solutions to reduce gas exchanges between the peat bogs and the atmosphere. The scenarios developed are notably based on modifying the hydrology of the sites and changing the vegetation in degraded areas.

Site in La Guette in Sologne (Cher). Re-planting of suitable vegetation to improve carbon sequestration in the soil.
© BRGM – L. ANDRÉ

Drone surveillance of the cliffs along the coastal road in Urrugne.
© Observatoire de la Côte Aquitaine / Com' by AVM

RISKS AND SPATIAL PLANNING

Increasing local and regional resilience by improving the control of risks and their impacts

Climate change and pressure on local and regional communities increase their vulnerability to natural hazards and anthropogenic pollution. A co-director of the IRiMa PEPR, BRGM is contributing to the development in France of an integrated approach to the risk chain, from prevention to adaptation via crisis management support, in order to further sustainable spatial planning at local and regional level. It is particularly active in coastal areas, with tools for monitoring, modelling and supporting the redevelopment of these areas, which are vulnerable to erosion and exposed to the risk of coastal flooding. BRGM has also developed specific expertise in managing and monitoring former mining or industrial sites and remediating contaminated soil.

OUTSTANDING RESULT

NATURAL RISKS

Moving towards nature-based responses to phenomena caused by weather events

BRGM was involved in the European Phusicos project, which aimed to assess the effectiveness of nature-based solutions (NBS) in preventing the occurrence of phenomena caused by climate-related events, particularly in mountain areas. For the purposes of the project, BRGM notably produced a reference database to facilitate the use of NBSs.

SÉVERINE BERNARDIE
Landslide Specialist

"Due to the effects of climate change, we need to move towards solutions that emit less CO2, or that are less 'grey', in order to reduce natural risks and protect people: nature-based solutions (NBS) make use of biodiversity or involve building structures and systems made of natural materials such as wood, stone, etc.," explains Séverine Bernardie, a Landslide Specialist.

Although BRGM has been working on these issues for a long time, in recent years it has focused on how NBSs can contribute to reducing water and gravity-related risks (rock falls, landslides, erosion, snow avalanches, debris flows) in mountain areas, as part of the H2020 Phusicos project (2018-2023). This project was coordinated by the Norwegian Geotechnical Institute (NGI), which brought together 15 partners from 7 countries with one objective: to demonstrate that nature-based solutions aimed at reducing the risk of phenomena caused by weather events are technically viable, cost-effective and applicable on a regional scale, while increasing the ecological, social and economic resilience of local communities.

Working hand in hand with local stakeholders

"We worked specifically on preventing rock falls on a site at Artouste, in the Pyrénéees," explains Séverine Bernardie. *"The choice of site was decided in consultation with local stakeholders, based on their needs, expectations and involvement in the project, as well as financial criteria. We carried out studies to characterise the risk, quantify the role that the existing forest played as an NBS and identify new, more appropriate solutions to reduce the risk further. These solutions were then implemented."* Consequently, wooden tripods were installed in areas where rock-falls could potentially start, in order to stabilise them. Wooden structures were also installed in areas into which rocks could fall, in order to hold them back.

These solutions will be assessed over several years, taking into account the benefits in terms of reducing the risk, as well as the economic, ecological and social co-benefits. *"We have drawn up a protocol that will ensure the quality and sustainability of the long-term monitoring and analysis of the solutions implemented in the area. This was done with the help of a local working group that was*

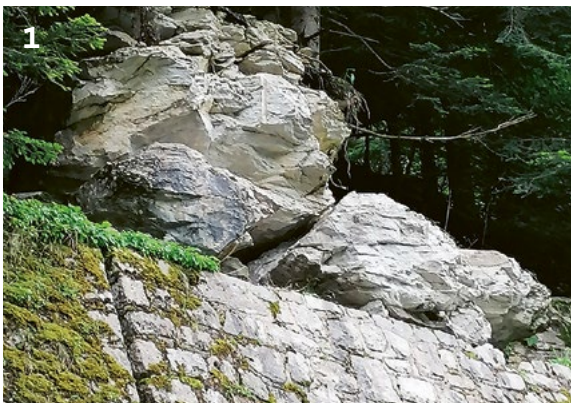

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Image 1 — Blocks of rock that have slipped down to the edge of the retaining wall above the road in Artouste. © BRGM

Image 2 — Example of a structure built in Artouste (French Pyrénées) to stabilise blocks of rock in areas above a strategic road (2022). © BRGM

Image 3 — 3D image of a slope overlooking a busy road that is exposed to rockfalls in Artouste. The nature of the ground was characterised over the entire hillside based on the joint analysis of the distribution of slopes and the broken terrain of localised zones at different scales. The results were validated by comparing them with observation points on the ground (points circled in black). This data was then used to model the propagation of fallen rocks down the slope. © BRGM

"Due to the effects of climate change, we need to move towards solutions that emit less CO_2, or that are less 'grey', in order to reduce natural risks and protect people: nature-based solutions (NBS) make use of biodiversity or involve building structures and systems made of natural materials such as wood, stone, etc."

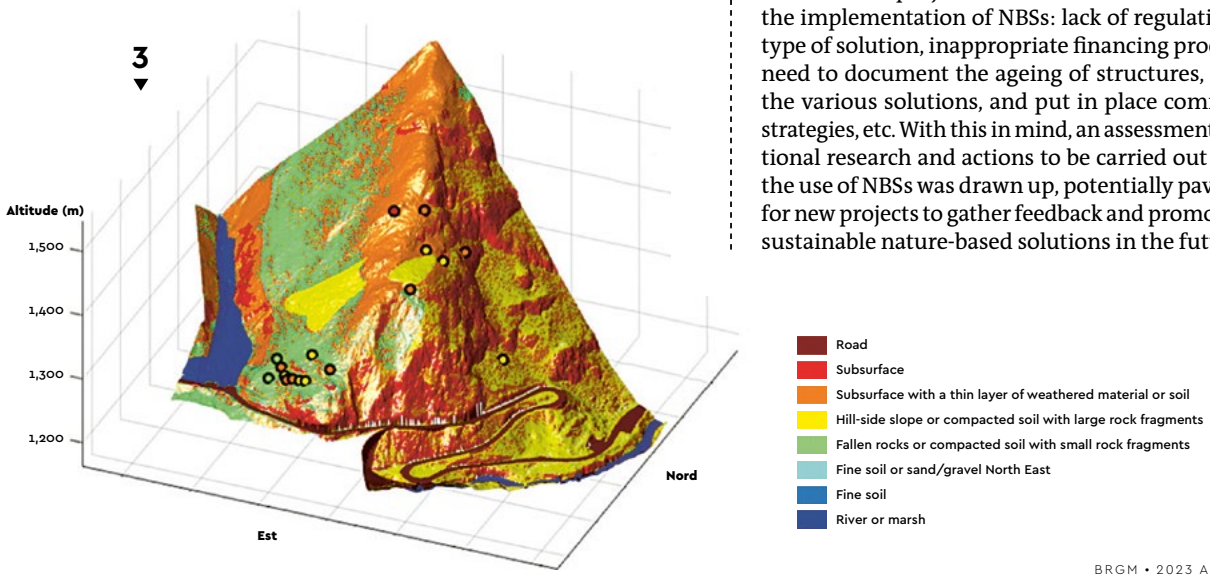
actively committed to the project." This approach will make it possible to test the performance of the timber structures in relation to impacts from rocks and ageing, with the ultimate aim being to standardise the design, sizing and use of these solutions.

Fifteen criteria taken into account

BRGM carried out this assessment in parallel with 187 other initiatives involving nature-based solutions implemented around the world. This project represented a significant amount of work in terms of documentation (description and analysis) structured according to a methodology based on fifteen criteria: the technical feasibility of the NBS, the cost of implementing it, its effectiveness in terms of reducing the frequency of the phenomenon concerned, management and maintenance, the number of jobs created in connection with the NBS in question, the protection of the environment and biodiversity, the involvement of the local community, the community's perception of the solution and the situation, etc. *"Based on this inventory and our assessment, we developed a database that can be used to determine in what context and under which conditions each NBS can be effectively implemented, with information about its performance and the impact it had, whether positive, negative or neutral"*, says Séverine Bernardie. This free-access web-based platform (phusicos.brgm.fr) will be continuously updated and enhanced with new case studies, in order to serve as a reference base for risk prevention and spatial planning using nature-based solutions.

Removing the main obstacles

The Phusicos project also identified the main obstacles to the implementation of NBSs: lack of regulations for this type of solution, inappropriate financing procedures, the need to document the ageing of structures, standardise the various solutions, and put in place communication strategies, etc. With this in mind, an assessment of the additional research and actions to be carried out to facilitate the use of NBSs was drawn up, potentially paving the way for new projects to gather feedback and promote effective, sustainable nature-based solutions in the future..



OUTSTANDING RESULT

ANTHROPOGENIC RISKS

Major advances in understanding and managing PFAS

Used in industry and in many everyday products, PFAS chemical compounds persist in the environment after use. Several BRGM teams are combining skills and tools to develop new ways of treating soil polluted by these substances. Last year saw a number of major, innovative advances in this area.

STÉFAN COLOMBANO
Research engineer in polluted sites and soils

CLÉMENT ZORNIG
Head of the Polluted Sites and Sediments Unit (3SP)

JULIE LIONS
Hydrogeochemical expert, coordinator of the H2020 PROMISCES project

ANNE TOGOLA
Environmental biogeochemist

NICOLAS DEVAU
Geochemist and modeller

PFASs are 'forever pollutants', well known to chemists, and also to environmentalists. The name covers per- and polyfluoroalkyl substances with highly specific chemical properties that justify their use in many industrial fields and in everyday products. They can be found in technical clothing, fire-fighting foam, stain- and water-resistant coatings, floor coverings, food packaging, etc.

At the same time, however, they persist for very long periods in the environment, lingering in soil, groundwater and other media. PFASs are harmful to the environment and also to human health. As a result, they are of huge importance from a scientific, media, legal and political standpoint. These forever pollutants need to be treated in such a way as to reduce concentrations in the soil and groundwater. This will involve major clean-up operations using appropriate techniques.

BRGM involved in several major projects

Given the complexity of this issue, managing PFASs raises a number of R&D challenges. Extensive technical support will be required in research studies to understand and treat polluted groundwater, sites and soil, at both local and national level. BRGM has initiated a number of studies combining a range of complementary scientific disciplines, since treating soil polluted by PFASs will require an approach that addresses the issue from several different angles: modelling, decontamination, analytical developments and destruction. BRGM has been working in all these areas for over five years, as part of a number of projects: PERFECT, PERMUTE, CONCERTO, PFAStwin and H2020 PROMISCES. Several major advances were made in this area in 2023.

Extracting PFAS from soil

A number of aspects have been addressed as part of the PROMISCES project coordinated by BRGM and financed by the European programme H2020 as part of the Green Deal, whose purpose is to "contribute to the deployment of the circular economy by reducing the risks associated with certain industrial pollutants, in particular PFASs". The PRIME platform for remediation and innovation in environmental metrology was also involved.

Modelling

BRGM has highlighted the fact that the transport of PFASs does not follow standard rules for the behaviour of organic pollutants when they are transferred from the

Treatability tests for PFASs using reducers.
© BRGM – D. Depoorter

Implementation of a large-scale experiment to monitor and decontaminate porous media, removing Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs) in the multi-metric pilot of BRGM's PRIME platform.
© BRGM - P. VASSAL

soil to groundwater. Interface effects must be taken into account in the models. This should make it possible to predict the migration of these substances in order to plan remediation work. To achieve this, numerical models have been developed to simulate experimental work from the laboratory to the field scale.

Remediation: extraction and destruction

On the one hand, remediation involves extracting PFASs from soils using so-called non-Newtonian fluids to treat the different lithological layers, even when they vary in permeability. BRGM has developed specific liquids called rheofluidifiers to overcome soil anisotropy (where properties vary depending on the direction considered) and to scan the different soil layers in a homogeneous manner. Through desorption (gas extraction) or solubilisation, these liquids can be used to extract PFASs! BRGM has also developed decontamination techniques to destroy certain PFASs using two different approaches: advanced chemical reduction and oxidation.

Analysis

Several approaches have been developed, ranging from the most comprehensive to the most specifically targeted. Analytical development has also made it possible to quantify and analyse more than 55 PFAS molecules in several types of environment.

"Understanding and treating groundwater pollution and polluted sites and soils, both locally and on a national scale: given the complexity of the issue, the question of PFASs poses a number of R&D challenges."

This entire chain of work involves researchers from several disciplines (chemistry, numerical modelling, fluid mechanics, etc.), all of which are prominent at BRGM.
Note that after analytical developments and laboratory experiments, BRGM's PRIME platform has enabled a change of scale for *in situ* demonstration and modelling, with a test phase on a multi-metric scale. This is a platform for testing monitoring methods under controlled conditions, studying the migration of PFASs in groundwater and soil and testing remediation techniques.

— PARTNER INTERVIEW

FABIENNE RICARD
Deputy Director DGALN/DEB/ELM,
Ministry of Ecological Transition and Regional Cohesion

"Faced with the effects of climate change, which will exacerbate the phenomenon of coastal erosion, BRGM has established itself as a key player in helping local authorities in coastal areas improve their knowledge of this risk and take it into account in their spatial planning policies."

How did you come to work with BRGM?

FABIENNE RICARD — Seaside areas are particularly attractive, with a population density 2.5 times higher than the national average. The geology and characteristics of these areas can vary greatly, but they are often exposed to changes in the shape of the shoreline at various points along the coast. We are trying to understand these coastal dynamics. Some 5,000 km of French coastline (excluding French Guiana), including 20% of the coastline in mainland France, are retreating due to erosion, which is a progressive, unrelenting and irreversible phenomenon. As a result of global warming, the rising sea level will further exacerbate this phenomenon. The fact that these areas have diverse characteristics and cover a large surface area make BRGM a key player in this field, due to the wide-ranging expertise it can mobilise.

What effects will this have on public policy-making?

F.R. — There will be major consequences for local residents and the economy in the areas concerned. We need to act now. In order to anticipate future situations effectively, we need to improve our knowledge of how and why coastlines retreat and better understand the issues in the areas affected, in order to define the appropriate measures to be taken locally. This adaptation policy will lead to the creation of local maps showing exposure to the phenomenon of shoreline retreat. Naturally, the Ministry of Ecological Transition and Regional Cohesion called on the technical and scientific expertise of BRGM to provide the local authorities concerned with recommendations for drawing up these maps.

How is BRGM involved exactly?

F.R. — To start with, they organised specific presentation and information meetings throughout the year 2023 with the coastal communities and the decentralised government departments in Metropolitan France and French Overseas Territories. These meetings took into account the diverse situations of each area or region. BRGM's teams worked hard and invested a great deal of time and effort to ensure they would be a success. In addition, BRGM actively helped to promote the paradigm shift introduced by the national integrated coastline management strategy, entitled *"Vivre avec la mer plutôt que lutter contre"* (Living with the sea rather than fighting against it). Natural ecosystems can act as physical barriers against storms and buffer zones to prevent flooding. BRGM is helping to change the way we look at the role of nature-based solutions. An example of this is its partnership with the French Coastal Conservancy as part of the Adapto programmes. In short, BRGM is a State operator that plays a key role in helping France's different coastal areas adapt to climate change.

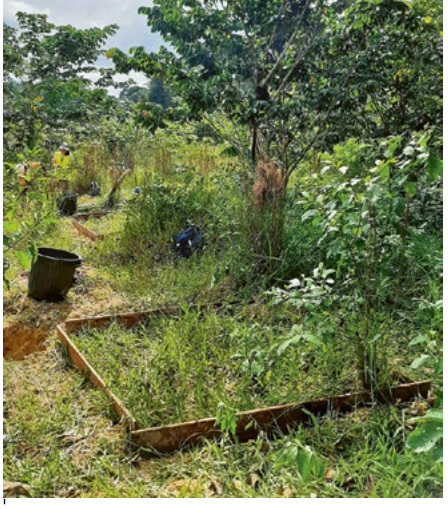
SUPPORTING THE DEPLOYMENT OF **COASTLINE RETREAT** EXPOSURE MAPS

In 2022, BRGM and Cerema drew up methodological recommendations under the auspices of the French Ministry for Ecological Transition and Territorial Cohesion for mapping areas at risk of coastline retreat in the medium (30 years) and long term (100 years), for use by municipalities implementing the new regulatory tools set out in the 2021 Climate and Resilience Act. Following the signing of an agreement with the Ministry in 2023, BRGM is now working with Cerema to set up a national programme to support decentralised government departments and local authorities in launching and monitoring the studies needed to produce these local maps. This will involve drawing up a set of specifications, providing technical support, organising regional and national information sessions and bringing a community of stakeholders into a network.

Field survey to locate soil and sediment samples in a catchment area subjected to radioactive fallout in the Fukushima prefecture.
© BRGM – O. EVRARD

IMPROVING PREDICTION OF RADIONUCLIDE DISPERSION AND ASSESSING THEIR IMPACT ON THE ENVIRONMENT

Coordinated by the Institute for Radiological Protection and Nuclear Safety (IRSN), the aim of the Amorad project was to optimise models for predicting the dispersion of radionuclides in the environment and assessing their impact on the marine environment and terrestrial ecosystems. Initially launched in 2013, this research programme was extended in 2019 to cover an assessment of the environmental impact of a nuclear accident. BRGM was tasked with proposing a method for quantifying the export of radionuclides from catchment areas to the sea. The developed model was calibrated near Fukushima and then integrated into a series of tools developed by IRSN and BRGM. It was used to produce the first model of the dynamics of caesium 137 (137Cs) transfer from surface deposits to the sea and to assess the direct costs of contamination of an area following a serious nuclear reactor accident.



Plots for measuring surface flows in an area rehabilitated two years ago (Awa site, Grand Santi).
© BRGM

THESIS ON THE REHABILITATION OF GOLD MINING SITES IN FRENCH GUIANA

In partnership with IPREM (University of Pau and the Pays de l'Adour), ISTERRE (IRD), SAS-GAIA and BRGM, Naomi Nitschke's CIFRE thesis examines what happens to mercury and lead in relation to the remediation of gold mining sites and the rehabilitation of soils in French Guiana. Several surveys to measure the temporal flows of these elements during periods of high rainfall were carried out at the Awa site in Grand Santi in western French Guiana, taking samples of water, suspended matter and soil. The project will be extended in 2024 through collaboration with the Directorate-General for Land and Sea (DGTM) and the French Guiana regional authority.

LAUNCH OF PFASTWIN WITH THE UNIVERSITY OF BELGRADE

The aim of the PFAStwin project is to build the capacity of the Faculty of Chemistry at the University of Belgrade (UBFC) in the analysis and (bio)remediation of areas contaminated with Perfluoroalkyl and Polyfluoroalkyl Substances (PFASs) and to manage Horizon Europe projects through collaboration with institutes in partner countries: France and Spain. Professor Vladimir Beskoski was welcomed to BRGM as a guest researcher in October 2023 to visit our premises and experimental facilities and to exchange views with our researchers. A workshop was held on the topic of PFASs, with presentations of work carried out on the subject at BRGM, UBFC and the Swedish Geotechnical Institute (SGI).

Agent collecting sargassum on Viard beach (Petit-Bourg, Guadeloupe, 2023).
© BRGM – S. CHAPRON

ENVIRONMENTAL IMPACT OF SARGASSUM: RISK OF ARSENIC AND CHLORDECONE

BRGM is coordinating the ANR SargAs&CLD project (2020–2023) with six partners, on the environmental risks associated with sargassum (brown seaweed) in the French West Indies. Sargassum, which washes up on beaches and is then stored inland, contains arsenic and chlordecone. It releases leachate with arsenic levels of up to 10 mg/L, produces arsine gas, and also contains potentially pathogenic microbial genera. This situation is of great concern to the local authorities and local populations. The sociological aspect of the project shows that 38% to 52% of those questioned trust the State to manage the crisis and only 5% to 10% trust scientists! BRGM's work shows that these substances in sargassum leachate can be eliminated using natural geomaterials from Martinique and French Guiana, and activated carbon doped with iron. BRGM is working with local authorities to design leachate treatment units and to study the environmental risk posed by sargassum on beaches and its storage in the ground.

PROTECTING MAYOTTE'S LAGOON FROM SOIL EROSION AND SILTATION

Mayotte's lagoon is under threat from terrigenous inputs, not only from the "padzas" (badlands) but also, and above all, from weeded agricultural plots (cassava, bananas) and the many construction sites aimed at coping with potential demographic pressure (+45% of inhabitants in 10 years). As part of the Leselam project undertaken in 2015 (to combat soil erosion and siltation of the lagoon in Mayotte), an observatory has been set up in three catchment areas to continuously monitor run-off and erosion. By integrating the data collected into the Watersed sediment transfer model, BRGM was able to produce the first quantitative map of the island's erosion, in 2018 and then 2022: in four years, the amount of soil ending up in the lagoon has increased by 17% (almost 25,000 tonnes in 2022)! The Leselam project also involves disseminating best practice among farmers, raising awareness among the local population, including children (presentations in schools) and various communication campaigns (films, cartoons, plays, etc.).

Panache turbide dans le lagon de Mayotte.
© BRGM

POST-MINING

Energy was a key topic in 2023. At the very start of the year, in January, we ensured the continuity of the power supply to pumping stations in the Nord-Pas-de-Calais basin to compensate for possible load shedding by ENEDIS. Among the many operations carried out, in relation to gas risks, we should note in particular the work conducted to ensure the safety of the former mine shafts in the Nord-Pas-de-Calais coalfield basin, as well as the discovery and treatment of a mine gas leak in Lorraine, two delicate operations carried out in an urban environment. We should also mention the work carried out to prevent the risk of collapse by infilling a near-surface cavity in the Normandy iron-ore basin, as well as the operations conducted to negate the environmental risk of two mine dumps in the Var *département*.

Nord-Pas-de-Calais: emergency monitoring and work on two former coal mine shafts

VALÉRIE WYPYCH
Deputy Director
DPSM-UTAM NORD

The Nord-Pas-de-Calais coal basin, which was the largest in Europe, was mined between 1734 and 1990. It covers an area of 100 km x 30 km and goes down to a depth of one kilometre. The sheer size of the site is impressive, with 100,000 km of galleries, 622 shafts and residual voids representing 1.7 km^3. More than 2.4 billion tonnes of coal were extracted from the mine over its life-time.

However, coal naturally contains mine gas (methane). This gas fills the residual voids where its pressure gradually builds up due to a number of factors, such as barometric pumping, stack effect or progressive flooding, which causes it to migrate to the surface. Five mine-gas reservoirs have been identified in the basin and these are monitored through 540 facilities.

This phenomenon, which can have an impact on people and property, has already been observed at several points in the basin. To remedy the problem, passive venting devices need to be installed. Considering the gradual increase in pressure and the gas's methane content, as well as the potential danger, this safety system sometimes needs to be reinforced.

Such steps have already been taken on two sites in the basin: at the Mon Désir North and South shafts on the Vieux-Condé concession, which were equipped with a remote manhole connected to a degassing vent in 2005. An in-depth assessment of their monitoring process was carried out by the DPSM (Mine Safety and Prevention Department) in June 2021. In 2023, the DPSM carried out emergency work to modify these vents. These are standard operations, which have been tried and tested in other basins; however, such steps are increasingly required in the Nord-Pas-de-Calais basin.

This work demonstrates the changing nature of the mine deposits and the need to monitor the reaction of the reservoirs to various natural phenomena (temperature, pressure, gradual flooding, etc.). This work is also representative of our core business..

Filling in the channel for the pipe linking the remote manhole to the vent hole of the Mon Désir North shaft.
© BRGM

Gas measurements being taken by DPSM-UTAM EST agents.
© BRGM

SECURING METHANE EMISSIONS IN THE URBAN ENVIRONMENT OF PETITE-ROSSELLE

In the Lorraine coalfield, GRDF has measured methane in the Petite-Rosselle municipality (57), above former mining areas. The DPSM took measurements to determine the extent of the phenomenon, quantify it and characterise the gases found (CH_4, H_2S, CO, O_2, CO_2), and to determine their origin. The field campaigns carried out by the DPSM-UTAM EST verified that the dwellings did not have any significant methane content. Isotope analyses indicated that the gases most likely came from a mine. The history of coal mining in this commune, as well as the presence of numerous geological faults, seem to explain how these gases migrated from the coal towards the surface. The DPSM has installed a drainage system at two depths, connected to an outlet, to prevent gas emerging in significant concentrations on the surface, and thus protect residents and road users.

Overall view of the Lenté mine dump under construction.
© BRGM

FILLING IN THE CAVITIES OF THE FORMER IRON ORE MINE AT MAY-SUR-ORNE

Since 2008, the DPSM-UTAM CENTRE-OUEST has been carrying out video-laser surveillance of a section of the "Z20a" gallery located under a building at a depth of just five metres, in the commune of May-sur-Orne (14). Given that it was close to the surface, the area had to be made safe. The chosen solution was to completely fill in the identified voids, in two phases, following the discovery of additional voids. This operation eliminated the risk of sink-holes (collapse of the ground on the surface) and reduced the level of risk from "high" to "low". But it also eliminated the need for an annual video-laser inspection of two boreholes.

Directional drilling with a 28° incline and a depth of 8.8 m, to search for voids under the building.
© BRGM

REHABILITATION OF HYDRAULIC NETWORKS AT MINE DUMPS IN FONTSANTE

The Fontsante fluorite mine in Tanneron (Var *département*), which operated from 1963 to 1986, produced 400,000 to 800,000 tonnes of tailings rich in fluorine and trace metals, including arsenic and aluminium, which are stored at the Lenté and Saint-Barthélemy mine dumps, 2 km upstream of the Saint-Cassien reservoir, which supplies drinking water to Cannes. Both dumps are monitored by the DPSM-UTAM SUD as part of its post-mining mission. Erosion of the covers of the dumped materials, a topography favourable to infiltration, as well as the occurrence of resurgences, with precipitation of iron oxyhydroxides on the periphery of the dumps and peaks in the concentration of arsenic and fluorine in the water reaching the Saint-Cassien reservoir, led the DPSM to recommend to government departments that these two deposits be restored by partially remodelling their covers and by consolidating their hydraulic networks. The work was carried out from October 2022 to April 2023, with the support of a project management team and ecological site-supervision. Clearing the land, followed by earthworks at the Lenté dump, involved stripping topsoil, stripping an asphalt model-aircraft runway, creating a storage cell for site waste, filling in topographical troughs and reprofiling the cover. This was followed by the rehabilitation and creation of hydraulic networks, the reseeding of areas exposed by the works, and finally the reinforcement of the peripheral anti-intrusion system around the two dumps (fences, access barriers, etc.).

Shredding circuit boards is the first stage of a gold and palladium recovery process.
© BRGM – D. Depoorter

MINERAL RESOURCES AND THE CIRCULAR ECONOMY

Drawing on knowledge and expertise to secure mineral supplies

Securing sources of strategic metals that are essential to digital and energy transformation has become a major challenge for Europe as a whole, as part of its industrial recovery. The new European regulation on critical raw materials, published in 2023, requires Member States to assess their mineral resource potential. In France, an inventory led by BRGM is due to be launched shortly. The institution, which covers the entire mineral materials value chain, is also specialised in life-cycle analysis and technological innovation to improve processing and recycling.

OUTSTANDING RESULT

Predictive modelling to optimise the search for and exploitation of mineral resources

Predictive modelling is used at every stage of the mineral-resource cycle, from helping to discover new deposits to the re-use of mining waste. The aim is to maximise yields, cut costs and reduce the environmental impact of exploration and exploitation operations, against a backdrop of a shortage in supplies of critical mineral resources.

Guillaume Bertrand, specialised in mineral resources, uses predictive modelling to assist exploration operations by producing a map of the likelihood of the presence of mineral deposits. This process is called 'predictive mapping'. *"It increases the probability of discovering deposits by guiding exploratory work towards the most favourable locations. This type of work is costly and requires increasingly invasive techniques as it progresses. Consequently, these operations need to be carefully targeted to optimise the cost/benefit ratio and limit their impact on the environment."* Since one of the uses of the subsurface involves the extraction of natural resources, predictive mapping also provides a decision-making aid for spatial planning.

There are a number of projects that aim to develop this type of tool, particularly in order to secure France's supply of the critical raw materials used in the energy and digital transition. This is the objective of the GSEU (Geological Service for Europe) project, launched at the end of 2022. The project brings together 48 organisations and aims to set up a geological service at the European level. BRGM is coordinating the section on mineral resources. *"GSEU follows on from the GeoERA-Frame project, which ended in 2021 and included a Europe-wide predictive-mapping programme for seven critical mineral resources,"* explains Guillaume Bertrand. *"The GSEU project extends the scope of the work to cover all the substances considered critical in Europe, with a focus on those required for the energy transition. It aims to fine-tune the mapping of major geological provinces such as the Iberian belt and the Fennoscandian shield."* The overall objective is to facilitate the discovery of new deposits in order to relocate part of the extraction and production of critical mineral resources to Europe, as provided for by the Critical Raw Materials programme.

GUILLAUME BERTRAND
Geologist specialised in mineral resources

DOUGLAS PINO HERRERA
Research Engineer in (bio)process engineering

SYLVAIN GUIGNOT
Research Engineer, Project Manager

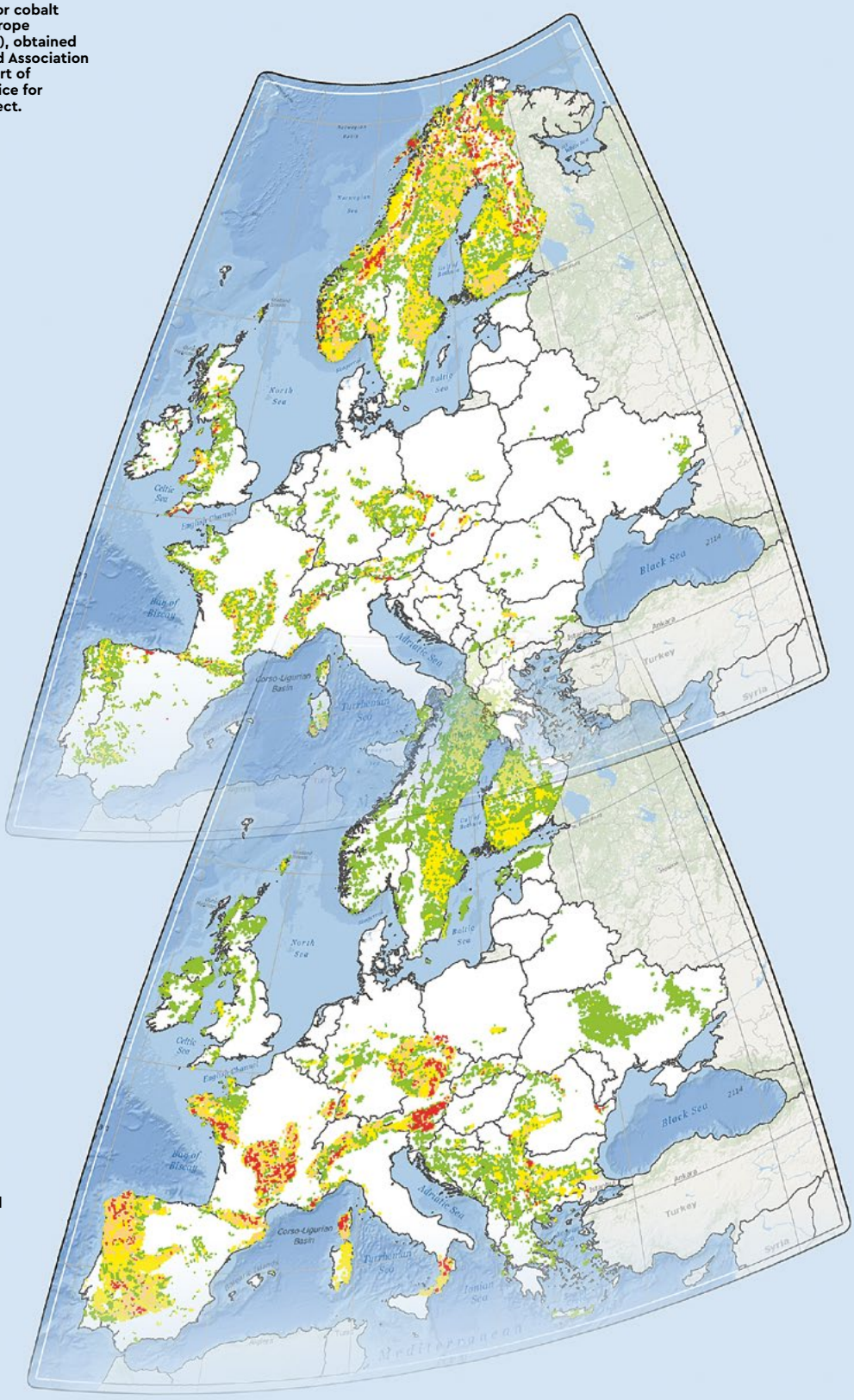
Predictive mapping can be enhanced – as in the case of the current EIS (Exploration Information System) project – by deposit models which increase its accuracy and reliability, by making it easier to understand the processes involved in the formation of mineral deposits.

Combining simulations and LCA (life cycle assessment)

Digital modelling is also used to study the processes for extracting metals from ores, in particular through bioleaching, a technique which uses bacteria. *"BRGM has developed Computational Fluid Dynamics (CFD) models, as well as kinetic and thermodynamic models, to describe, understand and predict the physico-chemical and biological phenomena at work during this process and to assess the consumption of reagents and energy,"* explains Douglas Pino Herrera,

Favourability map for cobalt mineralisation in Europe (preliminary version), obtained using the Disc Based Association (DBA) method as part of the Geological Service for Europe (GSEU) project.
© BRGM

Cobalt favourability
- Very low
- Low
- Medium
- High
- Very high



Favourability map for lithium mineralisation in Europe, obtained using the Cell Based Association (CBA) method.
© BRGM

Lithium favourability
- Very low
- Low
- Medium
- High
- Very high

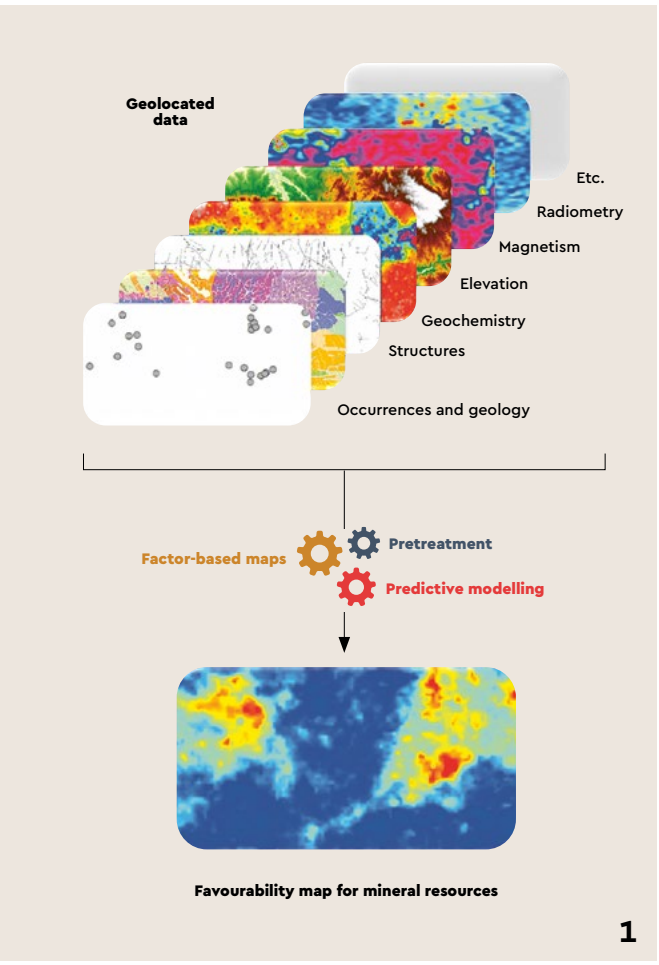


Image 1 — Diagram of the main types of data that can be used in predictive mapping and the main stages in processing them. © BRGM

Image 2 — CFD modelling of fluid behaviour in a stirred-tank bioleaching reactor. CFD helps predict the fluid's energy dissipation (left) and the speed and direction of its movement (right). © BRGM - C. LOUBIÈRE

a (Bio)Process Engineer. *"This allows us to determine which physico-chemical and hydrodynamic conditions improve efficiency and effectiveness."*

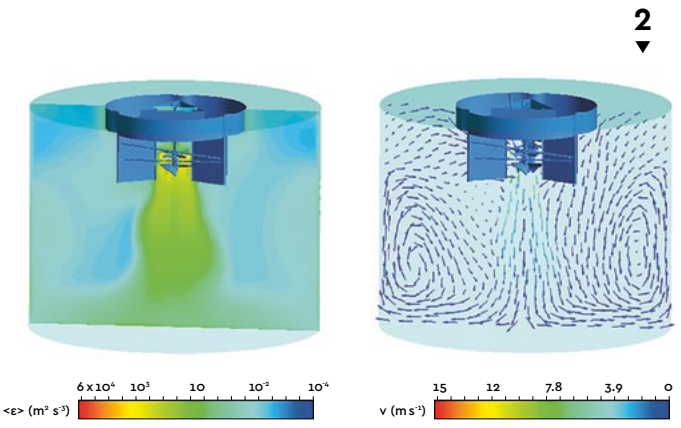
Process simulation can also be used as part of the life cycle assessment (LCA) method applied to mineral materials, in order to determine their environmental impact depending on the techniques used. *"This kind of method-coupling can be found in European projects such as HiQ LCA and CICERO, which started in 2023, or InnovTech, which is part of the "SUBSURFACE: a common good" French priority research and equipment programme (PEPR). These projects explore the eco-design of extraction and purification processes, particularly for nickel and cobalt,"* says Douglas Pino Herrera. Finally, modelling helps to assess the technical and economic feasibility of a process, from its development to its industrialisation. For example, the H2020 NEMO project, which ended in 2022, sought to reduce the costs of bioleaching to make the process viable for extracting metals from mining waste.

Recovering and reusing materials

The Iterams project, which was completed in 2020, already looked at recovering and reusing processing residues. *"This is still a key issue,"* says Sylvain Guignot, a Research Engineer

"We're particularly interested in the sludge produced by copper and nickel extraction, which represents several billion tonnes a year worldwide!" This sludge is discharged into large basins and represents a risk in terms of environmental pollution, particularly when it comes into contact with water, but it also contains elements that could be reused, such as silica and aluminium. *"The sludge has been solubilised; however, using geo-polymerisation techniques, it can be reformed into materials that can potentially be used on site to cover storage basins or as backfill for cavities created by mining, for example."* Consequently, BRGM has developed a geochemical model of these mechanisms, which can be used to assess the geo-polymerisation potential of sludge and predict the properties of the materials formed, particularly their compression resistance. *"This model effectively reflects the cases we have studied, but needs to be developed further before it can be generalised."*

"Predictive modelling increases the probability of discovering deposits by guiding exploratory operations towards the most favourable locations in order to optimise the cost/benefit ratio and limit their impact on the environment."



— PARTNER INTERVIEW

BENJAMIN GALLEZOT
Inter-ministerial Delegate for Strategic Metals and Minerals Supply (DIAMMS)

"BRGM is a key player in our strategy for strategic minerals and metals, a major issue for our industry."

What are the new challenges in terms of procuring strategic metals and minerals?

BENJAMIN GALLEZOT — The need for strategic metals is set to rise sharply over the coming decades, particularly as part of the energy transition. Ensuring a steady supply of these metals is a major issue for our industry, and the government has embarked on an ambitious policy to mobilise all stakeholders. BRGM has a very important role to play in this matter. It is one of the key players in our strategy, and one of the main partners responsible for its implementation. It already has extensive knowledge of critical minerals and metals, and is currently re-prioritising this issue as part of its activities.

What projects are involved?

B.G. — Firstly, OFREMI. Founded following the Varin report on the supply of strategic metals, the French Observatory of Mineral Resources for Industrial Sectors (OFREMI) was set up a year and a half ago. BRGM is one of the key players, coordinating the action of the various public institutions involved. Secondly, the inventory of mineral and mining resources (IRM). Following a decision announced by the President of France in September 2023, the aim is to relaunch an exploration and inventory programme that has not been carried out for many years, using new techniques and new know-how. BRGM is the project manager. We expect regular results, and cooperation with an ecosystem of companies, laboratories and university centres, so that we can apply the best technologies, particularly artificial intelligence. An important aspect will be to make this data available.

Does metal diplomacy also concern BRGM?

B.G. — In what we call 'metals diplomacy', international cooperation between geological surveys is crucial. BRGM is a major player in this technical cooperation in Europe and around the world, and we are stepping up our partnerships with new countries. Lastly, BRGM and DIAMMS are aiming for a better coordinated R&D strategy that brings together all the players in academia and industry, and that is more ambitious in terms of innovation.

OFREMI LAUNCHES AN OBSERVATORY STUDYING THE PRICE OF INDUSTRIAL METALS

In 2023, the French Observatory of Mineral Resources for Industrial Sectors (OFREMI), the Union of Metallurgical Industries and Trades (UIMM) and the Ore, Minerals and Metals Alliance (A3M) launched a new quarterly publication to provide French government and industry with an overview of the prices of metals listed on the London Metal Exchange (LME), along with a brief report of the economic situation. Statistical models for short-term price forecasts were also developed with the help of economists from the University of Paris Dauphine-PSL. The first issues – on copper and nickel – were published in July 2023 while the last will appear on 15 April 2024. The publication is available online. These issues will henceforth be incorporated into SI-OFREMI, a secure digital platform currently under development, which will bring together all the data and analyses produced by the observatory.

A SUSTAINABLE IONOMETALLURGICAL PROCESS FOR TREATING CERTAIN ORES

Launched in 2019 and completed in late 2023, the H2020 ION4RAW project involved 13 partners including BRGM. The project developed a soft leaching process using ionometallurgy, which has been tested on a pilot scale on different types of polymetallic ores from three countries (Spain, Peru and Scotland). Combining eutectic solvents and electrochemical recovery of the leached metals, this innovative process extracts the main economic metals Cu, Ag and Au, as well as concentrating a number of by-products not previously recovered, among the project's target metals (Bi, Co, Ge, In, Mo, Pt, Re, Sb, Se and Te). As part of this project, BRGM was asked to conduct a detailed characterisation of the chemical and mineralogical composition of the ores in order to understand the distribution of these small disseminated metals and to identify the carrier mineral species to understand the efficiency of the recovery process. A map has also been produced, assessing the potential of by-products in Europe.

AN AGREEMENT WITH MANAGEM FOR THE SUSTAINABLE EXPANSION OF ITS ACTIVITIES

In July 2023, BRGM signed a framework partnership agreement with Morocco's Managem, a major historic mining operator with 22 sites and 6,000 employees on the African continent. Based on jointly chosen strategic priorities, this collaboration should help the Moroccan group achieve its ambitions for developing its business in Africa and for sustainable, responsible growth. The first three projects under construction seek to understand the potential of various materials essential to the energy transition in several regions, including Marrakesh, the Sirwa massif and the southern provinces.

Cobalt cathodes produced and marketed by Managem.
© BRGM – C. BONIN

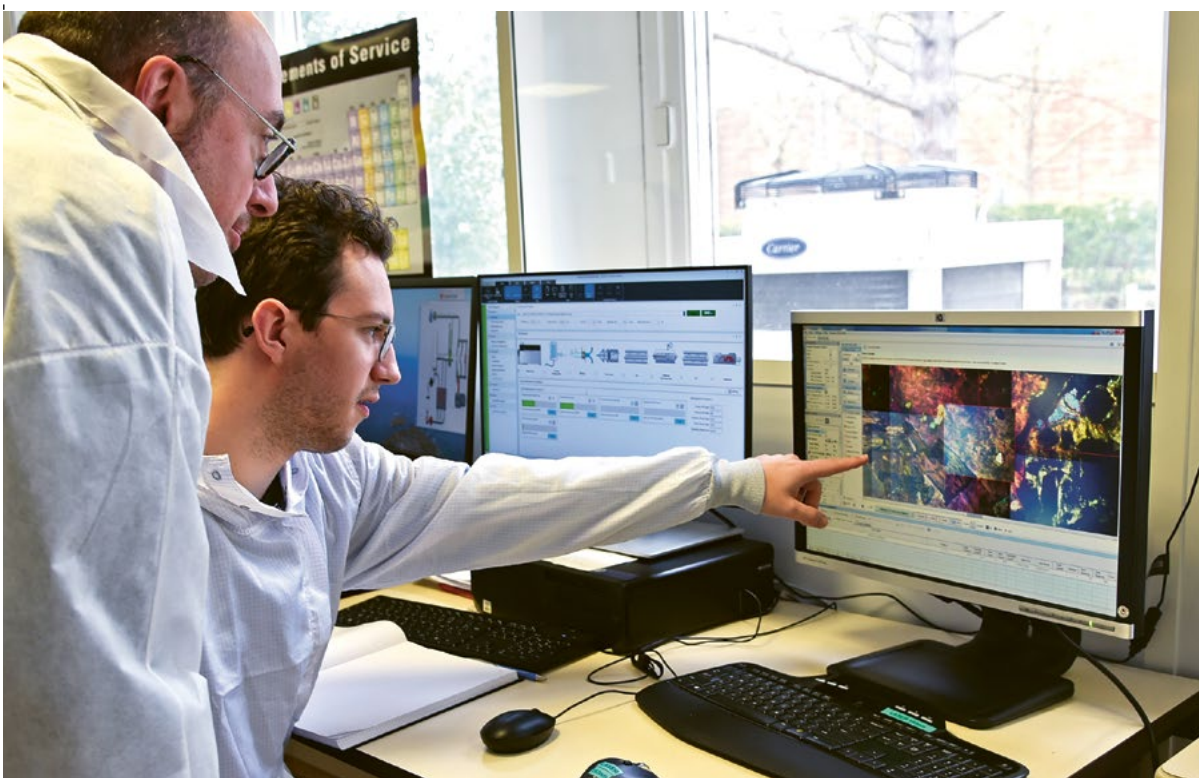
MADITRACE FOR MORE RESPONSIBLE SOURCING OF MINERAL RAW MATERIALS

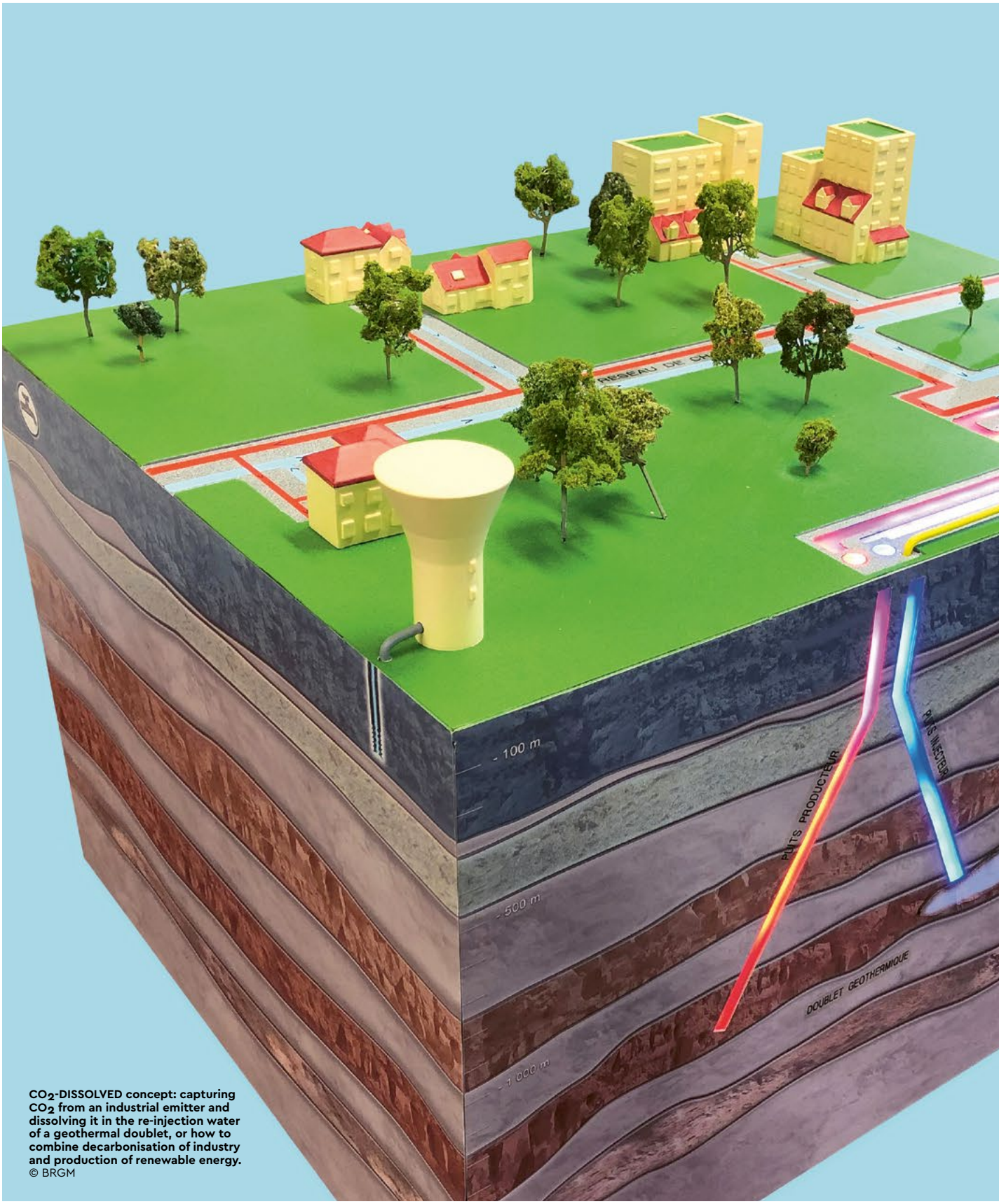
Focusing on the traceability of mineral raw materials for batteries and electric mobility (cobalt, lithium, graphite, rare earths), the Horizon Europe MaDiTraCe project aims to promote responsible industrial practices. The aim is to build a system that, via the "battery passport", clearly identifies the sources for end consumers, while ensuring compliance with international standards.
The methodology combines the advantages of traceability through geochemistry and materials science with those of digital tools such as blockchain. The aim is not only to secure the supply chain, but also to strengthen transparency and stakeholder confidence, and to respond to growing concerns about sustainability.

THE UNFC CLASSIFICATION FOR ASSESSING PROJECTS INVOLVING CRITICAL RAW MATERIALS IN FRANCE

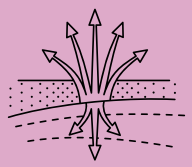
Previously, the European Commission (DG GROW) encouraged Member States to report annually on the progress of critical raw materials production projects using the UNFC mineral resources classification system developed by the United Nations. With the CRM Act making such monitoring mandatory, DG GROW is currently developing a comprehensive database for the European Union, with the support of the European Geological Surveys. Under an agreement with the Ministry of Ecological Transition and Territorial Cohesion, BRGM is responsible for adapting the UNFC methodology to the French context, and for identifying and classifying projects involving critical raw materials, through active monitoring. Already involved in European projects for which this system is implemented (GSEU, FutuRaM), the institution is also promoting the application of UNFC in France and taking part in international seminars to present its results.

Chemical purification of neodymium to study the traceability of rare earths contained in permanent magnets.





CO_2-DISSOLVED concept: capturing CO_2 from an industrial emitter and dissolving it in the re-injection water of a geothermal doublet, or how to combine decarbonisation of industry and production of renewable energy.
© BRGM



SUBSURFACE POTENTIAL FOR ENERGY TRANSITION

The subsurface also contributes to the energy transition

In a context of accelerating energy transition in Europe and rising energy prices, the subsurface and its properties can help to diversify the energy mix with renewable, low-carbon solutions at competitive costs. Underground space can be used for geothermal energy production and energy storage, as well as being an essential element in policies to reduce greenhouse gas emissions by storing CO_2. Drawing upon its know-how and R&D resources, BRGM is seeking to explore, study and exploit the potential of the subsurface, particularly at the regional level. In this way, it is promoting the implementation of economically viable systems with low environmental impact.

OUTSTANDING RESULT

Good practices for controlling induced seismicity in deep geothermal energy projects

BRGM, in collaboration with Ineris, published a good practice guidebook designed primarily as an operational tool for operators, in 2023. Together with a training course, it aims to improve the prevention of seismicity induced by these operations.

JULIE MAURY
Seismologist

PASCAL DOMINIQUE
Seismologist

On 12 November 2019, a widely felt earthquake hit the Strasbourg region. Not far from there, in Vendenheim, two boreholes were being drilled with a view to installing a geothermal doublet extending down to 5 kilometres underground. A committee of experts concluded that the operations had induced an earthquake. Although exploration of the site was halted, the event highlighted the need to better assess and address this risk. Hence the decision to draw up a guidebook aimed at reinforcing preventive measures for deep geothermal operations.

At the request of the General Directorate for Risk Prevention (DGPR) within the Ministry of Ecological Transition and Territorial Cohesion, and the General Directorate for Energy and Climate (DGEC) within the Ministry of Energy Transition, BRGM and Ineris are tackling the task, in the wake of the 2021 reform of the Mining Code and the Climate and Resilience Act. There are many, complementary challenges: *"The need is to secure the investments of deep geothermal energy operators, support the public policies of local authorities in terms of energy transition and reassure the population that operations are carried out in a responsible and controlled manner," explains Pascal Dominique, a seismologist. "In a context of climate change, this renewable, non-intermittent energy source can contribute to the transition to a lower-carbon energy mix."*

Applicable to all deep geothermal energy projects

Published in June 2023 and available on institutional (ministries, BRGM, Ineris, etc.) and specialist websites (geothermies.fr), the "Guide to good practice for controlling seismicity induced by deep geothermal operations" is aimed at all stakeholders in the sector: operators, public authorities, local residents, elected representatives and associations. It is also applicable to all deep geothermal projects, covering the different types of geothermal reservoirs and operating methods encountered in mainland France and the French overseas departments and regions. Designed as an instruction manual, it is based on extensive feedback, and on the ...

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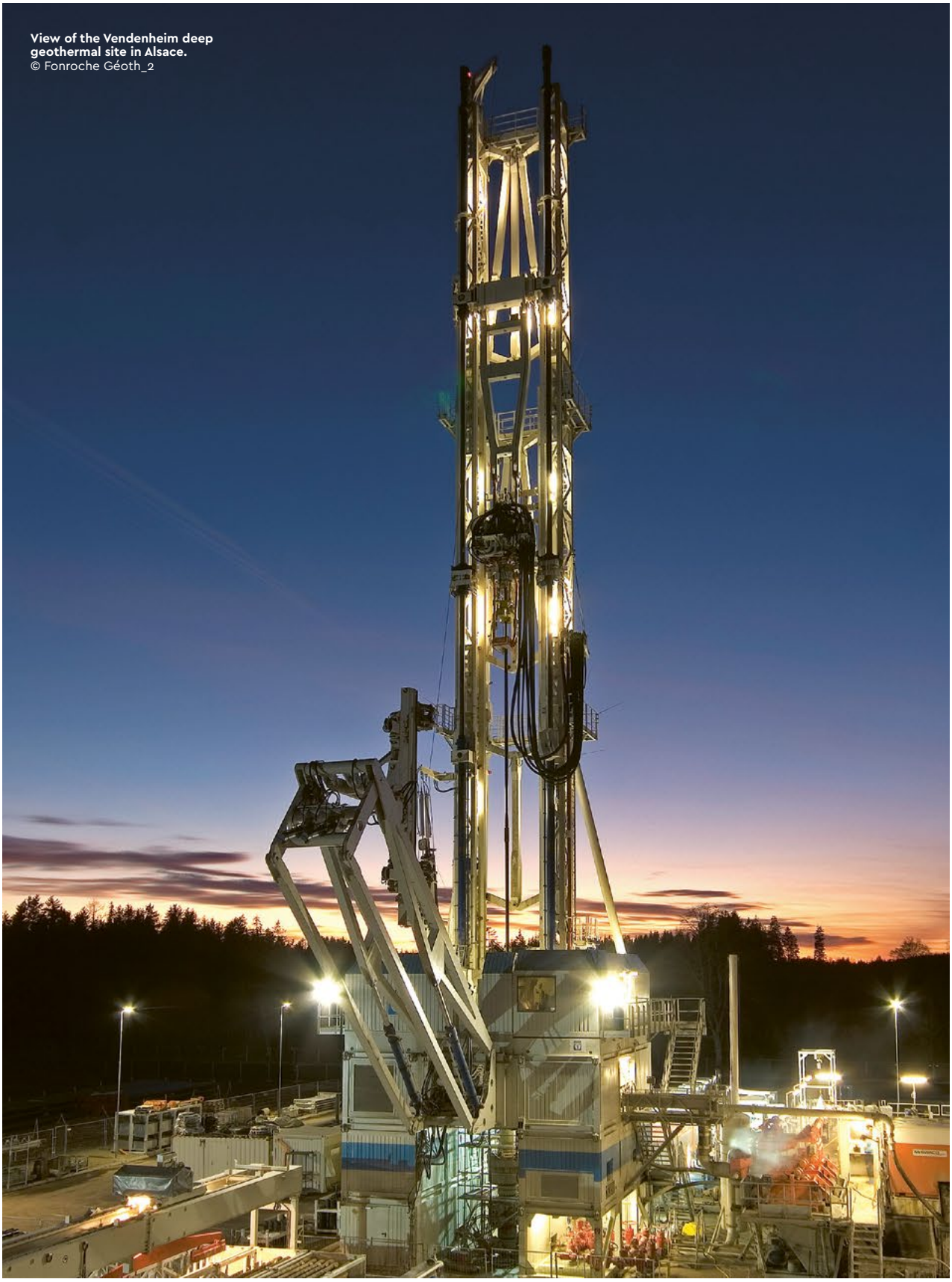

View of the Vendenheim deep geothermal site in Alsace.
© Fonroche Géoth_2

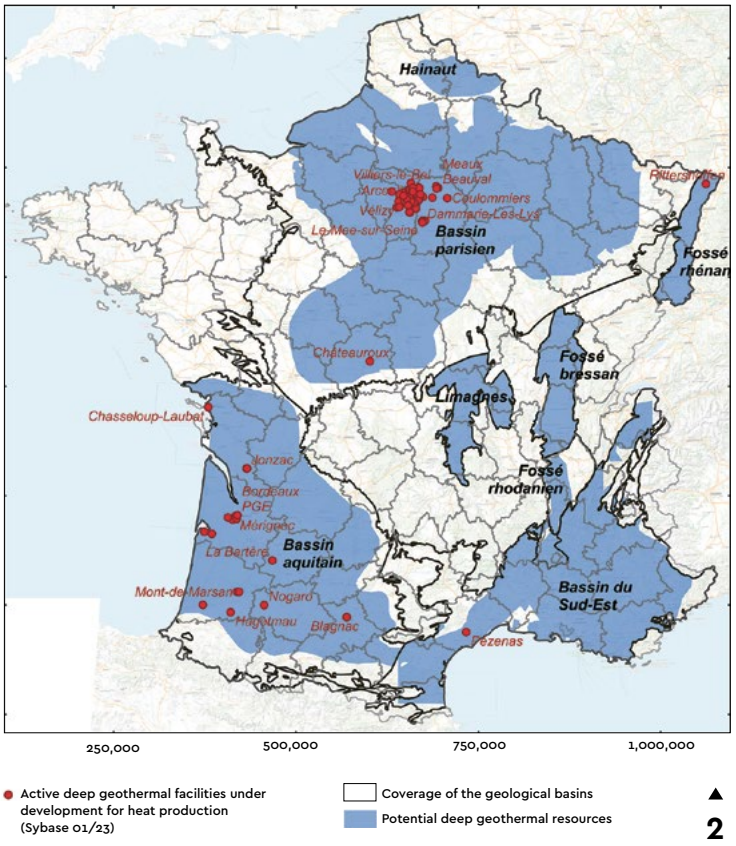

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Image 1 — The *Guide to good practice for the control of seismicity induced by deep geothermal operations* is intended to be enriched in the future by the experience and knowledge of the various players in the sector. © BRGM

Image 2 — Map of potential deep geothermal resources and active deep geothermal facilities under development for heat production. © BRGM

current state of scientific knowledge in the field of seismicity induced by the injection of fluid deeply into the subsurface and a method developed by BRGM and Ineris. *"We have chosen,"* explains Julie Maury, a seismologist, "*to propose 'decision trees': at each key stage of a project, from before the first drilling to the end of the activity, and during the stimulation periods, the guidebook helps operators to assess the level of induced seismic risk. It also provides recommendations on the data to be acquired to anticipate the hydromechanical behaviour of the reservoir as far as possible, as well as on the monitoring network and the management of operations according to the level of seismic risk.*" Furthermore, it lays the foundations for defining protocols for deploying operations based on the technologies used and the micro-seismicity detected.

At the interface between research and industry

The publication of this guide was accompanied by training days in October 2023. In addition, BRGM and Ineris will be offering a training course based on the lessons learned and the recommendations made, at the end of 2024 and every year thereafter. The aim is the same: to encourage operators to take more care to prevent the risks associated with seismicity induced by deep geothermal operations.

"This guidebook fills a real gap and enables the dissemination and sharing of best practice to encourage the continued development of deep geothermal energy in France, by strengthening project management."

"For any project of this type, it is essential to have thorough knowledge of the subsurface geology and to understand the natural phenomena, particularly seismic phenomena, likely to be triggered by the work, in order to minimise their probability and intensity," concludes Pascal Dominique. Located at the interface between research and industry, the guidebook will be updated regularly. *"Depending on the applications to which it is put, advances in knowledge and new feedback, the content may be enriched, clarified or modified,"* says Julie Maury. *"The guidebook,"* continues Pascal Dominique, *"is the first reference framework – there were none until now – for this risk. It fills a real gap and enables the dissemination and sharing of best practice to encourage the continued development of deep geothermal energy in France, by strengthening project management."*

SOPHIE MOURLON
French Director-General for Energy and Climate

"Whether for geothermal energy or using the subsurface, our collaboration with BRGM is extremely valuable. BRGM provides high-level expertise, and the complementarity between experts and administration is very effective."

Why has the DGEC decided to work with BRGM?

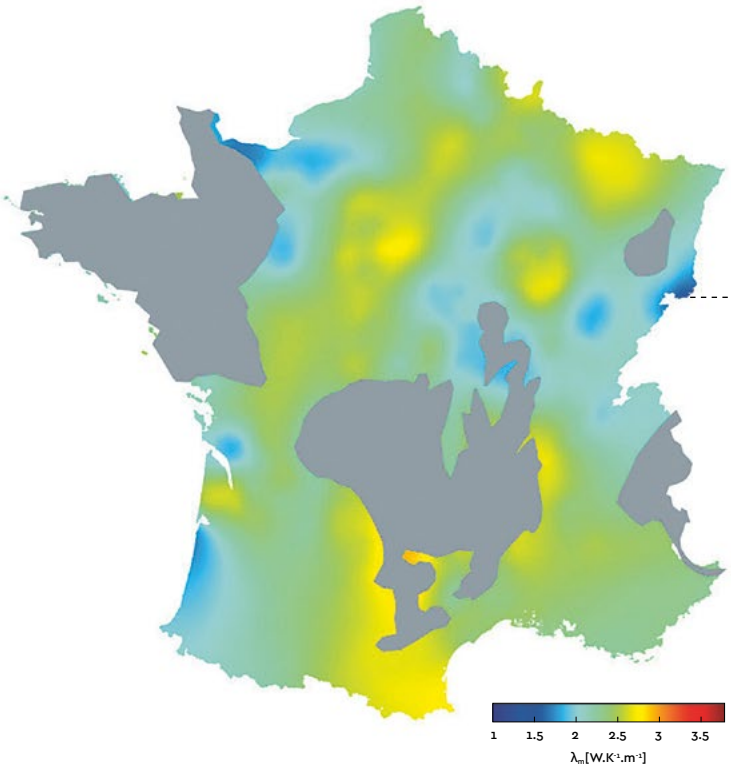
SOPHIE MOURLON — The task of the General Directorate for Energy and Climate (DGEC) is to draw up and implement policy on energy, energy raw materials and the fight against global warming and atmospheric pollution. With respect to the subsurface, the DGEC is working in particular to develop the geothermal sector, which has major potential for decarbonising heat production. The objectives of France's next energy and climate strategy call for a sharp increase in the pace of deep and near-surface geothermal energy projects. To accelerate this development, the government launched a national action plan in February 2023, which was then updated in December 2023.

What work is BRGM carrying out in this framework?

S.M. — To implement the plan, BRGM is working to improve knowledge of the subsurface and thus encourage the launch of deep and near-surface geothermal energy projects. For near-surface geothermal energy, the first step is to map the thermal properties of the ground so that vertical geothermal probes can be installed. For deep geothermal energy, the work requires identifying and analysing sufficiently recent geological data (boreholes, seismic lines), particularly in regions that are likely to be able to exploit the resources identified in the short term (presence of a significant number of heating networks to be decarbonised, prospects for the deployment of new heating networks, etc.).

What role does deep geothermal energy play in overseas France?

S.M. — Overseas territories such as Réunion, Mayotte, Martinique and Guadeloupe are all located in active volcanic island regions, making them ideal for the development of geothermal energy, which is non-intermittent and carbon-free, particularly for generating electricity. To date, only Guadeloupe has a geothermal power plant in operation. In the wake of the Act to accelerate the development of renewable energies, BRGM is preparing a report on the potential for geothermal energy in areas that are not connected to the French mainland grid, in particular La Réunion, which will be submitted to Parliament and made public. The geothermal potential of most of these islands is real, even though it needs to be confirmed by costly exploratory drilling (several million euros). ●



NEW STUDIES TO **PROMOTE THE DEVELOPMENT OF GEOTHERMAL ENERGY IN FRANCE**

As part of the government's plan to accelerate the deployment of geothermal energy, BRGM signed a multi-year agreement with the French government in 2023, covering a number of studies. A national deep geothermal inventory has thus been launched, with the aim of characterising deep geothermal targets more precisely. This tool should encourage project owners and operators to follow suit. BRGM has also begun to draw up a national map of energy labels for the deployment of vertical geothermal probes. The aim is to encourage the deployment of this technology, particularly for small-scale operations.

Estimation of the thermal conductivity of the subsurface over a depth of 100 m, one of the parameters required to calculate an energy label for the subsurface (shaded areas currently being assessed).
© BRGM

HYLIFE AND MICROBIAL IMPACTS ON HYDROGEN STORAGE

To guarantee the safety, efficiency and economic viability of its underground storage, it is crucial to understand the impact on hydrogen (H_2) of the many micro-organisms naturally present underground and likely to feed on it. The HyLife project, launched at the end of 2023, involves establishing a European overview of the diversity and activity of these micro-organisms, through the analysis and characterisation of several potential storage sites throughout Europe (salt caverns, aquifers, depleted reservoirs). The aim is to identify key factors and select the most favourable sites.

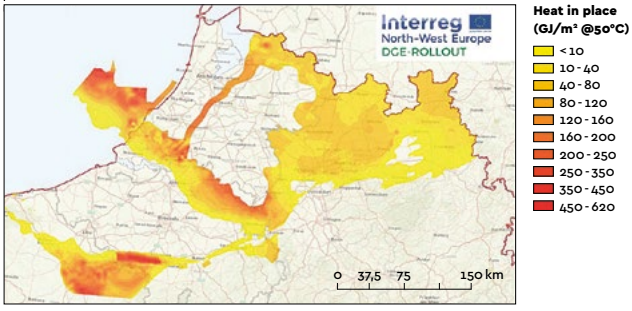
MIMAROC: THE PLATFORM IS OPERATIONAL

A BRGM laboratory, the MIMAROC platform, was inaugurated in 2023. It combines *in situ* experimental cells and digital image analysis resources for *in operando* monitoring of thermo-hydro-mechanical-chemical (THMC) processes. The THMC models developed in this way will enhance the ability to predict changes in underground systems on the time-scales needed to assess the safety of the technologies studied, particularly for geothermal energy and CO_2 storage.

SUPPORTING THE EXPANDED USE OF DEEP GEOTHERMAL ENERGY IN NORTH-WESTERN EUROPE

Bringing together France, Germany, the Netherlands and Belgium, the DGE-ROLLOUT project (2019–2023) aims to promote the use of deep geothermal energy in Dinantian limestone (Carboniferous) for district heating networks. Focusing on the Hauts-de-France region, BRGM has studied the potential for deep geothermal energy, including surface needs, in order to identify areas that are favourable for deploying this technology. Based on these results, Engie Solutions has proposed a geothermal energy project for the Renault plant in Douai, enabling 67% of its thermal needs to be decarbonised.

Heat in place map for the Dinantian reservoir in North-West Europe.
© BRGM



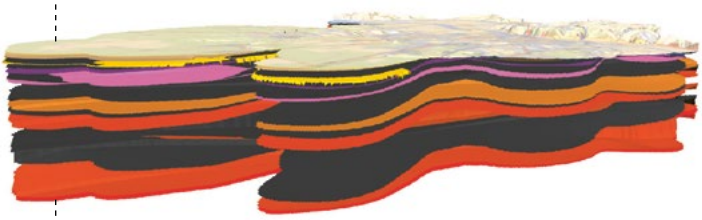
CO_2-DISSOLVED; TOWARDS INDUSTRIAL AND COMMERCIAL DEPLOYMENT

The CO_2-Dissolved project has entered a new phase. Following a positive technical and economic assessment of the concept, which combines the storage of dissolved CO_2 in an aquifer and the recovery of geothermal energy, a new partnership agreement has been signed between BRGM, SLB and Sageos to develop an initial commercial pilot. Two sites are being considered, in Centre-Val de Loire and Île-de-France, where pre-feasibility studies will begin in 2024. This first pilot could be operational within two to five years.

DEVELOPING SURFACE GEOTHERMAL ENERGY IN THE GREATER BORDEAUX AREA

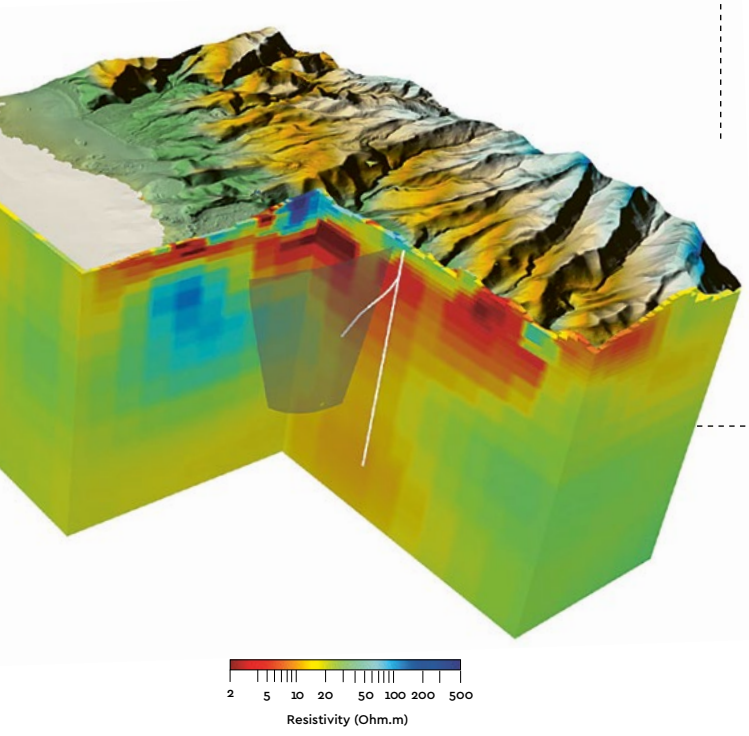
Between 2018 and 2023, BRGM worked with Bordeaux Métropole, with the support of Ademe, on an R&D programme to develop surface geothermal energy in the area. An online application was created to provide information on geothermal resources in the first few hundred metres of depth. A study of the potential for covering the needs of buildings using geothermal energy was also undertaken, but it was not possible to assess this due to a lack of data. Finally, support for project sponsors has enabled many geothermal facilities to be set up in the region.

Geological model of the Bordeaux Metropolitan area representing the subsurface to a maximum depth of 660 m. The layers shown are: in colour, the roofs of the main aquifers that make up the aquifer geothermal resources; in black, the roofs of the main low-permeability formations.
© BRGM



... AND THE CHARTRES METROPOLITAN AREA

Near-surface geothermal energy could cover up to 36% of Chartres Métropole's heating and domestic hot water needs. This is the conclusion of a BRGM study which, together with the Buildings Scientific and Technical Centre (CSTB), involved estimating the needs of buildings and assessing the energy potential of near-surface geothermal energy (assisted by heat pumps) in the region. The maps produced combine subsurface characteristics, building requirements, land zoning and regulatory constraints and urban density.

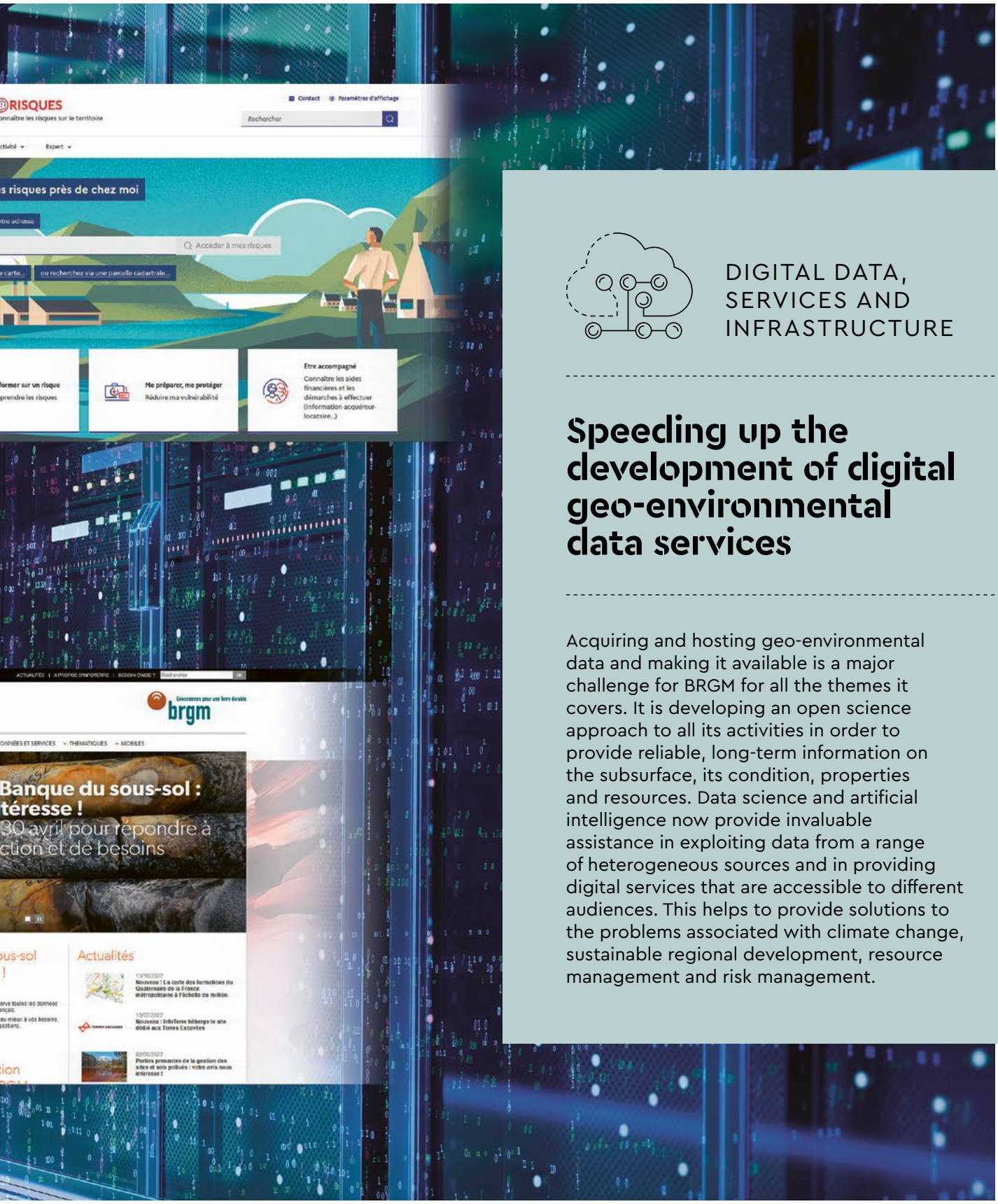


Resistivity model around the Bouillante power plant, revealing a potential geothermal reservoir. The model was produced for the first time using a joint land-sea electromagnetic acquisition method.

CARIBBEAN: TWO INNOVATIVE GEOTHERMAL EXPLORATION METHODS

As part of the Energy Transition in the Caribbean programme (Interreg V – TEC 2019–2023), BRGM has developed a new approach to geophysical exploration in Guadeloupe – subsequently exported to Saint-Vincent - based on a combination of suitable electromagnetic methods. This was used to assess the offshore continuity of the Bouillante geothermal reservoir. BRGM also carried out the first known study of the geochemistry of geothermal waters on the islands of Guadeloupe, Martinique, Dominica, Montserrat and Saint Lucia, one of the main outcomes of which was to improve estimates of the temperature of geothermal reservoirs. BRGM has also submitted a report to the French Parliament on the geothermal potential of the islands of Guadeloupe, Martinique, Réunion, Mayotte and Saint-Pierre-et-Miquelon.

BRGM is developing more and more digital services that structure geo-environmental data and make it accessible in response to societal challenges. © BRGM



DIGITAL DATA, SERVICES AND INFRASTRUCTURE

Speeding up the development of digital geo-environmental data services

Acquiring and hosting geo-environmental data and making it available is a major challenge for BRGM for all the themes it covers. It is developing an open science approach to all its activities in order to provide reliable, long-term information on the subsurface, its condition, properties and resources. Data science and artificial intelligence now provide invaluable assistance in exploiting data from a range of heterogeneous sources and in providing digital services that are accessible to different audiences. This helps to provide solutions to the problems associated with climate change, sustainable regional development, resource management and risk management.

OUTSTANDING RESULTS

EaSy Data collects 'long-tail' data on the Earth and the environment

Set up in 2023, EaSy Data is the national thematic warehouse for so-called 'orphan' or 'long-tail' data on the environment and the Earth system. Forming part of the Data Terra research infrastructure and supported by BRGM, EaSy Data seeks to capitalise on a whole range of public research data in the field of Earth and environmental sciences.

Unlike observational data, which is structured by nature, a significant proportion of the data generated by public research into the Earth system and the environment is not organised and/or shared. They are not systematically archived in warehouses, and not sufficiently documented. These data, referred to as 'orphan' or 'long tail' data, are nevertheless of strategic importance, with the goal being to build on the results of the research behind them.

This is a relatively broad issue, covering all areas of scientific research. However, while the Ministry of Higher Education and Research is keen to encourage the opening up and sharing of data, publications and source codes, through its national plan for open science, the issue has now been resolved in Earth sciences.

HÉLÈNE BRESSAN
Vocabulary and data quality project manager

Wide and compulsory dissemination of public research data

On 6 November 2023, the Ministry of Higher Education and Research inaugurated EaSy Data, France's national thematic warehouse for orphan or long-tail data on the environment and the Earth system.

Supported by the Data Terra national research infrastructure, this repository is operated by BRGM. More broadly, it is part of the national plan for open science initiated in 2018, whose purpose is to structure initiatives to promote the opening up and sharing of data, publications and source codes from publicly-funded projects.

A data warehouse developed by a virtual project team

Warehouses of this type allow researchers to store and reference the data from their work. A national platform, Recherche Data Gouv (RDG), has been created for this purpose, to bring data together. EaSy Data is one of the first components.

EaSy Data has been made available to the scientific community of the Earth system to help them address major environmental issues such as climate change, water resources, natural hazards, sustainable energy and so on. It will allow data to be compared, reused, shared and rediscovered.

This data warehouse applies the ISO 19115 standard for metadata, the international standard for geospatial data. The cataloguing tool used is GeoNetwork, an open source project. Data are stored in the BRGM data centre. The project involved a team of almost 20 people whose expertise was key to the developments carried out with the support of the infrastructure teams.

A 'virtual' steering team held meetings over a period of two years to set up the project: Véronique Bertrand,

The aim of the "EaSy Data" national data warehouse is to centralise, organise and share the large quantity of so-called orphan data on the environment and the Earth system. © BRGM

CNRS - Epos-France; Hélène Bressan, BRGM; Christelle Pierkot, CNRS - DataTerra; and Marine Vernet, IFREMER - DataTerra. An application overlay has been developed to facilitate data entry, tailored to the needs of researchers. A moderation team made up of data centre scientists and volunteers is also on hand to ensure compatibility with the scope defined.

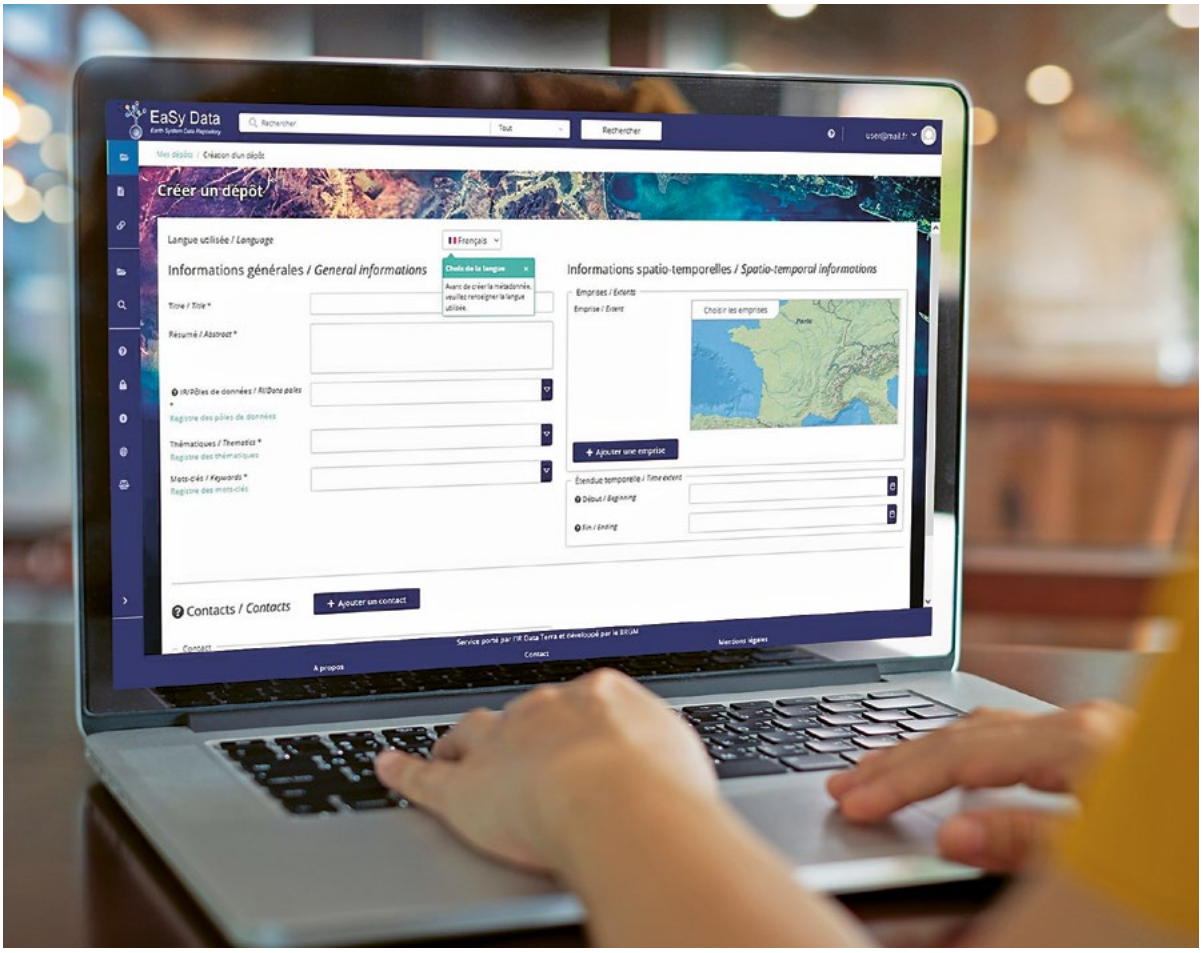
Encouraging feedback from data depositors

The data warehouse is a clear success for BRGM, as well as a great human story about four women who worked on EaSy Data over a period of two years as part of an exclusively virtual approach.

Researchers immediately began to deposit data. Feedback has been encouraging, and the warehouse has already allocated over 20 persistent digital object identifiers (DOIs), showing that it is meeting a real need among different communities. While depositing data is not compulsory, the practice is widely encouraged, as it is clearly in each researcher's interest to share their work, improve data citation and contribute to more reproducible research.

New prospects are already emerging, with efforts to improve access and work on vocabulary and semantics to make data filing easier, for example. The implementation of the EaSy Data warehouse reflects the actions carried out by BRGM as part of its open science policy.

"EasyData is part of the National Plan for Open Science, which seeks to open up and share data, publications and source codes."



The data entry interface for the dataset description allows users to enter the necessary information easily, in French and/or English. Depositors identify themselves using their ORCID or Renater ID, or by creating an account. © BRGM

— PARTNER INTERVIEW

ISABELLE BLANC

Ministerial Administrator of Data, Algorithms and Source Codes, Advisor to the Director General for Research and Innovation and the Director General for Higher Education and Professional Integration. National Chief data and software officer.

"BRGM is leading the way on one of the major issues at the heart of our policies, namely the opening up of its data and its re-use by researchers and society as a whole."

How would you describe the state of collaboration with BRGM with respect to data?

ISABELLE BLANC — BRGM has a head start on major issues at the heart of our public policies, namely the production, sharing and opening up of its data, and its re-use by researchers and society as a whole. The Ministry of Higher Education and Research (MESR) is one of BRGM's three supervisory bodies. As such, it supports BRGM's research on geological phenomena and the corresponding risks. In particular, it acts as an expert producer and disseminator of data on the ground, subsurface and resources. The combination of its research and data production contributes to studies aimed at anticipating and assessing natural hazards, the conservation of natural resources, the assessment of mineral resources, groundwater management, geothermal energy and renewable energies. Before the importance of open data was fully recognised, BRGM had already developed solid know-how in the collection of reliable geoscience data. By opening up its data more widely, BRGM is now establishing itself as a committed player in the fields of Earth and environmental sciences.

Can you summarise the main projects currently underway?

I.B. — BRGM contributes to the *Recherche Data Gouv* ecosystem for data sharing and opening, through two Data Terra projects: the EaSy Data portal for long-tail Earth system data and the Solid Earth data portal. BRGM also hosts one of the regional data centres approved by MESR. It also contributes to the development of research data policy through its Chief Data Officer.

More generally, what is your vision of the implementation of the Open Science policy within an institution such as BRGM?

I.B. — BRGM develops services based on the data it produces. These services are intended for communities beyond the research community. It has a strong public policy support mission and makes its data available to citizens, as well as to businesses for innovation. Its data services and expertise enable BRGM to forge public and private partnerships with industry and smaller companies.

LAUNCH OF THE EPOS SOLID EARTH DATA PORTAL

After more than 20 years of research and innovation, the EPOS (European Plate Observing System) data portal, the research infrastructure for solid Earth science, has been officially presented to the scientific community (EGU23, European Geosciences Union). To encourage multi-disciplinary research, the portal offers open and integrated access to more than 260 data sets and online services covering around ten themes (seismology, geomagnetism, geodesy, tsunamis, etc.). As part of the "Geological Information and Modelling" consortium which it coordinates, BRGM provides French geological map data at a scale of 1:1,000,000, borehole data and geological models.

www.epos-eu.org
www.ics-c.epos-eu.org

Thematic data services on the EPOS map portal. The pink circles are groups of geodetic measurement stations. The grey circles show groups of magnetotelluric measurement stations.
© EPOS ERIC

MAJOR OVERHAUL OF THE COMPUTERISED MANAGEMENT APPLICATION FOR FREQUENT AUTOMATIC-MONITORING DATA

The aim of the computerised management application for frequent automatic-monitoring data (GIDAF), offered to operators of facilities that are vulnerable to pollution, is to collect the results of analyses (water, air, noise) to check compliance with the requirements of facilities that are classified for environmental protection (ICPE), or for Water Agencies responsible for collecting water pollution charges. BRGM and the General Directorate for Risk Prevention (DGPR) have given it a major technical and ergonomic overhaul, with the emphasis on massive user consultation via a survey of their satisfaction and requirements.

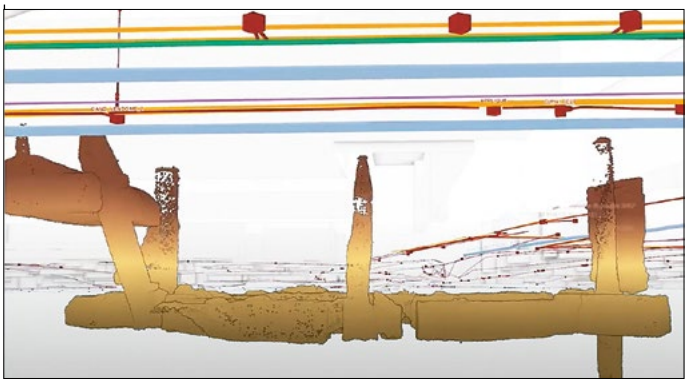
MINERALINFO MORE ACCESSIBLE

As part of the energy transition and the drive to reduce our dependence on fossil fuels, the Mineralinfo mineral resources portal offers a list of critical substances. The UX/UI user-centred approach has led to a better understanding of the information by the general public: use and consumption, global production, resources and reserves, etc., parameters that have become more accessible and intelligible, making it possible to understand how each substance ranks in a criticality matrix.

www.mineralinfo.fr

LAUNCH OF JUNON, DIGITAL TWINS AT THE SERVICE OF NATURAL RESOURCES

Bringing together ten projects, the JUNON programme aims to develop a digital research cluster devoted to the subject of the continental environment in the Centre-Val de Loire region. The development of the first digital twins has begun, and BRGM has made significant progress on the twins for WATER, notably with the characterisation of three sectors, each with a type of distinct behaviour, in the Beauce region. At the same time, user consultations and comparative studies on data management technologies have been carried out in order to better plan the architecture of future JUNON platforms.



Subsurface in the Orléans region: Location of buried pipe networks and 3D visualisation of cavities beneath the former Porte Madeleine hospital.
© ESRI [LIVE] SIG 2023

COMBINING THE RNDTS AND TRACKDÉCHETS PROJECTS TO BETTER MONITOR WASTE

A decision has been made to combine the two digital services that are currently used to track waste, excavated earth and sediments, namely: Trackdéchets – used for tracking hazardous waste – and the French national register for waste, excavated earth and sediments (RNDTS – *Registre national des déchets, terres excavées et sédiments*), which is used for declaring movements of waste, excavated earth and sediments. The aim is to simplify the procedures for checks by government departments and for users. BRGM is responsible for combining the two applications and guaranteeing their long-term robustness and viability. This will involve harmonising the design and creating a single authentication for logins and unique user profiles.

Classification of soil batches on a processing platform.
© BRGM – N. DUBRAC

STANDARDISATION OF GEOSCIENTIFIC DATA

As a member of the Open Geospatial Consortium (OGC), BRGM is working on the interoperability of geoscience and environmental data. Having already contributed to several standards (geology, hydrogeology, surface hydrology, API for exchanging observations), BRGM co-managed the review of the "Observations, measurements & samples" standard in 2023, in order to facilitate dialogue between scientific and technical communities. This could form the basis of many information systems used for observations or samples.

Open Geospatial Consortium

HUMAN RESOURCES

An HR policy based on the principles of professional competency, fairness, equality and career support

Despite the industrial action taken during the year concerning the employees' salary demands, which were duly passed on by the management to the supervisory ministries, the year 2023 saw an improvement in certain employee support schemes, as well as a review of the mapping of scientific and technical jobs. An independent assessment also confirmed the effectiveness of BRGM's Diversity-Inclusion policy.

MARIE BELOSSAT
Human Resources Director

ANNE GAUTHIER
Deputy Human Resources Director

"Mature" was the word chosen by Mixity (a consultancy specialising in diversity and inclusion) to describe BRGM's policy in this area, which received an overall score of 74/100. "This study enabled us to assess our policy objectively and situate ourselves in relation to other companies, while identifying areas for improvement," explains Marie Belossat. Several aspects were analysed, highlighting the company's performance in terms of disability inclusion (85/100), gender equality (80/100) and generational diversity (84/100). *"These positive scores are a result of a policy that has been in place for almost ten years. This policy is based on the principles of inclusion through the recognition of skills and the equal and fair treatment of all employees, based on formal commitments set out in company-specific agreements and actions aimed at reducing pay differences between employees, while also taking into consideration any difficulties employees may have."* A particular emphasis is also placed on awareness-raising campaigns, notably covering all forms of disability, including less visible ones. In addition, a new agreement on Job and Career Management is currently being negotiated with staff representatives.

However, two other areas of BRGM's Diversity & Inclusion policy need to be reinforced, starting with the situation of LGBTQIA+ people (55/100). *"We aim to prevent all forms of discrimination by raising awareness about sexual orientation and gender identity, notably through a major annual quiz," says Marie Belossat. A guide of best practices for supporting gender transition at work was also been produced and distributed in 2023. Equally, the multicultural aspect (56/100) needs to be improved "by reinforcing BRGM's attractiveness outside France and developing a policy to encourage the recruitment of foreign PhD students".*

Internal mobility encouraged

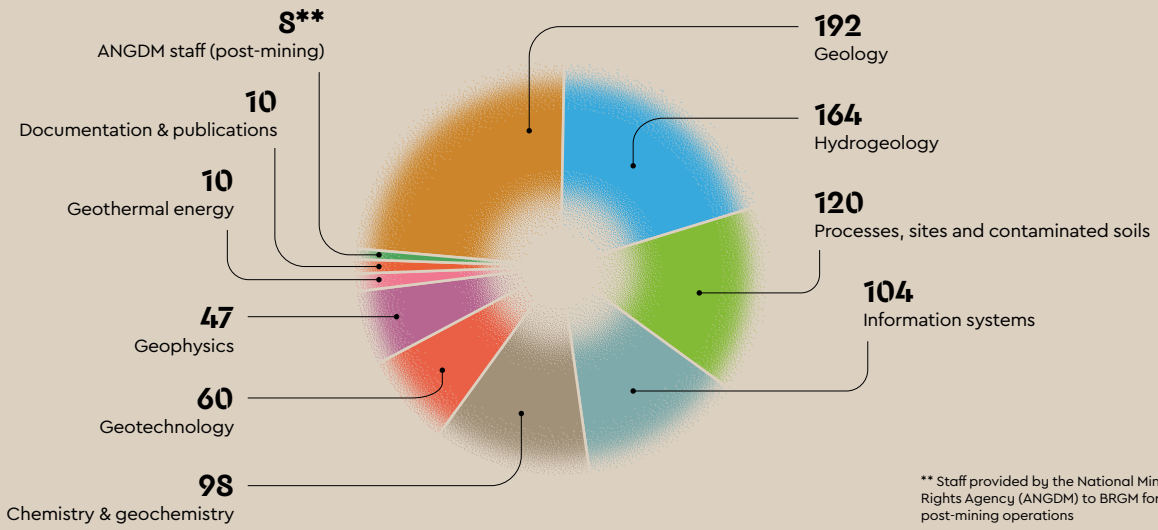
Internal mobility (69 employees in 2023) is another strong point of BRGM's HR policy, with 48% of job vacancies filled through this process last year (compared with a national average of 20%). *"This encourages the development of skills, and reinforces employee motivation and employability, while also improving our employees' understanding of the company, all with a view to retaining talents,"* says Marie Belossat. A new company-specific agreement was signed in 2023 to encourage internal mobility and provide better support for employees concerned by geographical relocation (with a specific section for French Overseas Departments). *"In addition to increasing the mobility bonus, it includes better provisions concerning the life-style changes involved in moving to a new place of work, both for the employee and his or her family."* For example, employees can now carry out on-site reconnaissance missions before making a decision. All these improvements are the result of

BRGM'S WORKFORCE
at 31/12/2023

* Including: 2 post-doctoral researchers, 16 PhD researchers, 1 civic service volunteer (VSC) and 57 sandwich-course students

BREAKDOWN OF THE WORKFORCE BY PROFESSION

Staff in Operational professions



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

"Our Diversity-Inclusion policy is based on inclusion through skills and a concern for fairness, with commitments formalised in establishment-specific agreements and actions to reduce the differences in remuneration of employees and take account of their difficulties."

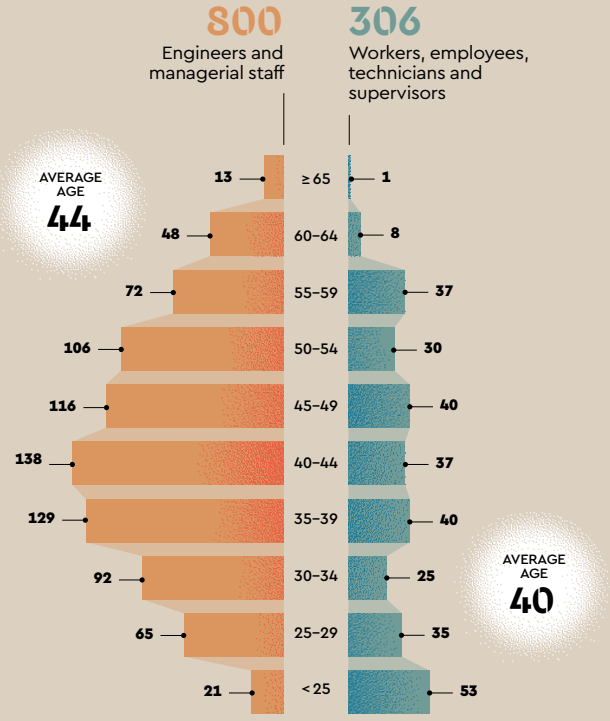
numerous discussions with employees who have already lived through the effects of geographical relocation as part of their mobility process.

A new map of scientific jobs

Following its HRS4R (Human resources strategy for researchers) accreditation in 2021, BRGM has revised the map of its scientific and technical jobs, taking inspiration from best practice and the Euraxess European database and building on the reform of its scientific-research programming. "This new map is clearer, more comprehensive and more representative of the specific features of these activities, in particular by integrating the expertise-research continuum," emphasises Marie Belossat. "It also shows the career paths available in each sector." By the end of 2023, all the jobs concerned (over 600) had been repositioned. This review will continue in 2024 with the support and management functions.

AGE PYRAMID BY CATEGORY

on 31/12/2023



SUSTAINABLE DEVELOPMENT

A comprehensive CSR policy that is expanding and gathering pace

As an integral part of its strategy and its 2023–2027 Contract of Objectives, Resources and Performance (COMP), BRGM's Corporate Social Responsibility (CSR) policy continues to develop and take shape. Designed and led by an enhanced team, it covers social, ethical and environmental issues and focuses particularly on reducing the carbon footprint of the institute.

In 2023, BRGM finalised its first carbon assessment (scopes 1, 2 and 3) using data from 2019, which was chosen as the reference year. This was then used as the basis for an initial transition plan - the foundation stone of the future Sustainable Development and CSR master plan - comprising around twenty priority activities. *"Half of them are aimed at improving data collection with a view to refining the measurement and management of our environmental footprint, which we will calculate every year in order to assess improvements and identify areas for improvement,"* explains Philippe Sabourault, CSR Manager, who states the objective as follows: a 10% reduction in greenhouse gas emissions in 5 years.

PHILIPPE SABOURAULT
Head of CSR

HERVÉ RIOLLAND
Head of Risk Prevention and Quality Auditing

"In our consultations, we want to introduce quantitative, in addition to just qualitative questions on the carbon footprint of the product or service on offer. On the basis of the answers we receive, we will assess the environmental impact of our services and more accurately calculate our carbon footprint. This will also promote positive dynamics among our suppliers."

Particular emphasis is placed on purchasing, which is responsible for most of BRGM's emissions. *"We want to introduce quantitative, in addition to just qualitative, questions into our consultations on the carbon footprint of the product or service on offer. The answers we receive will help us to assess the environmental impact of our offer and will contribute to the calculation of our carbon footprint. This approach will also stimulate positive dynamics among our suppliers."*

Other steps have been initiated or are being pursued, particularly in the area of mobility, with employee travel accounting for a quarter of the emissions. Renewal of the fleet with less carbon-intensive electric or hybrid vehicles is continuing, along with the deployment of new charging points. A modal shift towards soft mobility, in particular cycling, is encouraged through participation in events such as *Mai à vélo* and its Cycle Activity Challenge. In addition, alternatives such as video conferencing are being promoted to reduce business travel.

Building stock renovation

With regard to energy consumption, the move towards savings has gathered pace since 2022, following the war in Ukraine. In addition to the transition to less carbon-intensive energy sources (electric boilers, heating network), this involves a strategy to renovate the building stock at the Orléans site on the basis of an energy assessment of the buildings that were constructed between 1968 and 2003. The first studies were carried out in 2023. *"The resulting renovation plan will also optimise the use of space for remote working and hence the energy consumption involved. It will also make the buildings more accessible to people with disabilities."*

This aspect of BRGM's Diversity and Inclusion policy (see page 64) was expanded in 2023 with the implementation of a new institutional agreement and consideration of all disabilities, both visible and invisible (epilepsy, endometriosis,

Electric vehicle charging point. 19 charging points were installed at the Orléans science centre in 2023.
© BRGM - A. LEGENDRE

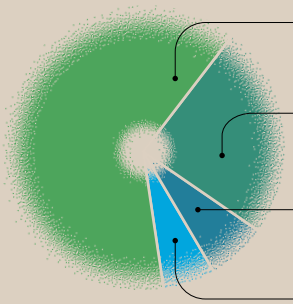
colour blindness, autism, etc.). The agenda for the European Week for the Employment of People with Disabilities, for example, included a range of events to raise awareness of neurodiversity and make BRGM an ever more disability-friendly establishment. Consideration has also been given to the situation of employees who need carers, in order to better meet their expectations. Finally, in terms of ethics, the institution intends to revitalise its system for guaranteeing ethics and integrity in its scientific and expert activities by overhauling its dedicated governance, stepping up employee training and spreading good practices.

A SOUND APPROACH TO CONTINUOUS PERFORMANCE IMPROVEMENT

The two quality and environmental management system (QEMS) certifications – ISO 9001 and ISO 14001 – have been confirmed for 2023. "The QEMS is both a structuring and a management tool, demonstrating the attention BRGM pays to satisfying its internal and external stakeholders, complying with regulations and controlling the environmental impact of its activities," stresses Hervé Riolland, Head of the Risk Prevention and Quality Auditing Department. Risk prevention was also expanded in 2023. The introduction of a quarterly review of the analyses required prior to any project means that the main risks can be identified and steps can be taken or adapted to control them. For its part, the project review introduced in 2022 provides feedback from project managers. More than 500 forms were received last year. Processing them helps to optimise BRGM's performance in terms of project management and the environmental impact of its activities.

BRGM GREENHOUSE GAS EMISSIONS

2019



63% from the purchase of goods and services

24% from business travel and commuting

7% from energy consumption

6% other

19 electric vehicle charging points provided for employees at the Orléans site by the end of 2023

More than 3,000 km cycled by employees during the 2023 Bike to Work Challenge

54 buildings on the Orléans site to be diagnosed as part of the energy audit of the building stock

328 employees attended the online conference entitled *" Et si votre collègue était un zèbre (HPI)?"* (What if your colleague was a zebra (with high intellectual potential)?), which was subsequently viewed in 70 replays

5.11% employment rate for disabled workers

78% success rate in 2023 for the massive open online course against sexist and sexual violence in the workplace, now compulsory training for new employees

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1


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Director, Regional Network

10 — **Natacha Girold**
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January 2024

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Louis Maréchal, Head of Minerals and Extractive Sector – OECD
Vanessa Salas-Pouget, Head of the Energy Unit – (Ministry for Europe and Foreign Affairs))
Rokhaya Samba Diene, Director of Exploration and Promotion of mining at the Ministry of Mines and Geology of Senegal, and President of the Organisation of African Geological Surveys (OAGS)
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Frédéric Maurel, Deputy Head of the Water and Sanitation Division – AFD
Didier Marquer, Policy Officer for Earth Sciences, Georesources and Geotechnologies, Research and Innovation Directorate (Ministry of Higher Education and Research)
Hervé Boisguillaume, Deputy Director of Strategy, Partnerships and General Affairs or **Chahoul Gaffar,** Head of Partnerships, Operators, and Projects Office (Ministry of Ecological Transition and Regional Cohesion)

National public-services strategy committee

January 2024

MINISTRY OF ECONOMY, FINANCE AND INDUSTRIAL AND DIGITAL SOVEREIGNTY
By delegation, the Director General of Development, Housing and Nature

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Director for Water and Biodiversity
Director-General for Infrastructure, Transport and Mobility
Director-General for Energy and Climate
Director-General for the Prevention of Risks

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Director-General for Research and Innovation

REPRESENTING THE MINISTRY OF AGRICULTURE AND FOOD SOVEREIGNTY
Deputy Director for Environmental Performance and Regional Development

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Director-General for Health

REPRESENTING THE MINISTRY OF THE INTERIOR AND FRENCH OVERSEAS TERRITORIES AND DEPARTMENTS
Director-General for Civil Defence and Crisis Management
Director-General for Overseas France

REPRESENTING THE MINISTRY OF CULTURE
Director-General for Heritage and Architecture

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BRGM CHAIR & CEO

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January 2024

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Denis Thiéblemont
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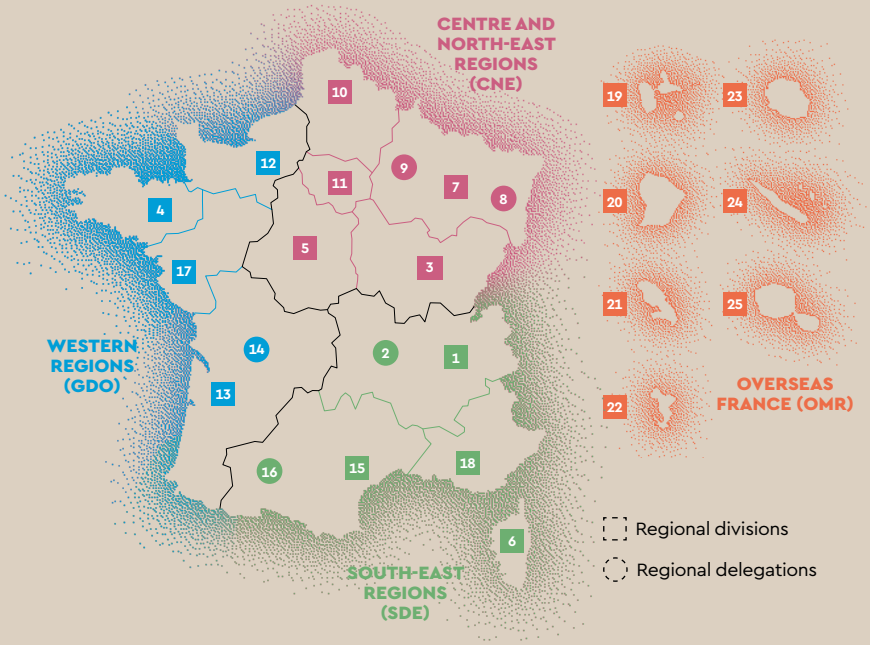
Florence Riou

Regional network



13
REGIONAL DIVISIONS IN MAINLAND FRANCE

5
OVERSEAS REGIONS

5
DELEGATIONS IN MAINLAND FRANCE

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A net profit for 2023 once again

2023 is the first year of the new Contract of Objectives, Means and Performance (COMP) signed in March 2023. The year was marked by the launch of the priority research and equipment programmes (PEPRs), the French Observatory of Mineral Resources for Industrial Sectors (OFREMI) and, more generally, by strong growth in business directly related to social issues. Despite an ongoing industrial action aimed at wage rises to keep pace with the cost of living, the increase in production and the rise in the activity rate bear witness to the employees' ongoing commitment.

Along with four other public research institutes (INRAE, CIRAD, IFREMER and IRD), BRGM acts 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 of "support for public-policy development in particular" and in "post-mining", as well as for two specific projects (Trackdéchets, RNDTS). Finally, it benefits from an SCSP subsidy under Programme 113 to finance the piezometric network.

At the BRGM Group level

The net consolidated profit for the group stands at €0.7M in 2023 (compared to €2.6 M in 2022). The contribution of the different entities to this net result is as follows:

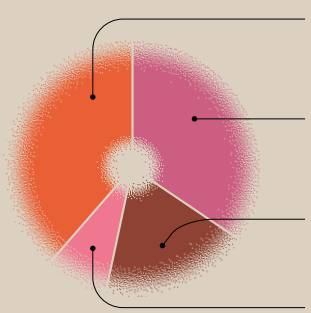
- The BRGM EPIC contributed €1.4 M, which corresponds to its net social result of €1.8 M, adjusted to take account of entries for transactions with subsidiaries (mainly write-back for €2 M in dividends received from SAGEOS);
- BRGM SA's loss-contribution was -€ 1.9 M;
- SAGEOS contributed €0.5 M to the group's result in 2023, which corresponds to its corporate result adjusted for dividends received from its subsidiaries and intra-group provisions;
- CFG and IRIS INSTRUMENTS contributed respectively +€0.1M and +€0.8 M; SOLTRACING's loss-contribution was -€0.1 M.

+ €1.5 M
BRGM EPIC operating result in 2023

€158.3 M
2023 operating income

€156.8 M
Operating expenses 2023

INCOME BREAKDOWN BY MISSION



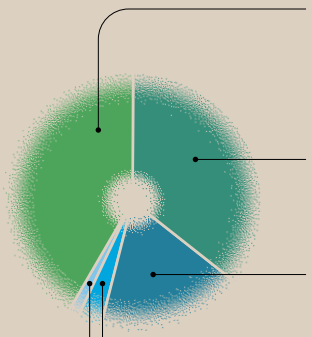
€59.5 M
Support for shaping public policy

€53.8 M
Research

€29.1 M
Post-mining

€11.7 M
International and French companies

BREAKDOWN OF ACTIVITY BY TYPE OF FUNDING



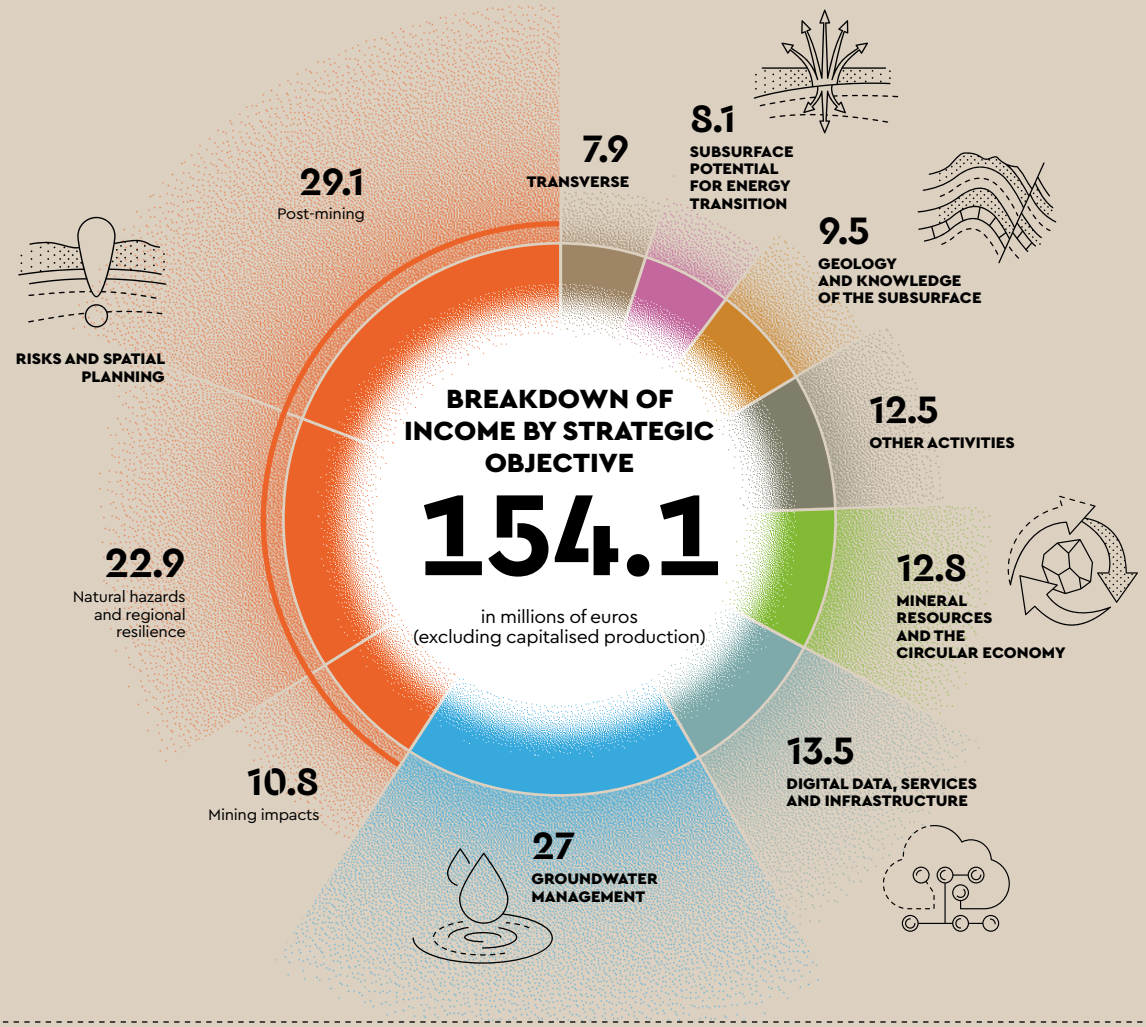
€66.3 M
Subsidies for public service expenses excluding post-mining activities
€55,7 M SCSP P172
€6,6 M SCSP P181
€4 M SCSP P113

€56.4 M
Contracts and agreements
€52,1 M Contracts and agreements France
€4,3 M International Contracts and Agreements

€29.1 M
Post-mining
€24,2 M SCSP P181
€4,9 M Interventions

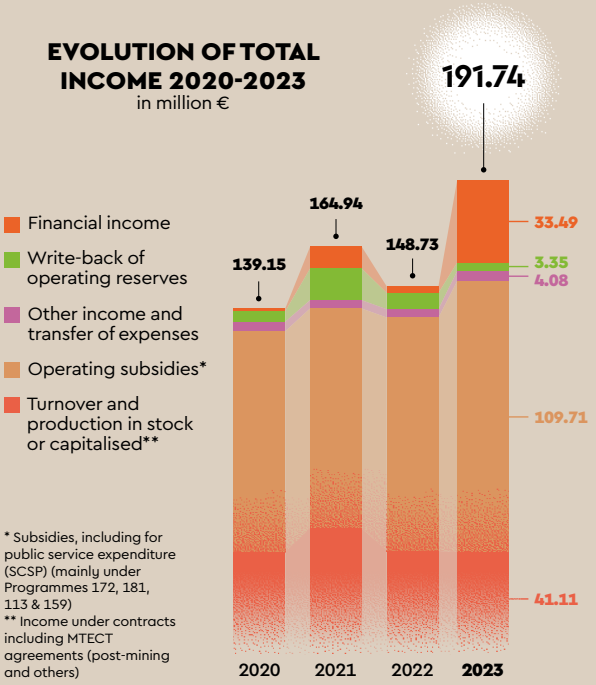
€2.1 M
Investment subsidies

€0.3 M
Capitalised production



EVOLUTION OF TOTAL INCOME 2020-2023

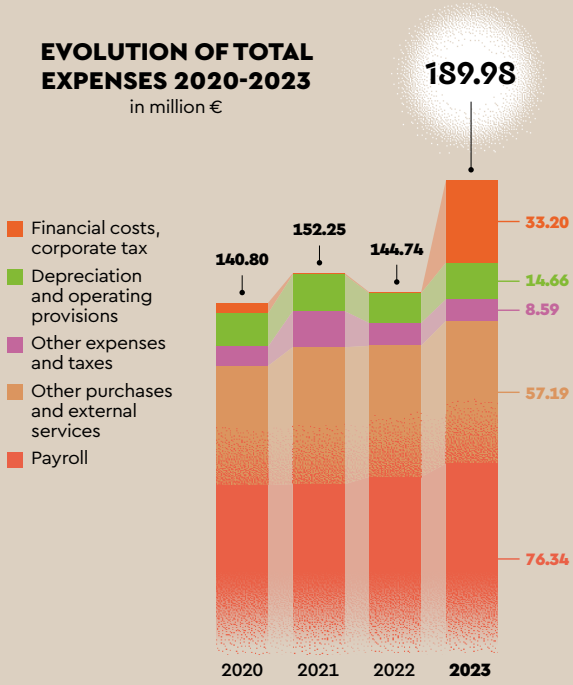
in million €



* Subsidies, including for public service expenditure (SCSP) (mainly under Programmes 172, 181, 113 & 159)
** Income under contracts including MTECT agreements (post-mining and others)

EVOLUTION OF TOTAL EXPENSES 2020-2023

in million €



Salient points of the 2023 financial year are various restructuring operations within the Group.

In the mining sector, NICRON, a company wholly owned by *Société Minière de CHESSY* (SM CHESSY), itself a wholly owned subsidiary of BRGM SA, was dissolved. SM CHESSY was then recapitalised. These operations were the first step towards SM CHESSY resuming operations in 2024 as part of the programme to update the National Inventory of Mineral Resources (IRM) announced by the President of France in September 2023, for the purpose of boosting mining investment in France.

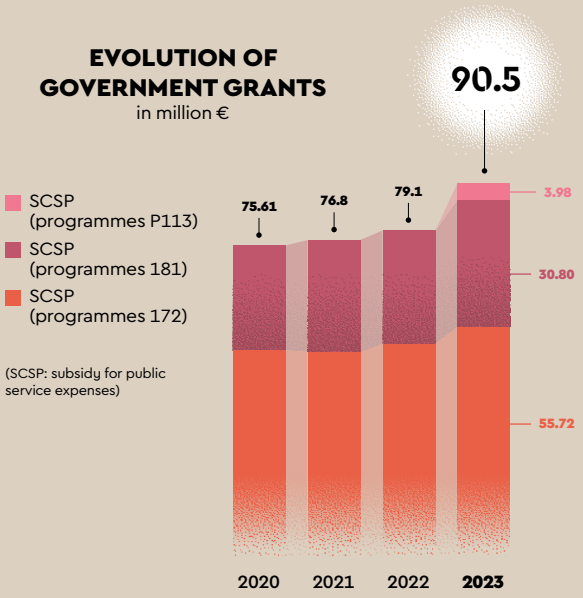
On the geothermal side, the search for a new industrial and financial partner for CFG, capable of providing the resources necessary for its development, continued in 2023 and should be finalised in early 2024.

At the BRGM EPIC level

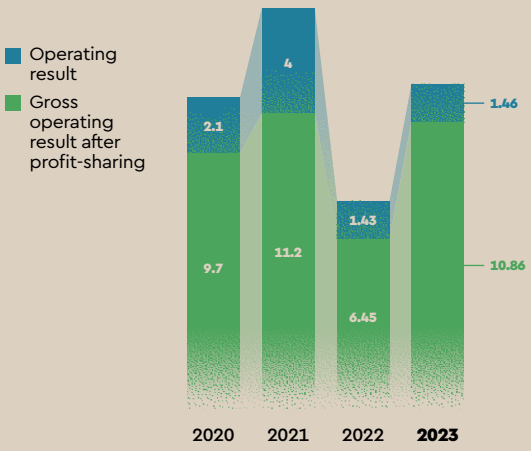
BRGM posted a net profit of €1.8 M for its 2023 financial year compared with a net profit of €4 M in 2022. The operating result was again positive, amounting to €1.5 M; for the record, the operating result amounted to €1.4 M in 2022. The financial result amounted to €1.1 M, down from €2.5 M in 2022. All these elements led to the payment of a profit-sharing bonus (€2 M) and will allow the Group to contribute to the company savings plan in 2024.

Funds from ordinary activities amounted to €152 M, an increase of 10.8% compared with 2022. At a total of €125 M, non post-mining resources were €13 M higher than in 2022 (+11.6%). As for post-mining resources, they amounted to €29.1 M, an increase of €2.3 M compared to 2022 (+8.7%).

EVOLUTION OF GOVERNMENT GRANTS
in million €



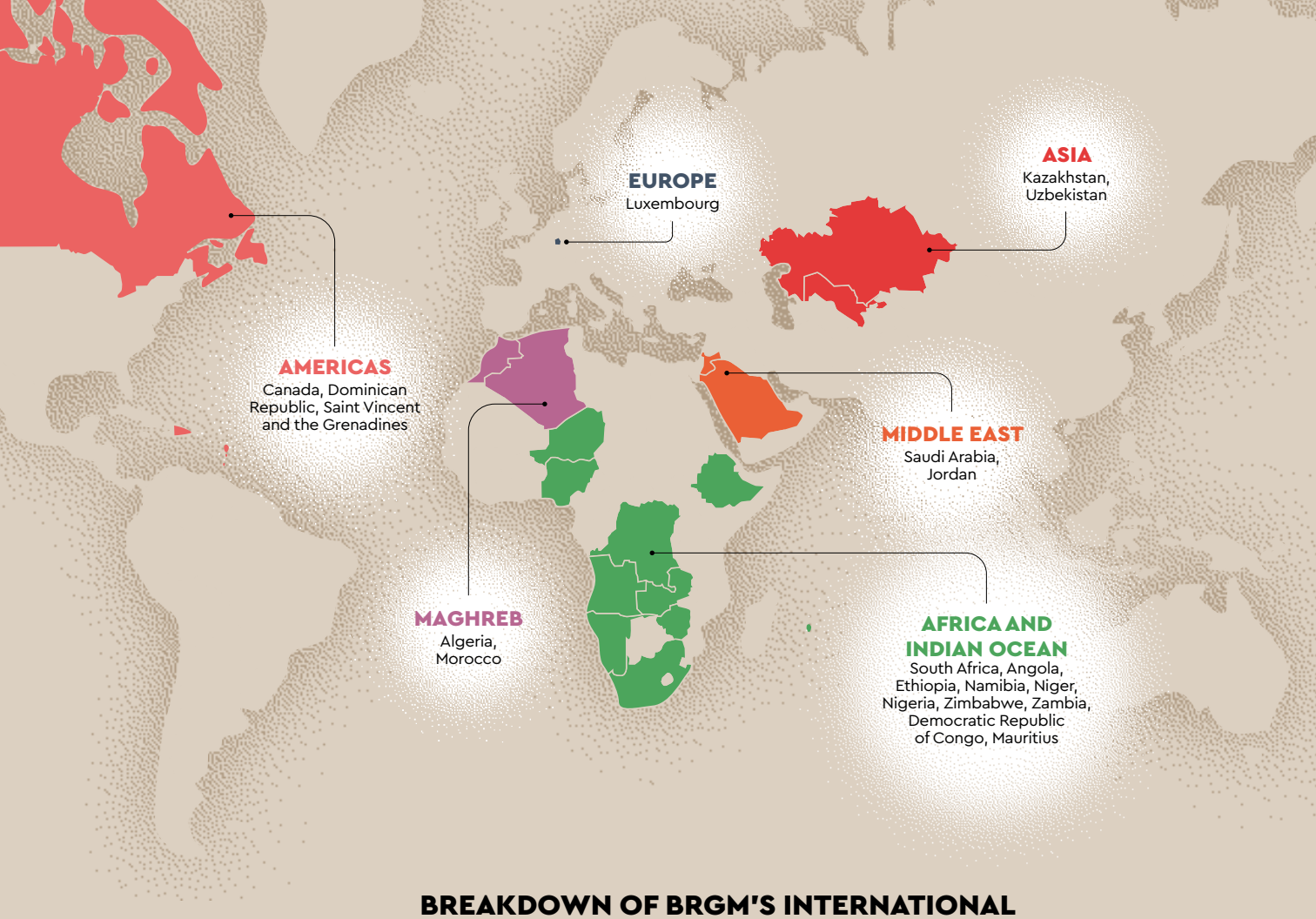
EVOLUTION OF OPERATING RESULT
in million €



INCOME UNDER CONTRACTS FOR SCIENTIFIC RESEARCH AND SUPPORT FOR PUBLIC POLICY DEVELOPMENT

(in million euros exclusive of VAT)

Contracts and agreements + capitalised production	**2021**	**2022**	**2023**
European Union + ERDF	4.618	6.517	6.678
ANR	2.410	1.854	2.724
Agencies other than ANR	8.900	7.549	6.057
Local and regional authorities	8.455	7.253	8.557
Government Ministries and departments	16.065	20.873	20.210
Companies	1.127	0.717	2.600
Sub-total research contracts and agreements + policy support (APP)	**41.809**	**44.763**	**46.826**



BREAKDOWN OF BRGM'S INTERNATIONAL OPERATIONS BY COUNTRY IN 2023

Excluding post-mining activities, the level of SCSP has risen compared with 2022 (+€10.5 M), due in particular to the change in the method of financing the piezometric network (now financed by SCSP from P113) and the DGPR Trackdéchets and RNDTS projects (financed by SCSP from P181); BRGM also received an exceptional non-renewable grant from the Ministry of Research (+€3.4 M from P172) to cover the increase in energy costs and to compensate for the increase in its payroll. The proportion of contracts and agreements (€56.4 M) was up by 4% compared to 2022.

The level of income from contracts relating to the public policy support mission was slightly lower than in 2022, at €29.7 M compared with €30.7 M in 2022, which was a record year. This decrease is artificial, given the change in the way the piezometric network is financed. Excluding the piezometric network effect, production under the public policy support (APP) contract for 2023 would be €33.5 M, which would be a new all-time record. Moreover, income from public research funded by contracts and agreements (€15.3 M) increased by €2.5 M compared with 2022. This was mainly due to the sharp rise in production under European contracts. International production remained stable compared with 2022, at €4.3 M (compared with €3.9 M in 2022). Sales in France grew slightly (from €5.0 M in 2022 to €5.4 M in 2023).

Income from post-mining business increased, standing at €4.8 M (up €1.4 M compared to 2022). The monitoring activity benefited from an additional SCSP of €0.7 M to partially cover the additional energy costs of the pumping stations.

Current operating expenses (excluding provisions and reversals) are €10 M higher than in 2022 (+7.2%), at €149.5 M. Excluding "exceptional" items (write-offs of €1 M in 2022), structural external costs increased by €2.2 M compared with 2022. The payroll also increased by €5.3 M compared with 2022, with the wage increase rate for permanent staff (RMPP) rising to 5%.

Net financial income was €1.1 M in 2023, mainly due to integration of the €2 M in dividends from SAGEOS. The Group's income resulted in corporate tax of €0.8 M in 2023.

Subsidiaries and holdings

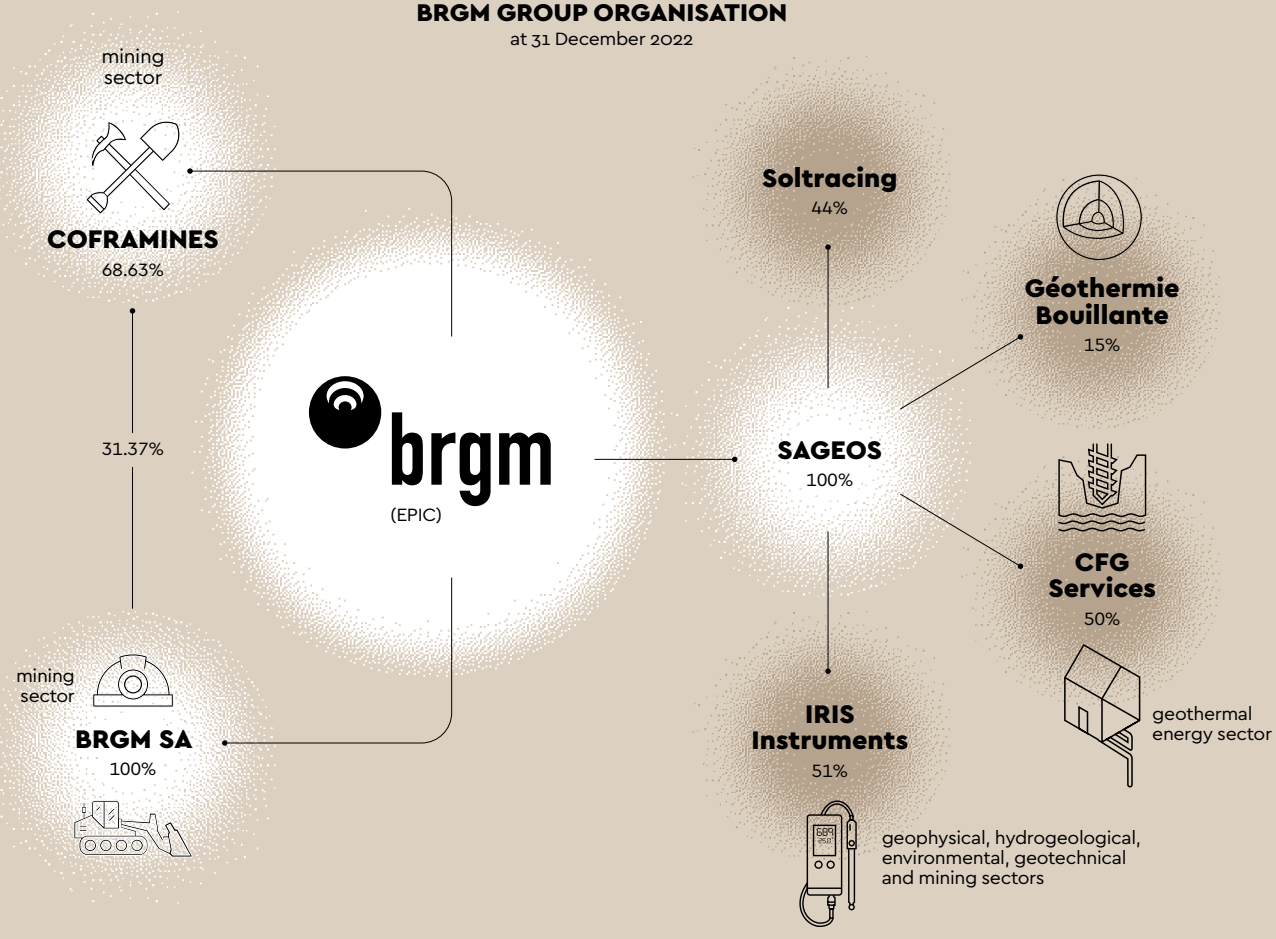
BRGM Group's subsidiaries and equity are divided between three holding companies each corresponding to a specific sector.

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 50% of the capital (BeicipFranlab Groupe IFPEN, of which it owns 50% since March 2024), 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 earth, it has a 44% holding in Soltracing (with HESUS owning 55%).

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.

BRGM GROUP ORGANISATION
at 31 December 2022



2023: Structuring and investment

2023 will be remembered as a landmark year for geothermal energy, in particular through the geothermal energy plan presented in February 2023, "an action plan to accelerate", one of the objectives of which is to increase the number of deep geothermal energy projects in France by 40%.

Thanks to political impetus, geothermal energy is positioning itself as a credible alternative for meeting the major challenges of the energy transition.

With its leading position in its markets, CFG has certainly benefited from a favourable economic climate, but has also been able to seize opportunities through efficient new approaches, thereby establishing its reputation with long-standing customers.

In order to meet its ambitions as set out in the "Ambitions 2030" strategic plan, the priorities have been to recruit new staff, particularly to strengthen its production teams, but also to develop new market segments.

Six new employees joined the Group in 2023 and since their recruitment, they are currently being groomed so that they are fully operational for the 2024 financial year.

CFG is now active in the geothermal energy market, offering geothermal energy to industrial sites to help them make the transition to a carbon-neutral energy future. Positioning ourselves in these markets requires a specific sales approach and agility, and in 2023 there were a number of changes in the way we operate.

As a result of its consolidation and involvement in the sector, CFG has taken part in preliminary studies to help minimise the risks to the resource in areas where it is less well known, notably in the west of the Paris region, in Hauts-de-France and in the Rhone corridor.

The Dogger underground project management business in the Paris region was buoyant, with drilling of the Saint Denis doublet and a first doublet at Pantin - Les Lilas. Preliminary studies carried out as part of project management assignments at Villetaneuse, Roissy-Charles de Gaulle (Paris Airport) and Dugny-Le-Bourget will culminate in the drilling of boreholes scheduled for 2024.

In terms of innovations, 2023 will remain a major year with the completion of the first all-composite doublet at Champigny-sur-Marne and the development of an innovative approach to the resources of related substances in geothermal brines. This approach has enabled CFG, as part of a partnership with Beicip-Franlab, to offer manufacturers technical solutions for optimising their strategy for mobilising lithium resources in France.

ÉRIC BERTET
CEO of CFG

CEO:
Éric Lasne

Turnover:
€5.300 M

SAGEOS holding:
50%

Beicip-Franlab holding:
50%

Staff:
25 employees

After two years devoted to obtaining exclusive exploration licences in island regions (Réunion, Mayotte, Guadeloupe and Martinique) for electricity production, 2023 was a year of transition and support for project owners in preparing additional exploration and scheduling future drilling.

Also in 2023, the supervision of the programme for three new boreholes on the Bouillante concession was completed, all of them successfully.

As part of what can be described as a classic year for maintenance and operational monitoring, CFG has decided to revitalise its activities in the field of corrosion-related microbiology expertise. Two leads have already been identified: research into innovative solutions for quantifying bacteria in an anaerobic environment, and the development of improved services for detecting leaks in underground pipes.

After an excellent 2022 FY in terms of results, boosted by a number of exceptional items, 2023 will be a year of investment and getting up to speed in order to provide the best responses to the many demands generated by a dynamic and growing market.

Drilling rig, Champigny-sur-Marne.
© OCÉANE DURIER

2023, a year of record achievement

Despite a complex economic and geopolitical context, 2023 was noteworthy at IRIS Instruments for intense activity with the launching of new products and numerous commercial and exploratory requests.

The very positive results for 2023 confirm the company's choice of long-term strategy, which in recent years has led to a significant increase in stocks of electronic components and other raw materials. This initiative aims to secure supply chains and better meet customer needs. IRIS Instruments is more than ever committed to ensuring that its products are robust and can be repaired. As part of its Corporate Social Responsibility (CSR) approach, these decisions, despite their heavy financial implications, keep IRIS Instruments in step with the times.

Backed by in-house electronics research and development, IRIS products are achieved through know-how acquired over decades. Technicians and engineers with varied and complementary skills are an exceptional asset that gives IRIS a unique strategic agility and adequate means to innovate.

IRIS equipment is distributed in more than fifty countries on five continents through a network of dedicated representatives. Local representatives, who account for half of global sales, are trained in the use of new products, and some of them are also trained in first-level repairs.

CATHERINE TRUFFERT
CEO, Iris Instruments

Turnover: **€7.986 M**
SAGEOS holding: **51%**
OYO holding: **49%**
Staff: **27 employees including one apprentice**

The mineral exploration, environment and groundwater research markets received equal attention.

In the field of mining exploration, a noteworthy event in 2023 was the launch of the TIP12, a unique, high-power (12 kilowatts), current- and voltage-regulated transmitter. This instrument follows on from its predecessor, the TIP6 (6 kilowatts), which can also be used with the ELREC and FULLWAVERS electrical resistivity and induced polarisation recorders used for investigations at depths of up to one kilometre. Despite market reluctance to invest in the mining sector, mining exploration accounted for a third of IRIS sales, with almost a quarter attributed to the new TIP6 and TIP12 transmitters.

SYSCAL resistivity meters continued to dominate the interconnected water research and environmental markets, with the addition of proton magnetic resonance for groundwater prospecting.

IRIS Instruments' success is due to its teams and partners who work daily to meet customers' challenges. In 2023, the number of training sessions led by IRIS geophysicists at its customers' sites exceeded that prior to the COVID crisis.

Faced with the magnitude of environmental and societal challenges, IRIS Instruments continues to pursue its research and innovation activities to meet emerging needs in imaging and time-series monitoring of the subsurface.

In 2023, research and development projects such as MEGAMU, involving the *Institut de Physique des deux infinis* in Lyon, IPGP, GEG Experts, the University of Geneva and Géosciences Rennes, have strengthened IRIS Instruments' position in the geothermal exploration market.

Demonstrating its commitment to quality and continuous improvement, IRIS is proud to announce the renewal of its ISO 9001 version 2015 certification in 2023.

Training on a SYSCAL PRO in Angola on behalf of GEOLANDER.
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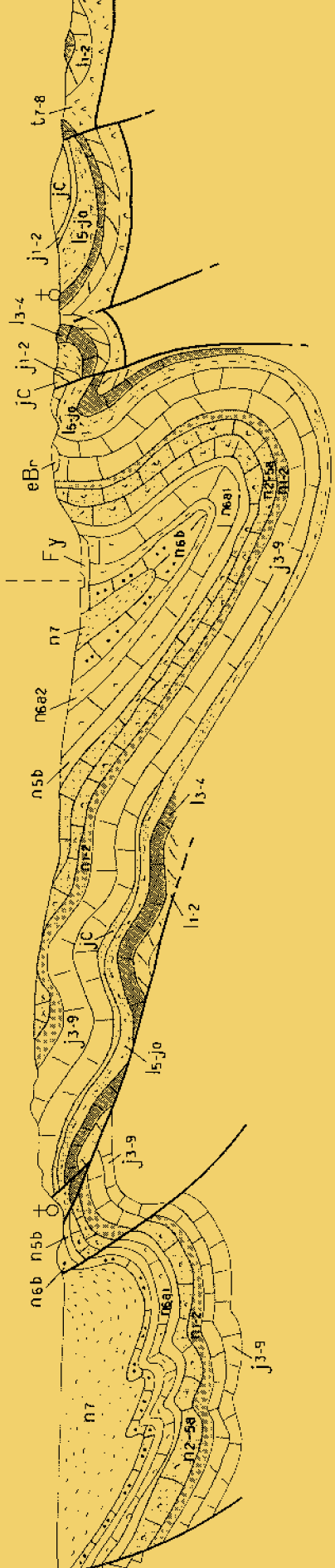

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