

# 1<sup>st</sup> Scientific-Technical Conference of the Geological and Mining Institute of Spain- National Center (IGME, CSIC)

July 12-13, 2022

IGME headquarters in Tres Cantos, Madrid

## PROCEEDINGS

Jorge Jódar Bermúdez  
Teresa Llorens González  
Jorge Colmenar Larena  
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Cesar Husillos Rodríguez  
Blanca Martínez García  
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Ignacio L. Marzan Blas  
Editors

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### **EDITORS:**

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## Preface

On July 12 and 13 we celebrated the 173rd anniversary of the IGME, CSIC, many years of a dynamic IGME constantly adapting to the times, always with the aim of providing the State Administration or the Autonomous Communities and to society in general, the knowledge and precise information in relation to earth sciences and technologies for any action on the territory.

The CN-IGME, CSIC already well into the 21st century, will continue to carry out geological and mining research of excellence (including cartography) and will address the challenge of ecological transition by reinforcing its focus on the basic resource for life, water; resources for the ecological transition (critical minerals, geothermal energy, underground storage or geological heritage, among others); and without a doubt the geological risks, serve as an example the work carried out in the face of the emergency of La Palma. This year the PLANAGEO project has also been successfully completed, an important milestone for IGME.

IGME is integrating within CSIC, with many stages already overcome, but others still remain, such as the consolidation within the CSIC. The result of this is the new structure of the IGME with two Scientific and Technical Vice-directions and the National Geological Service. This structure was ratified in November of last year, also configuring the 4 Scientific Departments and the research groups.

On the other hand, in the same way that the integration has contributed to changing and modernizing the IGME, it is also foreseeable that the IGME integration will modify the CSIC, contributing to a better visibility and evaluation of the technical work (including mandatory reports), which are undoubtedly a direct transfer to society. The presence of IGME in other administrations (ministries, autonomous communities, hydrographic confederations, city councils) is vital and is one of its symbols of identity. Our presence in numerous autonomous communities allows a very close knowledge of the territory.

Undoubtedly, all these changes have generated uncertainties in the staff of the Institute, but little by little they will become certainties revealed in the improvement of the services and infrastructures of the IGME, including the GeoMining Museum. Proof of this is the Recovery and Resilience Plan, which has made it possible to acquire new equipment that will also contribute to the modernization of our laboratories.

This Proceedings book is tangible proof of the excellence of the scientific-technical work carried out at the IGME, and of the quality of its infrastructures. It shows a modern IGME aligned with the Sustainable Development Goals and focused on the Ecological Transition. And above all, it shows a magnificent human team, capable of carrying out multidisciplinary research, in collaboration with many other institutions.

The scientific-technical conferences have been a success in terms of participation, contents and organization. They would not have been possible without a great team made up of Jorge Jódar, Teresa Llorens, Jorge Colmenar, César Husillos, Blanca Martínez, Juan López and Ignacio Marzán, thanks to all of them for their enthusiastic work and for making the IGME have a Happy Birthday.

Ana María Alonso Zarza  
Directora Instituto Geológico y Minero de España  
Madrid, July 2020



# INDEX

<b>Department of Water and Global Change.....</b>	<b>10</b>
Water and Global Change Department (CN IGME-CSIC) .....	11
The Research Group Water Resources and Related Ecosystems in the framework of Climate and Global Change (REACT) .....	12
Current international projects in the Duero and Miño-Sil basins.....	17
Pan-European map of groundwater resources, and harmonized characterization of karst aquifers. Project RESOURCE.....	18
Identification, delineation and data of Hydrogeological Areas for groundwater resources mathematical modelling in national River Basin Districts. Project Encomienda DGA (2019-2022) .....	19
Innovative tools for the integrated management of groundwater in a context of increasing scarcity of water resources: Interreg Sudoe AQUIFER Project .....	20
Hydrogeological processes and geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystem .....	21
Responding to the challenges of Water and Global Warming: Environmental Hydrogeology and Global Change Research Group (HYGLO-Lab) .....	22
Hydrogeology and geomorphology of high relief karst systems: Sierra de las Nieves (Málaga) and Sierra de Tendeñera (Huesca) .....	26
Water Sowing & Harvesting: an ancient Nature-Based Solution for Water Management ....	27
Environmental isotopes contribution to the characterization of the flow pattern of a large plain hydrogeological system.....	28
A methodology for simulating perched conditions in multilayer aquifer systems with 2D variably saturated flow .....	29
Hydrogeological researches in karstic lakes in the center of the Iberian Peninsula: two study cases .....	30
Computing tools to support the interpretation and management of hydrogeological variables .....	31
Assesment of climate change impact in mountain areas of special environmental value.....	32
Research Group on Applied Hydrogeology and Shallow Geothermal Energy (GIHAGS): general information and research lines .....	33
Hydrogeological aspects determining the appearance of a collapse in Undiano (Navarra)...	37
Groundwater User Communities (CUAS) advice on the improvement of hydrogeological knowledge .....	38
The SAGE4CAN project: The use of shallow geothermal energy from the Canary Islands.....	39

Design and operation of a quantitative control network in a complex river basin district: application to the Segura river basin district .....	40
The essential work of IGME linked to the strategic role of groundwater for urban supply ...	41
Eventual effect on groundwater in the hydrographic demarcation of La Palma due to the eruption of the Cumbre Vieja volcano .....	42
<b>Department of Geology and Subsoil .....</b>	<b>43</b>
Department of Geology and Subsoil (CN IGME-CSIC) .....	44
Geological mapping as a tool for scientific research. Group of Geological, Geomorphological and 4D Geology Cartography of Mountain Ranges and Basins .....	45
Tectonic Processes and GeoResources Lab.....	50
Growth and origin of the Iberian plateau. A multidisciplinary approach (PLATIBERIA): Lithospheric processes lab .....	52
Subsurface Geophysics and Geology (GEOFSUB).....	53
High-resolution imaging of the crustal-scale structure of the Central Pyrenees and role of Variscan inheritance on its geodynamic evolution (IMAGYN) .....	60
Passive seismic methods: a cost-effective tool for subsurface characterization.....	61
Geochemistry and Lithosphere Geodynamics group (Geoquímica y Geodinámica Litosférica, GEOLITHOS).....	62
Research on Marine Geology Resources and Extreme Environments at IGME-CSIC.....	66
Speciation and distribution of Critical Raw Materials in European seabed mineral deposits: MINDeSEA project results .....	68
Ferromanganese Crust and Phosphorites Pan-European Predictivity Cartography. MINDeSEA project results .....	69
Marine Geological Atlas of Spain .....	70
The EMODnet-Geology project: A Pan-European initiative to facilitate access to marine geological data and maps.....	71
Mineral microbial precipitation of subseafloor fluids at the submarine Tagoro Volcano hydrothermal system (El Hierro, Spain) .....	72
Enrichment of thorium and rare earth elements in an acid rock drainage: a case study in the Bierzo area (León, Spain).....	73
Composition and evolution of trace and rare earth elements in an acidic river basin (Tinto- Odiel) .....	74
Exergy and thermoeconomic assessment of the national recovery capacity of secondary resources essential for the ecological transition (RESET) .....	75
High-resolution geochemical characterization with multi-sensor core logger in sediment cores in the Bransfield Strait (Antarctica): Preliminary results.....	76
<b>Department of Resources for the Ecological Transition .....</b>	<b>77</b>

Geological Resources for the Ecological Transition: Challenges and Opportunities in the IGME National center .....	78
Mining waste and environmental geochemistry research group .....	79
Mining waste characterization in relation to recycling and rehabilitation processes .....	83
Mineral and thermal waters research group .....	84
Contribution to the knowledge of hydromineral resources in Andalusia.....	89
Economic Geology of Mineral Resources.....	90
Outlook on Spanish Nb-Ta mineralization and exploration potential (FRAME project's WP6) .....	95
The Importance of Spanish Data (BDMIN & PANORAMA MINERO) in the European Raw Materials Knowledge Base (EURMKB) .....	96
New hydrometallurgical treatment technology alternatives for refractory gold ores and primary polymetallic sulphides .....	97
Historic quarries associated with the architectural heritage in Andalusia .....	98
Strategic raw materials for the energy and digital transition in Spain .....	99
START Project: Sustainable Energy Harvesting Systems Based on Innovative Mine Waste Recycling.....	100
Geochemical sampling for mapping and exploration in Western Ossa Morena Zone (Huelva and Seville) .....	101
Geoenergy Group.....	102
Geothermal Potential Mapping in Spain. A crucial pending task with society and a great challenge as geological service .....	107
Laboratory Experiments on Early-Phase Supercritical CO <sub>2</sub> -Brine-Rock Interactions. Applications in Carbon Capture and Storage Projects .....	108
STRATEGY CCUS project: "Strategic planning of regions and territories in Europe for low-carbon energy and industry through CCUS" .....	109
pilotSTRATEGY project 2021-2026: "CO <sub>2</sub> Geological Pilots in Strategic Territories" .....	110
HySTORIES: "Hydrogen storage in European Subsurface" .....	111
Geothermal resources evaluation: Using O&G exploration data to evaluate low and medium enthalpy resources from deep sedimentary reservoirs.....	112
High enthalpy resources in Canary Islands: Geo-Energy Reseach Group .....	113
InSAR and paleostrain data acquisition and processing in the Hontomín CO <sub>2</sub> storage plant (Northern Spain).....	114
Heritage and Geodiversity (GEO-HERITAGE) Research Team at IGME-CSIC: challenges and main lines of action .....	115
Geological Heritage inventory of La Rioja (Spain). A small territory with a great geological diversity.....	120



International activity towards the conservation of geological heritage and heritage stone	121
RESCUHE Project: Cultural Heritage vulnerability in a changing and directional climate.....	122
<b>Department of Geological Risks and Climate Change.....</b>	<b>124</b>
Department of Geological Risks and Climate Change (CN IGME-CSIC).....	125
Research Group on Earth Observation, Geological Risks and Climate Change (OBTIER) .....	126
Palomares Fault: Geomorphological exploration and mapping, microtopographic analysis and classical trenching survey (NSOURCES PROJECT).....	132
Integration of data acquired using SfM orthoimagery correlation techniques and satellite InSAR techniques for the calculation of 3D displacements in densely vegetated unstable slopes .....	133
Geological applications of the PRISMA hyperspectral mission. Canary Islands scenario .....	134
Seismogenic characterization of active faults in Colombia for seismic hazard assessment of the city of Bogotá: Formal agreement between the Colombian Geological Survey and the Centro Nacional Instituto Geológico y Minero de España (CSIC).....	135
Geological Extreme Events: analysis and mitigation at IGME-CSIC .....	136
Research Group on Sedimentary Record of Climatic Changes–SERCC .....	142
<b>Technical Vice Direction .....</b>	<b>144</b>
Geominero Museum: past, present and... the future? .....	145
The Geological repository of CN IGME.....	151
Two new techniques for non-destructive core analysis: Hyperspectral reflectance spectrometer and modular core scanning platform .....	156
Classification and review of boreholes and documentation of the Andalusian regional community by the CN IGME core-repository .....	157
The General Laboratories of the Geological and Mining Institute of Spain, CSIC / Technical Vice-Directorate .....	158
Geological Information System Division .....	165
IGME's Information Systems contribution to the European Geological Data Infrastructure (EGDI) .....	166
EGDI Data Search. A web application to support geoscientific information discovery and access in Europe: Sistemas de Información Geológica .....	167
SILAB IGME's laboratory information system and new applications for IGME's services management: Geoscientific Information Systems and Institutional Databases.....	168
GESTEC, evolution and integration with IGAE tools: Geoscientific Information Systems and Institutional Databases .....	169
IGME's UAVs in La Palma volcano: STA (IGME's Aerial Works Service).....	170
<b>PLANAGEO Project .....</b>	<b>175</b>
UTE-PLANAGEO Project: national geology plan of Angola.....	176

Remote sensing applied to litho-structural and regolith mapping of the SW of Angola (PLANAGEO Project) .....	177
Geological mapping and geochronology of Southern Angola.....	178
Geographical Information System (GIS) and data base of Planageo Project.....	179
Gravimetric approach to the outstanding Kunene Complex (SW Angola): dimensions from modelling.....	180
Tectonostratigraphy of Benguela and Namibe sedimentary basins .....	181
Mineral resources and geochemical exploration in PLANAGEO (Angola) .....	182
Rocks and industrial minerals map of Angola (CARMINA) .....	183
Hydrogeological potential of the Kalahari basin in Angola .....	184

## Department of Water and Global Change



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## Water and Global Change Department (CN IGME-CSIC)

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### Abstract

The main target of the “*Departamento de Aguas y Cambio Global*” of the CN IGME-CSIC is to study the status and vulnerability of water resources and analyze sustainable management strategies. The role of groundwater and its strategic importance in the face of climate and/or global change are highlighted. The main research lines are: (1) study of the Status (quantity and quality) and vulnerability of water resources and their suitability for different uses (2) Planning and management of resources and reserves and (3) Water resources and facing climate and/or global change impacts.

The “*Departamento de Aguas y Cambio Global*” is structured into three Research Groups:

- (1) “*Recursos Hídricos, ecosistemas asociados y cambio climático y global (REACT)*”
- (2) “*Hidrogeología aplicada y geotermia somera (GI-HAGS)*”
- (3) “*Hidrogeología ambiental y cambio global (GI-HYGLO-Lab)*”



## The Research Group Water Resources and Related Ecosystems in the framework of Climate and Global Change (REACT)

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### Abstract

The REACT team is composed by a multidisciplinary group of researchers and technicians with 10 members. Its target includes the development and dissemination of multidisciplinary research in order to advance in the generation of knowledge and to contribute to the sustainable development, to train personal, and to advice public and private entities. We also aim to contribute to the internationalization of the IGME-CSIC activities. The group aims to study the status, vulnerability and resilience of Water Resources System (WRS) and associated ecosystems, and to analyze sustainable management strategies. The team works on monitoring, modeling and analyzing water resource systems at different scales, with special emphasis on groundwater. Historical periods and potential future scenarios are studied to evaluate adaptation strategies aimed at reducing the possible impacts of Climate Change (CC) and/or Global Change (GC). Participatory processes are incorporated allowing mutual learning and the transfer of results to the interested sectors. The interest of the proposed research lines is reflected in the significant number of project leaded by the team members related with them.

### Introduction

The multidisciplinary team REACT of the “Centro Nacional Instituto Geológico y Minero de España (IGME-CSIC)” includes 10 members, with diverse background: Dr. David Pulido-Velázquez is hydrologist with a Civil Engineering degree. He is senior researcher and coordinator of the Research Group; Dr. Jesús Causapé is hydrologist with a degree in Geology. He is senior researcher; Dr. África de la Hera Portillo, Dr. Juan M<sup>a</sup> Fornés Azcoiti and Dr. José Luis García Aróstegui are hydrogeologist with a degree in Geology. They are senior researchers at IGME-CSIC; D. Juan de Dios Gómez Gómez is hydrologist with a degree in Mining Engineer. Head of Service of Hydrogeological Techniques at IGME-CSIC; Dr. Juan Grima Olmedo. is hydrogeologist with a degree in Mining Engineer. He is senior researcher at IGME-CSIC; D. Jose Manuel Murillo is hydrogeologist with a degree in Mining Engineer. He is Technician at IGME-CSIC; Dra. Leticia Baena Ruiz is hydrologist at IGME-CSIC with a Civil Engineering degree; Dr. José Maria Orellana Macías is hydrogeologist with a degree in Geography.

The team has extensive experience in competitive and non-competitive research projects. It includes leadership activities in projects about impacts of CC and/or GC on WRS at different scales within the framework of the National Research Plan (8 projects leaded), and in diverse European research programs, Horizon Europe (STARS4Water) Horizon 2020 (eg. TACTIC, RESOURCE, NAIAD), INTERREG-SUDOE program (AQUIFER, current project coordinated by the

IGME-CSIC), COST action (HarmoSnow), LIFE (LIFE-IP-DUERO), UNESCO International Geosciences Program (IGCP-730), and other programs. Leadership in project oriented to advise the Government of Spain in matters of groundwater resources (2018/2022), river-aquifer relationship and associated ecosystems (2008/2010) and marine intrusion (2008/2009). Agreements with River Basin Authorities and regional governments. Leadership in international competitive projects funded by the Spanish Cooperation, both in the Intercoonecta Training Program and in Research Project Programs for Development.

The objective of the REACT Group is to study the status, vulnerability and resilience of WRS and associated ecosystems, and to analyze sustainable management strategies. We work on monitoring, modeling and analyzing water resource systems at different scales, with special emphasis on groundwater. Historical periods and potential future scenarios are studied to evaluate adaptation strategies aimed at reducing the possible impacts of CC and/or GC. Participatory processes are incorporated that allow mutual learning and the transfer of results to the interested sectors.

### Research and technical lines

Our research has a multidisciplinary character. We integrate information, knowledge and models from different fields (hydrogeology-hydrology, water quality and pollution, climatology, ecology, agronomy, economics, systems analysis, geostatistics, etc). Both, fundamental research (eg. new solutions or algorithms for modeling) and applied research (study of specific WRS) and technology transfer (development of user friendly software for use by administrations and companies related with the water sector) are carried out. Our works include: monitoring climatic and hydrological variables through field work, satellite and citizen science; generation of future local scenarios ("downscaling" techniques) to analyze potential impacts of climate change (CC) on water resources; use of different types of models (physical, conceptual and machine learning) are used for a better understanding of water resource systems, their internal operating mechanisms and their interrelationships, and for the analysis of sustainable management strategies, and their resilience capacity and adaptation to CC and GC. Data and results are analyzed applying statistical and geostatistical techniques. The interest of the described research lines is demonstrated taking into account the significant number of research projects that have been won in competitive calls. In this framework the main research activities of the group members are:

*D. Pulido-Velázquez:* a) Monitoring CC impacts using satellite information and a citizen approach; b) Generation of local CC scenarios, specially oriented to study drought propagation and the usefulness of satellite products in hydrological and WRS management studies; c) analyses of CC and GC impacts and adaptation strategies in water resources systems integrating hydrological (physical, conceptual, data driven models, etc), agronomical and management models (classical and hydro-economic). Special attention to mountain range, wetlands and coastal areas in semi-arid regions, especially vulnerable to CC impacts.

*J. Causapé:* environmental impact of agriculture in water quality; analysis and implementation of techniques aimed at improving irrigation efficiency and fertilization, the study of measures addressed to mitigate nitrate concentration by using green filters and wetlands and the hydrogeological assessment of water quality in agricultural basins.

*A. de la Hera Portillo:* a) Groundwater dependent ecosystems; b) surface-groundwater interactions; c) resilience of hydrogeological systems to anthropogenic impacts.

*J. M<sup>a</sup> Fornés:* a) Groundwater and aquatic ecosystems; b) groundwater management in Spain; and c) transfer of knowledge in the management of groundwater for the supply and sanitation of population centers in Latin America, within the framework of the Intercoonecta Plan of the AECID (Agencia Española de Cooperación Internacional para el Desarrollo).

*J. L. García Aróstegui:* hydrogeological research in semi-arid zones mainly focused on the analyses of groundwater sustainability, aquifer overexploitation, groundwater recharge, water resources, groundwater depletion and coastal aquifers linked to lagoons (Mar Menor).

*J. de Dios Gómez:* Assessment of impacts of CC on WRS and adaptation strategies, by applying conjunctive use modelling of surface and groundwater resources, and groundwater flow models. Seawater intrusion, quality and groundwater pollution, Water Framework Directive implementation, and regional hydrogeology.

*J. Grima:* Risk assessment and effective monitoring of emerging contaminants, specifically in the elaboration and validation of new assessment methods. Investigation of groundwater contamination and statistical treatment of environmental variables. Geological and hydrogeological characterization of wetlands.

*J. M. Murillo:* a) conjunctive use of surface water and groundwater including management of aquifer recharge; c) surface water-groundwater interaction.

*L. Baena-Ruiz:* Analyses of groundwater vulnerability to pollution, including coastal aquifers and sea water intrusion processes. Study of CC impacts on groundwater.

*J. M. Orellana Macías:* Risk assessment to groundwater pollution, including classification and mapping of hazard and specific vulnerability factors.

### Projects and contracts during the last 5 years

*D. Pulido* has been the leader of WP 5 (Assessment of sea-water intrusion problems and WP6 (Groundwater Adaptation Strategies) in the ERANET GeoE.171.008-TACTIC (01/07/2018\_01/03/2022). Now he is the PI of the National Research Projects SIGLO-AN (RTI2018-101397-B-I00; 01/01/2019–31/09/2022): Monitoring and assessing impacts of GC in WRS depending on natural storage from groundwater and/or snowpacks. He is the IGME lead within the WP4 (Appraisal, protection and sustainable use of Europe's groundwater resources) in the EU CSA "A Geological Survey for Europe" (01/09/2022-01/09/2027). He is also PI of project proposals submitted to different Research Programs: National Research Program (project focused on the study of protected areas); Ecological Transition call (project about co-design of adaptation strategies integrating quantity and quality issues); the Andalucía Excellence Research Project call (We propose to develop hydroeconomic models and tools); and PRIMA call section 1 (project about Natural Base Solutions).

*J. Causapé* is leading the National Research Project AGROSOS: Integrated Management of Sustainable Agro-Systems (PID2019- 108057RB-I00), which continues the work developed in four previous National Research Projects. The project aims at assessing measures and techniques to improve water quality in two agricultural basins with different characteristics.

*Á. de la Hera Portillo* is IGME leader for the H2020 European Project Nature Insurance value: Assessment and Demonstration (NAIAD) (Grant Agreement no. 730497) developed during the years 2016-2020. Currently, IGME-CSIC leader for the projects: (1) Supporting Stakeholders for Adaptive, Resilience and Sustainable Water Management (START4WATER), 2022-2026. Topic: HORIZON-CL6-2021-CLIMATE-01-01. Call: HORIZON-CL6-2021-CLIMATE-01. (2) IGCP-730 Hydrogeological significance of Mediterranean Geoparks, funded by the International Geosciences Programme (IGCP) of UNESCO, 2020-2025. And (3) LIFE16 IPE/ES/000019 LIFE-IP

RBMP-DUERO, 2022-2026 funded by the European Climate, Infrastructure and Environment Executive Agency (CINEA) of the European Commission.

*J. M<sup>a</sup> Fornés* is currently responsible for the Program entitled "Groundwater as a strategic resource for supplying population centers", which includes these five courses: a) Supplying population centers with groundwater (1<sup>st</sup> edition); b) the importance of groundwater in the integrated management of water resources: practical applications in international cooperation projects for development; c) supply of population centers with groundwater (2<sup>nd</sup> edition); d) positive and negative experiences in the development of hydrogeological projects related to the supply of groundwater to populations: analysis of practical cases by country; and e) well construction techniques. These activities are being developed throughout 2021 and 2022.

*J. Grima* works in the HOVER European Commission funded Project GEOERA (Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe). He is involved in the effective monitoring of emerging contaminants, specifically in the elaboration and validation of new assessment methods. He leads the task for developing recommendations for statistical analysis of monitoring data and evaluating existing results in terms of geological setting and land use/anthropogenic activities.

*J. de Dios Gómez* has been working in the last years in three Geoera projects: RESOURCE, TACTIC and HOVER. He has been leading the IGME's participation in RESOURCE, especially in the elaboration of the Spanish part of the Pan-European map of fresh groundwater resources. In the TACTIC project he has been involved in the assessment of CC impacts and adaptation strategies, and the assessment of seawater intrusion. In HOVER he has collaborated in new methods for the assessment of the vulnerability of aquifers, and evaluation of groundwater ages. He has also worked in two technological transfer contracts, one with the Spanish Ministry for the Ecological Transition, and the other with the Regional Government of La Rioja.

*J. L. García Aróstegui* is currently the coordinator and leader of the European project AQUIFER: "Innovative instruments for the integrated management of groundwater in a context of increasing scarcity of water resources" (SOE4/P1/E1045), co-financed by INTERREG-SUDOE (Period: 01/11/2020-30/04/2023).

*J. M. Murillo Díaz* is International Advisor of the Algerian Water Resources Agency; World Meteorological Organization; National Water Commission of Mexico; University of Sucre (Colombia) and Spanish Agency for International Cooperation in various experiences of Artificial Recharge. Responsible for the Agreement between the IGME and the United States Geological Survey (UTAH Delegation) for the realization of joint activities of Artificial Recharge and training activities of technical personnel. In Spain he has participated in several artificial recharge experiences. He has been part of the DGOH-IGME Joint Committee for the drafting, preparation and development of programs Nos. 15 and 16 of the White Paper on Groundwater entitled "Artificial Recharge of Aquifers" and "Conjunctive use of surface water and groundwater".

### **Scientific production and dissemination activities in the last 5 years**

During the last 5 years (2017-nowdays) the members of the team have produced: 52 SCI (30Q1); 6 Papers in other journals; 2 Books published and 5 book chapters. They have also produced multiple technical reports (20 technical reports), some of them, as the First Climate Change Mediterranean assessment Report (2020) has been also awarded with a prestigious award (North-South prize from the Council of Europe, 2020).

The team has had a significant involvement in dissemination activities. They have participated in the organizations of Conferences and Workshops (e.g., IAH Conference in



Granada, 2019). Members of the team have participated as invited speakers in international and national Conferences and seminars (e.g., COP25). They have also generated multiple contributions to international (more than 30) and national conferences (more than 20). A significant activity has been developed in social networks and different media (e.g., more than 50 appearances in the Media (Le Monde, El País, RTVE, El Mundo and others related to the problem of eutrophication of the Mar Menor and the implication of the coastal aquifer). The activity in social network has been oriented not only to the dissemination of works, but also to the involvement of citizens to monitoring climate change through a citizen initiative.

### **Training activities in the last 5 years**

The team has also an extensive participation in training activities. We would highlight 6 PhD thesis advised by members of the groups, some of them have been also awarded. They have developed significant teaching activities in official programs. For example, J. L. Arostegui is Assistant Professor of Hydrology in the Department of Ecology and Hydrology (University of Murcia) since 2013. He is teaching hydrology and hydrogeology in Environmental Sciences Degree and in master courses. D. Pulido has been also assistant professor in UCAM University since 2013 to 2018, teaching master courses about Water Resources management. Some members of the team have also organized and taught different training courses (e.g., J. Grima within the IGME training program or JM. Fornés and A. de la Hera in courses organized with the AECID).

## Current international projects in the Duero and Miño-Sil basins

A. de la Hera-Portillo<sup>1,\*</sup>, D. Pulido-Velázquez<sup>2</sup>, A. Prieto-Martín<sup>1</sup>, C. Husillos<sup>2</sup>, L. Moreno-Merino<sup>1</sup>, Javier Heredia<sup>1</sup>, H. Aguilera-Alonso<sup>1</sup>, M. Lorente-Isidro<sup>1</sup>, M. Corral-Lledó<sup>1</sup>, E. Galindo-Rodríguez<sup>1</sup>, J. López-Gutiérrez<sup>1</sup>, R. Mediavilla<sup>1</sup> and T. Orozco-Cuenca<sup>1</sup>

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### Abstract

This paper summarizes the research work that is being carried out within the framework of three international projects with a lifetime between 2022 and 2026: (1) LIFE-IP-Duero; (2) Supporting stakeholders for adaptive, resilience and sustainable water management; (3) IGCP-730. (1) and (2) are developed in the Duero river basin and are funded by the European Commission meanwhile (3) is being developed in the Duero and Miño-Sil basins and is funded by the International Geosciences Programme (IGCP) of UNESCO.

- LIFE-IP-Duero Project (<https://www.lifeduero.eu/>):

Water IP: Implementation of the river Duero basin management plan in the central-south part of the river Duero basin

This project aims to support the River Basin Authority in the implementation of the Water Framework Directive specifically, to achieve the good state for the Medina del Campo GWB. This project aims at showing how the knowledge on the nexus between water and other related fields like energy, food security and climate can be translated into lessons learnt and management and policy tools able to be integrated into future River Basin Management Plans.

- STARS4Water Project. Supporting STakeholders for Adaptive, Resilience and Sustainable Water Management.

This project aims to obtain better quantitative assessments and projections of the impacts of climate change on the water resources availability and water-related risks for society, ecology and economic sectors at river basin scale, in seven river basin hubs. The project will develop and deliver new data services and data-driven models for better supporting the decision making on planning on actions for adaptive, resilient and sustainable management of fresh water resources.

- IGCP-730 Project (<https://en.unesco.org/international-geoscience-programme/projects/730>). Hydrogeological significance of Mediterranean Geoparks.

The aim of the project is to demonstrate the Hydrogeological significance of Alternative Geoparks in the southern and north-western Mediterranean. The project focuses to topics addressing critical issues for the future sustainability. In Spain, the project is being implemented in two UNESCO Global Geoparks (UGGp): Las Loras (Palencia-Burgos, 950 km<sup>2</sup>) and Montañas do Courel (Lugo, 578 km<sup>2</sup>).

## Pan-European map of groundwater resources, and harmonized characterization of karst aquifers. Project RESOURCE.

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### Abstract

**Project RESOURCE.** This Project has been developed within the framework of the ERA-NET co-fund action GeoEra, with the collaboration of 45 national and regional Geological Survey Organisations. The RESOURCE project aims at demonstrating the potentials of the harmonization of information about Europe's groundwater resources through cross-border demonstrations projects, through harmonized characterization approaches for Karst and Chalk aquifers and through a first information product at Pan-European scale where available data is compiled and integrated to produce a map of the fresh groundwater resources of Europe.

**Pan-European map of groundwater resources.** As a product of work package 6 within the Resource Project, a groundwater resources map has been developed by collecting data on the depths and volumes of aquifers and aquitards and the corresponding fresh groundwater boundaries at a 10 x 10 km grid, thus realizing an appropriate spatial scale to achieve the goals at European scale. It also gives sufficient resolution to identify the main patterns and to interpret the recharge and the abstractions from the resource. This map intends to be useful for policy makers, but also substantially improve the base characterization needed for European and global scale groundwater models, describing flow and transport to rivers and seas.

A map viewer has been developed which allows the interested users to consult the results of the RESOURCE Project. Some parameters can be visualized such as aquifer types, total depth of active layers, groundwater storage, total thickness of saturated layers, and transmissivity (<https://geoera.eu/projects/resource9/resource-map-viewer>)

**Harmonized characterization of karst aquifers.** Work package 5 of the GeoERA RESOURCE project (also called 'CHAKA') focuses on typologies for karst and chalk aquifers. Phase 1 of WP5 has produced a review of the state of the art of existing classifications and typologies applied to karst aquifers (Deliverable 5.1 of GeoERA RESOURCE project). Phase 2 was dedicated to the identification and characterization of case studies and the development and testing of new karst classification methodologies. The case studies are described in Deliverable 5.2 of GeoERA RESOURCE project. The development of new methods for typology and classification and their application on karst/chalk aquifers case studies have been described in Deliverable 5.3. Additionally, there is a report that present the groundwater resources management recommendations associated with the outputs of the classification methodologies.

## Identification, delineation and data of Hydrogeological Areas for groundwater resources mathematical modelling in national River Basin Districts. Project Encomienda DGA (2019-2022)

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### Abstract

These studies have been developed within the framework of a Management Delegation Agreement signed with the Directorate General of Water (DGA) of the former Ministry of Agriculture, Fisheries, Food and Environment (MAPAMA). The project aims to develop various water planning tasks related to the inventory of groundwater resources and characterisation of shared aquifers on different River Basin Districts boundaries. The scope of this work extends to the entire national territory, both peninsular and insular, including the autonomous cities of Ceuta and Melilla.

Activity 1 aims at updating and improving the treatment of the groundwater component of the hydrological water cycle for the national water resources inventory. To this end, the identification and delineation of the Hydrogeological Areas used for quantification of water resources for national water planning has been carried out. The division into Hydrogeological Areas is based on the delineated and reported groundwater bodies of second River Basin Management Plans for implementing the Water Framework Directive.

This division has been made in order to apply the SIMPA (Integrated System for Rainfall-Runoff Modelling) tool for water resources assessment developed in the Centre for Hydrographic Studies of CEDEX. Hydrogeological Areas delineation based on groundwater bodies has been exclusively done in order to improve the knowledge of natural groundwater recharge and discharge processes at SIMPA modelling tool. The main criteria taken into account include the groundwater discharge to one or more rivers or, based on aquifers overlapping. From the 762 official existing groundwater bodies, 1288 Hydrogeological Areas have been obtained (in 61% of them, it was not considered appropriate to delineate more than one Hydrogeological Area, so that the whole groundwater body has been included). Hydrogeological Areas data sheets include: graphic outline flow conceptual model, geometrical features such as area of outcropping porous lithologies, hydrodynamics features such as aquifer transmissivity and storage coefficient, piezometric features such as estimated aquifer water level under natural regime, classification of interactions between groundwater and surface water, estimated lateral groundwater transfers with contiguous Hydrogeological Areas, etc.



## Innovative tools for the integrated management of groundwater in a context of increasing scarcity of water resources: Interreg Sudoe AQUIFER Project

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### Abstract

Integral aquifer management (i.e. compared to other water resources) , and integrated (i.e. considering mainly socio-economic and environmental aspects) , is absent or even neglected in many parts of the world. This is particularly critical in arid and semi-arid areas due to pressures on hydro systems and increasing demand for water, either directly (human supply) or indirectly (via consumer goods).

The main objectives of the AQUIFER project <http://www.aquifer-sudoe.eu/>), are to capitalise, test, disseminate and transfer innovative practices for the provision, monitoring and integrated management of aquifers. They will be particularly useful when making decisions on groundwater resources management by: 1) improving technology transfer to local actors, 2) creating new synergies and 3) developing common tools in a context of water scarcity and environmental threats.

The project considers the problem of groundwater in its entirety. Experiments are being carried out on the "quantity" and "quality" components of water and applied to case studies in Spain (Campo de Cartagena-Mar Menor) and France (Adour-Garonne) via groundwater flow modelling, real-time monitoring and forecasting of variations in piezometry at medium-term level. An innovative experiment of artificial recharge in the Aquifer of the Llobregat Delta (Spain) is also implemented. The agronomic aspects related to nitrate contamination of aquifers are taken into account, and monitored, in the Ribatejo area (Portugal).

Similarly, the project aims to detect, test and implement innovations through the 3 poles of water competitiveness linked to a network support tool to disseminate good practices through the creation of a permanent and free site k of actors and startups in the water sector, and the creation of a decision for all water stakeholders.

The AQUIFER project brings together Spanish (IGME-CSIC, CUADLL, CWP, CRCC), French (BRGM, AV) and Portuguese (AR, ISA-LEAF, PPA) partners with complementary profiles: scientists, users and private companies. This transnational design of the Project probably reduces ambitions in terms of scientific returns, but a window opens up for society to highlight the value of groundwater. The difficulty of understanding basic hydrogeological aspects outside the field of subject specialists is very significant, but stakeholders and users consider it very necessary to have a better knowledge of groundwater.

## Hydrogeological processes and geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystem

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### Abstract

Groundwater protection is a priority of the EU environmental policy. Water Directives provide a framework for pollution prevention and control, including provisions for assessing natural conditions or Natural Background Levels (NBLs). Determining NBLs of a substance is important, since groundwater naturally containing high concentrations of a certain substance should not be classified in poor status for this reason alone.

**(A) Pilot study:** For calculation of NBLs the Duero River Basin has been selected. NBLs are determined as the 90th percentile of the median concentrations at water sampling points over the 11-year study period for a specific groundwater typology. NBLs for sulphates obtained when considering Hover-lithology, provide a maximum value of 241 mg/L (Anthropogenically influenced values), while the value when human influence is removed is about 100 mg/L. Specifically, 97.7 percentile for Cenozoic lithology of the final data set is 900 mg/L. It is quite consistent with the threshold value established by the competent body, which is 1108 mg/L. Referred to chlorides, the NBL is 94 mg/L (97.7 percentile is 256 mg/L). The threshold reference value ranges between 303 – 441 mg/L. In conclusion, the proposed method is useful and provides coherent results when compared to the existing values. **(B) Sea water intrusion:** Different statistical approaches for derivation of chloride NBLs have been tested. The methodology has been demonstrated in porous coastal aquifers across the Mediterranean Coast of Spain that cover significantly different chloride concentration values and samples distribution. The final methodology combines results obtained applying selected statistical methods with an indicator of the degree of seawater intrusion. Because uncertainty is an inherent feature of saline intrusion analysis, the range of chlorides concentrations obtained varies between 115 and 261 mg/L. **(C) Monitoring of key parameters (environmental context, geological setting and risk assessment):** Depending on data availability, contaminants involved, the environment and the objective, several different approaches may be found to link concentration of CECs in groundwater with other external drivers. They vary from qualitative insight into patterns of distribution to complex statistical methods to identify and analyse all factors that could have an impact on groundwater concentration, including, but not limited to, the hydrogeological properties of the lithological units above them.

## Responding to the challenges of Water and Global Warming: Environmental Hydrogeology and Global Change Research Group (HYGLO-Lab)

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### Abstract

The current Global Warming of planet Earth is probably the most important geological phenomenon in the last 20,000 years of its history and for human race. This process is having nowadays notable effects on the climate, ecosystems and natural resources. Possibly the most important renewable geological resource is water. One of the most strategic phases of the water cycle is groundwater. Despite its low visibility, quantitatively (and qualitatively too) it is essential for life on Planet Earth. Foreseeable consequences on groundwater due to climate change and sea level rise will be very significant. Hydrogeology can provide answers to many of the questions that are beginning to be raised in relation to these impacts and their effects. Environmental hydrogeology is a way of understanding the set of disciplines mixed in Hydrogeology as a Science of Nature. The HYGLO-Lab Research Group of the IGME-CSIC National Center attempts, through its lines of research, with a double global and local component, to provide answers to some of these questions.

**Key words:** climate change, environmental impacts, groundwater, water cycle

### Background and composition of the research group

The Environmental Hydrogeology and Global Change Lab (Hidrogeología Ambiental y Cambio Global) is a research group of the IGME-CSIC National Center, created in July 2021. Comes from the Environmental Geology and Geomathematics Area belonging the former Research Department in Geological Resources, prior to IGME's incorporation to CSIC. The name of the group was decided by consensus among its members voluntarily adhered to it. It integrates a group of 27 people (27% women, 63% men), distributed among 2 scientific researchers, 9 permanent scientists, 1 Distinguished Researcher, 7 superior technicians and 8 assistants, contracted and training personnel. It is the largest research group in the IGME, accounting for 12% of its scientific-technical staff; its members develop their activity in the IGME centers in Madrid, Seville, Granada, Zaragoza, Palma de Mallorca and Valencia.

It has the following characteristics: high capacity for research, innovation, development and application in Hydrogeology and groundwater, in the most diverse environments.; it is one of the few existing research groups that contemplates the Hydrogeology from an ecological and environmental perspective; It has a very remarkable Know-how in the application of AI and the most modern statistical and geospatial data processing techniques to Hydrogeology and the environment; It has high transdisciplinarity, respects the gender perspective and shows a proven capacity for knowledge transfer and scientific-technical dissemination.

### **Scope of the Hyglo-Lab research group**

The overall objective of HYGLO-Lab is to study the functioning of natural hydrogeological systems and their responses to modifications derived from climate change. In particular, aspects related to: advanced hydrogeological methods, comprehensive and sustainable management of water resources, quality and contamination of groundwater (including emerging and micro-pollutants such as plastics), isotopic hydrogeology, numerical modeling of aquifers, artificial intelligence and machine learning applied to the management and protection of water resources, studies of water positive impact and sustainable activities through Nature-Based Solutions, geostatistics applied to hydrogeology and stochastic hydrogeology, spatial and temporal analysis of hydroclimatic data, development of software solutions urban and mining hydrogeology, interactions between geomorphology and hydrogeology and Karst, mountain, wetland and coastal hydrogeology

### **Main research lines and projects**

The group's activity is currently carried out through European and national research projects, international cooperation projects for development aid, coordination and participation in international scientific-technical networks, agreements with public administrations and assistance contracts for private companies and public bodies. These activities are carried out through scientific and technical projects, developed in Spain and in other Latin American, African and European countries, in collaboration with researchers and technicians from other Spanish and foreign universities and research centres.

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The main lines of research being developed by the members of the group are the following:

- Hydrogeology of wetlands and other protected natural spaces
- Methods for estimating aquifer recharge and, in particular, evaluating aquifer recharge in arid and semi-arid zones.
- Impact of Climate Change on Groundwater Recharge
- Geomorphological and hydrogeological study of karst terrain, including underground karst systems, natural or enabled for tourism development.
- Estimation of the environmental and economic effects of forest fires on aquifers and groundwater
- Chemical quality of groundwater, role of contaminants of emerging concern, including microplastics
- Analysis of Nature-Based Solutions in relation to ancestral techniques for recharging low-permeability aquifers (including the coordination of an international CYTED network for "Planting and Harvesting Water in protected natural spaces in Ibero-America)
- Geomathematics applied to Hydrogeology and advanced mathematical and statistical developments (Big data, machine learning)

- Hydrogeological investigation of medium and high mountain aquifers
- Study of multilayer systems with perched aquifers
- Development of methodologies for carrying out inventories of places of Hydrogeological Interest and for the protection of the Hydrogeological Heritage.
- Study of coastal aquifers and freshwater-saltwater interaction processes
- Study of geosphere-atmosphere feedbacks of mass and energy fluxes and its impact from Climate Change
- Development of computer tools for the interpretation of hydrogeological data
- Hydrogeological studies in extreme environments, particularly in Antarctica. A subgroup on Polar Hydrogeology and Global Change has recently been created, integrated into the POLAR-CSIC Platform, whose scope of work extends to the entire field of Polar Hydrogeology: a) study of the Antarctic hydrological cycle, b) analysis of the effect of global warming over said cycle, c) study of polar hydrodiversity, d) study of anthropogenic impact indicators based on the presence of pollutants and micropollutants in Antarctic continental waters, and f) analysis of the effects of global warming and direct anthropic activity on sensitive elements of the Antarctic water system, especially shallow aquifers and wetlands.

In addition to these lines of scientific research, the Group has three permanent channels of collaboration with two institutions:

- The Associated Unit of "Advanced Hydrogeological Studies" between the IGME and the University of Malaga, which has more than 15 years of successful experience in training activities, research, technology transfer and scientific dissemination.
- The permanent scientific-technical facilities for in situ measurement of Natural Infiltration in the Doñana National Park.
- International cooperation and training, in collaboration with the Water Fund Program of the Spanish Agency for International Development Cooperation (AECID).

### **Training and dissemination**

The members and HYGLO-Lab carry out important training work at all levels, participating in the direction of international courses (for example, the Hidrokarst course, with 14 editions held to date), active participation in master's degrees at Spanish universities (such as the Master's Degree in Water Resources and the Environment-RHYMA, from the University of Malaga), as well as directing doctoral thesis, master's thesis and degree projects at various Spanish universities.

In the field of highly popular science, they carry out numerous activities, having recently received several prizes in competitions related to the popularization of Earth Sciences, such as the First Prize for Scientific Short Films in the Science in Action Contest for the video entitled "Hydrogeology, the science of groundwater" in 2019. More recently, another informative scientific video ("Water and climate change in Ordesa and Monte Perdido") was presented at the 9th World Water Forum held in Diamniadio (Senegal) in March 2022. The "Hidrogeodia" in Madrid and the coordination of the "Hidrogeodia" at a national level (activity promoted by the International Association of Hydrogeologists-Spanish Group) are carried out by group personnel.

### **Forward-looking approach and concluding remarks**

Active projects at the time of writing this summary will allow the maintenance and development of the lines of research described in the previous section. Furthermore, in the



immediate future, the Group will develop in collaboration with various entities some relevant projects related to the following topics:

- Water footprint of mining activities and establishment of environmental compensation measures and water positive impact for sustainable activities, in collaboration with international mining groups.
- Investigation of land subsidence by means of radar interferometry and their relationship with the oscillations of the water table levels of some of the most important Spanish aquifers, in collaboration with the Institute of Geosciences (IGEO-CSIC) and with funding from the General Directorate of Water of the Ministry for the Ecological Transition and the Demographic Challenge of Spanish government (Dirección General del Agua del Ministerio para la Transición Ecológica y Reto Demográfico del gobierno de España).
- Investigation of the presence, origin and functioning of the methane contained in the groundwater of the peridotite materials of the Serranía de Ronda, in collaboration with researchers from the IGME-Universidad de Málaga associated Unit for Advanced Hydrogeological Studies.
- Microbiological aspects of karst groundwater with unique physical-chemical characteristics, in collaboration with the Mediterranean Institute for Advanced Studies (IMEDA-CSIC) of Mallorca.

## Hydrogeology and geomorphology of high relief karst systems: Sierra de las Nieves (Málaga) and Sierra de Tendeñera (Huesca)

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### Abstract

High relief karst systems with a well-developed network of karst conduits (caves and supercaves) along the vertical (Z-supercaves) are geological structures that have an important value by a number of reasons (water resources, geodiversity, biodiversity, planetary geology, among others) and that require a special methodology of research. One relevant line of work of the research group Environmental Hydrogeology and Global Change (HYGLO-Lab) focuses on developing novel tools to facilitate hydrogeological and geomorphological research of high relief karst massifs.

Because of their high altitudes, rough topography and accessibility limitations, the hydrogeological information in high relief karst massifs is scarce. In general, there are not boreholes and pumping test that provide information on water heads and transmissivities, respectively. The most valuable information has traditionally been karst springs where hydrographs, chemographs and thermographs can be measured. In addition to the later information, the main contribution of the research group along the last years have been the integral study of high relief karst systems with the inclusion of geomorphological, geophysical and speleological information to the traditional research lines of karst hydrogeology.

The first target has been the Sierra de las Nieves karst massif, a high relief karst system in the province of Málaga in Southern Spain. In this karst massif was proved the strong connectivity between the geomorphology of the landscape and the delineation of the hydrogeological basins that fed the main karst springs, as well as the great importance and relevance of speleological information.

In the last years, the methodology has been extended to the study of the Sierra de Tendeñera karst massif. Sierra de Tendeñera is another high relief karst system but located in the Pyrenees in the province of Huesca in Northeastern part of Spain. Sierra de Tendeñera reaches higher altitudes than Sierra de las Nieves and its main difference is that snow is seasonal rather than occasional as in Sierra de las Nieves. Thus, snow plays an important role in the geomorphology and hydrogeology of the karst system. The seasonal presence of snow implies a different recharge regime and a shifting in the recession of the karst springs with a delay of the minimum discharges further than the end of the summer as is the usual in systems without the influence of snow. This research is being developed by the HYGLO-Lab research group in the framework of competitive projects.

## Water Sowing & Harvesting: an ancient Nature-Based Solution for Water Management

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### Abstract

It's almost unknown that Nature Based Solutions for Water Management through Water Sowing and Harvesting techniques (WS&H) have been applied in southern Spain for more than one thousand years. Surface runoff from snowmelt and rainfall is guided and infiltrated (sowing) in the subsoil to be collected (harvested) sometime later. Previous research conducted by some members of the Hidrogeología Ambiental y Cambio Global (HYGLO-Lab) research group, demonstrated that such WS&H techniques have been applied in the southern slopes of Sierra Nevada, and they are still in use.

Indeed, since the 8th-10th centuries, farmers and shepherds of Sierra Nevada (Granada and Almería, southern Spain) infiltrate the runoff from the melting water in the upper slopes of the mountains, to recharge the underlying aquifers, and therefore to increase both the springs discharge and river flow rate during the summer. To this end, they use the locally known “*acequias de careo*”, which consist of long channels excavated in the soil that allow the flowing water to infiltrate. The previous research in the river Bérchules (Granada) has confirmed that the aquifer recharge through the careo channels duplicates the natural recharge, thus increasing the river baseflow, specially during the low flow season, while generating a water storage surplus in the aquifer to be discharged during the following hydrologic year. These results underline high efficiency of such a “simple” system for water management, and the high resilience of the system along, at least, 1200 years of operation.

These works constitute a part of developing lines of work of the HYGLO-Lab research group within the framework of various competitive projects.

## Environmental isotopes contribution to the characterization of the flow pattern of a large plain hydrogeological system

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### Abstract

Bajos Sumeridionales (BBSS) is an extensive region (54 280 km<sup>2</sup>) on the Chaco Austral in Argentina. Mean annual precipitation is 950 mm, ranging from 400 mm/y to 1600 mm/y due to the occurrence of hydroclimatic extremes. Potential evapotranspiration reaches 1500 mm/y, and mean annual temperature is 21°C. It is located at the distal portion of the Salado-Juramento fluvial mega-fan and presents a smooth NW-SE slope (gradient < 1 ‰). The north-western and eastern surface watersheds are defined by the Otumpa Hills and the Vera block, respectively. Both are raised blocks originated by regional neotectonic movements. However, the regional bound of the hydrogeologic system is unknown. It could extend from a recharge zone on the Subandean mountain range on the West end of the region, up to a regional discharge level imposed by the Paraná River on the East end. As is typical on large plain hydrogeological systems, local recharge-discharge vertical flows condition the flow pattern, though regional flows exist. Intermediate scale flows are not relevant due to low topographic gradients. All flow types discharge locally in numerous surface water bodies and crypto-wetlands, and their interaction is dependent on hydroclimatic pulses. These flow features make difficult to contrast Toth's hydrogeological conceptual model proposed for sedimentary basins. Nonetheless, some previous works postulated the validity of this model, although with limited field contrast. A new geological interpretation of the regional system allowed defining consistent hydrogeologic regional units with the environmental isotopes results (<sup>18</sup>O y <sup>2</sup>H) presented in this work enabled establishing a complex and sectorized hydrogeologic flow system for the BBSS. In the southern portion, water circulation would correspond to the current fluvial mega-fan of the Salado-Juramento River, with recharge originating on the Sub Andean mountain range. In the northern portion, it would correspond to local flows, with a likely contribution from deep thermal flows. Both sectors would discharge into the Golondrina-Calchaquí stream which is a tributary of the Salado-Juramento River. This sectorization would highlight that the uplift of the Otumpa Hills, which occurred after the formation of the mega-fan, conditioned its primitive flow pattern. This study is developed under project nº 2559 from Instituto Geológico y Minero de España, project nº 2010-214-16 from ASaCTel (Santa Fe, Argentina), and project PICT-2016-1334 from Agencia Nacional de Promoción Científica y Tecnológica, Argentina.

## A methodology for simulating perched conditions in multilayer aquifer systems with 2D variably saturated flow

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### Abstract

Simulating flow through multilayer aquifer systems is essential for groundwater management applications such evaluating natural recharge, assessing managed aquifer recharge (MAR), the characterization of surface water–groundwater interactions, and groundwater pollution risk analysis. However, dealing with flow through variably saturated porous media with perched water tables is a difficult task. Usual codes for groundwater flow modeling such as MODFLOW, TOUGH2, and FEFLOW require tedious procedures based on simplified assumptions and approximations. This paper presents a simple approach to simulate two-dimensional flow through perched aquifers and aquitards in deep vadose zones by combining the Dirichlet and Neumann boundary conditions that may apply to any code simulating unsaturated flow. The proposed approach is illustrated with the unsaturated flow code VS2DTI.

The main strengths of the proposed methodology are (a) variably saturated flow in the multilayer system is solved using Richards' equation, taking into account the lateral flow that sustains observed water levels in perched aquifers and variations in recharge; (b) a Dirichlet-type boundary condition at the top perched water table is substituted by a Neumann-type boundary condition, allowing for the representation of any disturbance (e.g., infiltration from ponds, pumping from wells, etc.), regardless of duration and intensity; and (c) the impact of the disturbance is evaluated by comparing the responses of the undisturbed and the disturbed systems. The versatility of this methodology is applied to a MAR case study of a deep aquifer in a sedimentary basin where aquitards limit its feasibility.

This methodology was applied to study the impact of a surface spreading MAR over the deep regional aquifer of Medina del Campo groundwater body projected by the Duero River Basin Authority. The conclusions were:

- The MAR will not have a relevant impact on the regional deep aquifer, thus it is not considered an appropriate action for its recovery.
- The MAR will have a significant impact just on the immediate surroundings of the watercourse (approximately 500 m), being this impact quite stable seasonally. Therefore, it would be a positive action for the restoration of the riverside ecosystem.

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## Hydrogeological researches in karstic lakes in the center of the Iberian Peninsula: two study cases

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### Abstract

The study of two groups of lakes or lagoons of karstic origin in the interior of the Iberian Peninsula is presented. They are two of the most interesting protected natural spaces of karstic nature in Spanish territory: The Ruidera Lakes Natural Park, located between the provinces of Ciudad Real and Albacete; and the Natural Monument of the Lagoons of Cañada del Hoyo, located in Cuenca province. Both present very interesting geomorphological evolutions and hydrogeological functionings. The research analyzes the anthropic influence on the natural functioning of the lakes/lagoons with the objective of recovering the Natural Area conditions prior to the anthropogenic impact, thus returning the hydrological systems to a morphological and functional state as close as possible to their original state.

In the case of Ruidera lakes, where important anthropic impacts have been reported since at least two centuries, the most important works carried out have been: the characterization of the water environment, with water sampling for chemical and isotopic analysis to establish the water balance and the relationships between surface water and groundwater in the lacustrine system; and impact analysis by mapping the geological elements of the system and an assessment of its state of conservation (Figure 1). These two approaches will allow us to define the restoration strategy.

In the case of the Cañada del Hoyo lagoons, the objective is to determine the origin of the color change experienced by the Turtle Lagoon (also called Pink Lagoon), one of the seven lagoons of the Natural Monument, which since 2019, during the autumn and winter, its waters turn pink. In this hydrological system, the work carried out has consisted of taking samples of the water from the seven lagoons for its hydrochemical characterization; sampling water at different depths and taking sediment from the bottom of the Turtle Lagoon for microbiological analysis (Figure 2). The results indicate that the massive presence of the *Thiocapsa sulfobacteria* is responsible for the color change of the water from blue to pink. No signs of anthropic contamination have been found that are related to this process, so the phenomenon is considered a natural process, linked to the presence of sulfur in the water and environmental changes at certain times of the year.

## Computing tools to support the interpretation and management of hydrogeological variables

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### Abstract

The continuous technological progress, the reduction in the cost of instrumental and analytical techniques, the diversification of data sources (e.g., satellites, remote sensors, etc.) together with the growth in the capacity of databases, as well as the easy-open access to them, have led in recent years to an exponential increase in the hydrogeological information available. One relevant line of work of the research group Environmental Hydrogeology and Global Change (HYGLO-Lab) focuses on developing novel tools to facilitate hydrogeological data's graphical, cartographic, and statistical interpretation. This line started with the INAQUAS software that allows the calculation of hydrochemical parameters and the realization of traditional graphs in spreadsheets. However, these tools have proved to be insufficient in the face of large databases, especially some of the most commonly used graphs, such as the Piper diagram. In this context, the D-Piper software has recently been published, which allows the creation of a modified Piper diagram based on the spatial point density and data distribution characteristics. This graph provides information about the facies distribution on the diagram, increasing its precision with the number of analyses available. Also, a methodology integrated into the Q-Facies software (Q-Facies) has been developed to treat the spatial or temporal evolution of the hydrochemical facies as a continuous variable, thus overcoming the difficulties of working with the few discrete qualitative values of the traditional representation. In the hydrogeological characterization of the unsaturated zone, progress has been made in developing tools (R-Infiltrometry) to visualize and interpret in situ tests of unsaturated hydraulic permeability of soils, including double-ring infiltrometry, single ring infiltrometry, and other methods.

On the other hand, the development of tools based on machine learning (ML) and geostatistics has allowed the building of inexpensive saturated hydraulic conductivity maps for land management and planning. Machine learning has also been used to find patterns and relationships between hydrochemical variables undetected by conventional statistics in large sets of analyses of groundwater for tap supply or bottling. In all the above developments, the tools are freely available upon request.

These works constitute a part of developing lines of work of the Hidrogeología Ambiental y Cambio Global (HYGLO-Lab) research group within the framework of various competitive projects.

## Assesment of climate change impact in mountain areas of special environmental value

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### Abstract

The Ordesa y Monte Perdido National Park (PNOMP) and the Parc National des Pyrénées have a high number of national, supranational and cross-border environmental protection figures. They constitute the highest carbonated mountain massif in Western Europe, which causes a shortage of surface water, as much of the precipitation (rain and snow) infiltrates into the subsoil (recharge), feeding the aquifers. Most of the water resources generated originate from groundwater (GW) discharge, either through springs (some as emblematic as the Cola de Caballo and the Gavarnie waterfalls) or through groundwater diffuse discharge to the main rivers (Arazas, Bellós, Yaga, Cinca and Gavarnie).

The strategy adopted to assess the impact of climate change in this area combines (1) numerical modelling of water resources with (2) the assessment of surface and groundwater quality problems caused by tourism. This sector is located between the Monte Perdido Massif and the Cola de Caballo, on a karstic aquifer developed in the Paleocene-Lower Eocene limestone. To study the system behaviour, a detailed geological cartography has been generated, automatic sensors monitoring different environmental variables have been installed, precipitation, surface runoff and GW have been sampled to study their chemical and isotopic composition and several dying tracer tests have been conducted.

The obtained results indicate that the system behaves as a dual porosity aquifer, one related to the karst conduits and the other associated with minor fractures, fissures, and primary porosity. The former controls the fast system response during rainfall events, while the latter does so mainly during the snow accumulation and melting seasons. It is the recharge from snowmelt that controls both the geomorphological evolution and the hydrological behaviour of the system in terms of GW discharge, T and EC. However, the short transit times estimated both in the conduits (5-9 days) and in the rest of the system (just over a year) indicate a high vulnerability of the system to both climate change and pollution. Besides, the increase in temperature due to climate change will generate less snow accumulation in the recharge zone and a progressive anticipation of the thawing season, which, together with the short transit time of groundwater, will lead to a decrease in the quantity and quality of available water, thus affecting biodiversity and associated ecosystems downstream, and economic activities such as tourism.

## Research Group on Applied Hydrogeology and Shallow Geothermal Energy (GIHAGS): general information and research lines

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### Summary

The GIHAGS combines the two basic facets that constitute the National Center: technical and research, always with an applied interest, in order to develop works and proposals in which groundwater can contribute to the economic and social development of the territory.

The activities of the Group contemplate three ways of action: a) research projects, b) agreements with other public administrations and c) technological support contracts with public and private entities.

At present, the Group is developing 4 research projects, 7 agreements and 10 technological support contracts. It also carries out infrastructural or horizontal functions, basic for the development of other projects, such as the maintenance and updating of the Water Database, the elaboration of queries to this database, the maintenance and application of the Mobile Hydrogeology Unit or the management of data requests to the AEMET. In addition to these activities, there is a clear vocation to transfer results to society in order to contribute to the dissemination of hydrogeological knowledge and its enhancement.

### Background and generalities

The GIHAGS was constituted in November 2021, basically from the members of the Applied Hydrogeology Area of the IGME, with some additional incorporations during the formation phase of the Research Groups.

Integrated in the Department of Water and Global Change, it is made up of 23 members: 2 full scientists from OPI's, 11 specialised senior technicians from OPI's or similar scales, 5 research assistants from OPI's, 1 research assistant from OPI's and 4 graduates in technical and professional activities.

It comprises the two basic facets of the IGME-CSIC CN: technological and research, both with a clear vocation to serve society, in which groundwater and Hydrogeology, as the science that studies it, can contribute to the resolution of logistical and environmental problems, in general, and to the improvement of the well-being of the people who make it up, in particular. One of its specific features is the application of hydrogeological science to improve knowledge of groundwater in order to achieve its optimal and adequate protection and use, both in terms of its traditional uses (urban, industrial, agricultural) and in aspects relating to its energy and environmental aspects, as well as the analysis of its interaction with human activities of all kinds, among which public works, including large linear structures, should be highlighted.

In addition, the Group is a pioneer in developing other innovative aspects, such as the collaboration between Archaeology and Hydrogeology, a hybrid and multidisciplinary field of study that, through the application of research techniques from both areas of knowledge, establishes the determining factors of human settlements in different civilisations throughout

history, or the study of deep aquifers that can be defined as strategic water reserves in emergency situations.

It also makes contributions to the transfer of knowledge to society through articles, dissemination and diffusion in the media and the preparation of publications, both of high scientific dissemination and guides and manuals, which include nature-based solutions compatible with climate change, the updating and redefinition of Groundwater Bodies for their incorporation into basin hydrological plans or the valuation of groundwater for the adaptation of cities to climate change.

### Technical-scientific objectives

For practical purposes, the technical-scientific objectives of the Group are to carry out hydrogeological studies, on different scales, by means of field and office work. Among the former, it is worth highlighting the collection of spatial and temporal data: geological, inventory of springs and boreholes, piezometric measurements, gauging of watercourses, characteristics of catchments, sampling and hydrochemical and isotopic analysis, survey of lithostratigraphic columns, inspection of boreholes by means of video recordings and geophysical testification. Among the latter, different technologies are available and applied: hydrogeological databases, technical management for the construction of groundwater abstraction works and their assessment by pumping tests, hydrogeological mapping, mathematical models of flow and transport, statistical analysis, etc.

The Group's most important activities include advising the water administration on hydrological planning, analysis of sustainable water management strategies, study of ecosystems associated with groundwater and the establishment of observation and monitoring networks for groundwater resources.

To achieve these objectives, multidisciplinary work is carried out on the basis of existing information and the identification of hydrogeological uncertainties and their proposed solutions.

### Technical and research lines under development

In general terms, they involve activities aimed at the integrated management of water resources for better adaptation to human needs, with particular attention to processes related to climate change and the problems of overexploitation and pollution of groundwater. More specifically, the following groups of activities can be distinguished:

- Studies of groundwater supply to population centres.
- Advice to the hydraulic administration in hydrological planning and contributions to improving knowledge of hydrological plans, as well as advice to the hydraulic administrations with regard to the prevention of effects on groundwater derived from anthropic activities.
- Application of hydrogeological knowledge to the execution of civil works, such as building foundations, location of urban waste disposal facilities, layout of linear works, design and construction of tunnels, etc.
- Studies of groundwater-dependent aquatic ecosystems, with determination of their functioning and effects on volume and quality. Development of conceptual models of the functioning of natural areas under environmental protection.



- Research into the hydrogeological implications of geothermal exploitation of shallow aquifers, including analysis of the potential thermal impact and the application of advanced models of heat flow and transport in groundwater, enabling expert advice on the management of thermal discharges to water authorities.
- Definition and characterisation of deep aquifers as strategic groundwater reserves in the face of the effects of climate change or possible emergencies due to contamination or deficit of conventional resources.
- Dissemination of the physical, social and cultural environment of natural spaces with figures of environmental protection and the influence that water has on culture, society and cultural, material and immaterial heritage.
- Collaboration between Archaeology and Hydrogeology (Hydrogeoarchaeology), which is often decisive in defining the reason for certain human settlements throughout history.
- Specialised knowledge on the hydrogeological functioning of Spanish aquifers, which allows for qualified and expert advice to the different public administrations on various issues related to the water environment. In this context, we respond to the requests made to the CN IGME-CSIC by different bodies with the preparation of official reports on environmental studies, studies on the effects of human activities on groundwater, solid urban and industrial waste disposal facilities, liquid effluent discharges into the ground, etc.
- Methodological developments for the research, study and analysis of impacts on groundwater derived from the interaction between surface water and anthropic activities with aquifers located in urban environments (urban hydrogeology).
- Studies on ground movements due to alterations in the piezometric level.
- Updating, maintenance and optimisation of the IGME's Water Database, whose inventory of water points is around 140,000 abstractions, with temporary data from five decades ago. Within this activity, there is extensive experience in the establishment of piezometric, hydrometric and groundwater and surface water quality observation and control networks, both in the collection of point data and in the installation and control of dataloggers.
- Maintenance and application of the Mobile Hydrogeology Unit, consisting of modern instrumentation capable of carrying out video and geophysical surveys in boreholes, as well as recording water quality and flow at depth, taking water samples in boreholes at different depths and by pumping.

These technical-scientific lines are divided into three sections: research projects, collaboration agreements and technological support contracts. The following lines list those that the Group is developing during the current year 2022.

#### *Research projects*

The European and National Plan projects related to shallow geothermal energy, the hydrogeology of volcanic rocks and the study of wetlands related to groundwater stand out. These are specified in the following projects:

- Managing Urban Shallow Geothermal Energy. GeoERA. 2018/22. H2020 European Union Programme.

- Shallow Geothermal Energy for the Canary Islands. 2021/24. State Programme for Knowledge Generation and Scientific and Technological Strengthening of the R&D&I System.
- Climate resilient-regions through systemic solutions and innovations. 2018/22. H2020 European Union Programme.
- Hydrogeology and environmental services of the Ozama Wetlands (Dominican Republic). 2017/22. FONDOCYT 2015.

#### *Collaboration agreements*

Most of them correspond to those established with hydrographic confederations and provincial councils. They are specified in the following table (Table 1).

Table 1. Agreements in force in 2022 GIHAGS

Duration agreement	Organisation	Expected income in 2022 (€)
2019/23	Diputación provincial Granada	38.152
2020/23	Diputación provincial de Jaén	58.000
2019/22	AD Comarca Condado de Jaén	12.700
2020/23	Confederación Hidrográfica Guadiana	42.000
2021/23	Confederación Hidrográfica Miño-Sil	36.000
2020/24	Confederación Hidrográfica Guadalquivir	125.000
2020/24	Ciudad Autónoma Melilla	56.500
	TOTAL	368.352

#### *Technology support contracts*

These correspond to technology support contracts entered into with public administrations, public and private business entities and public law entities. Those in force in the current year are shown in Table 2.

Table 2. Support contracts in force in 2022 GIHAGS

Duration contracts	Organisation	Expected income in 2022 (€)
2019/23	Consejo Insular Aguas de La Palma	13.645
2020/23	CUAS Mancha Occidental II	9.500
2019/22	Agencia del Agua de CLM	11.495
2020/23	Consorti Ribera i Valldigna	7.580,65
2021/23	Gestión Integral de Residuos Sólidos	7.883,15
2020/24	Confed. Hidrográfica Cantáb. Occidental	10.000
2020/24	Ayuntamiento de Denia	6.500
2020/24	Ayuntamiento de Denia	8.500
2020/24	TRAGSATEC	36.543,02
2020/24	TRAGSATEC	7.000
	TOTAL	118.646,82

As can be seen in both tables, in addition to improving knowledge and solving specific problems for society, the Group generates considerable economic income. In 2022, those corresponding to agreements amount to 368,352 € and those from technological support contracts amount to 118,646.82 €.

## Hydrogeological aspects determining the appearance of a collapse in Undiano (Navarra)

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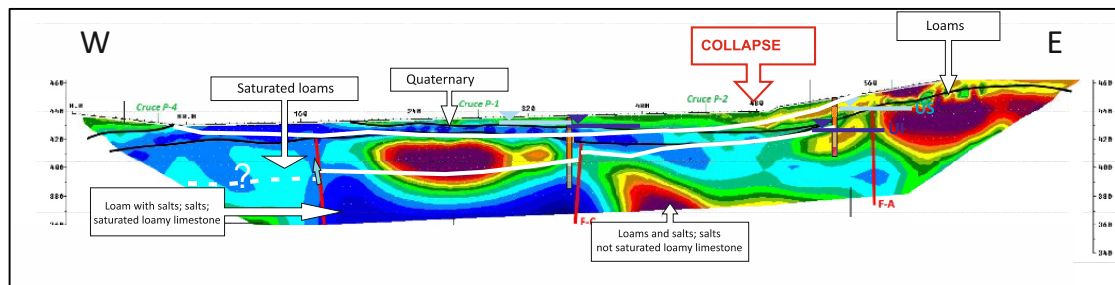
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### Abstract

In June 2019, a collapse, with approximate size of 3 x 4 x 10 (depth) m, took place in the surroundings of the locality of Undiano (Navarra). At the request of E. M. of Navarra, the CN IGME-CSIC researched the case with the aim of determining what factors may have acted as determinants and/or triggers.

The study area, located in the southern sector of the Pamplona Basin, is formed by clayey and loamy lithologies preponderate (very low permeability or almost impermeable), and limestone and sandstone, with a Quaternary cover. Only Quaternary deposits, limestone and sandstone can constitute aquifers. The relation of the subsidence with potash mining was excluded due to there is no gallery under the collapse. For the characterization of the materials, 6 boreholes and a geophysical investigation (6 electrical tomography profiles) were carried out. The results allowed establishing a conceptual operating model (Figure below):

- Hydrogeological units: Upper Unit (US) – alluvial/eluvial and marl and Lower Unit (UI) – marl with salts, salts and marl limestone.
- The groundwater flow in the US takes place from E to W. In the western zone, the piezometric level, very close to the surface, originates a permanent lagoon. Groundwater in the UI circulates predominantly in sectors affected of dissolution/karstification. In addition, there is an ascending vertical circulation of the UI flow in favour of fractures, so, probably, the lagoon is the place of discharge.
- The Undiano subsidence was a natural process induced by the circulation of the underground flow. Fracture lines, more favourable for dissolution/ karstification processes, are preferential for the circulation of groundwater. Through which, the dragging and washing of finer materials is increased, generating gaps that, due to the loss of sustainability, result in collapses on the surface.



## Groundwater User Communities (CUAS) advice on the improvement of hydrogeological knowledge

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### Abstract

Groundwater User Communities (CUAS) are public law entities, attached to hydrographic confederations, which ensure control, management and responsible use of water resources within a groundwater body. Most of them are formed by irrigators and, to a lesser extent, by livestock farmers or industrial uses. CUAS represents and defends all users' rights and interests, as they are part of the socioeconomic framework of the territory in which the groundwater body is located.

CN IGME-CSIC has been collaborating for years with several Groundwater User Communities attached to Guadiana Hydrographic Confederation. It provides geological and hydrogeological advice to CUAS on its own mass, in order to improve knowledge and contribute to a good quantitative and qualitative status.

Users collaboration by collecting information is needed to achieve these purposes. Their information is essential to improve hydrogeological knowledge since it allows describing groundwater bodies characteristics and identify and amend information gaps to understand their function and relationship with boundary masses.

Configuration and implementation of a piezometric observation network is one of the main objectives of this advice. Aquifer points must come from the information given by CUAS users (mainly irrigators) and IGME-CSIC provides them with an appropriate training to enable them to locate and measure those points, so users can manage the network themselves. IGME-CSIC labour also includes training for database creation to store and manage the information obtained.

Knowledge of groundwater quality is another major objective. Chemical sampling and analysis campaigns are carried out by CN IGME-CSIC to achieve it, and the Information obtained is provided to CUAS users.

CN IGME-CSIC advice is fundamental to allow CUAS users to acquire geological and hydrogeological basic working knowledge to understand how groundwater works (how it moves and reacts to human pressures). Information is shared with all users through meetings, chats and presentations.

## The SAGE4CAN project: The use of shallow geothermal energy from the Canary Islands

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### Abstract

The use of shallow geothermal energy (SGE) resources in oceanic volcanic environments entail additional challenges when compared to continental sedimentary/plutonic settings. The efficiency of shallow geothermal heat exchangers heavily depends on the geology and hydrogeology of the terrain where they are placed. Volcanic rocks in small oceanic islands (<5,000 km<sup>2</sup>) are the result of volcanism, erosion and tectonic collapse. All these processes conform highly heterogeneous formations with complex hydrogeology whose thermal response to shallow geothermal systems requires a good understanding of heat transfer in such environments. The SAGE4CAN project will concentrate on SGE resource assessment taking into account characteristic heterogeneity of volcanic formations, both at local and insular scale. To this end, the Canary Islands are selected as representative volcanic oceanic islands, to define SGE implementation barriers including but not limited to (1) heterogeneities of thermal properties intrinsic to volcanic formations (volcanic dikes, red layers, landslides, etc.), (2) heat advection in the context of complex groundwater flow in the unsaturated (dominate in midlands and highlands) as well as in the saturated medium (coast), (3) enhanced geothermal gradients, (4) transient effects of urban and volcanic activity, (5) heating and cooling demand, (6) shallow geothermal energy installations design and optimization, as well as (7) energy transition strategies in energy dependent islands. The SGE4CAN project will investigate novel approaches to overcome such boundary conditions of oceanic volcanic islands in the estimation of the renewability of the resources, developing novel procedures to conduct cost-efficient and open-access Thermal Response Tests (TRTs), investigate the performance of existing SGE systems, assessing environmental impacts associated with SGE use. The knowledge generated from this project will be used on its final stage to identify adequate strategies for the integration of SGE into heating and cooling policies and action plans, as well as to raise awareness about the technology so that it gets the recognition.



## Design and operation of a quantitative control network in a complex river basin district: application to the Segura river basin district

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### Abstract

The Segura River Basin District (SRBD) has groundwater resources of 628 hm<sup>3</sup>/year and 219 hm<sup>3</sup>/year of overexploitation. In the SRBD there are 63 groundwater bodies (GWB) and 242 aquifers. Among the GWB, there are 31 with more than one aquifer, and in 41 of them there are 177 aquifers without monitoring piezometer.

Due to the hydrogeological complexity and the intensity of groundwater abstractions, a strong modification of the groundwater flow in the aquifers is being caused. Currently, their control through piezometric and hydrometry networks presents difficulties in terms of implementation and representativeness of the measurements obtained.

The interpretation of the time series of spring flow rates and piezometry requires the consideration of hydrogeological factors specific to each aquifer and/or measurement point (well or spring) as may be: sectoring of the groundwater flow; the representativeness of water table measured; the possible communication through the well of overlapping aquifer sections; the presence of perched aquifers; or the effect of pumping in nearby wells.

It is proposed to create a control methodology that allows the characterisation of the aquifer state and the GWB based on the evolution of the hydrogeological parameters of quantitative control in the most objective way possible pointing out the uncertainties in knowledge and the actions required for their reduction. Likewise, the quantitative monitoring network should also take into account the areas of greatest hydrogeological interest, differentiating between those that are most appropriated for piezometric, hydrometric or mixed monitoring. It will necessary the use of interpretative guidelines and technical reports that show the results obtained.

The hydrogeological knowledge existing must be considered for the establishment of new monitoring points and control networks will be designed and interpreted jointly. In the case of the piezometry, to get hydrogeological representativeness, suitable construction of the observation piezometers will be essential.

## The essential work of IGME linked to the strategic role of groundwater for urban supply

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### Abstract

During 2018, 4,236 cubic hectometers of water were supplied to public urban supply networks. Approximately three quarters (3,188 hm<sup>3</sup>) were volumes of registered water, i.e., measured at users' meters. The remainder (1,048 hm<sup>3</sup>) were unregistered water volumes (not measured or estimated by gauging). The 17% of the water supplied for urban supply has a groundwater origin.

In Andalusia, the provinces of Granada and Jaen have the highest density of water catchments; specifically, in the province of Granada, 80% of its municipalities are supplied with groundwater. Since the beginning of the PANU in 1975, the IGME has been linked to this strategic and essential activity, which is the supply of populations with groundwater, having intervened in 90% of these supplies. Currently, through technical assistance agreements, initiated in 1982, it continues to carry out hydrogeological research aimed to satisfy the demand for water for urban use in the 174 municipalities of the Province.

## Eventual effect on groundwater in the hydrographic demarcation of La Palma due to the eruption of the Cumbre Vieja volcano

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### Abstract

The volcanic eruption that has taken place on the island of La Palma between September 19 and December 13, 2021, in the municipality of El Paso, has generated the need to know the possible effect that this event could have on the groundwater of the island, and therefore an advisory contract has been carried out between the Consejo Insular de Aguas de La Palma and the Instituto Geológico y Minero de España of the CSIC.

The purpose of the study is to assess the possible qualitative and quantitative variations in the island's aquifers, in order to establish and understand the degree of impact on groundwater related to the eruption of the Cumbre Vieja volcano.

The methodology of the study is being carried out by means of:

- Hydrometeorological analysis of the review of the natural recharge to the system.
- Establishment of a piezometric observation network in the MASbs of La Palma that could be affected by the Cumbre Vieja volcano eruption, through the installation of sensors for continuous recording of groundwater level and temperature.
- Sampling and chemical analysis of majority and minority elements and isotopes in a series of determined water points.
- Basic hydrogeological characterization of the MASbs that could be affected by the eruption.

During the reconnaissance carried out in the first field campaign, performed in January 2022, we have proceeded to the collection of specific piezometric data, the installation of sensors for continuous recording of piezometric values and water temperature, and the collection of samples for laboratory analysis, of which in its initial assessment an alteration in some physical and chemical characteristics of groundwater is perceived.



## Department of Geology and Subsoil



Fotografía: Ruth Soto

## Department of Geology and Subsoil (CN IGME-CSIC)

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### Abstract

The “*Departamento de Geología y Subsuelo*” of the CN IGME-CSIC investigates, produces, combines and transfers reference and multiscale geological information. It is a multidisciplinary Department working on the understanding of different Earth systems. Their objectives and activities are crucial for improving; (i) the use and sustainable management of resources (e.g. water, energy, minerals), (ii) predicting and adapting to the impacts of climate change, (iii) anticipating and mitigating natural risks, and (iv) planning and transferring knowledge to other Earth Science disciplines, the productive sector and the society.

The “*Departamento de Geología y Subsuelo*” is structured into six Research Groups which research mainly focus on:

- (1) “*Paleontología de ecosistemas terrestres y marinos: respuestas a las crisis bióticas y ambientales del Fanerozoico*” Research Group. Study of Cambrian to Holocene fossil record, its palaeoecology and palaeobiogeography, and diversity and extinction events occurred in the past.
- (2) “*Cartografía Geológica, Geomorfológica y Geología 4D de Cordilleras y Cuencas (GI-CARTO)*” Research Group. Production of geoscience knowledge structured into harmonized and multiscale data and information (e.g. geological maps and map data sets).
- (3) “*Geofísica y Geología del Subsuelo (GEOFSUB)*” Research Group. Acquisition, use and/or integration of geophysical and geological data to improve our subsurface knowledge.
- (4) “*Geología Aplicada a los Recursos Marinos y de Medios Extremos (GI-GEOMAR)*” Research Group. Study of marine geological resources (e.g. minerals, energy and geohabitats), submarine hydrothermal systems and extreme acidic environments.
- (5) “*Geoquímica y Geodinámica Litosférica*” Research Group. Analysis of the geodynamic evolution of orogenic systems, their igneous and metamorphic processes, petrogenesis and petrochronology.
- (6) “*Procesos Tectónicos y Recursos Geológicos*” Research Group. Characterization of the structure of multiscale geological bodies and the tectonic processes involved.



## Geological mapping as a tool for scientific research. Group of Geological, Geomorphological and 4D Geology Cartography of Mountain Ranges and Basins

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### Abstract

The GI-CARTO research group is articulated around geological mapping as a research methodology developed in many projects. The activities of the team can be distributed in various working lines:

- 1.- Research activities devoted to the solving of specific geological problems
- 2.- Systematic geological mapping
- 3.- Implementation of a new geological information model
- 4.- Edition and preparation of new geological maps
- 5.- International activities

### Introduction

Geological mapping is a central research activity in Earth Sciences. Every geological object in Earth has to be located in its geological context to ensure that the information it provides can be useful; out of its place no a proper interpretation can be made. The geological map is the right place where all this information has to be positioned for a correct interpretation of the data. Consequently, the GI-CARTO Group activities are based in geological mapping as a main research tool.

The group integrates advanced research activities in specific geological issues as the IBERSUTURES and Cantabrian mountains projects, but also assumes the responsibility of maintain and develop the geological map infrastructure of Spain and to make it evolve as the GIS and database technologies improved.

The results of this systematic and continuous survey, embodied in the Plan Cartográfico Nacional, have multiple uses in the design and application of environmental policies on the territory, in the search for mineral resources for the new green technologies, in hydrogeological and global change research, in geological hazards evaluation or in the interpretation and geological modelling of the subsoil for its use as storage of green hydrogen or CO<sub>2</sub>. Likewise, it favours and encourages the development of research activities in other centres of the CSIC, OPIS and Universities.

Its activities are articulated in conventions and agreements with public administrations, technological support contracts and competitive research projects.

### IBERSUTURES Project

IBERSUTURES (Suture zones of the Iberian Massif) is a project funded by the Agencia Estatal de Investigación (PID2020-112489GB-C22) leaded by Rubén Díez Fernández and Francisco Javier Rubio Pascual.

IBERSUTURES is partnered with a project carried out at Universidad Complutense (The ophiolites of the Iberian Massif), and both constitute a coordinated project referred to as OPHITURES. In the context of a coordinated project to investigate the ophiolites and suture zones of the Iberian Massif, IBERSUTURES proposes specific actions on the suture zones and the respective major tectonic blocks that define them, in order to enhance the knowledge of the history and structure of the Iberian Massif. Suture zones may hold an intricate and complex history, and their actual geometry may derive from a considerable number of deformation events, sometimes linked to the same orogenic cycle or to different and superimposed cycles. In the case of the Iberian Massif, there are three major cycles: Cadomian, Variscan and Alpine. The Variscan and Cadomian cycles are related to a characteristic dynamics and tectonics, but there exist controversy regarding: (1) the number of suture zones associated with each of those orogenic cycles; (2) the primary geometry of each suture zone (subduction polarity); (3) the existence of suture zones linked to the Cadomian cycle; (4) the extension and distribution of each of the major tectonic blocks (upper and lower plate) related to each suture zone; (5) the interference between suture zones from the same orogenic cycle or between those from different cycles. All these questions are key to reconstructing the geodynamic evolution of the Iberian Peninsula.

IBERSUTURES aims to generating new data, with particular attention to the geology of SW Iberian Massif. Data that is being obtained is mostly structural and petrologic, including their representation in geological maps. The research team in IBERSUTURES includes researchers with extensive experience to tackle each of the posed questions, for each of which the project proposes a specific study area within the geology of the SW Iberian Massif to develop geological mapping as well as detailed structural analysis, from the macro- down to the microscale.

A member of IBERSUTURES (Rubén Díez Fernández) is co-supervising a PhD thesis with a member of the other coordinated project (Ricardo Arenas). The core of this PhD thesis is Geological mapping and structural analysis.

Most of the results of this project are potentially transferable to the databases hosted at IGME and can be transformed into cartographic products that will update part of the geological maps of the crystalline basement of SW Iberia.

### **Variscan and Alpine structure superposition in the Cantabrian mountains**

The PhD thesis project entitled “Variscan and Alpine structure superposition in the Cuera and Picos de Europa mountain ranges (Cantabrian Mountains, NW Spain)” is being carried out by Brais Gonzalo Guerra, a CN IGME-CSIC predoctoral researcher. The PhD thesis is being developed in the University of Oviedo (UNIOVI), granted by the “Severo Ochoa” fellowship 2019 program (Asturian Autonomic Government) and supervised by Nemesio Heredia (IGME) and Pedro Farias (UNIOVI).

The main objective of this work is the recognition and analysis of the relations between the structures -essentially faults- linked to the Variscan and Alpine orogenic cycles in the Central Cantabrian Mountains (i.e. Picos de Europa and Cuera mountain ranges), as well as their interplay and influence in the mountain building processes. Therefore, a central issue studied in this project is the reactivation of structures produced during the Variscan Cycle (Variscan thrusts and Late Variscan strike slip faults), in later tectonic events of the Alpine Cycle (the Permian-Mesozoic extension and the Cenozoic compression) occurred in the studied area. The applied methodology, central to achieve these objectives, is the detailed geological mapping and the

intensive field data collection, followed by the geological cross-section building and analogue/digital modelling.

Since the PhD thesis is based in a range of versatile and multidisciplinary geological mapping techniques, this project provides new data for the Geological Mapping Plan internal project of the Geological Survey of Spain, thus allowing improving the current 1: 200,000 and several 1: 50,000 scale geological maps where the study area is located.

Also, surface geology, geological mapping and cross-section making carried out in this PhD project will allow the data integration, harmonization and calibration within geophysical surveys, as well as the interdisciplinary participation in the CANALAB-S1 project (PID2020-118228RB-C21) of the UNIOVI. The supply of these additional data to geophysical researchers will enable to constrain the deep interpretations in the western geological transect proposed in the mentioned I+D+i project.

Finally, the improvement of the previous geological maps, including new fault traces, especially regarding Late Variscan faults, sheds new light on regional tectonic interpretations, as well as information on the features controlling the location of relevant mineral and thermal spring resources.

### **Systematic geological mapping**

To fulfil its duties of actualise and maintain the geological map infrastructure of Spain, the group has obtained external funds from regional governments interested in complete the geological knowledge of their territory. Now there are two active projects:

#### *Geological mapping agreement with Andalucía government*

The objective of this arrangement is to complete the geological map coverage of the region of Andalucía with two new 1:200,000 and four 1:50,000 geological maps. This work is developed in collaboration with other IGME–CSIC research groups. The project develops between 2018 and 2022 with a funding of 420,665 € from the Junta de Andalucía.

Our team is focused in the mapping of the Almadén de la Plata (919) and Córdoba (923) 1: 50,000 sheets. Production of our group is supported on intensive field work, structural and petrological data acquisition and analysis, new valuable U-Pb geochronological data and the use of thermodynamic modelling on selected samples. Preliminary research outputs from new geological mapping point to important contributions unravelling the polyorogenic processes and deformational polyphase interference structure of some not well-known regions of the Ossa-Morena basement. New data goals attend to:

- Regional extension and importance of the different Lower to Middle Cambrian volcanic episodes in the Ossa-Morena Zone.
- Magmatic Cadomian history and geochronological evidences.
- Thermobarometric conditions in Cadomian metamorphic basements.
- Structure of the Variscan sutures in SW Iberia.
- Variscan structure of fold interference in the Ossa-Morena Zone.
- Structural and metamorphic controls on Ni-Cu-Pt-Au mining exploration.

The agreement also includes the realization of two new 1: 200,000 geological maps: Jaén (77) and Morón de la Frontera (82). Main research items, investigated jointly with the Tectonic Processes and GeoResources group, include the development and structural evolution of minibasins controlled by salt tectonics Sedimentary stacking patterns of minibasins above the

mobilized salt and the role of extreme crustal thinning, tectonic inheritance and salt tectonics during the evolution of the South-Iberian paleomargin from Mesozoic rifting to Cenozoic continental subduction.

#### *Geological mapping agreement with the Institut Cartogràfic Valencià*

The objective of this accord is to obtain a new digital, seamless geological map at 1: 25,000 scale of a sector of the littoral sector of the Comunidad Valenciana. The project develops between 2020 and 2024 with a funding of 500,000 € from the Valencia government. At this moment a new map of the Sierra Calderona sector is available. This area constitutes a portion of the SE termination of the Cordillera Ibérica against the Valencian coast, and constitutes a geological domain characterized by the predominance of the classical Permo-Triassic formations (Buntsandstein, Muschelkalk and Keuper) with a lower- middle Jurassic cover only preserved in reduced areas. This sector exhibits a very complex structural pattern of distensive structures as a result of the interference between the original NW-SE Iberian directions and the Neogene NNE-SSW extensional faults related with the aperture of Valencia Trough. The preliminary results of this research will be presented in the next meeting of the Tectonic group of the Sociedad Geológica de España in October.

Current research is being developed in the quaternary deposits south of the city of Valencia and in the southernmost Iberian Mesozoic fold and thrust belts ranges of Serra de Corbera and Serra de les Agulles.

#### **Tectonic map of Iberia and its adjacent mountain ranges**

The Tectonic map of Iberia at 1:1,125,000 scale represents the main tectonic features of the Iberian massif, the alpine orogens which surrounded it, including the complete extension of the Pyrenees and Betics, and the Cenozoic basins. The structural information of the continental platform is also represented. The map is the result of a detailed and accurate work compiling the knowledge accumulated on the different structural units of the Iberian Massif, the age and characteristics of the magmatic events, the data of the Mesozoic depocentres of the alpine ranges and the character of their compressive structures and represents a general synthesis of geological, structural, petrological and geophysical knowledge acquired in Iberia in the last years. This map is being developed under the auspices of the Commission for the Geological Map of the World (CCMW).

#### **The new geological information model**

A new geological information model based on the INSPIRE and GeoSciML standards has been developed. This model will be the new structure in which all the new information should be generated and delivered. This model allows the digital storage of information in a more detailed and interrelated way, which enables more analysis options and convert it into basic information for the development of other research activities.

In addition, the model allows geological elements, their characteristics and properties to be described in a standardized way through the use of lists of standardized terms, which facilitates their understanding and use in more national and international settings.

The objective of this activity is to promote the representation of geological information in this model, in such a way that it represents an advantage in the description, exchange and analysis of geological information. Another important objective is to achieve the maximum reuse of the data. This model aims to make this information available to users in the most useful and

interoperable way for its exploitation, trying to reach the greatest possible number of users, constituting a basis for research, professional activities and dissemination.

### **Edition and production of geological maps**

Edition and production of geological maps is a primary goal for a Geological Survey. The objective is making available to researchers, technicians, companies and the general public all the information generated in the current projects of geological, geomorphological and derivative mapping, in a readable and high-quality format. The GI-CARTO group holds these activities between his duties. These actions comprise: (1) Compilation of geological and thematic cartographic information and the related reports carried out by the responsible for cartography projects in any format. (2) Review of all the elements included in the geological/geomorphological maps, assuring the coherence both in format and content. Contrasting with the information included in the explanatory reports. (3) Generation of postscript files in accordance with Cartography Edition Regulations for publication (paper and online) and GIS files.

### **International activities**

In the last years, the group has carried out an active research overseas. The main areas of work have been the Andean cordillera (PALEOANDES project) and the Antarctica.

#### *PALEOANDES project*

Between 1993 and 2020, an IGME research group worked continuously in the Chilean-Argentinean Andes and the Antarctic Peninsula. This work was mainly carried out in collaboration with the Servicio Geológico y Minero Argentino (SEGEMAR) and the universities of Barcelona (UB) and Oviedo (UNIOVI) jointly with other institutions of Argentina, Chile and Brasil.

These activities started as a result of the participation of the IGME in the development of a geological mapping program of the SEGEMAR Argentine Geological Survey (PASMA Project) continuing later thanks to another several funding sources: AECI, BID (Banco Mundial), FEDER-UE, Plan Nacional de I+D+I, IGCP-UNESCO, FONCYT (Argentina) and IAA (Argentina).

The PaleoAndes Group is currently a reference in the study of the Paleozoic evolution of the Andes, participating in the organization of various international symposiums and meetings, publication of books and special volumes of scientific journals, evaluation of R+D projects in Argentina and Chile, review of book chapters and journal articles, guest conferences and postgraduate courses.

#### *Antarctic geological and geomorphological mapping*

An agreement between the CN-IGME-CSIC and the Argentine Antarctic Institute (IAA) have had as a result the publication of the Geologic and Geomorphologic maps of Seymour (Marambio) island at 1: 20,000 scale and the Geologic and Geomorphologic maps of Hope Bay at 1: 10,000 scale and their corresponding published reports.

These maps and reports, published with the support from the Spanish Polar Program are the result of an international collaborative effort led by the IGME and the Argentine IAA with participation of researchers from different universities and research centers.



## Tectonic Processes and GeoResources Lab

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### Goals

The main goal of the Tectonic Processes and GeoResources Lab is to explore the lithospheric processes operating during extension and orogenesis, and their influence on the distribution of georesources.

More specifically, our research focuses on:

- The structure, thermo-mechanical behavior and deformation of the lithosphere
- The effects of igneous and metamorphic processes on the rheology of the lithosphere
- The evolution of topography, erosion dynamics, and sediment transfer and deposition
- The characterization of reservoirs and seals to evaluate groundwater, mineral and energy resources, and gas storage solutions

The current research lines are:

- Inversion of hyperextended rift systems
- Salt tectonics
- Deformation mechanisms within the lower crust and lithospheric mantle
- Impact of crustal and mantle dynamic processes on topography
- Characterization of reservoirs for green hydrogen storage
- 3D modelling of reservoirs and deep aquifers

### Methodology

- **Geological mapping and structural fieldwork**, including the study of structural fabrics (e.g., salt structures, fold axes, bedding, fault surfaces, etc.), and fault kinematics (e.g., slicken-fibres, fault zone fabrics, stratigraphic cut-off lines, etc.).
- **Logging and correlation of well-exposed stratigraphic sections** to determine thickness, lithology, texture, color, sedimentary structures, fossils, paleocurrents, vertical cycles, sampling position, facies interpretation and diagnostic key surfaces.
- **Microstructural analysis** from conventional petrography to correlated micro-computed tomography ( $\mu$ -CT) and electron backscatter diffraction (EBSD) to reconstruct deformation mechanisms and microstructural evolution at the thin section-scale, and deformation flow trajectories at the map-scale. Particular emphasis is placed on the temporal relationship between HT deformation events and fluid/melt-rock reactions.
- **Estimating high-resolution surface uplift and erosion histories** to quantify the impact of crustal deformation on surface uplift rate histories.
- **Geophysical-petrological modelling** of present-day and past lithospheric structure, along with upper mantle convection and their joint impact on surface uplift.

- **Interpretation of seismic reflection data** to delineate the structure of the sedimentary basins using Kingdom Suite, and Geographix software.
- **Gravity and magnetic data acquisition, processing and modeling** to characterize the subsurface structure through the development of 2D and 3D models, using GeoModeller and Oasis Montaj software.
- **Time-Domain Electromagnetic (TDEM) and Electrical Resistivity Tomography ERT) data acquisition, processing and modeling** to constrain the distribution of conductive and resistive layers from a few tens to hundreds of meters depth.
- **Estimating metamorphic conditions** from petrographic studies and electron microprobe (EPMA) chemical analysis of mineral phases. PT conditions for each metamorphic event are estimated using conventional thermobarometry and pseudosections. Metamorphic ages are obtained using <sup>39</sup>Ar-<sup>40</sup>Ar on micas and amphiboles in low-grade terranes, and using U-Th-Pb and U-Pb systems on zircon, rutile, titanite and monazite in high-grade metamorphic rocks.
- **Construction of cross-sections and sequential restorations** using Move (Petroleum Experts) software
- **Construction of 3D geological models** using Move (Petroleum Experts), GeoModeller and SKUA-GOCAD software.

#### Potential applications and perspectives

- Geological Mapping
- Basin Analysis
- Orogenic studies
- Active Tectonics
- Aquifer Characterization
- CO<sub>2</sub>, Natural Gas and Green Hydrogen Storage
- Hydrocarbon Exploration
- Reservoir and Seal Characterization

#### Active research projects

- Inversion of the Iberian Paleomargin (IP: A. Pedrera). JA - Plan Andaluz de Investigación, Desarrollo e Innovación (2014-2020)
- Rift inheritance, orogenic EVolution and SEismicity in the Western Betics (REViSE-Betics) (IP: A. Pedrera and K. Hidas). Convocatoria 2020 - «Proyectos de I+D+i»
- Growth and origin of the Iberian plateau. A multidisciplinary approach (PLATIBERIA). (IP: J. Babault). Convocatoria 2020 - «Proyectos de I+D+i»
- Selección y caracterización geológica de potenciales almacenamientos de hidrógeno (UNDERGY) (I.P: C. Marín-Lechado). Geología De Exploración Y Síntesis (Gessal)
- Geological and Aerogeophysical Mapping of the Karamoja Region (Uganda) (IP: K. Hidas). Technical and Research Collaboration Contract with Xcalibur Geophysics Spain S.L. 2021-2022

## Growth and origin of the Iberian plateau. A multidisciplinary approach (PLATIBERIA): Lithospheric processes lab

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### Abstract

The history of surface uplift rates in the Iberian Meseta, as well as the deep and shallow mechanisms that generated and currently support its characteristic elevated topography, are still debated.

The objective of our project is to quantify the degree to which contributions to topography in the Iberian Meseta partition into crustal, lithospheric mantle, and sublithospheric mantle dynamic processes.

Addressing the problem at hand requires an interdisciplinary approach to integrate the two very different, yet intimately connected, crustal and upper mantle scales that operate here. Our coordinated project, built upon the synergy between geomorphic, geological, geophysical and geodynamic modelling approaches is defined by two differentiated and complementary subprojects with the following objectives:

Subproject 1) new estimates of high-resolution surface uplift and erosion histories and quantifying the impact of crustal deformation on surface uplift rate histories (IGME);

Subproject 2) integrated geophysical-petrological modelling of present-day and past lithospheric structure, along with upper mantle convection and their joint impact on surface uplift (UCM).

The results of each subproject will allow for a comparison of surface uplift histories predicted independently by surface evolution models and deep-Earth models. A probabilistic (Bayesian) approach will allow us to estimate the level of confidence of the crustal and subcrustal components of surface uplift and quantitatively test the level of confidence of the hypotheses on the origin the Iberian Meseta.

## Subsurface Geophysics and Geology (GEOFSUB)

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### Background

The geophysics line at the IGME began in 1927 as a Geophysics Section dedicated to subsurface exploration. During all this time, it has been developed in order to support and give expert service in all IGME's activities both as a geological service and public research institution, as well as a research and development work itself. On the other hand, in recent years the IGME has promoted a line of research aimed at the characterization and 3D modeling of geological structures and formations, the development of dedicated software and the evolution and sophistication of computer equipment. The new scenario of incorporation of the IGME to the CSIC as a national reference center in the field of Earth Sciences has allowed the establishment of the GEOFSUB Research Group (Subsurface Geophysics and Geology). It is constituted by 21 members who had been collaborating regularly of the IGME former scientific-technic areas Geophysics and remote sensing (Área de Geofísica y Teledetección) and Subsurface geology and 3D geological modelling (Área de Geología del Subsuelo y Modelización Geológica 3D). Our main differentiating element is our extensive knowledge of geophysical and geological techniques, which allows us to characterize the subsoil in an optimal way.

### Objectives, work areas and potential application sectors

The main objective of GEOFSUB research group is to generate 2D and 3D geological and geophysical knowledge, both at deep and/or in the shallow subsurface, using terrestrial and/or marine data, to characterize and model geological structures and formations and their correlation at depth. In parallel, this Research Group aims to obtain new geological and geophysical data that feed and maintain the IGME (CSIC), SIGEOF and SITOP databases, together with other national and international databases. This purpose allows the generation of new geophysical cartographies in both national and international projects.

Geophysical and geological modeling is identified in some of the Horizon 2020 strategies as a fast and efficient tool for the evaluation of geological structures. It is applied in projects for the characterization of favorable structures susceptible to geological storage, resource exploration and hydrogeological and geothermal purposes, and for the detection and remediation of pollution, essential as a strategy for climate change mitigation and in the ecological transition. It is fundamental in regional knowledge, resolving deep geological structures mapped at surface.

The objectives and aims of the group include:

1. To characterize and model the main regional geological structures at different scales and geodynamic contexts.
2. To develop, optimize and implement methodologies, tools and workflows in 3D geophysical and geological modeling and reconstruction.

3. Collecting new data and generating 2D and 3D geological and geophysical models. Obtaining geological data (structural geology, stratigraphic, sedimentological, dredges, gravity and piston coring among others) and geophysical data (airborne, marine platforms, surface or boreholes: electrical, gravimetric, magnetic, radiometric, electromagnetic, petrophysical, paleomagnetic, core-logging, both active and passive seismic, marine multichannel and single channel reflection and high resolution, bathymetric, backscatter among others).

4. To maintain a knowledge infrastructure that allows support to other actions and projects that require expertise in geophysics, 3D geological modeling, paleomagnetism, paleoceanography and tectonics.

5. To develop quality and rigorous research through the different research projects of the National Plan, European and regional, and national and international dissemination and outreach.

The GEOFSUB group carries out research activities in the Spanish territorial surface, both emerged and its continental margins. Exceptionally relevant are the works carried out in the Pyrenees region, the Galician, Cantabrian, Valencian, Canary continental margins and Gulf of Cadiz, as well as specific actions throughout the entire Spanish geography. Research actions in other countries and international territories includes Angola, Argentina (Andes and Tierra del Fuego), Australia (Tasmania), Morocco, Uganda, European and Caribbean continental margins, and very relevantly in Antarctica.

Finally, the potential applications of our know-how include: - Planning and organization of the territory. - Search and management of geological resources (water, minerals, geothermal, industrial rocks, energy resources...) - Search and characterization of geological stores for resources (natural gas, geothermal, H<sub>2</sub>) and waste (CO<sub>2</sub>) in subsurface geological levels that are environmentally and socially safe onshore and offshore. - Delimitation and monitoring of areas likely to experience geological risks (floods, landslides, earthquakes, subaquatic instabilities, tsunamis, volcanic eruptions). - Management and conservation of natural heritage. - Search for buried archaeological and historical heritage. - Biomagnetism, Biomedical and Environmental Sector- Basic research, education and scientific dissemination.

### Human and material resources

Currently, the research group is composed of 21 researches and technicians. Nineteen members hold a permanent position (14 scientists and 5 technicians) and 2 members have a temporary contract (1 Juan de la Cierva grant). With regard to their training, it should be noted that 16 members hold a PhD degree. With respect to gender distribution 48% are women and 52% men and they are distributed geographically in Tres Cantos/Madrid (14), Zaragoza (6) and Barcelona (1).

Our expertise covers different fields of geophysics and geology. We have planned important data acquisition campaigns both on land, at sea and airborne both in Spain and in other regions (Angola, Argentina, Antarctica) with the support of national or foreign Scientific and Technical Singular Infrastructures (ICTS) (e. g. oceanographic vessels) or using important geophysical companies. We are also responsible for smaller geophysical equipment such as: 4 differential GPS; 2 ground-based relative gravimeters, 2 proton magnetometers, a magnetometer/gradiometer, a 24-channel refraction seismic equipment, a 10-station passive seismic equipment, a 72-channel active/passive seismic equipment, 2 electrical tomography equipments, a magnetotelluric and electromagnetic equipment, 2 paleomagnetic sample



acquisition equipments and 2 portable susceptivimeters. Additionally, we have specialized software in geophysical and geological modeling (Move, Geomodeller, Oasis Montaj, Skua GOCAD, Fledermaus, Rayfract, WellCad, Seismic Unix, Geopsy, GMT among others) together with our own procedures and software.

### Active research projects

The GEOFSUB research group has led and continues to lead projects financed through competitive calls for proposals from the National, European or Regional Plan. It also carries out projects derived from collaborative agreements and government requests. The projects currently active or finished in the last year 2021 are listed below:

- National Plan:

**TASDRACC.** Timing and main tectonic processes involved in the onset and evolution of the Antarctic Circumpolar Current (ACC): development of continental margins and oceanic basins (CTM2017-89711-C2-2-P) led by F. Bohoyo and A. Maestro. 2021

**SCORE.** Modelo de facies en contornitas arenosas del Golfo de Cádiz (IODP Expedición 339): caracterización e implicaciones en la exploración de hidrocarburos (CGL2016-80445-R). Led by E. Llave.

**UKRIA.** Cinética de las remagnetizaciones por enterramiento; una aproximación integrada en 4D (paleomagnetismo, geotermometría and geocronología) (PID-2019-104693GB-I00). Led by J.C. Larrasoana y E. Pueyo

**ICEFLAME** "impact of ICE-sheet retreat and geological controls on Fluid flow dynAMics of the antarctic pEninsula continental margin ". (PID2020-114856RB-I00). Led by R. Urgeles (ICM-CSIC) and R. León

**IMAGYN.** Imagen de alta resolución de la estructura cortical de los pirineos centrales y el papel de la herencia varisca en su evolución geodinámica (PID2020-114273GB-C22). Led by C. Ayala and R. Soto .

Red **MAGIBER.** Paleo/Geomagnetismo en Iberia; Nuevos retos (Ref. CGL2017-90632-REDT). Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia, Acciones de dinamización "Redes de Excelencia" 2017. Led by E. Pueyo.

- European:

**3DGEO-EU:** 3D geomodeling for Europe- Optimizing reconstructions of the subsurface to reduce structural uncertainty in 3D models. GeoERA-Eranet. Led by E. Pueyo.

**GARAH:** Hydrate assessment in the European continental margin and related risks. GeoERA-Eranet. Led by R. León.

**HRSM:** High Resolution Seabed Mapping. EMODnet-Bathymetry. Led by R. León.

**Cost Action-Geothermal DHC Research network** for including Geothermal technologies into Decarbonized Heating and Cooling grids (CA18219/ OC-2018-2-23361). Proposer and commission (E. Pueyo).

- Agreements:

**PLANAGEO:** Plan de Cartografía Geológica, Geofísica y Geoquímica de Angola. **UTE IGME-LNEG-IMPULSO:** Led by J. L. Garcia-Lobón and with the involvement of different members of the group (C. Rey, T. Mochales, J. M. Llorente, F. M. Rubio).

**3D-CCVC.** Reconstrucción y modelización 3D de la Cordillera y de la Cuenca Vasco-Cantábrica. Led by F. Bohoyo

**GEOZEEE.** Plan de investigaciones geológicas y geofísicas de la Zona Económica Exclusiva Española (ZEEE). Led by A. Maestro

In addition, to contribute as Co-proposal of the IODP proposal "Iceberg Alley 382"- Drilling successfully conducted during March to May 2019, in the Scotia Sea. Antarctica (F. Bohoyo). We also participate as research staff in other projects of the National Plan, European or regional as H2020 Pilot Strategy and NAIAD, Eranet GeoERA and Goleta (National Plan in Antarctica) etc. We have submitted three new proposals to different National Plan calls during 2021 (now in evaluation). Finally, it is worth highlighting the vocation of a large part of the group in specialized technical assistance in geophysical prospecting as support for different IGME projects.

### Dissemination and scientific achievements (2017-2022)

The GEOFSUB research group is characterized by an important activity of dissemination of results during the period 2017-2021 and through different channels. It is worth noting the publication of 78 publications in international journals of high impact (45 Q1) indexed in the SCI and 17 non-indexed publications, mostly national, 20 international book chapters, 5 national book chapters and 4 books. In addition, a large number of communications have been presented at international (+200) and national conferences (+100). The group has demonstrable experience as editors of national and international journals such as the Boletín Geológico y Minero, Frontiers and Geosciences, reviewers in several international journals and guest editors in international monographs.

In this period the members of the group are participated in the organization of international symposiums as IX SIMPOLAR held in Madrid (IGME and MNCN venues) with 200 participants along 3 days (September 2018) and the EAGE Near-Surface Geophysics Conference (Bordeaux, France, 2021), different sessions of the XIII International Symposium of Antarctic Earth Sciences and the EAGE Near-Surface Geophysics from 2017. International workshops related with Europeans projects as GARAH and field-trips in collaboration with the AAPG and the SGE. Invited talk in the World Geological Congress (India 2020) by C. Ayala about 3D geological modelling.

During this period, different cartographic products have also been produced, including 37 Ecocaracter Maps of the Spanish Exclusive Economic Zone sector of the Galician Margin and Cantabrian margin (16 maps and 19 maps, respectively, at a scale of 1:200.000 and 2 at 1:500.000) published in the series Geología y Geofísica nº6 and nº7 of the IGME. The first Bathymetric Map of the Drake Passage (Antarctica) in collaboration with the British Antarctic Survey (of which more than 500 hardcopies have been produced and distributed). The Magnetic Map of Antarctica ADMAP-2 (published in Geophysical Research Letters) and 6 maps of diverse geophysical nature published in the international specialized journal Journal of Maps (Galicia Margin, Drake Passage, Pyrenees...) where "Morphological and geological features of Drake Passage, Antarctica, from a new digital bathymetric model" have more than 9000 downloads from: <https://www.tandfonline.com/doi/full/10.1080/17445647.2018.1543618>. Finally, it is worth mentioning the participation and coordination of the marine sector of the Tectonic Map of the Iberian microcontinent and its adjacent orogens, in progress, showed at the last National Geological Congress 2021.

The members of GEOFSUB group are very active in committees and commissions. On behalf of the IGME, they participate in the international sphere: Group of Experts of the European Geological Services-EuroGeoSurveys (B. Benjumea, R. Soto), of the Spanish Delegation to the

International Seabed Authority (Kingston, Jamaica) (A. Maestro), and in the Legal and Technical Committee of the International Seabed Authority (ISA) (A. Maestro). In the national sphere: National Commission of Geodesy and Geophysics (F. M. Rubio, IGME institutional alternative member, and C. Rey, F. Bohoyo -Applied Geophysics section- and E. Pueyo -Geomagnetism and Aeronomy section-), Interministerial Commission for Marine Strategies (CIEM) (E. Llave) and Commission for Coordination and Monitoring of the Activities of Oceanographic Vessels (COCSABO) (F. Bohoyo).

At the international level, it is also worth mentioning the participation or representation in committees related to the Scientific Committee on Antarctic Research (SCAR), specifically in the SDLS-Antarctic Seismic Data Library System for Cooperative Research (SCAR Database Committee) (F. Bohoyo) and in the International Bathymetric Chart of Southern Ocean (IBCSO) (F. Bohoyo); linked to the latter in the Regional Mapping Board of the Southern Ocean region of Seabed 2030 Project (GEBCO-Nippon Foundation) (F. Bohoyo) and in European committees such as EPOS, and COST actions among others. Other notable commissions in the national panorama are those of the Sobrarbe Geopark (R. Soto, E. Pueyo), in the CENIEH (E. Pueyo), in the SGE (Women and Geology, Paleomagnetism, Marine Geology, and Tectonics Groups). In terms of Evaluation, many of the members has participated in this period in Panels of the National Plan Research Projects, Infrastructure, Industrial and human resources Juan de la Cierva Training and Incorporation, Ramón y Cajal, Technical support personnel PTA. In addition, E. Llave is collaborator from 2020 in the Earth and water sciences subarea (CTM-CTA) and F. Bohoyo is the coordinator from 2021 of the Polar Research subarea (CTM-POL) in the State Research Agency. Additionally, we have review proposals of foreign Research Agencies (Belgium; Poland, Argentina, France, Ireland).

As for the training activity and specifically regular university teaching, two members of the group teach in Geology and Environmental Sciences at the Complutense University of Madrid (UCM) and Autonomous University of Madrid (UAM) respectively, as associate professors and another six are part of the Master's Programmes of different universities (University of Zaragoza and Complutense University of Madrid). In addition, up to 10 members of the area have taught at university level. In this period (2017-2022) one Doctoral Thesis has been read and five are in progress. Different members of the group have supervised five Final Degree Projects and 10 Master's Degree Projects. Finally, we have enjoyed in this period of 10 Internships in foreign research centers (USA, France, Australia and Argentina).

## Outreach

The area develops an important activity of scientific outreach, highlighting those in which it has participated in the organization and coordination of scientific dissemination activities in the last years:

- In relation to the Geological Society of Spain (SGE): - Geolodía (Zaragoza 19 and Navarra 17, 19 and 20), -GeoCharlas since 2018, - Day of Women and Girls in Science 2019 and 2020.
- Participation in the preparation of Geological Field Guides (Sobrarbe and Pyrenees).
- Popular science articles in the journals Naturalmente CSIC (2019) and Enseñanzas de Ciencias de la Tierra (2019 and some more from 2010).
- C. Ayala was member of the jury of the Inspiraciencia short story competition organized by the CSIC (2018, 2019 and 2020); and for two years (2019 and 2020) member of the jury of the AMIT-Cat Awards for baccalaureate research work on the contributions of women in the field of science and technology.

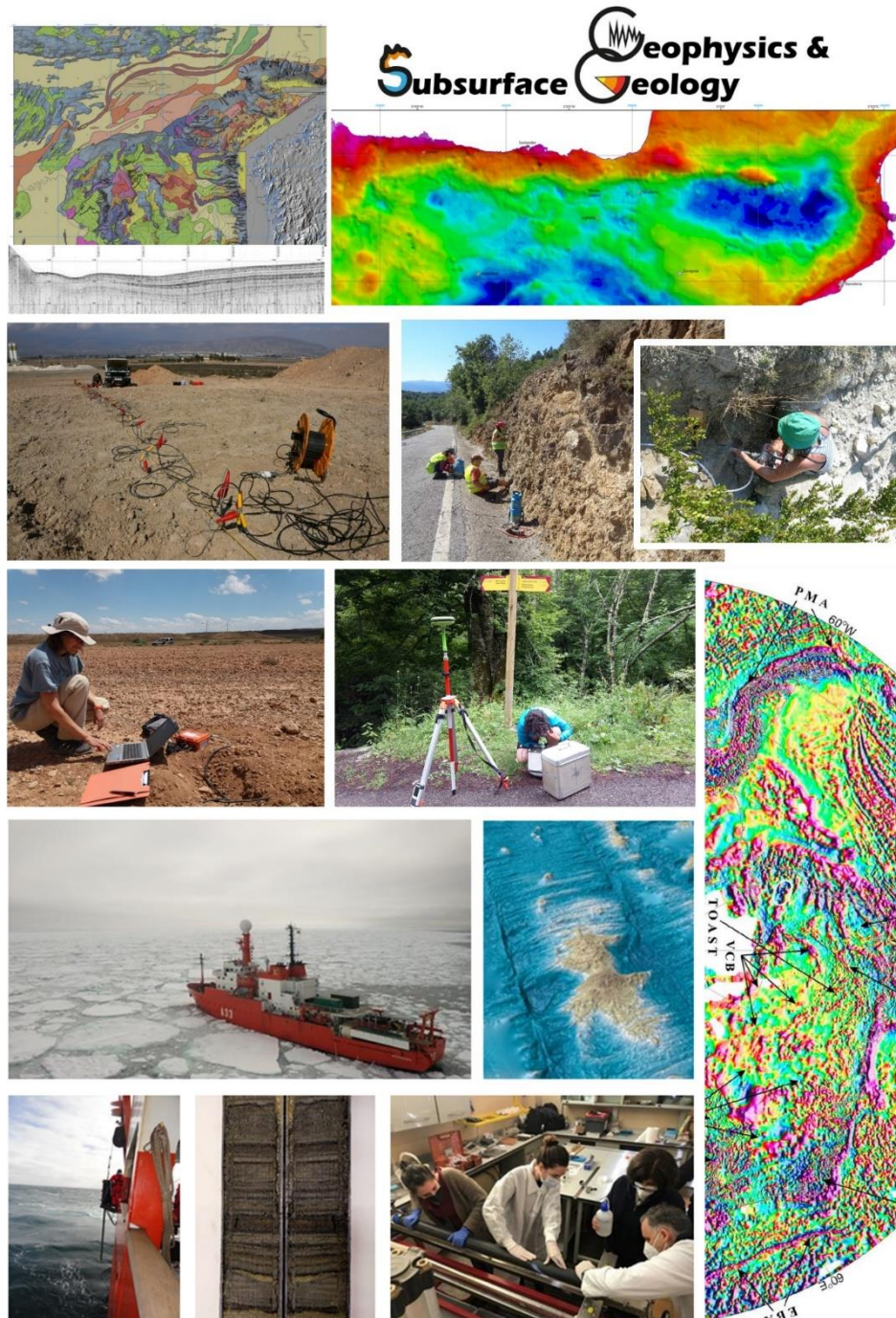
- In relation to Antarctica: Interviews in RNE, and in the written press (ElPais, El mundo, Diario 16, ABC, ElMercurio among others) in relation to the DRAKE2018 and POWELL2020 campaigns. Blogs and Twitter <https://tasmandrake.wordpress.com/> (~21000 visits) and @Tasmandrake.

We have also regularly given talks on geology, Antarctica, women in science, the Pyrenees in different ESO centers including direct connection from Antarctica expeditions.

Figure 1. Illustrative collage of some of the activities carried out by the GEOFSUB Research Group. From left to right and up to down. Echo-character map of the Galician Margin, GEOFSUB Logo, Bouguer anomaly map of the Iberian Peninsula, high resolution seismic profile, acquisition of: electric tomography profile, paleomagnetism samples, passive seismics and gravity,



Hesperides vessel in Antarctica, bathymetry model, Magnetic map of the Antarctica (ADMAP), gravity coring, sedimentary core, opening cores at IGME labs.





## High-resolution imaging of the crustal-scale structure of the Central Pyrenees and role of Variscan inheritance on its geodynamic evolution (IMAGYN)

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### Abstract

One of the goals of the IMAGYN project is to obtain a high-resolution imaging of the crustal-scale of the Central Pyrenees by integrating geophysical and geological data. The subsurface structure and geodynamic evolution of the study area, a sector with scarce seismic reflection and/or wells, will be defined combining (1) gravity, (2) magnetics, (3) magnetotelluric, (4) passive seismic and (5) analysis of anisotropy of magnetic susceptibility. This project spans from September 2021 to August 2025.

In the central part of the Pyrenees, the internal architecture of the orogen consists of an antiformal stack of basement-involved units dominated by Palaeozoic rocks (Axial Zone) and two fold-and-thrust belts involving Mesozoic and Cainozoic units flanking the Axial Zone to the north and south. The study area is a sector of the Central Pyrenees encompassing the southern half of the Axial Zone and the northernmost part of the South-Pyrenean Zone. This area is key for understanding the Variscan inheritance on the Alpine basement thrust sheets and the role played by the Triassic evaporites on the mechanical decoupling between the basement and cover rocks.

We will carry out field surveys to acquire new gravity, structural, magnetotelluric, passive seismic and magnetic data and rock samples to obtain petrophysical data and AMS and paleomagnetic specimens that will be processed and analysed. The acquisition of new gravimetric and petrophysical data will be carried out to construct a set of NNE-SSW serial cross-sections 100-120 km-long that will allow us to model the entire crust down to the Moho. Also in specific places, a denser measurement distribution will be done to better constrain the models. The magnetotelluric and passive seismic data will be acquired along two specific profiles, where some unknowns exist. The models will be further constrained using available aeromagnetic data. Sampling for the analysis of Anisotropy of Magnetic Susceptibility (AMS) and paleomagnetism will be carried out in volcanoclastic Permo-Carboniferous rocks to improve our understanding related to the geodynamical evolution of the study area in the context of the Pangea amalgamation and early break-up.

## Passive seismic methods: a cost-effective tool for subsurface characterization

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### Abstract

Seismic methods are commonly used for subsurface imaging and geological characterization. Two different types of methods can be distinguished based on the origin of the seismic waves that are analyzed. Active seismic methods study the propagation of artificially generated elastic waves using a controlled seismic source to obtain subsurface information. In the last years, there has been an increase interest in the use of passive seismic methods, mainly based on ambient noise analysis, for subsurface studies since they do not imply the use of any active sources, reducing the logistical complexity of the surveys. In general, these methods have a lower resolution than the active seismic techniques due to the lower-frequency content of the ambient noise wavefield. Among these methods, we find the horizontal-to-vertical component spectral ratio (H/V) technique and the autocorrelation technique. The H/V method consists of obtaining the spectral ratio between the horizontal and vertical components of a 3-component record. The frequency corresponding to the H/V maximum is related to the acoustic impedance contrast depth providing valuable subsurface information. The autocorrelation method allows extracting the reflectivity response of the subsurface from time windows autocorrelation and subsequent stacking. The result would be equivalent to a single seismic trace of a seismic reflection section. Several authors have successfully applied this technique for crustal structures delineation. Its application for shallower studies is novel. In this work, we present some examples of the application of both passive seismic methods carried out by IGME-CSIC in the last year focusing in the study of Cenozoic Basins. In particular, we show some results obtained within the framework of H2020 Pilot-Strategy project in the Ebro Basin. We include as well the results obtained of applying these ambient noise techniques to datasets acquired during the Topolberia project and by the Spanish Seismic Network (IGN). The recent acquisition of new instrumentation by IGME-CSIC will provide a valuable tool for extending the application of these methods to other targets that can range from potential geological storages imaging to mining exploration.

## Geochemistry and Lithosphere Geodynamics group (Geoquímica y Geodinámica Litosférica, GEOLITHOS)

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### Introduction

The Earth's crust has been shaped as result of the chemical differentiation processes behind the phenomena of magmatism and formation of igneous rocks, and the transformation of rocks by metamorphism. Magmatism and metamorphism are key to understand how the lithosphere dynamics and Earth's plate tectonics system work. New oceanic crust is formed by melting of the mantle at spreading ocean ridges. As this newly formed crust ages and gets transformed by metamorphism, it becomes denser, collapsing and sinking into the mantle forming a subduction zone. New continental crust is formed in the volcanic arcs above subduction zones by flux melting of the down-going plate and the overlying mantle, generating new magmas that form a felsic, buoyant, and thicker continental crust. Subduction zones are destructive plate margins where oceans are been consumed leading to the collision of continental crust and the formation of orogenic belts. As a group, we are interested in these igneous and metamorphic processes and their fundamental role in shaping the dynamics of Earth's lithosphere.

We have an extensive experience mapping metamorphic and igneous complexes in the Iberian Massif and overseas (e.g. Caribbean orogen, Angolan craton); and bridging fieldwork with detailed petrological and geochemical studies and instrumental analytical work. Our group is formed by scientist that belonged to the former Geology and Geophysics and the Analytical Laboratories units of IGME. Our common interest is the use of petrological tools and analytical instrumentation to decipher the geological evolution and architecture of the Earth's crust studying the texture, mineral and chemical composition of igneous and metamorphic rocks.

### Group background, expertise and research lines

Five members, four researchers and one technical specialist in geology, all holding Ph.D's, currently form our group. We are a trace element analyst and four geologists, one of them a U-Pb geochronologist, with a background in igneous and metamorphic petrology. We carry out work in igneous and metamorphic complexes, coupling geological mapping with structural geology and petrological studies. We have experience with geochronology, mineral thermobarometry (TWEEQU and Domino multiequilibria calculation and pseudosection work using PERPLEX), petrofabric studies and determination of P-T-t-d trajectories of metamorphic rocks, geochemical modelling of igneous petrogenetic processes, and trace element and isotopic fingerprinting of mantle and crustal magma sources.

Our members, P. Valverde Vaquero and M. Castillo Carrión, work at the geochemical laboratories of IGME in Tres Cantos and have expertise in U-Pb ID-TIMS geochronology (P.Valverde Vaquero ) and trace element analysis by ICPMS (M.Castillo Carrión). We share clean-laboratory space where we have a Millipore water distillation system to produce ultrapure water and two separate Teflon sub-boiling distillation systems to produce ultrapure acids. The U-Pb geochronology laboratory has its own clean room space with class 100 fume hoods and an additional Mattison Teflon distillation system. Two spikes, a 208Pb-235U and a triple 205Pb-

$^{233}\text{U}$ - $^{235}\text{U}$  spike, are used for isotope dilution (ID), and a Triton multicollector thermal-ionization mass spectrometer (TIMS) is used for isotope ratio measurement. The laboratory routine dates different U-Pb geochronometers such as: zircon, monazite, xenotime, titanite or rutile. The spikes have been calibrated in the Earthtime interlaboratory experiment and Earthtime artificial solution are routinely used to check that accuracy and precision stay at 0.1%. The ICPMS laboratory does analyses of ultratrace elements in different geological matrixes ranging from natural waters and mine drainages to solid minerals and rocks. For solids, different sample digestion methods are used. Trace elements such as Rare Earths (REE's) or Platinoid group elements (PGE's) are analysed. The ICPMS laboratory is accredited by ENAC for mineral water analysis and participates in GeoPT interlaboratory experiments of the International Association of Geoanalysts (IAG) to assure accuracy and precision. As part of our group's research interest, a special emphasis has been put in the analyses of the HFSE (Zr, Hf, Nb and Ta) in different types of rocks, and in carrying out in-situ trace element analyses in pyroxene, olivine and plagioclase using a 266nm CETAC Nd YAG solid-state laser system. The laboratory is currently equipped with two Agilent ICPMS instruments, a 7500 CE and a recently installed 7900 ICPMS. A new NWR 193 nm excimer (ArF) laser ablation system is going to be installed soon, which will open the capabilities of the laboratory to carry in-situ U-Pb LA-ICPMS dating and trace element analyses in different matrixes with spots down to 5 microns. As part of the analytical laboratories of IGME, we provide these techniques to internal and external users.

Most of our work has been done in igneous and metamorphic complexes in the Iberian Massif (Spain) and abroad. We have worked on the pre-Variscan and Variscan tectonothermal and magmatic events in the Iberian Massif. Overseas, we have been working in the Caribbean orogen for more than a decade, in different igneous and high-pressure metamorphic complexes of the Dominican Republic, carrying on the work initiated by IGME with the SYSMIN mapping project (see. Spec. Vol. "Geología y Minería de la República Dominicana", Bol. Geol. Min. IGME, vol.128, Escuder-Virue et al. (eds), 2017). This has been of our interest, as the arc-continent collision of the Caribbean arc with the North American continental plate provides some of the best exposures in the world of the different elements that make up a volcanic arc and the associated subduction zone. Since 2015, we have been involved in the PLANAGEO geological mapping of Angola, working with rocks ranging in age from 1.37 to 2.7 Ga, which has open our interest in the Proterozoic and Archean geodynamics of the lithosphere.

As a group, we have the following interests:

- 1) The formation of the oceanic crust (ophiolites) and the continental crust, the resulting mantle compositional heterogeneities, the igneous processes governing these processes, (e.g. boninitic cumulates of the Rio Boba plutonic complex, Dominican Republic; Escuder-Virue et al., 2022, G3, 23, e2021GC010101).
- 2) The studying of the metamorphic reactions, deformation and the rock-fluid interactions that take place during subduction (e.g. Siuna Serpentinite Melange, Nicaragua; Escuder-Virue et al., 2019, Lithos, v.340, 1-19) and the architecture of the modern Caribbean volcanic arc (Escuder-Virue et al., 2020, Tectonophysics v. 796, 228631).
- 3) Petrochronology, dating geological events through the integration of U-Pb geochronology (ID-TIMS) of different thermochronometers (zircon, monazite, xenotime, titanite, rutile) with petrological and textural studies. In-situ trace element analyses by LA-ICPMS to characterize the elemental and isotopic composition of crystals, fluids and magmas.
- 4) The tectonothermal, metamorphic, and magmatic evolution of crystalline basements and orogenic hinterlands of collisional orogens. Proterozoic and Archean tectonics: magmatism, deformation, sedimentation and partial melting and reworking of the Angolan Shield (PLANAGEO project). Modern collisional orogens, Variscan belt: magmatism, tectonothermal

events and sediment provenance studies (e.g. Gonzalez-Clavijo et al., 2021, Solid Earth, 12-4, 835-867).

5) Mineral Systems and tectonics: formation of mineral deposits and their host magmatic systems in subduction zones and their remobilization during metamorphism (e.g.; ophiolites of the Caribbean orogeny and the Andean cordillera). Mineralization, new mineral U-Pb thermochronometers (U-Pb dating of wolframite and columbite-tantalite) and ICPMS analyses of PGE's (Platinoids) and HFSE's (Nb,Ta, Zr, Hf).

### Group background, expertise and research lines

During the 2017-2022 period, we have published 23 scientific paper in SCI journals, with 10 papers in the Q1 category. We have done 10 scientific communications and 12 invited talks. We have produced 20 geological maps, at 1:50.000, 1:100.000 and 1:250.000 scales and compilations maps at to 1:500.000 and 1:1.000.000 scale for PLANAGEO, plus 21 scientific/technical reports and 5 book reports. We have participated in nine projects, leading four of them: one from the Plan Nacional de I+D+I and three international technology transfer projects, in the Dominican Republic and Angola.

We have one active project from Programa Retos, Plan Nacional de I+D+I, Project **MISYAP: Recursos minerales en la litosfera de arcos volcánicos intra-oceánicos: procesos geodinámicos, evolución tectono-magmática y arquitectura corteza-manto (Ref. PID2019-105625RB-C22)**. The project líder (IP) is J. Escuder-Virue and the participants are P. Valverde Vaquero (full time) and M.Castillo-Carrión (1/2 time), duration 2020-2024.

In the Dominican Republic, collaborating with the Servicio Geológico Nacional (SGN) and with founding from the Fondo Nacional de Innovación y Desarrollo Científico y Tecnológico (FONDOCYT; Ministerio de Educación Superior, Ciencia y Tecnología ,MESCyT) , J. Escuder Virue has co-lead the Project "Geodinámica, Neotectónica, Sismotectónica y Tectónica activa en la Cordillera Septentrional de la República Dominicana" (Ref. 2015-1B3-118, Project leaders: Yésica H. Pérez Alejandro (SGN) and J. Escuder-Virue; 2016 to 2018, extended to 2021) and is currently involved with the Project " La amenaza de movimientos en masa en la República Dominicana: factores desencadenantes e implicaciones en la vulnerabilidad y gestión del riesgo"(Ref. 2018-19-1A4-008; Project leaders: Maria Betania Roque (SGN) and J. Escuder-Virue; duration 2020-2022)

In Angola, we have participated in leading roles in the **PLANAGEO project (Plan Nacional de Cartografía Geológica de Angola)** financed by el Angolan Government. This project done as part of the UTE PLANAGEO partnership formed by LNEG (Portuguese Geological Survey), IGME and Impulso S.A. to provide new 1:250k and 1:100k geophysical and geological maps for Angola's Geological Institute (IGEO). Participation: Geological mapping project leader J. Escuder-Virue (2015-2019), E. Merino Martínez (2019-present); geochronology manager: P. Valverde-Vaquero (2015-present).

In non-leading roles, the group members have participated in the following technology transfer project: "*Evaluación metalogenética y estudio geológico-estructural del distrito polimetálico San Antonio de los Cobres, provincias de Salta y Jujuy, República Argentina*". Finance: Convenio de cooperación y asistencia técnica en materia de geología y minería (de 11/09/2013) between the Argentinian Geological Service (SEGEMAR) and IGME (IGME Project leader: Nemesio Heredia Carballo, participant, J. Escuder-Virue; duration 2018-2019).

Members of our group have also participated in the following EU-funded projects: **FRAME "Forecasting and Assesing Europe's Strategic Raw Materials Needs"** Project Ref: GeoE.171.010; 2018-2021), *Workpackage 6, Conflict free Nb-Ta for the EU*. (IGME Project lider: Susana Timón; Participant: P.Valverde Vaquero); and *CO<sub>2</sub> Geological Pilots in Strategic Territories* –



**PilotSTRATEGY.** 101022664 (2021-2026), IGME project leader P. Fernández-Cantelí, participant M. Castillo-Carrión) M. Castillo Carrión also participates in the project “Carbonate reservoir characterization in extensional settings: depositional architecture, controls, geofluids and simulation models (CARB-RES) RTI2018-093613-B-100 (IP: Idoia Rosales Franco/IGME, duration 2019-2021).

## Research on Marine Geology Resources and Extreme Environments at IGME-CSIC

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### Abstract

The research group *Marine Geology Resources and Extreme Environments (GI-GEOMAR)* at [IGME-CSIC](#) focuses on studies applied to the knowledge of the geological resources of the seabed (minerals, energy and geo-habitats) and mining environments for sustainable development. Studies of extreme media such as underwater hydrothermal systems, natural emissions of hydrocarbons and mud volcanoes, hypersaline settings, ferromanganese oxide and metalliferous deposits and acidic waters formed in mining areas are of special interest. The hydrochemical and bio-geochemical processes of mineral formation and concentration of strategic and critical metals with high interest in Biomining, Circular Economy and Blue Economy are in the scope of our Research Group.

GI-GEOMAR has a broad multi- and inter-experience in the field of the marine geology (tectonic, sedimentary and mineralization processes in continental margins and oceanic basins and their associated extremophilic organisms) and in the natural resources, especially in marine mineral deposits like ferromanganese deposits, phosphorites and those derived from hydrocarbon and hydrothermal emissions, both recent and fossils. The team has also a proved experience backed up by the planning and development of numerous national scientific projects of the Plan Estatal I+D+I (TASYO, GADES, RG-1, ERGAP, CONTOURIBER, SUBVENT, MINLIFE, TINTORREM, EXPLOSEA), CONSOLIDER INGENIO projects (TOPO-IBERIA), H2020 European projects of GeoERA (MINDeSEA, FRAME), EMODnet-Geology, EUROCORE-EUROMARGINS program (MOUNDFORCE, MVSEIS), COST Actions (PERGAMON), scientific projects in collaboration with the Foreign Office, Autonomous University of Madrid, TRAGSA, and IGME seabed cartographic projects.

The research of underwater geological resources and extreme environments is based on multidisciplinary techniques and experts. The research team combines the experience in methods of marine geophysical and ROV prospection in deep environment, with experts in generation of cartographies, databases and GIS analysis; mineralogical and geochemical analysis, water hydrochemistry; methods of microbiological and geo-habitat analysis, and analytic techniques and study of mineral deposits derived of hydrothermalism or sedimentary processes. High-resolution technologies for the study of mineral systems and associated mineral deposits are available in the framework of the Research Team associated centers and the network of EuroGeoSurveys. The team collaborates with various national and international research centers contributing with the results of the investigations to the ISA, INTERRIDGE, EMODnet and GeoERA research programs.

The scientific group has planned and managed numerous oceanographic cruises in Antarctica, Canary Island, Gulf of Cádiz, Galician and Cantabric area, and Mediterranean Sea on board R/V Sarmiento de Gamboa, R/V Miguel Oliver, R/V Hespérides, R/V Cornide de Saavedra, R/V Paula Navarro, R/V Odón de Buen, R/V Prof. Logachev, R/V Urania, R/V Le Suroit, R/V

L'Atalante, R/V Celtic Explorer, and R/V James Cook. GI-GEOMAR is part of the Expert Groups of Marine Geology and Mineral Resources at EUROGEOSURVEYS and the Commission on Global Geochemical Baselines.

Actually, there are seven principal lines of research at GI-GEOMAR:

- 1) Seabed mineral deposits
- 2) Geo-bio systems, extreme environments and biomineralization processes
- 3) Seabed mapping
- 4) Hydrochemistry and remediation in mining areas and open pit lakes
- 5) Antarctic research
- 6) Extension of the Continental Shelf
- 7) Expert assessment

Specific objectives of GI-GEOMAR research plan include:

- Characterize the different types of underwater minerals deposits.
- Characterize the mineralogy and geochemistry of mineral deposits including their strategic and critical elements.
- Identify extreme environments and their relationships with geo-habitats and biomineralization processes.
- Develop harmonized marine cartographies and databases, as well as potential and prospectivity studies for critical minerals.
- Develop studies of remediation and biomining in mining areas.
- Advise to national and international authorities concerning Continental Shelf extending beyond 200 nautical miles.
- Demonstrate how case studies are useful in advising Authorities on marine geological resources, environmental monitoring and mining restoration.

This research has been partially funded by the Spain's Recovery and Resilience Plan included in the MINECRITICAL project "Strategic critical metals for the energy transition" (C17.I7).

## Speciation and distribution of Critical Raw Materials in European seabed mineral deposits: MINDeSEA project results

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### Abstract

The MINDeSEA project is the result of the collaboration between eight GeoERA Partners and four Non-funded Organizations with the common interest in the investigation of marine mineral deposits. The main aim of the project is to generate an integrative metallogenetic study of the principal marine mineral resources: ferromanganese crusts, polymetallic nodules, massive sulphides, phosphorites and placers. These marine mineral deposits concentrated several critical raw materials (CRMs) depending on the minerals and genetic process involved in their formations. CRMs are a group of elements and materials that are necessary for the development of the society and have a high supply risk. European Commission revised the CRMs list in 2020, most of the elements recovered in this list are concentrated in the different marine mineral deposits studied under the MINDeSEA project.

MINDeSEA project recovered bibliographic and reports data, including almost 1200 samples from all the European seas. The mineralogical and geochemical data together with the bathymetric information from the EMODnet project resulted in the creation of different cartographies that collect information of the CRMs concentrated in each occurrence and deposit type. These data were also used both to generate metallogenetic maps for each deposit, and potential/predictive maps for future investigations. Results, expressed as mean, show that ferromanganese crusts and nodules concentrated the higher contents of cobalt, vanadium, tellurium and rare earth elements (3400, 830, 36 and 2400 µg/g respectively), with interesting contents of base metals as Mn, Ni and Cu (10 wt.%, 2000 and 800 µg/g respectively). REY are also concentrated in phosphorites (1000 µg/g) rich in P and F (respectively 9.5 and 1.7 wt.%). On the other hand, massive sulphides are enriched in several base metals like Cu, Pb and Zn (respectively up to 9, 6.5 and 34.5 wt.%) with high potential for different critical elements like Ga, Ge, and Li. Finally, placers concentrated several erosion-weathering resistant elements (Au, Ti, REE, Sn, Th, U, etc.) depending on the geology and the hydrography of the near continents.

This research is a contribution to the project MINDeSEA (grant agreement no 731166), and has been partially funded by the Spain's Recovery and Resilience Plan included in the MINECRITICAL project "Strategic critical metals for the energy transition" (C17.I7).

## Ferromanganese Crust and Phosphorites Pan-European Predictivity Cartography. MINDeSEA project results

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### Abstract

MINDeSEA is a project framed in GeoERA whose general objective is to obtain a metallogenetic study of the main types of mineral resources existing in the bottom of the European seas: hydrothermal sulphides, ferromanganese crusts, phosphorites, marine placers and polymetallic nodules. One of the specific objectives of the project is to develop databases and harmonized cartography of the mineral deposits of the seabed, the latter providing predictivity maps, among others.

For the elaboration of predictivity maps of ferromanganese crust and phosphorites, a model of the marine environment has been made based on bathymetric data, distance from the coast and age of the oceanic crust, using a geographic information system. In the first place, the location of possible seamounts, an ideal location for the formation of these deposits, has been automated. Secondly, a cartographic model has been made that considers depth, slope, distance from the coast and age of the crust. By assigning favourable and limiting values to these parameters, suitable zones and unfavourable zones for the deposit of Fe-Mn crusts and phosphorites have been identified. The superposition of this model with the possible locations of seamounts has resulted in the mapping of potential areas in which this type of deposits could be found.

This research is a contribution to the project MINDeSEA (grant agreement no 731166), and has been partially funded by the Spain's Recovery and Resilience Plan included in the MINECRITICAL project "Strategic critical metals for the energy transition" (C17.I7).



## Marine Geological Atlas of Spain

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### Abstract

The objective of this recently published Atlas is the development for the first time of a digital geological cartographic base of the Spanish continental margins to provide a reference tool, support and source of information for all those who carry out their work in the field of marine geology. The Atlas consists of the following thematic maps in digital and georeferenced format, prepared to be used with geographic information systems:

- Geological Map
- Geomorphological Map
- Map of Volcanic Edifices
- Map of Structures associated with Fluid Emissions
- Seabed Sediment Map
- Maps of Mineral Resources (Polymetallic Nodules, Polymetallic Sulphides, Placers, Cobalt-rich Ferromanganese Crusts, Evaporites, Rock, Pegmatite and Vein-hosted mineralizations and Phosphorites)

The maps are presented on a hillshade that allows visualizing the relief of the seabed. Along with these maps, other auxiliary information of interest is provided such as: Map of Toponyms and Map of commercial and research wells. In addition, map images (jpg files) are included at a scale of 1: 500,000, with their corresponding legend.

The geographic area covered by the Atlas includes the Mediterranean and Atlantic continental margins (Bay of Biscay, Galicia and Gulf of Cádiz), and the Canary Islands, as well as the adjacent abyssal plains. From the point of view of the United Nations (UN) Convention on the Law of the Sea, this Atlas includes the Exclusive Economic Zone (1.2 million km<sup>2</sup>) and the extended continental shelf areas requested and registered with the UN Commission of the Limits Continental Shelf (431.416 km<sup>2</sup>).

## The EMODnet-Geology project: A Pan-European initiative to facilitate access to marine geological data and maps

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### Abstract

The EMODnet- Geology project is aimed to facilitate the access and use of geological marine information to public and private users with the purpose to strengthen Blue Growth in Europe and to support the Green Deal. It is one of seven discipline-based projects (Geology, Chemistry, Biology, Physics, Bathymetry, Seabed Habitats and Human Activities) within the European Observation and Data network ([www.emodnet.eu](http://www.emodnet.eu)), a long term marine data initiative of the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

The EMODnet-Geology project provides harmonized and standardized marine data and multi-scale digital maps about sea-floor geology (Quaternary and Pre-Quaternary), seabed substrate and sediment rates, coastal behaviour (migration and erosion), geological events (volcanic centers, submarine landslides, active faults, earthquakes, tsunamis, non-volcanic fluid emissions), marine resources (aggregates, hydrocarbons, gas hydrates, marine placer deposits, phosphorite deposits, evaporite deposits, polymetallic sulphides, polymetallic nodules, cobalt rich ferromanganese crust, metal rich sediment, rock pegmatite and vein hosted mineralization) and submerged paleolandscape features produced by the geological surveys of 35 European countries. The geographical scope of the project includes the Baltic, Barents, Black, Caspian, Mediterranean, North Sea, the Celtic Sea and Bay of Biscay, the Iberian Margin and Macaronesia. The outputs (maps, documents and additional data) are publicly available and freely delivered through an Internet portal (<http://www.emodnet-geology.eu>).

EMODnet-Geology, now in its fifth phase, is consolidating the existing products, updating data and maps and developing new contents. By adding the Caribbean Sea, it is also extending into non-European waters.

This project is funded by the European Commission (EASME/EMFF/2020/3.1.11/Lot2/SI2.853812).

## Mineral microbial precipitation of seafloor fluids at the submarine Tagoro Volcano hydrothermal system (El Hierro, Spain)

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### Abstract

Microbial organisms are known to participate in the (bio)mineralization and (bio)precipitation of certain compounds as found in hydrothermal vents. This includes metabolic processes acting directly on the precipitate formation (iron-oxidation, sulfate-reduction) or indirectly by the acceleration of mineralization promoted by the presence of microbial cells that act as nucleation sites, such as for opal-A. Here, we present the findings of different microbial precipitation processes at a novel low-temperature and shallow-water hydrothermal system at the summit of the Tagoro volcano (80–120 m water depth). This system is characterized by seafloor and basanite-hornitos covered by Fe-flocculate deposits, with micro-cracks and degasification vesicles filled mostly by pyrite and covered by sulfur-oxidizing bacterial mats.

SEM micrographs from Fe-rich precipitates revealed the presence of biogenic twisted stalks and sheaths covered by iron-silica deposits, indicating the oxidation of iron driven by microaerophilic iron-oxidizing Zetaproteobacteria. Environmental 16S rRNA gene sequencing also exposed the presence of microorganisms actively involved in sulfur and methane cycles. Furthermore, SEM micrographs from hornitos' samples revealed silicified microorganisms coated by Fe-rich precipitates, suggesting a rapid silica-precipitation indirectly promoted by microbial surfaces acting as nucleation sites.

The discovery of this mineralization system and associated microbiota identifies a potential Fe-based ecosystem. These chemosynthetic microbial-mineral interactions contribute to the primary production in these environments, highlighting not only the importance of geomicrobiological interactions in shaping mineral deposits on Earth, but to the trophic sustainability of these ecosystems.

This research has been partially funded by the Spain's Recovery and Resilience Plan included in the MINECRITICAL project "Strategic critical metals for the energy transition" (C17.I7).

## Enrichment of thorium and rare earth elements in an acid rock drainage: a case study in the Bierzo area (León, Spain)

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### Abstract

The construction of a highway in El Bierzo (Spain) produced large dumps of black shales (Luarca Formation) that presented high contents of pyrite. The oxidative dissolution of pyrite generated Acid Rock Drainage (ARD), characterized by sulphated acid waters with high concentration of heavy metals that contaminated La Silva stream. Anomalies in dissolved thorium (Th), uranium (U) and rare earth elements (REE) values were detected, indicating an enrichment of several orders of magnitude when compared to natural waters. High values of REE were identified in local lithology and Th enrichment in precipitates. Black shales contain phosphate detrital minerals (monazite and xenotime) rich in Th and U that are finely distributed in the rocks. In turn, these shales are rich in organic matter and pyrite, which in presence of water have given rise to oxidative processes of pyrite and the formation of acidic waters that cause corrosion and dissolution of monazite and xenotime, yielding values of U, Th and other trace elements such as REY (eg., Ce, La, Nd, Y). Furthermore, these elements can form sulphated ionic complexes (e.g.  $\text{Th}(\text{SO}_4)_2$ ,  $\text{UO}_2\text{SO}_4$  and  $\text{REYSO}_4^+$ ) that help the mobility.

Iron precipitates have been characterized as schwertmannite and goethite. Th was the most abundant trace element up to 768  $\mu\text{g/g}$ , followed by Cr, As, Cu, Ba, Zn, Ni and U. Th adsorption can be favoured by the presence of several factors as the presence in the streams of ligands like phosphate, organic anions and sulphated anionic species ( $\text{Th}(\text{SO}_4)_3^-$ ). Precipitates presented little contents of Ce, Nd, Y and La, despite REY tend to be eliminated from solution through aluminium precipitation at  $\text{pH}>4$ . The presence of these elements may be favoured by the formation of dissolved anionic species as  $\text{REE}(\text{SO}_4)_2^-$  that enables adsorption.

The ARD generated in this area contaminated La Silva stream causing mortality of fish and affecting the vegetation. Nevertheless, REE have become critical raw material to several technologies. Most of the production is situated in China, and finding alternative sources of REY has become a need for the rest of countries. Hence, ARD can be seen as potentially promising source of REE.

This research has been partially funded by the Spain's Recovery and Resilience Plan included in the MINECRITICAL project "Strategic critical metals for the energy transition" (C17.I7).

## Composition and evolution of trace and rare earth elements in an acidic river basin (Tinto-Odiel)

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### Abstract

Overbank sediments are a high representative sampling medium used for geochemical regional studies. Formed by vertical accretion of alluvial material during flood events, they provide as well, a historical record of successive flood depositions. Tinto and Odiel Rivers drain part of the biggest metallogenic zone in the world, the Iberian Pyrite Belt. These rivers present low pH and high concentrations of dissolved heavy metals. The objective of the study is to estimate the influence of this acidic environment over trace and rare earth elements (REE) composition and patterns.

Three vertical profiles have been studied in order to have a historical overview of the Basins. In Tinto river, the profile was sampled upstream of San Juan del Puerto and two profiles were sampled in Odiel river, in Gibralfuente area. Total trace and (REE) contents were determined (ICP-MS) and some of the samples were subjected to a Tessier sequential extraction.

Tinto profile is heavily affected by the increase of mining activities in the XXth century, showing a net rise of metal contents in the upper sections. After a factor analysis in Tinto profile, it is observed a “mining factor”, while REE were grouped in a specific factor. There is a slight enrichment in LREE, being higher in the uppermost level. Europium and Ce anomalies are both near unity, and quite constant along the vertical profile. Rare and trace elements are concentrated in the residual fraction. Odiel-1 profile contains a layer that probably comes from a dam scape in the 80's. REE here follow a pattern very similar to Tinto profile. Meanwhile, in Odiel-2 profile REE present a wider distribution in all Tessier fractions. Besides, positive Ce anomaly is detected along this latter profile and Eu contents are higher too.

Sequential extraction confirms that in Odiel-1 and Tinto sediments, the most mobile fractions have been leached to waters, and that the vertical distribution is only a reflection of the REE present in mineral lattices. In Odiel-2 the REEs, as well as other metals (e.g. Pb, Cu, Zn), have not been so heavily lixiviated, and the observed Ce positive anomaly is presumably related to the adsorbed fractions. This anomaly, as well as Eu higher contents found in this profile, are usually related to a neutral or high pH environment, since in this conditions Ce tends to fix on the clays and Eu in water precipitates at pH>6.5. In this area, there is a strong influence by acidic waters, especially in the Tinto and Odiel-1 profiles, while Odiel-2 showed distinct characteristics due to higher pH values. There is a great sensitivity of REE to pH fluctuations, showing a distinct behavior in their patterns.



## Exergy and thermoeconomic assessment of the national recovery capacity of secondary resources essential for the ecological transition (RESET)

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### Abstract

It is estimated that there are about 14.000 closed or abandoned mining waste facilities in Spain, including more than 900 tailings dams. An important progress has been made in mineral processing techniques. In addition, minerals and substances that in the past were not employed in the industry, are today an important demand. For these reasons, abandoned mining wastes might contain valuable resources including critical raw materials. Reprocessing mining waste, searching for valuable resources, enables to introduce mining wastes into the Circular Economy circuit and contribute to reduce the associated environmental impact. The aim of this activity is to map secondary raw materials from mining wastes, establishing the recovery potential of these resources in Spain in particular of critical raw materials. With geological criteria, it will be firstly established the suitability of those sites to host potential critical raw material resources in the waste deposits will be done. Then based on the knowledge acquired during the inventory and risk assessment of more than 130 mining waste facilities all around Spain, a preliminary screening of potentially valuable resources will be conducted. In order to select the sampling sites for conducting detailed studies, criteria of suitability for the recovery of secondary raw materials will be determined and applied. Finally, sampling sites will be selected based on those criteria. Sampling campaigns imply the collection of non-oxidised samples. This requires deeper sampling. A composite sample, representative of the facility will be obtained. Geochemical characterization of samples will be carried out at IGME's labs, determining granulometry, pH 1:1, Sulphur and sulphate anions, major and trace elements, rare earth elements and mineralogy. This information is essential for determining the suitable methodologies for extracting metals contained in the wastes. For the different mining waste sites identified in previous tasks as being potentially of used, an exergy assessment will be carried out. The advantage of doing this analysis in exergy and not in tonnage terms is that in addition to quantity, we will be able to assess the quality of the resources available, considering composition and specific ore grade in just one numeraire and compare it with primary resources from worldwide mines. Based on the screening of mining wastes carried out, a selection of a site with an important number of secondary resources will be done. For this type of waste, the different beneficiation and refining processes will be modeled.

## High-resolution geochemical characterization with multi-sensor core logger in sediment cores in the Bransfield Strait (Antarctica): Preliminary results

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### Abstract

A preliminary geochemical and sedimentological study was proposed in seabed gravity cores collected in the western of Bransfield Strait during the EXPLOSEA (EX1) expedition. Cores were cut in half during research cruise to do the macroscopic description and the identification of hydrothermal events, layer of volcanic sediments (lapilli) and others. We used the Geotek Multi-sensor Core Logger equipment to analyze Magnetic Susceptibility (MS) and Electrical Resistivity (RES); and the continuous X-ray fluorescence (XRF) for Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Br, Rb, Sr, Y and Zr. The collection interval was 1 cm.

Six cores were analyzed: EX1-TG01, -TG03, -TG04, -TG05, -TG07 and -TG8, with 90, 210, 196, 198, 145 y 25 cm of length, respectively.

Macroscopic descriptions generally show silt-clay sediments that towards the bottom become clay-silt; except in TG8, which is coarse to very coarse sandy throughout the record. Sediments are mainly dark gray and very homogeneous, with eventual localized stratification. The first 5 cm of TG1, TG03, TG04 are very liquefied due to the high interstitial water content. Important bioturbation is observed in the first 30 cm of TG5 and TG7, also between 48 and 65 cm deep in TG5. Mild bioturbation is also observed at 52 and 65 cm depths of TG3. There are several levels of volcanic rock fragments (lapilli): 55-58 and 85-88 cm (TG1), 173-177 cm (TG4), 89-100 cm (TG5), and 72-76 and 82-86 cm deep (TG7). Likewise, patinas of Fe-Mn oxyhydroxides were observed in the first centimeters and at 90 cm in TG1, and in the last centimeters of the control in TG8. Oxidation layers were observed from the surface to 2 cm and 1 cm deep in TG5 and TG8, respectively; and indications of hydrotroilite (at 39, 137 and 152 cm depth in TG4).

The information of MS, RES and geochemical semi-quantitative values, preliminarily differentiate to a great extent the levels of lapilli found, mineralogical differences, as well as the first centimeters of the witnesses that have less consistency and greater amount of water (pores and interstitial). This abstract is part of the preliminary results of the EXPLOSEA project (CTM2016-75947-R), and partially funded by the Spain's Recovery and Resilience Plan included in the MINECRITICAL project "Strategic critical metals for the energy transition" (C17.I7).



## Department of Resources for the Ecological Transition



Photo: Susana Timón

## Geological Resources for the Ecological Transition: Challenges and Opportunities in the IGME National center

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### Abstract

The study of the geological processes leading to the formation of ore deposits and the identification of priority areas for extraction of primary and critical raw materials is of paramount importance for the economic and industrial development of our society and helps diminish our dependence with respect to other countries with respect to the supply of these raw materials. Our main challenge is the search of mineral resources critical for the ecological transition, with the goal of ensuring fulfillment of the Green Deal promoted by the European Commission.

Mineral and thermal waters are also important raw materials for different industries located in economically impoverished areas, so that the study of these waters may help guarantee the sustainability of this valuable resource and maintain the natural equilibrium of the exploited system. The study of mineral waters represents a valuable tool for the preservation of this cultural and natural resource.

Another strategic research line of our Department is focused on the environmental protection of natural resources (waters, soils, plants) and ecosystems from mine-related pollution (e.g. mine wastes, mine waters). We aim to reduce this environmental impact and we also promote the recycling of these wastes to recover primary and critical raw materials through different technologies, thus supporting the development of sustainable mining and circular economy.

The research line of Geoenergy is another important tool for the ecological transition, now that our society is demanding cleaner and safer energy sources that may help reduce our dependence from other nations. We conduct scientific research on the potential of our geological formations for the generation of clean energy resources (e.g. geothermic) and their capacity to store H<sub>2</sub>, CH<sub>4</sub> or compressed air, as well as fossil fuels like CO<sub>2</sub>.

Finally, the investigation of our geoheritage, geodiversity, geopreservation and geotourism also represents a powerful tool to promote transforming actions in our territory, which includes many protected natural areas and world-class geoparks. We promote the protection of this geoheritage through an innovative and modern vision that evaluates the different risks (e.g., degradation, erosion) and elements with special vulnerability in the current context of Global Change.



## Mining waste and environmental geochemistry research group

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### Abstract

The MINING WASTE AND ENVIRONMENTAL GEOCHEMISTRY RESEARCH GROUP (REMINGAM) focuses on the problems associated with abandoned mining waste and their characterization. The characterization of mining waste has been approached from a dual perspective: environmental (inventory and mineralogical, chemical, hydrological and geotechnical characterization, risk assessment, structural stability), and economic (estimation of restoration costs and environmental suitability, the potential for reuse and extraction of secondary raw materials). The Group also addresses research lines to evaluate the effectiveness of corrective measures for environmental impacts, for the reduction of environmental alterations derived from mining exploitation, and for the study, risk assessment, and recovery of valuable elements from abandoned mining wastes. We also apply several research techniques, both laboratory and in situ, to study many other types of environmental contamination in surface watercourses, soils, and sediments, including toxic metals, as well as other emerging contaminants of an organic nature, from various anthropogenic activities.

### Capacities

The IGME-CSIC laboratories are a fundamental pillar for the performance of the research group. A large number of analytical techniques available provide a wide range of possibilities when it comes to addressing physical characterization of samples, pollution problems related to mining, and other environmental damages not necessarily linked to mining. We apply a diverse variety of research techniques, both laboratory and in situ, to the study of many other types of environmental contamination of water, soils, and sediments, including toxic metals, as well as other emerging contaminants of an organic nature and that come from various anthropic activities. Members of the research group have developed experimental work, in the laboratory, where some natural processes can be simulated under different environmental conditions, as well as geochemical modeling work. Another of the group's strengths is its extensive experience in field survey, mapping, inventory, environmental monitoring, and taking all types of samples (solid, liquid, biological, etc.) for different purposes.

### Old mining waste facilities

The old mining waste facilities that have been closed or abandoned without any kind of restoration, or where the rehabilitation has been incomplete or negligent, represent a permanent potential risk for the population and the environment, especially when they contain dangerous and contaminating substances. Especially when these wastes include highly reactive minerals (such as sulfides), they represent a serious threat due to their potential contamination. It can generate mine waters with high acidity, sulfate, and/or toxic metal contents that can cause irreparable damage to ecosystems of streams, rivers, lakes, or reservoirs, and can strongly affect the use of these valuable water resources.



The Directive 2006/21/CE, on the management of wastes from extractive industries, urged the Member States to create and periodically update an inventory of the closed waste facilities, including the abandoned waste facilities, which could have a serious environmental impact or which might become, in the medium or short term, a serious threat to human health or to the environment (Figure 1).



**Figure 1.** Tailings impoundment at El Soldado Mine (Villanueva del Duque, Córdoba).

These inventories should be drawn up by applying methodologies or procedures of risk evaluation. The IGME was commissioned to perform and periodically update the Spanish inventory of closed or abandoned mining waste facilities and to develop the methodology for risk assessment. The transposition of the Directive was carried out in Spain by means of Royal Decree 975/2009, on the waste management of extractive industries and on the protection and rehabilitation of the space affected by mining activities. In accordance with this Royal Decree, the inventory of closed mining waste facilities will serve as a basis for drawing up a program of measures (establishing priorities for rehabilitation). The aim of the rehabilitation activities should be based on the reduction of the risks. Within this framework, the group has been carrying out an inventory and associated risk assessment using a methodology designed for this purpose. Currently, the National Inventory of Closed or Abandoned Mining Waste Facilities with Risk to Health, Property, or the Environment has been updated to 2022. Work has been carried out in coordination with the Ministry for Ecological Transition and with the Autonomous Regions for risk assessment and prioritization of actions in this type of facility.

#### **Acid mine waters and water pollution**

In the field of the study of the scope and characterization of mine water pollution, not only from mining waste but also from underground and open-pit mines, there is a high level of knowledge on a national scale. We have developed research in the main mining districts of the country, which are reflected in books, monographs, databases, and dozens of scientific publications, detailing the different mechanisms of migration and transport of different toxic

metals in the natural environment, as well as the design of treatment and pollution attenuation systems using various passive and semi-passive techniques. Today the group is a well-established reference at world-scale in the field of mine water and pit lake hydrogeochemistry and biogeochemistry.

Other research work includes the study of the dispersion of potentially toxic elements by erosion processes, which can be used as geochemical indicators of sediment or soil contamination processes originated by the more or less close presence of abandoned mining wastes.



**Figure 2.** Acidic effluent seeping from Riotinto mines and feeding the Tintillo river (Iberian Pyrite Belt, Huelva).

### Physical stability

There are numerous references to damage caused by breach due to a loss of physical stability in these structures, whether active or abandoned. In Europe, accidents such as those at Baia Mare (Romania), Aznalcóllar (Spain) or Ajka (Hungary) have led to greater social sensitivity to the risk that this kind of mining waste facility represents. The rehabilitation or remediation of abandoned mining areas involves, as a first objective, physical and chemical stabilization. The study and assessment of aspects related to the physical stability of mining facilities is essential to achieve the maximum degree of certainty about the long-term behavior of these structures.





Figure 3. Studying a destabilized zone in a tailings impoundment located at La Unión (Murcia).

### **Circular economy**

Finally, mining waste can be studied from a Circular Economy point of view. Today, significant advances have been made in mineral processing techniques. In addition, minerals and substances that were not used by industry in the past are in demand today. Thus, abandoned mining waste can contain valuable resources. The reprocessing of mining waste, and the search for valuable resources, make it possible to introduce mining waste into the Circular Economy circuit and contribute to reducing the associated environmental impact.

The research group aims to know the secondary raw materials from mining waste, and establishing the recovery potential of these resources in Spain, in particular of critical raw materials. Furthermore, mining wastes can be studied from the point of view of the Circular Economy. Nowadays an important progress has been made in mineral processing techniques. In addition, minerals and substances that in the past were not employed in the industry, are today under an important demand. Thus, abandoned mining wastes might contain valuable resources. Reprocessing mining waste, searching for valuable resources, enables to introduce mining wastes into the Circular Economy circuit and contribute to reduce the associated environmental impact. The aim of this activity is to map secondary raw materials from mining wastes, establishing the recovery potential of these resources in Spain in particular of critical raw materials. The group has developed different research works related to the recovery of elements of economic interest (e.g., Cu, Zn, Co, Ni) from mining wastes or areas degraded by acid mine drainage.

## Mining waste characterization in relation to recycling and rehabilitation processes

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### Abstract

The characterization of mining waste is a long-standing activity at IGME. It has been approached from multiple perspectives, including their assessment as a source of contamination, their capacity to support vegetation, and, more recently, their susceptibility to recycling.

One of the perspectives is the geochemical and mineralogical characterization of mining wastes to define realistic toxicity thresholds for this type of wastes. For example, the acid-base accounting method has been used for the prediction of acid-generating capacity. Concerning trace elements, a great deal of work has been done to determine the total contents, and several contamination indexes have been used, through comparison with background levels (baseline) or regional reference levels for soils, taking into account the possibility of dispersion by water or wind erosion that could affect soils, sediments, and surface water.

However, from the chemical point of view, the mobility of toxic elements does not depend so much on their total contents, but on the species in which they are present. Mobility of toxic elements is closely related, among other factors, to oxidation conditions, grain size, drainage conditions, climate of the area, and the nature of the secondary minerals formed in the upper layers of the deposits, mainly as result of the sulfide oxidation processes. Among the tests used for the environmental characterization of mining wastes, we have also worked with sequential extraction procedures, as well as with simple leaching methods, such as TCLP (Toxicity Characteristic Leaching Procedure) or deionized water leaching methods. It would be desirable to explore further the application of toxicological tests, although, indirectly, some work of this type has been developed.

Nevertheless, mining wastes can also be inert, when the content of toxic substances is low or when it is not possible to release toxic elements. Some mining wastes can be employed as raw materials for construction, reconstruction of landform, or rehabilitation of mining areas. Sometimes, mining wastes can be viewed as soil substitutes or new soils, and it is useful to apply characterization formulas taken from soil science or agronomy.

More recently, works towards the study of the potential of mining waste for recycling valuable elements are being carried out. In the context of the development of the circular economy, several projects are underway to address this possibility.

## Mineral and thermal waters research group

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### Abstract

The Mineral and Thermal Waters Group is a multidisciplinary team of 6 members, whose main objective is to advance in the different fields of knowledge regarding these waters, to ensure the sustainability of the exploitation of this resource through a correct aquifer protection. In order to achieve this goal, it is necessary to study the geology, hydrogeology, vulnerability and the physical-chemical characterization of these mineral resources. This knowledge is necessary to ensure a correct preservation of the resource, from a qualitative and quantitative point of view.

Besides, this would go in accordance with the Spanish Mining Act, the Spanish Mining General Regulation and the Spanish Sanitary and Technical Regulation of Natural Mineral Waters and Spring Waters. Those laws require the completion of mandatory reports to approve the declaration and authorization of use mineral and thermal waters.

### Introduction

Mineral and thermal waters usually have distinctive physicochemical characteristics due to their mineralization degree and temperature, as groundwater deep circulation is normally related to long periods within the aquifer. As groundwater constantly interacts with the aquifer, it might be affected by the dissolution of some substances, the precipitation of others, and the incorporation of gases such as CO<sub>2</sub>, methane or helium. The prolonged interaction with the environment might affect the dissolved substances and the isotopic composition of the water, facilitating the incorporation of certain natural radionuclides.

The thermodynamics and kinetics of the interactions between the groundwater and the rocks are complex because of the existence of different types of waters and their distinctive reaction with all types of rocks. In Spain we can find a high diversity of geological characteristics, from grounds formed by sedimentary processes to others that are a consequence of igneous, volcanic, and metamorphic ones. These grounds date back (according to the Geological time scale) to diverse periods that go from Precambrian to Quaternary. Therefore, these landscapes have been through different orogenies that have affected both the geological structures and the groundwater flow, as well as the relation between the materials and the runoff of rainwater and surface water. Among mineral waters, there are different degrees of mineralisation in accordance with the lithological characteristics of the grounds, the contact time between the water and the rock, as well as other physicochemical and biological processes that have intervened.

### Research and technical lines

The Mineral and Thermal Waters Group have developed multiple studies and framework on diverse topics related to this field, such as:

- Study of the mechanisms that give rise to these waters and the characteristics of the geological formations that house them, as well as knowledge of the geological,



hydrogeological and hydrochemical model that gives rise to them, which allows the optimal use of the resource and its effective protection.

- Given the great variability of mineral waters, with different physical-chemical composition and reflecting the variety and existing lithological and structural complexity, studies were carried out in order to obtain a better understanding of the origin and nature of this resource. This research gave rise to the definition and delimitation of 19 "Hydromineral Domains" in Spain, which are defined as "groups of geological formations related to each other geographically and stratigraphically, which include materials whose lithology and structure allow the storage and circulation of groundwater with physical-chemical characteristics similar to each other so that, in each of these domains, certain hydrogeochemical facies predominate". The definition of those domains motivated other works under different agreements with the Spanish Regions to define and characterize hydromineral subdomains within their territory. These subdomains have already been identified for Castilla y León and Galicia, and are currently being done in Andalucía.
- Investigate the origin of singular points, that is, those that present anomalous geochemical characteristics with respect to the geology of the environment, both due to their general composition and the content of certain elements that indicate deep circulation.
- Research about the geodiversity of these mining resources, as a reflection of the existing variety and lithological and structural complexity, deepening the knowledge of their origin and mineralization.
- Compilation of information about the industries that exploit hydromineral resources in Spain (bottled mineral water plants, balnearies and salt extraction plants) in order to carry out annual socioeconomic analysis and online publication of the main statistical data of the sector.
- Research work on the geodiversity of these mining resources, as a reflection of the existing lithological and structural complexity, deepening the knowledge of their origin and mineralization.
- Compilation of information on the industries that exploit hydromineral resources in Spain, in order to carry out annual socioeconomic analysis and online publication of the main statistical data of the sector.
- Mineral and thermal waters constitute the raw material for different industries frequently located in economically depressed areas, so their study constitutes a tool that favors the reactivation of these hydromineral resources, through the enhancement of historical points, contributing in this way to the defense and conservation of this cultural and natural heritage.
- Identification of potentially viable points for the establishment of new exploitations that take advantage of this hydromineral resource.
- Management and updating of the Mineral Water Database as a tool for knowledge and dissemination of the importance of mineral waters.

#### **Projects and contracts in the last 5 years**

- Management of the hydromineral resources of Andalucía. Partnership agreement between the Geological Survey of Spain and the Government of Andalucía in order to improve the geological and geochemical cartography, the inventory of historical quarries, critical minerals research, and to update and promote the documentary collection of the Spanish Region Andalucía. 2019-2022.

- Geodiversity of bottled mineral waters. Project within the framework partnership agreement between the Geological Survey of Spain and ANEABE. 2021-2022.
- Database of mineral resources, historical quarries and Panorama Minero. 2018-2022
- Collaboration in “Hydrogeological processes and geological settings in Europe that control geological and anthropogenic dissolved elements in groundwater of importance to human health and the state of dependent ecosystems”. GeoEra Program. 2018-2022.
- Statistic and socioeconomic analysis of mineral and thermal waters in Spain. Provision of services to the Official Lab José María de Madariaga (LOM) by the Technical University of Madrid. 2020-2021.
- Update on the knowledge of hydromineral resources in the province of Cuenca, within the agreement between the Cuenca Provincial Council and the Geological Survey of Spain, looking forward to better understanding, use and protection of waters, as well as investigating the geological and hydrogeological wealth. 2019-20122.
- Hydrogeological Significance of Mediterranean Geoparks. Historical data collection in the use of water and other mineral resources within the project. IGCP-730. 2021-2025.
- Statistical work concerning mineral and thermal waters in Spain. Provision of services to the Official Lab José María de Madariaga (LOM) by the Technical University of Madrid. 2019.
- Statistical work concerning mineral and thermal waters in Spain. Provision of services to the Official Lab José María de Madariaga (LOM) by the Technical University of Madrid. 2018.
- Statistical work concerning mineral and thermal waters in Spain. Provision of services to the Official Lab José María de Madariaga (LOM) by the Technical University of Madrid. 2017.
- Colaboration with the project “Actions for the development of the strategic plan for natural heritage and biodiversity 2011-2017 in relation to geodiversity and geological heritage”. 2013-2017.
- Recruitment of a degree-qualified technician. Technical and professional activities within the Project: Utilisation of hydromineral resources in Andalucía. Convention between the Geological Survey of Spain and the Government of Andalucía, in order to improve the geological and geochemical cartography, the inventory of historical quarries, critical minerals research, and to update and promote the documentary collection of the Spanish Region of Andalucía. 2019-2022.

#### Projects and contracts in the last 5 years

- Díaz Muñoz J. A.; Corral Lledó M.M.; Galindo E.; Ontiveros Beltranena C.; Fernández Portal J.M.; y Martínez Pledel B. 2022. “Mineral and Spring Waters in Andalucía”. Carlos Ruiz Celaá Award.
- Corral Lledó M.M.; Díaz Muñoz J. A.; Galindo E. y Ontiveros Beltranena C. 2022. “Cuenca. History and Current Picture of its Mineral and Spring Waters”. Editors: María del Mar Corral Lledó, José Ángel Díaz Muñoz, María Elena Galindo Rodríguez, Carlos Ontiveros Beltranena. NIPO: 833-22-032-0. ISBN: 978-84-00-10951-6. Currently in the process of post-production and layout development.
- Corral Lledó M.M.; Díaz Muñoz J. A.; Galindo E. y Ontiveros Beltranena C. 2022. “Mineral and Thermal Waters of Andalucía”. Editors: María del Mar Corral Lledó, José Ángel Díaz Muñoz, María Elena Galindo Rodríguez, Carlos Ontiveros Beltranena. NIPO: 833-22-031-5. ISBN: 978-84-00-10952-3. Currently being carried out.
- De la Hera-Portillo A.; López-Gutiérrez J.; Marín-Lechado C.; Martínez-Santos P.; Ruíz-Constan A.; Corral-Lledo M.M.; Galindo-Rodríguez E.; Mediavilla R.; Santisteban J.I.;

- Rodríguez-Jiménez E. y Callaú-Lopes M.F. 2021. "Integrating current and historical water chemistry data with long-term piezometric records to develop a regional-scale conceptual flow model: Las Salinas spring, Medina del Campo, Spain". *Journal of Hydrology: Regional Studies* 34 (2021) 100781. Elsevier. <https://doi.org/10.1016/j.ejrh.2021.100781>
- Spain in maps. A 2019 geographical synthesis. NIPO: 162-17-012-2. ISBN: 978-84-416-3952-2
  - Díaz Muñoz J. A.; Pardo Igúzquiza E.; Corral Lledó M.M.; Ontiveros Beltranena C. y Galindo E. 2018. "Packaged natural mineral waters and Premium waters". Abstracts Book. XIV International Congress of Energy and Mineral Resources.
  - Corral Lledó M.M.; Díaz Muñoz J. A.; Galindo E. y Ontiveros Beltranena C. 2018. "Mineral Bottled Watters and the Sustainability of its Aquifers". Editors: Geological Survey and ANEABE. ISBN: 978-84-09-04613-3.
  - Díaz Muñoz J. A.; Ontiveros Beltranena C.; Galindo E y Corral Lledó M.M. 2018. "The industrial exploitation of salt mines in Leintz-Gatzaga (Guipúzcoa)". Second International Congress regarding the salt. Historical exploitation of salt: investigationa and its value.
  - Díaz Muñoz J. A.; Ontiveros Beltranena C.; Galindo E. y Corral Lledó M.M. 2018. "Principal characteristics about thermal waters in Granada's depression". Iberic Congress about Spring Waters, Environment, Health and Patrimony.
  - Galindo E.; Ontiveros Beltranena C.; Díaz Muñoz J. A. y Corral Lledó M.M. 2017. "Evolution of mineral bottled water in Spain". 2nd International Interdisciplinary Conference on Mineral Waters: Genesis, Exploitation, Protection and Valorisation – MinWat2017. Abstracts Book.
  - Galindo E.; Ontiveros Beltranena C.; Díaz Muñoz J. A. y Corral Lledó M.M. 2017. "Socioeconomic aspects of medicinal and thermal waters in Galicia". II Syposium Internacional de Calidad de Vida (SCTV-II)/ IInd International Symposium on Healing SPA and life Quality. Campus da Auga, Ourense, Spain, 2017.

#### Conferences and seminars in the last 5 years

- Organization of the second seminar on "Mineral and thermal waters: a renewable resource for the socioeconomic development of rural Spain". Celebrated on June 8 and 9, 2022. Granada.
- Second seminar on "Mineral and thermal waters: a renewable resource for the socioeconomic development of rural Spain". Speaker: José Ángel Díaz. Contribution to the knowledge about the current landscape of mineral and thermal waters in Andalucía. 2022.
- Second seminar on "Mineral and thermal waters: a renewable resource for the socioeconomic development of rural Spain". Speaker: Carlos Ontiveros Beltranena. Mineral waters of Granada. 2022.
- Second seminar on "Mineral and thermal waters: a renewable resource for the socioeconomic development of rural Spain". Speaker: María del Mar Corral Lledó. Synergies between the utilisation of mineral waters and waters for human consumption. 2022.
- First seminar on Water and Health, organised by TERMATALIA. September 16 and 17, 2020. Speaker: María del Mar Corral Lledó. Panel discussion: "Exploitation of thermal resources for therapeutical and ludic utilisation".
- Seminar on Sustainability within the Mineral Waters sector: Product-Planet-People, organised by ANEABE. November 26, 2020. Speaker: María del Mar Corral Lledó. Panel discussion: "The value of natural mineral water".

- Formative action “The Mineral Waters Industry”, organised by ANEABE in Madrid. April 9 and 10, 2019. Speaker: María Elena Galindo Rodríguez. “Hydrogeology - Mineral waters”.
- Seminar: Sustainable thermalism for the 21st century”, organised by the association of balneary centres in Galicia. November 27, 2019. Speaker: María del Mar Corral Lledó. Panel discussion: “Protecting the resource in order to ensure the future”.
- Cafes of Europe. The other side of water: sustainability strategies in thermal destinations. October 3, 2018. The event is within the General Assembly of the Association and Itinerary of Cultural European Historical Thermal Cities. Speaker: María del Mar Corral Lledó. “The protection of natural resources as a source of wealth and environmental sustainability.
- Seminar “The mineral water sector and the circular economy”, organised by ANEABE. October 16, 2018. Speaker: María del Mar Corral Lledó. Protection of a renewable and unique resource. Panel discussion: “Bottled mineral waters and the sustainability of its aquifers”.

## Contribution to the knowledge of hydromineral resources in Andalusia

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### Abstract

Andalusia is one of the most important regions of Spain in the field of mineral and thermal waters, due to its historical tradition and the economic activity that these waters generate today through its active balnearies, bottling plants and salt industries. In 2018, the Geological Survey of Spain and the Andalusian Government signed a collaboration agreement to carry out scientific research activities, which include getting a deeper knowledge of the mineral and thermal waters of this Spanish region. Related to these waters, the main achievements of the agreement are:

More than 700 mineral and/or thermal waters have been identified. More than 300 of these collections have been visited on-site, some of them active, others practically disappeared. Physical and chemical analysis have been carried out on most of them and a complete study has been carried out for each active balneary or bottling plant.

In previous research, the Geological Survey of Spain defined up to 19 hydromineral domains in Spain, those hydromineral domains are defined as "groups of geological formations related to each other geographically and stratigraphically, which include materials whose lithology and structure allow the storage and circulation of groundwater with physical-chemical characteristics similar to each other so, in each of these domains, certain hydrogeochemical facies predominate". Starting from the physical and chemical analysis the hydromineral sub-domains of Andalusia have been established. Within the sub-domains some "singular waters" have been identified.

Some non-active mineral and/or thermal waters have a big potential to be exploited on new bottling plants and balnearies in the region, taking into account strictly technical aspects (such as water flow and quality) and other socioeconomic, such as the distance to large population centers. Up to 6 of the non-active waters have been selected to analyze their potential as the basis of new industries.



## Economic Geology of Mineral Resources

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### Abstract

The study of mineral resources of our country was, and still is, one of the foundational objectives of *Instituto Geológico y Minero de España* (IGME), that began to carry out studies on them and to elaborate maps of occurrences and ore deposits. Since the 70's of the 20<sup>th</sup> century, the metallogenic map has been the main tool for the transmission of knowledge in this field. In the European context in which we work, the present place us in front of the great challenge of identifying the supply potential of critical and strategic raw materials for the energy transition, in order to comply with the Green Deal promoted by the European Commission.

The Economic Geology of Mineral Resources research group (GI-GECOMIN) is made up of 17 members including researcher, specialized senior technician and higher graduate of technical and professional activities, with extensive experience in the study of geological resources. This work aims to describe the main objectives, the accredited experience, and the most relevant scientific-technical activities carried out by the GI-GECOMIN, grouped in four research lines.

### Research Overview

GECOMIN's activities include four areas: (1) Characterization, genesis and assessment of mineral resources; (2) Mineral processing and metallurgy; (3) Mining heritage; and (4) Natural stone, historical quarries and architectural heritage (Figure 1). Moreover, the most relevant aspects of the GECOMIN's curriculum vitae may be viewed in Table 1.

#### *Characterization, genesis and assessment of mineral resources*

The main objective is to study the geological processes leading to the formation of mineral deposits, to assess the quantity and quality of resources, both of primary and secondary origin, and to identify areas with undiscovered mineral resources or with potential for future supply of raw materials (metallic, non-metallic and industrial), with special emphasis on critical or strategic ones, with the ultimate aim of increasing interest in mineral exploration.

To achieve these goals, the following studies are developed: mapping, geochemical exploration of rocks, minerals and sediments, geochronology, isotope geochemistry and fluid inclusions. It contributes to complete the existing databases, search for mineral resources and elaborate the genetic models to be applied in the evaluation of resources. Among the results of our work, it is worth mentioning: the National Database of Mineral Resources (BDMIN), metallogenic maps, predictive mineral potential mapping, maps of rocks and industrial minerals,

systematic geochemical exploration maps, at different scales, and the Geochemical Atlas of Spain.

Currently, major efforts are focused on the analysis of the regional and national mining potential for certain critical minerals, defined by the European Commission, and other elements that are considered fundamental for the fulfilment of the objectives of the Ecological Transition policy (implementation of renewable energies, electric mobility, etc.). Reports are prepared on the substances studied, highlighting the most promising areas and indicating recommendations to improve the degree of knowledge. In addition to working on the systematic maintenance of the databases and the updating of the mining cartography, it is planned to develop a database of critical mineral resources according to the INSPIRE directive requirements, under the international reporting standards (CRIRSCO) and the United Nations Framework Classification for Resources (UNFC). The results of this research have direct practical application, providing valuable information to geological resources managing bodies to facilitate strategic decision-making aligned with the Sustainable Development Goals of the 2030 Agenda, which translates into collaborations with public administrations.

This activity is combined with the development of fundamental research projects, focused on the study of the genesis of ore deposits. The mineral systems under investigation are: a) rift- and subduction-related magmatic-hydrothermal systems: rare-metal granites, pegmatites, greisen, skarns and quartz veins enriched in Sn, W, Nb, Ta, Li and Be; b) peralkaline magmatic systems and carbonatites; c) hydrothermal systems in shear zones: orogenic gold-type deposits and polymetallic sulphide deposits; d) continental marine basin systems: sedimentary exhalative (sedex-type deposits), iron-manganese oxides, black shale deposits, etc.; e) volcanogenic submarine hydrothermal systems: massive sulphide deposits; f) mafic and ultramafic magmatic systems: Ni-Cu-PGE sulphide deposits, Fe-Ti-V and, and Cr deposits; g) IOCG systems; and h) surface weathering systems: placer-type deposits. When research involves abandoned mining areas, comprehensive studies are carried out, including the use of mining waste (tailings ponds and dumps) to respond to the Spanish Circular Economy Strategy. This work is performed in close collaboration with the Mining Waste, Mineral Waters and Environmental Geochemistry research group.

The group actively has participated in projects on raw materials in FP7 and H2020 programs, such as Promine, Foram, Minerals4EU, GeoERA (Frame, Mintel4EU), and now, through the Horizon Europe framework programme, in projects such as Start, designed to research sustainable energy harvesting systems based on innovative waste recycling. In addition, the group also collaborates in international projects in Latin America and Africa, such as the National Geology Plan of Angola (Planageo), carrying out geochemical exploration in areas of mining interest. Within the framework of Planageo, the Carmina project is being developed for the exploration of industrial rocks and minerals and the elaboration of the corresponding cartography.

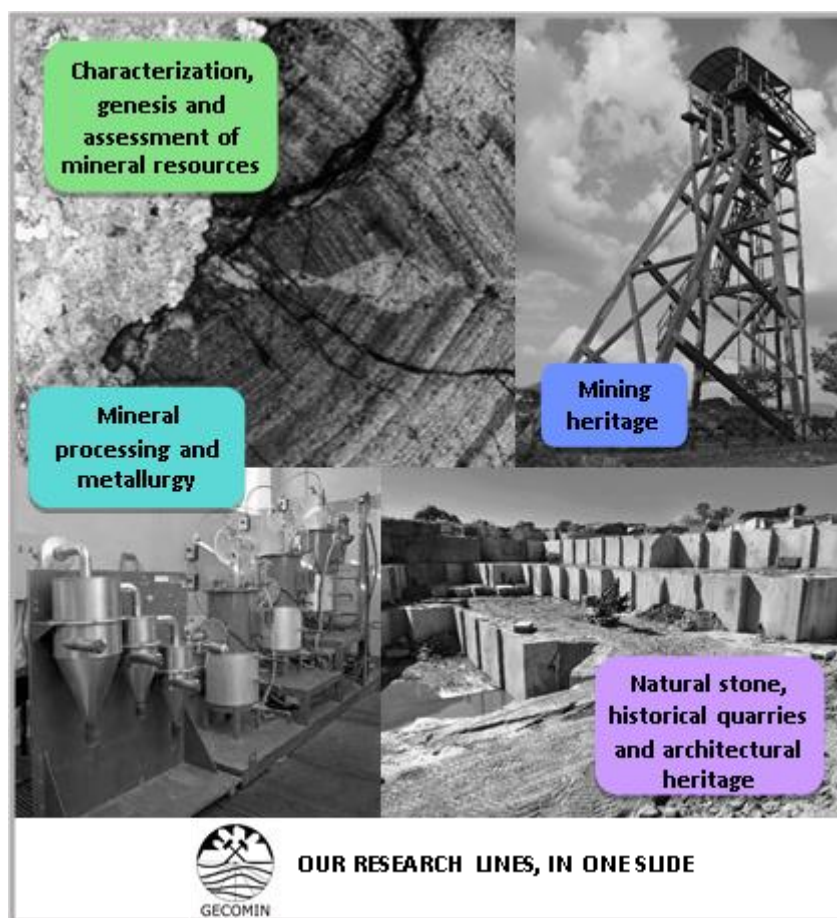


Figure 1. Research lines of the Economic Geology of Mineral Resources Group.

GECOMIN is also involved in European associations such as the Mineral Resources Expert Group (EGS-MREG), the Geochemistry Expert Group (EGS-GEG) and the Network of Practitioners-Europe (NoPE), as well as in other international organizations, such as the Association of Iberoamerican Geological and Mining Surveys (ASGMI).

#### *Mineral processing and metallurgy*

This research line is focused on the study of the viability of new environmentally friendly metallurgical treatment processes, for the use of both primary and secondary mineral resources, with the ultimate aim of providing a complete picture of the potential of geological resources. For this purpose, physical-chemical processing techniques are applied, such as flotation, gravimetric, magnetic and electrostatic separation, which allow the concentration of the minerals of interest, with the aim of achieving the best grade/recovery curve and identifying all potential products and by-products of the process.

Part of the R&D&I work that IGME has developed in the field of ore beneficiation has been focused on the search for alternative processing of the polymetallic sulphides of the Iberian Pyrite Belt. With the goal of reducing operating costs, two aspects have been considered: the recovery of the gold contained in sulphides and the extraction of any other metal present of economic interest. In the field of hydrometallurgy, research is aimed at improving hydrometallurgical treatments, on the one hand, to increase the recovery of non-ferrous metals

(Cu-Pb-Zn), which are quite abundant in the Iberian Pyrite Belt and, on the other, to recover the gold contained in refractory minerals with alternative processes to conventional cyanidation.

As a consequence of these studies, IGME, together with Protón Ingenieros company, has developed and patented a new hydrometallurgical process for the treatment of complex sulphides, which has also led to the construction of a pilot plant for leaching copper and zinc sulphides during 2017-2018.

### *Mining heritage*

The IGME's Inventory of Historical Mining Heritage aims to systematically identify, research and contribute to the preservation of historical mining in Spain. It offers the possibility of evaluating mining entities according to the criteria proposed in the Plan Nacional de Patrimonio Industrial (National Industrial Heritage Plan) and in the Bierzo Charter, in order to prioritize their research, evaluation and protection. Furthermore, it contains a catalogue of protected mining heritage.

The Inventory got started in 2003 with the completion of the Pilot Study Case of the Mining District of the Alcudia Valley, and was subsequently expanded, in 2009 with the Inventory of Extremadura through a project co-financed by the Junta de Extremadura, and in 2013 with the Inventory of Galicia, within the framework of the European project Atlanterra GreenMines.

The Inventory methodology, is based on that established in the aforementioned Pilot Study Case, on the guidelines of the National Plan of Industrial Heritage, and on the Spanish Inventory of Places of Geological Interest implemented by the IGME.

We are currently working on the development of a new institutional database in SQLServer, with the aim to disseminate the previous work and resume the development of the Inventory in a multidisciplinary, collaborative and participatory way, in accordance with the principles of Citizen Science.

### *Natural stone, historical quarries and architectural heritage*

The main objective is to study the natural stone and its technological and constructive applications in the Architectural and Monumental Heritage and in civil and current works. The areas where the rock used in construction was quarried (historical quarries) are located and characterized. Furthermore, technological tests are carried out to restore or treat pathologies, or replace the architectural asset.

The experience in this line of work includes the elaboration of the Inventory of Historic Quarries associated with the Architectural Heritage of the Autonomous Communities of Extremadura and Andalusia; the advice on ornamental rocks and industrial minerals, for MAGNA geological mapping; and the elaboration of specific cartographic databases, adapted to the mapping of industrial rocks and minerals and to the location and characterisation of historical quarries of construction rocks.

At the European level, through the GeoERA H2020 Programme, the group has participated in the Eurolithos project, with the aim of generating a European Atlas of the main ornamental and construction rocks. As a result of the collaboration with the Institute of History (IH-CSIC) and the School of Arabic Studies (EEA-CSIC), the group is participating in projects granted by the Spanish National Plan for Scientific and Technical Research and Innovation, such as those related with the Archaeology of the Hispanic churches of the 10<sup>th</sup> century.

In addition, work is being carried out on the creation and development of the INCHaPA Programme, National Inventory of Historic Quarries used in the Architectural Heritage.

Currently, the INCHaPA-Andalusia is being carried out, financed by that Autonomous Community, 541 quarries have been located and 863 architectural monuments have been studied. As a result of these studies, there are two registered industrial property titles associated with the CONSTRUROCK Network. CONSTRUROCK is a scientific-technical network, linked to natural stone and its relationship with historical-monumental heritage and civil works. It was created in 2008, coordinated by the IGME, and made up of 25 members, such as universities, public and private research organizations, technology centres, laboratories and business associations of the natural stone sector.

Table 1. GECOMIN curriculum summary (2017-2021).

32 publications in international peer reviewed journal (SCI) Q1=7, Q2=14
15 Competitive research projects participation (1 HorizonEU, 8 H2020, 5 Plan Estatal I+D+i, 1 Junta Castilla-La Mancha)
13 Non-competitive research projects (4 own projects, 5 collaboration agreements: Junta de Andalucía, Principado de Asturias and Diputación de Jaén, 2 Spain's Recovery, Transformation and Resilience Plan, 2 Services)
1 Patent (Hydrometallurgical plant for the treatment of complex sulphides) 2 Industrial Property Titles (Construrock Network)
1 New application (Development of Carmina Database - Angola)
Participation in Research Networks (ASGMI, EGS, NoPE)
2 Supervision of PhD Thesis, 2 Theses read by members of the research group, 5 Supervision of Master Thesis, 3 Degree Final Project Supervision; 4 training students. Participation in projects of innovation and teaching improvement.
2 Organization of symposiums and 1 international congresses, 4 invited talks.



## Outlook on Spanish Nb-Ta mineralization and exploration potential (FRAME project's WP6)

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### Abstract

Project FRAME (Forecasting and Assessing Europe's Strategic Raw Materials Needs) is designed to research the critical raw materials and strategic minerals in Europe. Work package 6 (WP6) focuses on the study of niobium (Nb) and tantalum (Ta), two critical metals with unique properties that make them essential components in a range of applications and products including electronics and superalloys. One of WP6's objectives is to carry out a study of Nb-Ta mineralization across Europe with the aim of increasing interest in mineral exploration.

On a continental scale, one of the regions with the best exploration potential for Nb and Ta in Europe is the Iberian Variscan Massif. In Spain, the most relevant primary Nb-Ta deposits occurs in evolved granite-pegmatite-aplite systems, belonging to the Galicia Trás-os-Montes Zone and Central-Iberian Zone and they are closely associated with Sn-W deposits. Nb-Ta mineralization associated with peraluminous Rare Metal Granites (RMG) occurs as disseminations in the apical or marginal parts of small, fine-grained leucogranite massifs, typically comprising Ta-enriched cassiterite, columbite-type minerals, microlite and tapiolite. Associated with RMG are also swarms of mineralized dikes of aplites, LCT-type pegmatites and quartz veins. Ta mineralization is mostly concentrated to the albite zone and consists of columbite, ixiolite and microlite.

The most viable production of Nb and Ta in our country is likely to focus on the exploitation of ore deposits where these metals can be extracted as a co-product and/or by-product of other mining production. Some Li, Sn-W or REE deposits showing Nb and Ta enrichment are postulated as potential candidates, because the extraction of these metals could add value to the mining operation. In addition to primary resources, it is also important to consider the potential for Nb and Ta recovery from tin mine tailings. A current example is the Penouta mine, where Strategic Minerals Spain has processed the tailings and ponds of the old Sn mine, and now, it has started mining the primary deposit for Sn and Ta.

The current demand for mineral raw materials that play an important role in the energy transition, such as lithium, provide incentives for exploration, development of new projects and reactivation of mines with Li and associated Ta-Nb resources.

FRAME is part of the GeoERA Program (<https://geoera.eu/>) co-funded through the European Union's H2020 research and innovative programme under grant agreement N° 731166.

## The Importance of Spanish Data (BDMIN & PANORAMA MINERO) in the European Raw Materials Knowledge Base (EURMKB)

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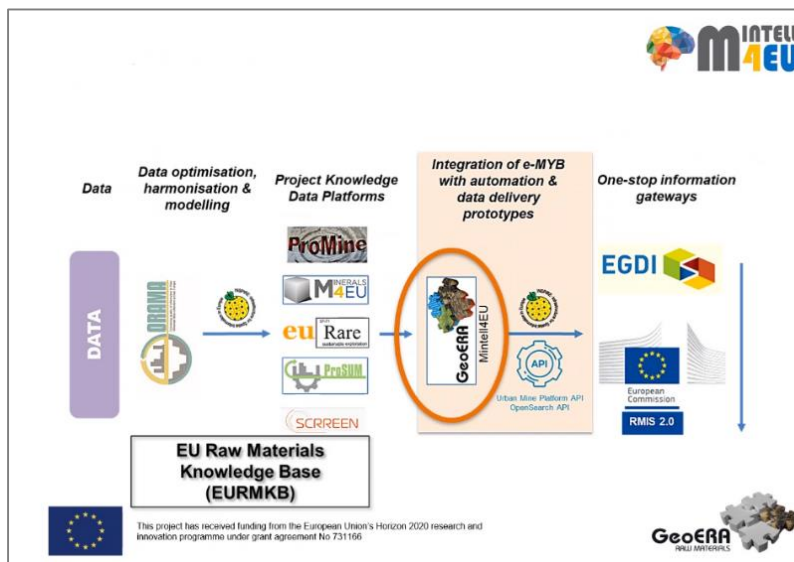
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### Abstract

The **IGME** has an extensive experience in the field of mineral resources and the main source of information is the **Mineral Resources Database (BDMIN)** that integrates the geological-mining information on occurrences, mines and exploitations (active and inactive) of metallic, non-metallic and industrial minerals, and rocks in Spain.

In addition, since 1981, the **Panorama Minero** has been carried out with the aim of providing reliable data on Spanish mining production, based on the Spanish Mining Statistics (MITERD). This information includes data on the national production of minerals, in tonnage and value, metallurgical production, foreign trade, etc. Other sources include the National Mining Cadastre and Foreign Trade statistics from the Tax Agency.

**IGME** participation -during the period 2014-2022- in the European projects **ORAMA** (Data optimization, harmonization and modeling) **ProMine**, **Minerals4EU** and **ProSUM** (Project Knowledge Data Platforms) and **GeoERA-Mintell4EU** (Integration of electronic European Mineral Yearbook) has allowed that the information related to mineral resources in Spain had been integrated into the **EGDI** (EuroGeoSurveys) and **RMIS 2.0** (JRC & DG GROW) platforms that constitute the **European Raw Materials Knowledge Base (EURMKB)** as can be seen in the diagram below.



## New hydrometallurgical treatment technology alternatives for refractory gold ores and primary polymetallic sulphides

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### Abstract

In recent times, the Spanish Geological survey (CN GME-CSIC) has played an important role in many areas related to research, prospect and use of gold. It has carried out an important research on state reserves, and has inventoried and valued an important part of the national resources. In the field of hydrometallurgy, research has been carrying out since the 1990s, aimed at improving hydrometallurgical treatments, on the one hand, to increase the recovery of non-ferrous metals (Cu-Pb-Zn) in which the Iberian Pyrite Belt is rich and, on the other, to enable the use of the gold contained in refractory minerals as well as the extraction of any other metal present that could be of economic benefit, which would contribute to reduce the operating costs. Through different collaboration agreements with the Junta de Andalucía and the company Protón Ingenieros a hydrometallurgical plant patent was developed, which serves as the starting point for this project.

Gold is one of the key minerals in the energy and digital transition. One of the most important sources of gold in the Iberian Peninsula has been massive sulphide deposits. Here the gold appears irregularly distributed, especially in zinc-rich zones, more rarely in copper-rich zones and at the base of some gossan. Gold is also found within arsenopyrite and presumably as invisible gold (refractory gold) in all pyritic ores, although in very low concentrations.

The growth in the demand for gold worldwide and the exhaustion of gold ores easily extracted requires the need to exploit; even those refractory minerals or hard to extract, so we are looking for new alternatives or pre-treatments that help us increase the percentage of gold. The resistance offered by these materials to the direct extraction of gold by conventional alkaline cyanidation techniques determines the refractoriness of gold ores. In general, a gold ore is considered refractory if the level of extraction by a conventional dynamic cyanidation process does not exceed 80%.

The project presented is justified from a technological point of view as it aims to improve the yield in the extraction of gold from refractory minerals in a sulphide matrix by means of an oxidation pre-treatment of the matrix, with ferric sulphate in an acid medium and working at atmospheric pressure and a temperature below 100 °C, which will lead to an increase in the profitability of gold recovery.

## Historic quarries associated with the architectural heritage in Andalusia

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### Abstract

In order to locate and characterize the historic quarries in relation to the construction of an Architectonic Heritage from Andalusia, and in consequence to preserve and put them in value, the Spanish Mining and Geology Institute starts in 2018. Together with the Andalusian Authorities, the first Andalusian Historic Quarries Inventory in relation to the Architectonic Heritage, with which it is intended to cover systematically the whole area of Andalucía.

As a result, it will be obtained a systematic cartography of the historic quarries, at a regional level, whose patrimonial, geological and historic data are charged in a database associated to a polyvalent GIS. All this information will be valuable for Administrations and professionals of the natural stone area, the heritage refurbishment, Archeology, History, Tourism, etc.

The methodology encompasses review historical and geological documentation as well as aerial photographs and to sample the building stone in the monument for its chemical analysis and petrographic study. Later, a geological exploration is accomplished in order to look for the rock outcrops which may have been exploited in the past and which are still associated with the building. This detailed cartography of the historical extraction areas allowed for the differentiation and georeferencing of the different typologies of exploitation marks preserved.

From this project, the existence and characteristics of the signs of exploitation located in the historical quarries associated with the Architectural Heritage of Andalusia is highlighted, for which reason we have proceeded to point out extraction areas that could allow their conservation. In this sense, a figure of protection that allowed its conservation while allowing the study work and punctual extraction of material for restorations would be paramount.

Taking advantage of the growing tourist interest of the area, its Monumental Heritage and the proximity of the areas of extraction to these, its value is proposed through the creation of didactic routes in which the built heritage, geology and historical activities are integrated - extractable, in order to bring closer to citizens and tourists the existing relationships between built heritage and its surroundings, not only in large towns such as Seville or Cordoba, but also in small buildings.

## Strategic raw materials for the energy and digital transition in Spain

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### Abstract

One of the main concerns of the European Commission is critical raw materials (CRM), necessary for daily life in a wide range of goods and applications. The EU's industry and economy depend on international markets for many important raw materials, which are produced and supplied by third countries. These CRMs are closely linked to clean technologies, technological progress and quality of life. Concern about access to CRMs led the European Commission to draw up a first list of critical raw materials (CRM) in 2011, and to schedule its review and update every three years, the last being in 2020.

Based on the methodology of the European Commission for the determination of CRM, a list of critical and strategic raw materials for Spain has been drawn up. This methodology includes two major parameters, (i) economic importance and (ii) supply risk. These two parameters, which may seem simple, actually include a multitude of factors to take into account.

Economic importance is intended to provide information on the importance of a material in the economy in terms of end-use applications. It is related to the use made by the different economic sectors (CNAE classification) and the contribution of these sectors to the Gross Added Value of the evaluated territory. This parameter is corrected with the rate of substitution of one raw material for another.

Supply risk reflects the risk of material supply disruption. It is usually represented by global governance tabulated indices for each supplying country, weighted according to the proportion of the raw material provided by said producer. Within this parameter, some indices tabulated by international organizations are taken into account, such as the Herfindahl-Hirschman Index and the World Governance Index, and others must be calculated, according to export and import data and recycling rates. Substitution and recycling are considered risk reduction measures.

This study is part of a work package within the collaboration with the General Subdelegation of Mines, which we have called the MINCE Project, referring to the study of CRM and Strategic Minerals for Spain.



## START Project: Sustainable Energy Harvesting Systems Based on Innovative Mine Waste Recycling

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### Abstract

START project primary objective is to build an innovation ecosystem in the European Union (EU) based on the development of sustainable and economically viable thermoelectric (TE) waste heat harvesting systems to be applied in heavy industry and in maritime industry as well as primary power source for off-grid sensors and IoT devices. This objective will be achieved by incorporating abundant sulphides (mainly tetrahedrite mineral series), at present an environment hazard in mine tailings, collected in five European countries, in the production of advanced sulphide p-type TE thermoelements. In contrast, current commercial TE devices incorporate p-type and n-type TE thermoelements that are produced from expensive and rare elements, namely tellurium, which is predominantly sourced in China. The impact of START project approach on endorsing a more sustainable and resilient EU comes from three inputs. First, by reducing EU's dependence on primary critical raw materials. Secondly, through the promotion of circular economy processes that will create value in EU by building a strategic ecosystem based on a high-abundant mineral. Just recently, it was demonstrated by our team that the mineral was amenable to processing to single phase p-type tetrahedrite. Thirdly, by the production of TE energy harvesting systems offering a contribution to the reduction of fossil fuels consumption with a great impact on the increase of the overall efficiency of energy production and consumption systems, as well as on the reduction of the greenhouse gas emissions.

START is EU co-funded project under the Horizon Europe H-CL4-2021-RESILIENCE-01-07 with grant agreement nº 101058632. START project aggregates research organizations, with strong background and knowledge on geology, materials science and renewable energies, and industrial organizations that guarantee the entire production and exploitation supply chain. The project is coordinated by the Portuguese National Laboratory for Energy and Geology (LNEG) with 15 partners (plus 1 affiliated entity) covering 10 EU Member States and 1 associated country. The duration of the project is 48 months. The total eligible costs are 9.194.441,25 €.

The CN IGME-CSIC contribution to the START Project is in WP1 (Coordination and management), WP2 (Selection of mine waste sites; physical minerals separation and concentration), WP 4 (Materials characterization), WP6 (Dissemination and communication) and WP7(Innovation and exploitation strategy). In Spain, 40 sites have been selected with tailings rich in tetrahedrite. They can be find in different geological contexts.

## Geochemical sampling for mapping and exploration in Western Ossa Morena Zone (Huelva and Seville)

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### Abstract

Geochemical mapping represents an application of conventional geochemical methods to the knowledge of the natural environment. This is the most useful way to determine the current levels of geochemical amounts -geochemical baselines- to comprehend the spatial distribution and variability of the different elements, and to document variations in their levels in natural materials at the Earth surface. Those changes, usually are shown in geochemical distribution maps produced by geochemical mapping projects, can often indicate areas affected by possible anthropic pollution activities or even anomalies related to known or to unsuspected mineralizations. Nowadays, geochemical mapping is one of the main activities performed in the national geological surveys and organizations for several research fields. Following the recommendations included in the Final Report of the Project 259 for the International and National Geochemical Programs.

The study area corresponds to the western part of the Ossa Morena Zone (OMZ) in Huelva and Sevilla Provinces, covering approximately 6.200 km<sup>2</sup>. We have collected 1.639 stream sediment samples and 244 heavy mineral concentrated, at an average sampling density of one samples per 4 km<sup>2</sup> in stream sediments and one sample per 25 km<sup>2</sup> in heavy mineral concentrated. These samples were processed in accordance with protocols described by Atlas Geoquímico de España and were sent to Actalbs Laboratories in Canada for chemical analyses of 64 chemical elements.

A complete database with all analytical results, data from field campaigns and other outstanding characteristics is being prepared for statistical computation. After that univariate and multivariate statistical analysis and spatial distribution will performed in order to show the single-element geochemical distribution, relationships and associations among the different elements.

This type of geochemical surveys can help to improve the previous geological studies and discover new exploration targets for mineral exploration.

## Geoenergy Group

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### Abstract

One of the key elements that have allowed the astonishing socio-cultural and economic development achieved in Europe during the last part of the 20<sup>th</sup> century is the use of fossil fuels as energy source. However, it has been proved that these types of energy sources affect the global climate and increased the amount of pollutants in nature. Our society is now immersed in a global and sustainable energy transition period that will entail the use of clean energy. The GeoEnergy group works on this direction with the creation of geological and technological knowledge on clean energy, both from the subsurface sources such as geothermal energy, and the search, characterization, and evaluation of geological storage sites for energy (H<sub>2</sub>, CH<sub>4</sub> or compressed air) and greenhouse gases (CO<sub>2</sub>).

### Introduction

Currently, the group is made up of 8 people, with interdisciplinary profiles that cover various topics of Earth Sciences: geology, geophysics, geochemical, and engineering. This allows not only the geological characterization of the geothermal sources or geological stores, but also estimate their potential, management needs, and future actions.

The techniques that we apply are based on mineral and hydrocarbons exploration, starting from geological identification of potential areas of interest; structural, stratigraphic and petrophysical characterization of identified reservoir; and static and dynamic modelling. The behavior of the selected rock or sediment in presence of the fluid of interest or the brine is also studied; in certain cases, based on in-house reactor and procedure at laboratory scale. The objective of all these techniques is to identify areas of interest, characterize potential resources for geothermal energy or geological stores and estimate technical and economic viability, taking into account the different characteristics of the subsurface and the socioeconomic aspects. To carry out these tasks, the group has the support of other specialists from CN-IGME research groups and other national and European centers.

The number of European and National projects in which the members of the GeoEnergy group collaborate is eighteen (18), of which it leads six (6). In addition, the team also participates as IGME representative in several international groups (GeoEnergy Experts group of EuroGeoSurvey; European Network of Excellence of CO<sub>2</sub> Geological Storage, CO<sub>2</sub>geoNet; European Strategic Energy Technology Plan, SET-PLAN, by Join Research Centre of European Commission; European geothermal platforms (RHC-ETIP and ETIP-DG) and in the European geothermal training organization (GeoTrainet), and national ones (advisory programs for different administrations; technological platforms as GEOPLAT and PTECO<sub>2</sub>); also, it should be mentioned an existing network with industrial partners (Repsol, Naturgy, Enagas,...) that support and contribute their knowledge in both National and European technical and research projects, which facilitates the transfer of knowledge to the productive sector.

## Geological Storage

### *General aspects of Geological Storage*

The geological CO<sub>2</sub> storage aims to store large volumes of anthropogenic CO<sub>2</sub> from fossil energy consuming centers to reduce its emission in the atmosphere. For it to be effective, it is vital that an adequate characterization is carried out that allows both a correct evaluation of the economic viability and the prevention of the risks associated with these technologies. The development of CO<sub>2</sub> storage technology is internationally verified, so specific studies have currently been proposed in detailed areas to CO<sub>2</sub> store within the country.

In the case of H<sub>2</sub> and compressed air, they are promising energy sources at an economic and social level, but the existing knowledge regarding the feasibility of their geological storage is still incipient. The initiatives on this subject, through projects and contracts, are beginning to be developed, as well as the research about their behavior according to the different types of reservoirs (saline diapirs, depleted reservoirs or porous saline deposits) existing in Spain.

Studies of characterization and evaluation of geological structures range from microscale geological knowledge, such as the mineralogical composition of the reservoir and the seal, to macroscale, such as the geological structure or regional tectonics, which covers practically all the Earth sciences.

The first task is to identify regional areas of interest. Then, the identification potential structures and characterization of its reservoir and seal formations, based on collecting exiting data- including exiting seismic surveys and well data, and obtaining new ones, if it is possible with new seismic survey or wells, or identifying analogs. For which, we have to study their stratigraphic, sedimentological, mineralogical, geochemical and petrophysical characteristics. Once the formations of interest are known, it is also essential to know the structural configuration of the subsurface, for which geophysical tools (seismic, gravimetric, electrical, or electromagnetic) are used. All these data allow the construction of 3D geological models that collect and unify the numerous data, so that decision-making is as accurate as possible, minimizing uncertainties.

Based on the static model, a dynamic behavior of the fluid and rock are also considered, with the aim of analysing and estimating the potential storage capacity, establishing the level of maturity of calculated estimated capacity, and evaluate technical and economic viability.

A differentiating element of the group is the progressive increase in the use of tools for the characterization of reservoirs, which is allowing us to grow in our knowledge of the subsurface in a multidisciplinary approach. Likewise, the increase in knowledge of 3D model construction techniques in recent years allows us to improve the evaluation of the structures and estimation of capacities, and then, taking decisions based reduced uncertainty models, and even begin to advance in the temporal evolution of these resources.

### *The work carried out by IGME*

Some of the members of the research group have participated in the last 15 years in different projects to evaluate the country's storage capacity. The initial projects in the IGME were European projects in a first objective to know the storage capacities on a European scale such as GeoCapacity, COMET and CGS Europe. Thus, between 2009 and 2014 the group participated in several projects on a national and European scale. So, it led the national program for the selection and characterization of areas and structures suitable for geological storage in Spain carried out by the IGME (ALGECO<sub>2</sub>), of which a national atlas of structures with CO<sub>2</sub> storage potential and estimated capacity was published in 2015 (Figure 1).

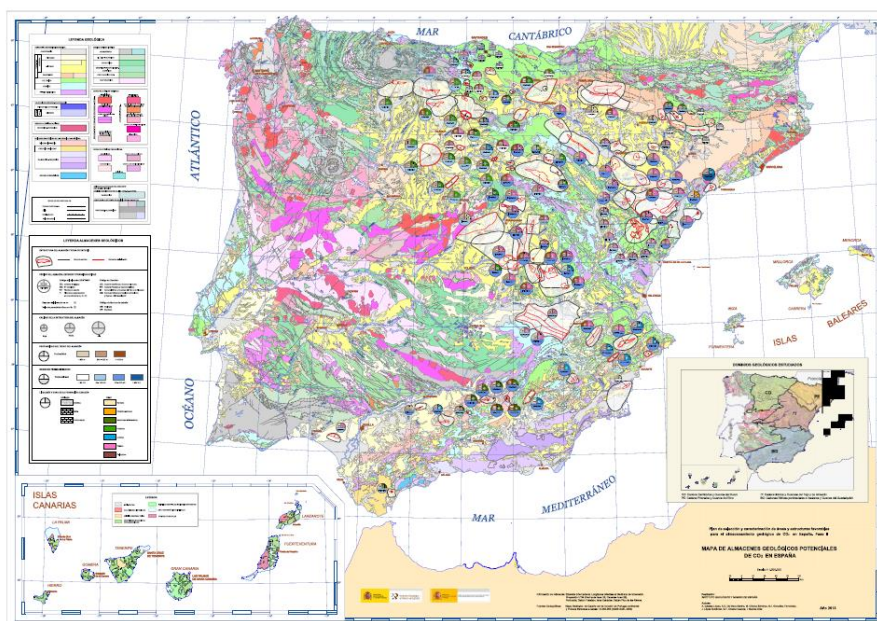


Figure 1. Picture of the Map of potential CO<sub>2</sub> geological stores in Spain (ALGECO2).

In 2009, we also participated in the “CO<sub>2</sub> PORE” Project, which allowed the generation of various publications on the subject of rock+brine+CO<sub>2</sub> interaction. The group continues to work on this topic in both porous rocks and basic rocks, and since last year it has also been working on the rock+brine+H<sub>2</sub> interaction.

In recent years, we have participated in various studies of the CO<sub>2</sub> storage pilot plant in Hontomin (Burgos) with the European ENOS and SENSE projects. And more recently and as a result of the evaluation work on areas of interest of the European STRATEGY CCUS project, we participate in the PILOT-STRATEGY storage project, where the viability of two reservoirs in Spain is studied and in which states entities and industrial partners, such as Ciemat and Repsol, participate too. As well, we work with industrial partners in the technical and economic evaluation of storage structures for those industries that have to deal with decarbonization, such as Enagas or Oficemen.

Regarding projects related to H<sub>2</sub> storage, we participate in two (2) projects, one at European scale (HYSTORIES) and another national (UNDERGY), to evaluate possible areas of interest and study in detail a depleted gas field, respectively.

## Geothermal Energy

### *General aspects of geothermal energy*

GEOTHERMAL ENERGY means “energy stored in the form of heat beneath the surface of solid earth”; it is defined as renewable non-fossil source in the DIRECTIVE (EU) 2018/2001 of the European Parliament and of the Council, of 11 December 2018 on the promotion of the use of energy from renewable sources. GEOTHERMIC is the science that studies the thermal energy existing in the earth's crust and its possibilities of use. It includes, therefore, conventional geothermal resources (high, medium or low enthalpy resources that allow their use for electricity production or for direct uses of heat), shallow geothermal resources (or geothermal exchange, which take advantage of the thermal stability of the subsoil and the materials it contains to provide cold and/or heat for different applications), enhanced geothermal resources (which enable the use of deep resources from low permeability materials) or thermal energy storage systems in the subsoil through geothermal systems.



Geothermal energy offers numerous key advantages:

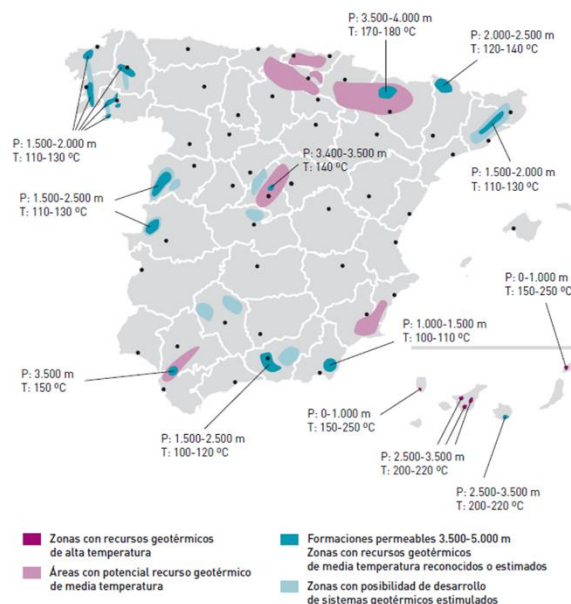
- is available 24 hours a day, 365 days a year (manageable)
- is present in any location (shallow geothermal)
- enables a high energy efficiency (especially geothermal exchange)
- enables a high capacity factor in electricity production
- needs significant initial investment but low operating costs: very competitive costs
- is environmentally friendly and allows sustainable use

#### *The work carried out by IGME*

The activities of IGME in the field of geothermal energy have been carried out mainly for almost 50 years and have allowed to know the potential of the geothermal resources existing in the Spanish subsoil and not only in what refers to conventional geothermal but extended to shallow geothermal energy and new technological developments that allow the use of geothermal energy in territories where previously they were not considered of interest.

In these decades, exploration techniques not used in Spain so far have been developed and adapted, the main areas with the greatest possibilities for geothermal uses have been delimited and extensive reports, databases and cartographies have been generated. All these documents allow to know the thermal regime in the Spanish subsoil and serve as a basis for addressing exploitation projects of great interest. Furthermore, new technologies have been developed for the use of existing resources as well as for the storage of thermal energy in the subsoil. Meanwhile, IGME has offered technical advisory on Spanish geothermal potential, its possibilities of use, and regulations that affect it. Finally, big efforts have been made to spread knowledge on geothermal energy and to contribute to the training of technicians and specialists in exploration and use of these resources (Figure 2).

Figure 2. Map of medium and high temperature geothermal resources and possible stimulated geothermal systems.



#### *Geothermal energy in Spain*

Currently there are no significant uses of conventional geothermal energy in Spain. It is a rather small market and there are not many entities that develop their activity in this field in any country. In recent times there has been a growing interest, after the collapse suffered in 2012 because of the "dry brake" to renewables. This interest has been expressed by both Spanish

companies and other European countries that, for years, have put Spain, and especially the Canary Islands, in their objectives in terms of geothermal energy.

Shallow geothermal energy has developed in Spain during the twenty-first century period. At certain times, growth problems were detected in the sector with a certain intrusiveness that produced results in inadequate works. Currently these problems can be considered overcome and there are numerous small companies that develop their activity in this field, although a boost is still needed for the take-off of the activity as in other nearby countries.

#### *Lines of work in geothermal energy*

- **I+D+i:** Creation of geological and technological knowledge. This includes:
  - Investigation of resources and thermal characteristics of the subsoil
  - Creating and maintaining an accessible data infrastructure
  - Research on exploration techniques
  - Research on exploitation technologies
  - Research on geothermal potential of the Spanish territory
- **Difussion measures: Promotion of the use of geothermal resources minimizing geological risk**
  - Accessibility to existing information
  - Development of publicly accessible cartographies
  - Support for strategic projects
  - Active participation in national and European platforms
  - Regulatory development that ensures the quality of the works
  - Dissemination of results
- **Training: Technical teams training**
  - Specialists in geothermal research
  - Specialists in geothermal exploitation
  - Designers of shallow geothermal installations

## Geothermal Potential Mapping in Spain. A crucial pending task with society and a great challenge as geological service

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### Abstract

Shallow Geothermal energy is theoretically available anywhere on the Earth's surface and has the potential to play a key role in minimizing polluting emissions, making a significant contribution to the new economic model referred to as the green economy.

The production of shallow geothermal energy, although it is an efficient process, it has a cost benefit varying from one site to another depending, but not only, on site-specific natural factors. The needed deployment of this resource in Spain requires a previous study of geothermal energy possibilities and geographical distribution at national scale, as a necessary decision-making tool for planning production, incentives, and investment to support cost effective investments by administrations and the private sector.

GIS-based Multi Criteria Decision Analysis (MCDA) techniques provide appropriate analytical tools for geothermal prospectivity mapping. These tools involve the use of geographical data, weights, and an MCDA aggregation function that combines spatial data and weights of criteria to evaluate locations.

The application of a GIS-based MCDA method allows to compare as many different shallow geothermal relevant factors as possible (lithostratigraphic, structural and hydrogeological conditions, associate vulcanism, climate), for targeting potential geothermal resources. By means of this powerful tool, a geolocalized suitability index can be obtained to draw an applicability/favourability map for the development of shallow geothermal energy in Spain.

## Laboratory Experiments on Early-Phase Supercritical CO<sub>2</sub>-Brine-Rock Interactions. Applications in Carbon Capture and Storage Projects

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### Abstract

This work describes the laboratory experiments of exposition of rocks (eg. limestone, sandstone, gabbro) to supercritical (SC) CO<sub>2</sub> conducted in the autoclave system of the IGME, in the framework of different projects (i.e. CO<sub>2</sub> Pore Plan Nacional, Pilot UE Project, InCarbon Portugal 2020).

The aim of these experiments was to demonstrate/study the effects of experimental injection of CO<sub>2</sub> into potential reservoir rocks. In detail, to reveal qualitative and quantitative changes in porosity, mineralogical composition and texture in rock samples after injection of i) supercritical CO<sub>2</sub>-rich brine and ii) dry supercritical CO<sub>2</sub>, under similar experimental conditions (P ≈ 8 MPa, T ≈ 40°C, 1- 64 days exposure time and no CO<sub>2</sub> flow). The experiments were conducted in an autoclave, for a maximum of 64 days, using a CO<sub>2</sub> and brine (most cases) under pressure and temperature conditions similar to those expected around an injection well during early-phase CO<sub>2</sub> injection at a depth of approximately 800 m.

The effects of experimental injection of CO<sub>2</sub>-rich brine during the first injection phases were studied at rock matrix scale, in a i) potential deep detrital reservoir in northern Spain (Utrillas unit, at the base of the Cenozoic Duero Basin), ii) plutonic mafic rocks in Portugal (cumulate gabbro and gabbro-diorite specimens from the Sines Massif), iii) vuggy carbonates (“Carniolas”) of the Puerto de la Palomera formation (Hettangian) in the western Basque-Cantabrian Basin, North Spain.

Mineralogical composition and pore space were characterized using optical microscopy, scanning electron microscopy and image analysis. In addition, X-ray fluorescence analyses were performed to refine the mineralogical information and to obtain whole rock geochemical data. Furthermore, brine was analysed by ion chromatography and ICP-OES before and after each experimental run.

Overall, the study indicates that the adopted injection conditions induce mainly dissolution with mineralogical/textural readjustments on the external area of the studied samples. The results obtained on the CO<sub>2</sub>-treated samples indicate a porosity increase (i.e., in sandstone due clay matrix detachment, in limestone due carbonate dissolution) and a qualitative permeability rise. Textural changes were also encountered: variations in the roughness of grain-pore contacts, pore shape and aspect ratio. Qualitative and quantitative assessments of petrographic and geochemical features can be important tools in this study for the interpretation of the rock texture and mineralogy.

## STRATEGY CCUS project: “Strategic planning of regions and territories in Europe for low-carbon energy and industry through CCUS”

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### Abstract

Strategy CCUS (2019-2022) is funded by the EU to support the development of low-carbon energy and industry in Southern and Eastern Europe up to 2050 (PN: 837754).

STRATEGY CCUS is focusing on eight regions identified as promising for CCUS – based on the existence of industry clusters, potential CO<sub>2</sub> storage sites, transport infrastructure and opportunities for CO<sub>2</sub> usage and/or hydrogen production and use-, which together account for around 45% of Europe’s CO<sub>2</sub> emissions from industry and energy production: Paris Basin and Rhone Valley in France; Ebro Basin in Spain; Lusitania Basin in Portugal; Northern Croatia in Croatia; Upper Silesia (Poland); West Macedonia (Greece) and Galati area in Romania.

The STRATEGY CCUS project aims to elaborate strategic plans for carbon capture, utilisation and storage (CCUS) in the short term (up to 3 years), medium term (3-10 years) and long term (more than 10 years).

Specific objectives are to develop: (i) local CCUS development plans, with local business models, within promising start-up regions; and (ii) connection plans with transport corridors between local CCUS clusters, and with the North Sea infrastructure, in order to improve performance and reduce costs, thus contributing to a Europe-wide CCUS infrastructure.

Detailed mapping of CCUS technical potential of the regions, together with a comprehensive mapping of local stakeholders and a process for their engagement, will pave the way for CCUS deployment scenarios including assessment of 'bankable' storage capacity, and economic and environmental evaluation. CCUS development plans will be elaborated in close cooperation with stakeholders, through the Regional Stakeholder Committees and the Industry Club, to ensure plans can be implemented, i.e. socially acceptable

It involves 16 research partners from seven European Countries Total budget, coordinated by BRGM (*Bureau de Recherches Géologiques et Minières*, France). The Spanish team is formed by IGME-CSIC (coordinator or Spanish region) and CIEMAT: 3 million Euros.

Web page: [www.strategyccus.eu](http://www.strategyccus.eu)



## pilotSTRATEGY project 2021-2026: “CO<sub>2</sub> Geological Pilots in Strategic Territories”

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### Abstract

The pilotSTRATEGY (2021-2026) is investigating geological CO<sub>2</sub> storage sites in industrial regions to support development of large-scale carbon capture and storage (CCS). It is focused on deep saline aquifers—porous rock formations filled with brine several kilometres below ground – which promise a large capacity for storing captured CO<sub>2</sub>. The goal of the characterisation is to assess the site’s containment, injectivity, capacity, integrity, hydrodynamics, and monitorability in order to ensure safe and permanent storage of CO<sub>2</sub>. PilotSTRATEGY covers the initial stages of project development up to the pre-final investment decision (pre-FID), regulatory approval and permitting of storage, and applied on selected structures of Paris Basin in France, the Lusitanian Basin in Portugal and the Ebro Basin in Spain, and in lower detail, in West Macedonia in Greece and Upper Silesia in Poland.

The Spanish region –Ebro Basin- includes two potential deep saline aquifers (one onshore and other offshore) with the mandate of selecting one of them on the month 18th (October 2022) to complete the studies. The selection of the most suitable structure will be based on a multi-criteria analysis included not only geological or technical features but also environmental, economical, regulatory and social aspects.

The project has received funding from the European Union’s Horizon 2020 programme (10.1 million Euros, No. 101022664). It involves 16 research partners from seven European countries and builds on research carried out by the **STRATEGY CCUS project**. BRGM (France) is the project coordinator, and the Spanish team is formed by IGME-CSIC (coordinator of the Spanish region), CIEMAT, and REPSOL as industrial partner.

IGME-CSIC is also leading the WP4: “Pilot Development” aiming to provide detailed information to the optimum development concept for the proposed pilots to help decide whether they are viable, and co-leading WP7: “Communication and impact”.

Web page: [www.pilotstrategy.eu](http://www.pilotstrategy.eu)

## HySTORIES: “Hydrogen storage in European Subsurface”

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### Abstract

The Hystories project (2021-2022) addresses the main technical feasibility questions for underground storage of pure hydrogen in aquifers or depleted fields, and will provide market, societal and environmental insights on the deployment of underground storage of hydrogen in Europe.

Hydrogen technologies could be one of the pillars of future European energy and transport systems, making a valued contribution to the European Union (EU) transformation to a low carbon economy by 2050. Renewable hydrogen, when combined with large scale underground storage in aquifers, depleted fields or salt caverns, enables transportation of energy through time balancing out the impacts of variable energy production from renewable energy sources. While storing pure hydrogen in salt caverns has been practiced since the '70s in Europe, hydrogen storage has not yet been carried out anywhere in depleted fields or aquifers. Although many aspects will be similar to the existing industry of natural gas underground storage, technical developments are still needed to validate this solution, particularly in terms of bio- and geo-chemical impacts of storage on the subsurface and in terms of the quality of hydrogen subsequently extracted from the store.

IGME-CSIC participates of the geological assessment of potential opportunities for H<sub>2</sub> geological storage, as Third party of CO<sub>2</sub>GeoNet Association. The Geological assessment will advance a database of geological storage opportunities both on and offshore through addition of data with specific relevance to geological storage of hydrogen: improvements will be at the European scale, HyStorIES being able to collate data for at least 19 European countries.

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 101007176, supported by from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and Hydrogen Europe Research. Total budget 2,5 million Euros.

Web page: [www.hystories.eu](http://www.hystories.eu)

## Geothermal resources evaluation: Using O&G exploration data to evaluate low and medium enthalpy resources from deep sedimentary reservoirs

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### Abstract

Geological resources of low enthalpy (and in many cases, also of medium enthalpy) are located mainly in large sedimentary basins with normal geothermal gradients in permeable formations (reservoir); fluid (brine) with high content on dissolved salts circulate through the reservoir; by depth and after a high time of circulation through the reservoir, the fluid reach the temperature level corresponding to that depth.

Low-enthalpy resources can be used for direct use of heat. An acceptable level of economic profitability is achieved when they allow its use for a district heating network (of the order of 3000-4000 connected homes) by means of a doublet (extraction well and reinjection well) at depths of the order of 2000-3000 meters. Medium enthalpy resources require greater depths (3000-4000 m) for their use for the production of electricity through a binary power plant.

Given the high cost of the investments required by these equipment (two or more boreholes, titanium plate exchanger, binary plant, etc.) it is not possible to apply greater investments during the resource research phases; so it is necessary to use the information provided by hydrocarbons explorations and, in any case, complement it with detailed studies for the location of the drillings.

In this sense, the study of the existing information in the Jaca-Sabiñánigo area is carried out, where the existence of medium enthalpy resources is presumed. The work is developed through a TFM with the participation of IGME, UCM and Repsol.

## High enthalpy resources in Canary Islands: Geo-Energy Research Group

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### Abstract

Since the end of the 40s last century, IGME has developed research work on the geothermal resources in the Canary Islands. In the 70s, with the National Inventory of Geothermal Manifestations in the national territory and despite the blow that the result of the survey that culminated the research carried out in Lanzarote by the CSIC meant for the development of geothermal energy, the research was resumed and in the following years it was developed, with budgetary ups and downs; a research process that allowed, years later, a company of Australian origin, to address subsequent phases of research.

In recent years, two projects have been developed funded by the RETOS program in which the IGME has participated and whose results allow us to understand the results of the previous work and propose the lines of action for the use of high enthalpy resources (or high temperature exclusively in some areas) for the production of electrical energy.

The information currently available allows us to expect great possibilities of using geothermal energy for electricity production in the islands of Lanzarote, Tenerife and La Palma, as can be verified with the overlap and coincidence of results of the different geological, geochemical, geophysical research techniques and the drillings carried out that validate the models currently available.

## InSAR and paleostrain data acquisition and processing in the Hontomín CO<sub>2</sub> storage plant (Northern Spain)

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### Abstract

The project “Assuring integrity of CO<sub>2</sub> storage sites through ground surface monitoring” (SENSE) aims to investigate and develop cost-efficient monitoring tools for the time periods comprised during and after CO<sub>2</sub> injection at long term, comprising ground motion detection along with geomechanical modelling and inversion.

The IGME-CSIC team is committed to study and determine the ground motion around the pilot-plant Hontomín geological CO<sub>2</sub> storage, by interpreting the processed InSAR data prior, during and after the injection operations that took place during 2014. In order to achieve this goal, the team carried out two different processing: 1) FASTVEL algorithm, developed by TRE-Altamira for generating differential interferograms or PSI-based mean displacement velocity maps from a set of Sentinel-1 or ASAR images; 2) P-SBAS stands for Parallel Small Baseline Subset and it is a DInSAR processing chain for the generation of Earth deformation time series and mean velocity maps. Obtaining the ground surface deformation from InSAR data, combined with geomechanical models, allows to obtain information on pressure distribution and hydraulic behaviours of the storage system and therefore, modify the reservoir geomechanical characteristics avoiding CO<sub>2</sub> leakage and monitoring the underground CO<sub>2</sub> plume.

This action is complemented with the reconstruction of the tectonic field evolution from the Late Triassic to Middle Miocene in the nearby of the Hontomín Pilot Plant Facilities (40 km away) from more than five-hundred kinematics data on fault planes, completing the data obtained in the already concluded project “ENabling Onshore CO<sub>2</sub> Storage in Europe” (ENOS). The reconstruction of the tectonic field evolution is considered with the purpose of: a) preventing fault reactivation and related earthquake triggering due to injection processes and the active natural tectonic field; b) minimizing the potential consequences of reservoir leakage and seepage, and therefore preserve the integrity of the reservoir; and c) monitoring the long-term reservoir behaviour.

This study will allow to differentiate in more detail the seismicity present in the Hontomín field and determined by seismographs by *Ciudad de la Energía* Foundation (CIUDEN), influenced either by the present-day tectonic field that reactivates former tectonic structures, or by the injection tasks carried out in recent times.



## Heritage and Geodiversity (GEO-HERITAGE) Research Team at IGME-CSIC: challenges and main lines of action

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### Abstract

IGME-CSIC has developed lines of research and action on geological heritage, stone heritage and geodiversity since the 1970s, and has been one of the pioneers at international level in the development of the discipline of geoheritage and geodiversity. Since the enactment of Law 42/2007 on Natural Heritage and Biodiversity, IGME-CSIC has led geoconservation, both in Spain, with the development of the Spanish Inventory of Geological Sites of Interest (IELIG, since 2009), and internationally, with the Global Geosites project (2004-2008) and the IUGS Geological Heritage Sites project (IGCP 731, 2021-2023). The experience of the IGME-CSIC GEO-HERITAGE research team with legislation and methodological developments on inventories has allowed its members to represent Spain in the most important international bodies and committees on geoconservation: IUGS, IUCN, UNESCO, ProGEO, SCAR, ASGMI and EuroGeoSurveys. Spanish participation in these international bodies has thus been reinforced, in collaboration with other Spanish scientific organizations (SGE and SEDPGYM). More than 170 years after its foundation in 1849, the integration of IGME within the Spanish National Research Council (CSIC) in 2021 began a new phase with the creation of the GEO-HERITAGE Research Team on 'Heritage and Geodiversity'. As a result, key topics relevant to society towards the ecological transition and adaptation to the new global scenario have reached the highest priority, including research about the impact of global change and climate change on the conservation of geoheritage and stone heritage. Another priority of the GEO-HERITAGE team is the identification, protection and conservation of movable geological heritage (minerals, rocks and fossils in museums and collections), in collaboration with the regional and national administrations of Spain. Since 2017, the citizen science program 'Save a Rock' (*Apadrina una Roca*) allows to monitor and protect the Geological Sites of Interest of the IELIG with the involvement of society in the conservation of geoheritage with volunteers from all Spanish provinces that support this highly successful initiative.

### Background

The GEO-HERITAGE research team was created in 2021 within the National Center *Instituto Geológico y Minero de España* (IGME-CSIC) by Royal Decree 202/2021, of March 30, which restructures several research institutions of the Spanish Public Administration. This group nucleated from the staff dedicated to geological heritage in the former 'Geological and Mining Heritage Unit' created at IGME in 2007, together with researchers specializing in stone heritage and movable geoheritage. This provided a more holistic view of heritage and geodiversity so as to form in 2022 a robust team of 10 professionals (Fig. 1).



Figure 1. Personnel of the GEO-HERITAGE research group working on heritage and geodiversity in 2022, and formed by 5 tenure scientists, 4 advanced technicians and 1 research assistant. The gender composition of the team is 2 women and 8 men.

### Lines of research of the Heritage and Geodiversity research team

(1) *Spanish Inventory of Geological Sites of Interest (IELIG) and methodology for its development.*

During the last 15 years, knowledge about geoheritage has improved considerably in Spain, especially thanks to Law 42/2007 on *Natural Heritage and Biodiversity*, reinforcing the pioneering work already developed at IGME since the 1970s. The IELIG was one of the national inventories enacted by RD 556/2011 for the development of the *Spanish Inventory of Natural Heritage and Biodiversity*. The methodology was developed in compliance with a specific strategic plan (RD 1274/2011; García-Cortés et al., 2019; García-Cortés and Cabrera, 2021). In 2014, IELIG's database was publicized and given free access through a web viewer: <https://info.igme.es/ielig/>. Currently (April 2022), the IELIG shows information on a total of 4089 LIG (acronym of geosite in Spanish), inventoried with the participation of regional governments. Some had already made their own official inventories, such as Andalusia, Catalonia, Basque Country, Aragon and Murcia, and others have completed their inventory following the IELIG methodology, such as the Canary Islands and La Rioja (Galindo et al., under review; Salazar et al., under review).

(2) *Methodology for the integration of geoheritage in Environmental Impact Assessments.*

This novel methodology was developed in 2012 in collaboration with the Directorate General of Environmental Quality and Assessment, currently under the Ministry for the Ecological Transition, Government of Spain (Vegas et al., 2012), and has been presented at international congresses (Vegas et al., 2016). The pioneering method was developed to integrate geoheritage into environmental impact assessment studies by actively including it as one of the most effective tools for conservation.

(3) *Citizen Science Program 'Save a Rock' for the protection of Spanish geological heritage.*

This program helps to improve the protection and monitoring capacity for all LIG identified by the IELIG. Citizens participate in the surveillance, protection and monitoring tasks, contributing data to the program through <https://www.igme.es/patrimonio/ApadrinaUnaRoca>, and obtaining knowledge, awareness and recognition for their participation in site protection. At the beginning of 2022, the program had 3368 volunteers from all over Spain, sponsoring a total of 1655 LIG from the inventory (Vegas et al., 2018, 2021; Cabrera et al., 2019, 2021).

(4) *Global inventory of geological heritage with international relevance.*

The IGME-CSIC GEO-HERITAGE research team is strongly contributing to the methodological and conceptual development for the implementation of the database for the world inventory of geological heritage. This is done (a) through project 'IUGS Geological Heritage Sites' (IGCP 731, funded by UNESCO and IUGS) as members of the International Commission on Geoheritage (ICG) of the IUGS, and (b) with the methodological development for the inventory of geological heritage of Antarctica, leading the Geoconservation Working Group for the Standing Committee on Antarctic Research (Carcavilla et al., 2019; Hughes et al., 2020).

*(5) Indicators of the state of conservation of geoheritage and built stone heritage.*

The development of specific indicators to estimate the state of conservation is carried out in the two strands of the research team: geoheritage (García-Cortés et al., 2015; Díez-Herrero et al., 2018; Carcavilla et al., 2022) and stone heritage (Martínez-Martínez et al., 2017a; Martínez-Martínez et al., 2022). This line of research includes the study (assessment, quantification and analysis) of the deterioration processes affecting the elements that make up cultural heritage, as a basis for the proposal and development of mitigation actions for the preventive conservation of natural and cultural heritage.

*(6) Impact and threats of climate change and global change for the conservation of geoheritage and stone heritage.*

Methodology for the identification of geohazards associated with different global change scenarios that threaten geological and cultural heritage (IVRIPARC Project in Vegas et al., under review; RESCUhE Project in Martínez-Martínez et al., 2022).

*(7) Study and assessment of historical areas of raw materials (mines and quarries) as vulnerable heritage elements.*

Between 2009 and 2013, the Atlanterra project promoted the recovery and enhancement of mining heritage in Galicia within the INTERREG program, funded by the ERDF (Ferrero et al., 2012; Jiménez and Díaz Martínez, 2013; Ferrero et al., 2018). In the same research line, and through different contracts with the administration and collaborations with multidisciplinary research teams, important historical quarries linked to architectural heritage have been located and characterized, such as the quarries of Ortigosa del Monte and La Granja (Segovia), Espejón (Soria), Macael (Almería), Nueva Tabarca or Novelda (both in Alicante) (Martínez-Martínez et al., 2017b; Corbí et al., 2019; Martínez-Martínez, 2021; Riquelme et al., 2022).

*(8) Conservation of geoheritage and stone heritage in industrial and anthropic sites.*

In this line of research, the RESCUhE project develops the analysis of the directionality of erosive agents affecting heritage, and the elaboration of proposals and guidelines for its preventive conservation with physical barriers. This line also pays special attention to the evaluation and conservation of elements with heritage value in mining environments.

*(9) Methodologies for the assessment of movable geological heritage (minerals, rocks and fossils).*

Development of protection actions and recommendations for holding, trade and management of moveable geological heritage (Delvene et al., 2018; Vegas et al., 2018). This line of research addresses innovative issues rarely developed, such as the analysis of those LIG that contribute specimens to movable geoheritage and the collection of geological elements.

*(10) Dissemination and enhancement of geoheritage and stone heritage.*

Knowledge transfer to other administrations and society in the field of geoheritage, stone heritage and geodiversity, both in protected natural areas (Gordon et al., 2018), UNESCO Global Geoparks (Hilario and Carcavilla, 2021) and in urban environments (Vegas and Díez-Herrero,

2021). The final objective of these activities is to make these heritages known and raise awareness in society for their protection and sustainable use.

*(11) Organization of fieldtrips and other outreach activities related to geoheritage.*

Coordination and participation in the annual activities (guided tours, talks, etc.) organized for Science Week, Geology Day (*Geología*) and Hydrogeology Day (*Hidrogeología*) for different provinces. Design, edition and publication of geological guides, videos, interviews, workshops, etc. (<https://www.igme.es/patrimonio/>).

*(12) Knowledge transfer through training in cooperation with national, regional and local administrations.*

Since 2007, the GEO-HERITAGE research team has collaborated in the delivery of training courses in the discipline of geological and mining heritage for regional administrations in Spain, mainly aimed at environmental technicians, forestry agents and national park rangers. In 2015, this training moved to the international arena, through a collaboration agreement with the Colombian Geological Survey, with two training courses conducted for its staff, including field practices. Between 2017 and 2019, the team led WP-6, the training on geoheritage and geoconservation for African geological services, of the first phase of the European-funded PanAfGeo project (Díaz-Martínez et al., 2019). A second phase, PanAfGeo2, is currently under way for 2022-2024.

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## Geological Heritage inventory of La Rioja (Spain). A small territory with a great geological diversity

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### Abstract

In 2021, the General Directorate of Environmental Quality and Water Resources (Government of La Rioja) commissioned the Geological and Mining Institute of Spain (IGME, CSIC) to carry out a new inventory of geological heritage of La Rioja. The inventory has been performed with the methodology of the Spanish Inventory of Sites of Geological Interest (IELIG) and has been integrated into its database (<https://info.igme.es/ielig/>). The antecedents of this task was the inventory carried out in 2007 by the GEOMARE consultancy for La Rioja and the inventory of the Iberian Range carried out in 2013 for IELIG. The new inventory of La Rioja include 65 sites of geological interest or geosites (19 new ones), which represents 1.6% of the geosites currently present in IELIG. Considering the small area of La Rioja (5,045 km<sup>2</sup>; 1% of Spain), that represents a relatively high number of geosites compared to the entire country (4,089 geosites in 505,990 km<sup>2</sup>).

This accumulation of sites of geological interest is the result of several key facts. Although La Rioja is relatively small, its geological diversity is quite remarkable, since it has three different geological regions (Basque-Cantabrian Basin, Ebro Basin and Iberian Range), includes an extensive geological record (Cambrian to Quaternary), a great variety of rocks, minerals and fossils, Alpine and Variscan tectonic structures and, due to a high relief energy (more than 2,000 m) and a transitional climate between Oceanic and Mediterranean types, a wide spectrum of geomorphological environments, from glacial to semi-arid.

Among the places added or revised, the following stand out for their high scientific value. 18 geosites belonging to the geological framework of international relevance (Global Geosites for Spain) "*Fossils and ichnofossils of the continental Mesozoic of the Iberian Peninsula*" (IB200 – IB200r), deposits of the Berriasian tidal plain of Cervera-Valdemadera (IB241), mammal site and Pliocene - Quaternary succession of Villarroja depression (IB245, IB236), the fossil trunk of Igea (IB240), glacial valleys, cirques and periglacialism of Picos de Urbión (IB018) and Navajún and Ambasaguas pyrite deposits (IB121), all of them in the Iberian Range; the Miocene paleontological site of Autol (EB005), Cenozoic evaporite deposits of Alcanadre and Agoncillo (EB002) and the fluvial bars and meanders in Sotos de Alfaro (EB008), all three in the Ebro Basin; and the Cretaceous section and gorge of Hoz in Foncea (CV025) in the Basque-Cantabrian Basin.

## International activity towards the conservation of geological heritage and heritage stone

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### Abstract

Since its foundation in 1849, the Instituto Geológico y Minero de España (IGME) developed a strong international activity, not only with the organization of conferences, such as the XIV International Geological Congress in 1926, or the 10<sup>th</sup> International Congress on Carboniferous in 1983, but with its active participation in international scientific organizations. We herein summarize the milestones of its participation in the advancement of geoconservation at the international level, and comment about the perspectives for the future. In the 1990s, IGME participated in the first geoconservation initiative taking place worldwide (Digne, France), in the first geoconservation scientific organization (ProGEO), the constitution of related working groups, and the organization of international meetings on the subject. IGME made it possible for Spain to be the first country to complete the inventory of geological sites of international relevance (UNESCO and IUGS Global Geosites) and to later incorporate it into our own legislation. We have been collaborating with the development of the geopark model since its inception, and currently are the second country in the world with more UNESCO Global Geoparks (UGGp). We participate in working groups of international organizations (IGC of IUGS, GSG of WCPA-IUCN, SCAR, etc.), promoting the development of geoconservation actions and policies at the national and international level. In an attempt to promote geoconservation in Africa, we led the 1<sup>st</sup> phase and currently are part of the 2<sup>nd</sup> phase of the geoheritage work package of the PanAfGeo project (Pan-African support to geological sciences and technology, Africa-EU partnership), funded by the European Commission with 8M€ for 2021-2024.

In the field of heritage stone, we collaborate with academia (Iran, Italy, México, Switzerland and Tunisia) and participate in international research projects focused on cultural heritage and its building materials, carrying out studies on monuments and cultural landscapes of Morelia (México), Kandovan (Irán) and Vardzia (Georgia).

Our results are published in international scientific journals and specialized books on the subject. Interestingly, all this has been done without an explicit national geoconservation policy and without adequate funding for it. The future is uncertain, as we have achieved visibility and recognition abroad that is not being compensated with the necessary official support to maintain it.

## RESCUHe Project: Cultural Heritage vulnerability in a changing and directional climate

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### Abstract

RESCUHe Project (Improving structural RESilience of Cultural HERitage to directional extreme hydro-meteorological events in the context of the Climate Change) is a coordinated IGME-UAM research project funded by Spanish Government (MCIN/AEI/10.13039/501100011033).

The framework of this research is the predicted increase in climate change vulnerability of heritage sites and the current disconnection between both environmental research on material decay and the practical aspects of designing preventive conservation measurements.

The main aim of the coordinated project is to establish the scientific-technical basis for optimum design of innovative preventive measures that mitigate its current and future vulnerability of cultural heritage. Special attention is paid to the directionality of extreme events. This global objective is treated from two different perspectives (each one framed in a different subproject). The first one offers a holistic view, analysing the climatic hazard and the properties vulnerability by means of theoretical models and experimental procedures (subproject 1, led by IGME). The second subproject (led by UAM) applies the methodologies and results obtained from the subproject 1 to five case studies, establishing the methodological criteria for the design and resizing of preventive barriers.

This main aim is built around four specific objectives:

- Development of novel 'Climatic Risk Indexes' focuses on quantifying more precisely the vulnerability of cultural heritage.
- Analysis of the relationship between 'exposure' (climate conditions and relative orientation) and 'durability' (closely linked to *vulnerability*) of different materials.

- Application of theoretical and experimental results to real case studies
- Development of a methodology, based on scientific-technological criteria, for increasing the effectiveness of physical shielding barriers (natural and/or artificial) designed for preventive conservation of cultural heritage.

## Department of Geological Risks and Climate Change



Photo: Andrés Díez



## Department of Geological Risks and Climate Change (CN IGME-CSIC)

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### Abstract

The IGME-CSIC CN Department of Geological Hazards and Climate Change currently has 46 members, with an equal balance between women (52%) and men (48%). It is made up of an equal number of technical and scientific staff, and 20% of young researchers recruited under competitive projects.

The main objective of the Department is to provide society with scientific information, methods, tools and solutions to mitigate the impact of geological hazards and the effects of Climate Change. It includes research on: earthquakes, tsunamis, volcanic eruptions, landslides, floods, droughts, sea level, ocean productivity and acidification, etc. Its priority lines of research are defined as follows:

1. Characterisation, analysis, monitoring, modelling and prediction of geological hazards. Geology applied to hazard studies.
2. Evaluation of geological risks and resources considering Climate Change projections and scenarios.
3. Palaeoclimatology: palaeoclimatic variability and palaeo-oceanographic reconstructions. Application of Climate Indices.
4. Advice on management and communication in the field of geological hazards.

The Department of Geological Hazards and Climate Change is currently leading **21 initiatives** involving the management of **3.1 million Euros**: 11 national competitive projects; 5 international competitive projects; 2 research contracts; 3 collaboration agreements and is leading an intramural project to continue the work started during the Tijogaite volcanic eruption (La Palma, 2021).

The Department is structured into three research groups:

1. **Extreme Geological Events and Heritage (EGE&P)**, with 13 members. EGE&P deals with the analysis of extreme geological events and proposals for measures to mitigate their associated hazards, especially on cultural and natural heritage. The group is the germ of URGE: *Unidad de Respuestas Geológicas a las Emergencias*, which has played a fundamental role during the volcanic emergency in La Palma.
2. **Sedimentary Record of Climatic Changes (RESCLIM)**, with 11 members. This group investigates the imprint left in the sedimentary record by climatic changes in the past, both in marine and continental environments.
3. **Earth Observation, Geological Hazards and Climate Change (OBTIER)**, with 22 members. The main objective of this group is to build a bridge between society and the scientific/technological capabilities of Earth Observation to mitigate the effects of geological hazards and contribute to their prevention, prediction and monitoring, in a context of Global Change.

## Research Group on Earth Observation, Geological Risks and Climate Change (OBTIER)

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### Abstract

Within the framework of the IGME-CSIC Department of Geological Hazards and Climate Change, the OBTIER research group was created in July 2021 and currently has 22 members, including scientific and technical staff, as well as young people with contracts linked to competitive national and international research projects. The main objective of the group is to provide society with scientific information, methods, tools and solutions to mitigate the impact of geohazards and the effects of Climate Change. OBTIER is currently leading 6 competitive projects (4 European and 2 national), as well as several projects in agreement with other national and international administrations. It is an active member of the EuroGeoSurveys Earth Observation Expert Group and the ASGMI Geological Hazards Group. OBTIER offers society a wide range of capabilities on: earthquakes, tsunamis, landslides, land subsidence, volcanic eruptions, droughts and floods. In 2021, the group published an article in *Science* entitled: Mapping the global threat of land subsidence with significant media coverage around the world.

### Framework and missions of OBTIER

OBTIER is part of the IGME-CSIC's Mission, Functions and Objectives, as set out in its current Strategic Plan (2022-2025). Linked to Initiative 9 of the Strategic Plan, where the IGME aims to promote lines of research aimed at Protecting the Planet, this group aims to strengthen research on Climate Change, leading national and international projects on the subject, especially in the lines that investigate the effects and impacts of Climate Change, as well as adaptation and mitigation strategies. Among the geological hazards that OBTIER incorporates into its lines of research are the following: earthquakes, tsunamis, landslides, land subsidence, volcanic eruptions, droughts and floods.

This group was one of the most relevant milestones of the last 5 years at IGME with the publication of "Mapping the global threat of land subsidence" in the journal *Science* (Herrera et al. 2021). This work was led by the IGME in the framework of the UNESCO International Expert Group on Subsidence. The research shows (Figure 1) that, for a 2040 global change scenario, land subsidence will affect 19% of the world's population, which represents 8% of the surface of the globe; 15 of the 20 most populated cities in the world will be affected by this process (e.g., Jakarta, Mexico City, Venice) and the economic damage is estimated at 12% of global GDP.

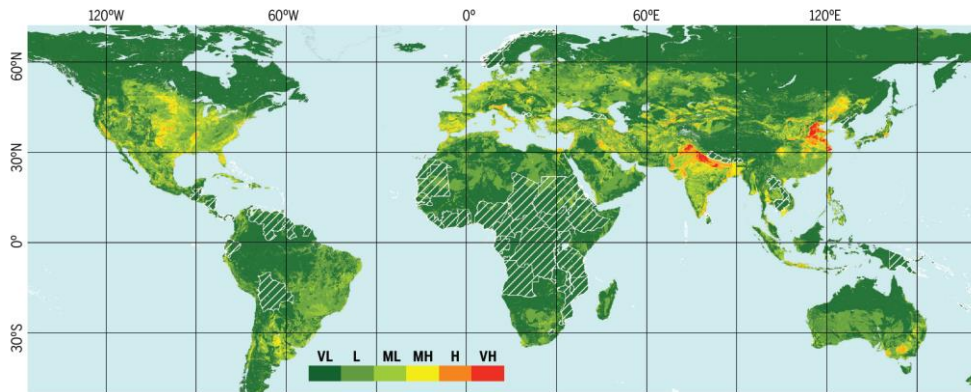


Figure. 1. Mapping the global threat of land subsidence by (Herrera et al. 2021). This work published in the Journal Science is one of the most relevant milestones at IGME during the past 5 years

This research group is an active member of the Earth Observation Group of EuroGeoSurveys, with a large panel of international experts that has materialized in numerous European projects (SAFETY, U\_GEOHAZ, RISKCOAST, etc.). OBTIER also belongs to the Geological Hazards Expert Group of the Association of Geological and Mining Services of Latin America (ASGMI), representing the IGME in the Seismic Hazards subgroup.

#### Projects led by OBTIER

Currently, OBTIER is leading 6 competitive projects: 4 international projects: RESERVOIR, RISKCOAST, RASTOOL and EuroGEOSS Showcases and 2 national projects: SARAI and PROMETEO. In addition, it is leading a project on tsunamis, in agreement with the Consorcio de Compensación de Seguros; a project on landslides related to mining in the Laciana valley (León), in agreement with the Junta de Castilla y León (Figure 2); the UNDERGY-Ayterra project, which consists of a contract derived from a CDTI MISSIONS project for the study, using DiNSAR, of historical movements in a pilot area to inject gas and produce green hydrogen. An international collaboration agreement has also recently been signed with the Colombian Geological Service to carry out a seismic hazard study on the Colombian plains. In the Latin American context, we also participate in the OLLIN project of the UNESCO international geosciences program on the identification of seismogenic faults in populated areas of Latin America. At the same time, risk assessment is provided to the Diputación de Granada and other public administrations.

#### OBTIER's current and future objectives and lines of research

*Characterization, analysis, monitoring, modelling and prediction of geological risks. Geology applied to hazard studies.*

- Contribute to the knowledge of hazardous processes through geology and related disciplines: causes and effects.
- To generate scientific information on geological hazards in order to offer society an open and up-to-date service that is useful for preventing catastrophes and reducing their consequences.

*Management and communication advice on geohazards*

- Provide information, training, products and services to public administrations.



- Improve the social perception of geohazards and promote citizen science to achieve a more prepared and adapted society.

*Assessment of geohazards and geological resources considering Climate Change projections and scenarios.*

- Promote the development of methodologies and tools for the risks derived from Climate Change and the adoption of criteria and measures for adaptation.
- Introduce the climate perspective in disaster risk assessments, especially in strategic areas.



Figure. 2. Landslides in the Laciana Valley (León) induced by coal mining activity, a project led by OBTIER in agreement with the Junta de Castilla y León

#### **OBTIER competences and capabilities**

*Territorial and specific analysis of seismic hazard* for the creation of knowledge infrastructure related to earthquake occurrence and recent fault activity for the development of applications in the field of seismic-resistant regulations, territorial planning for the location of critical infrastructures, the assessment of earthquake and tsunami losses, as well as for establishing seismic load in the design of infrastructure stability.

*Geomechanical numerical modelling for the development and application of geomechanical numerical models* (with proprietary software) for the study of geological, geotechnical and mining hazards related to ground motions and stability of geostructures. Equilibrium conditions (Factor of Safety) and deformations associated with slope slides, subsidence, ground collapse,



rock falls, debris flows, avalanches, soil liquefaction, seismic amplification, tsunamis in reservoirs, dumps, waste dumps, mine cuttings or tailings dams can be evaluated quantitatively (for predefined conditions).

*Data mining or exploitation with advanced statistical techniques* of spatio-temporal data related to geological hazards. In order to understand and predict the processes related to geological hazards (e.g., floods, earthquakes or subsidence), classical geostatistics, state-of-the-art time series analysis or artificial intelligence models are applied. In addition, these techniques allow multidisciplinary analyses to support decisions to mitigate such risks. On the other hand, for the enhancement proposed by OBTIER on the study of the impacts of climate change, future climate series projected by the IPCC are used. This type of spatio-temporal series requires the application of statistical analysis techniques in their pre- and post-processing.

*Application of remote techniques to Earth observation and geohazards.* The team of the Radar and Geological Hazards Modelling Laboratory (<https://www.igme.es/insarlab>) uses Earth Observation techniques, such as radar interferometry (InSAR), to detect movements of the Earth's surface associated with different geological processes (subsidence, landslides, earthquakes). The integration of these displacement data with geo-thematic layers, in situ observations and numerical models allows us to develop products for the prevention and mitigation of geological risks (Figure 3).

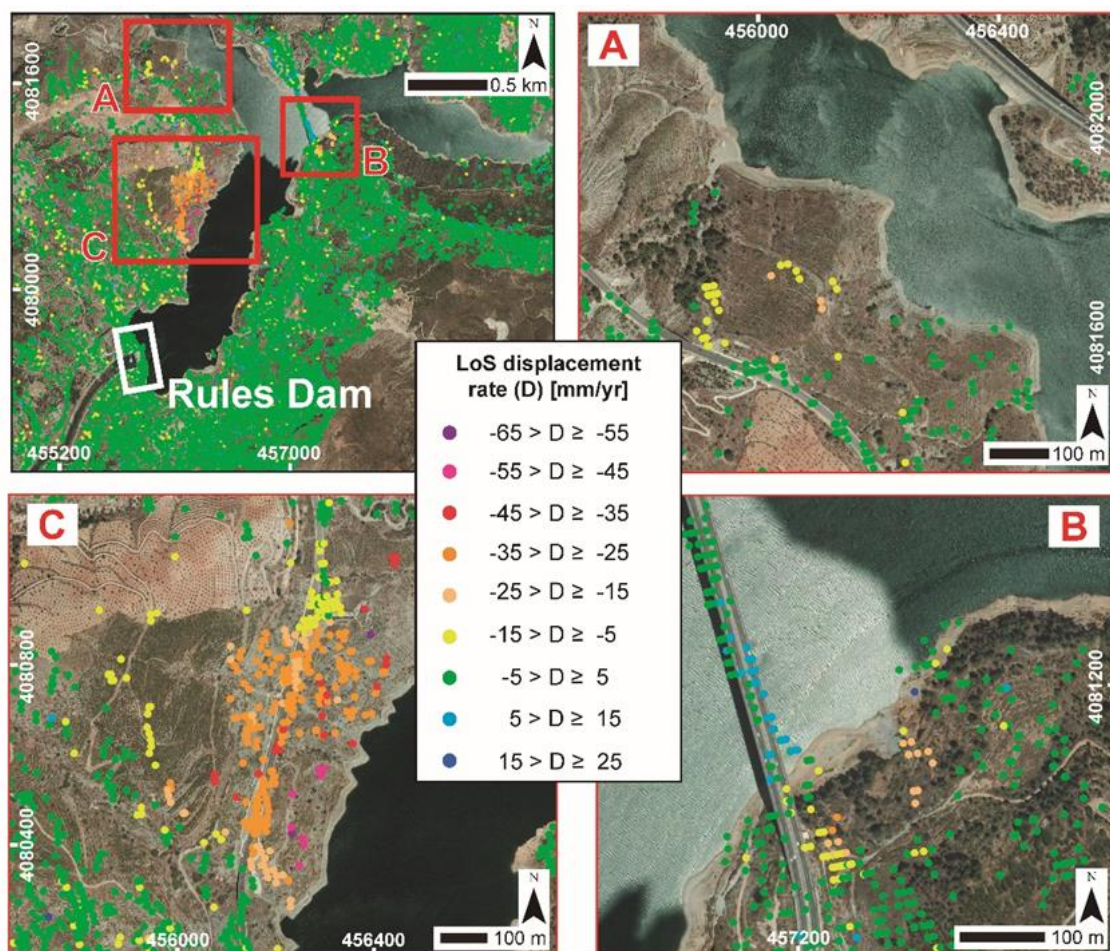


Figure 3. DInSAR techniques applied in the Rules reservoir (Granada) for monitoring the activity of landslides (Reyes et al. 2020; RISKCOAST project)



Hyperspectral remote sensing data, both airborne and satellite-borne sensors, collect spectral information on the Earth's surface with a continuous spectral resolution. Each image has a large number of 2D data that require special digital processing algorithms, capable of scanning airborne flights with high spectral resolution, and digitally mapping. Work is currently underway on the monitoring of mining waste in the Iberian Pyritic Belt and in the lavas of the Cumbre Vieja volcanic eruption (2021, La Palma, Canary Islands).

#### *New techniques and methodologies applied to rockfalls*

- Numerical modelling of rockfall: the group has extensive experience in rockfall modelling at both local and regional scales (Figure 4).
- Early warning systems for rockfalls: the definition of rainfall thresholds that produce rockfalls to establish early warning systems. The effect of climate change on the increased occurrence of rockfalls will be introduced based on the analysis of the scenarios proposed by the IPCC.
- Multi-hazard approach in rockfall analysis: due to its influence on landslides, the cascade effect produced by seismicity and forest fires is being studied.

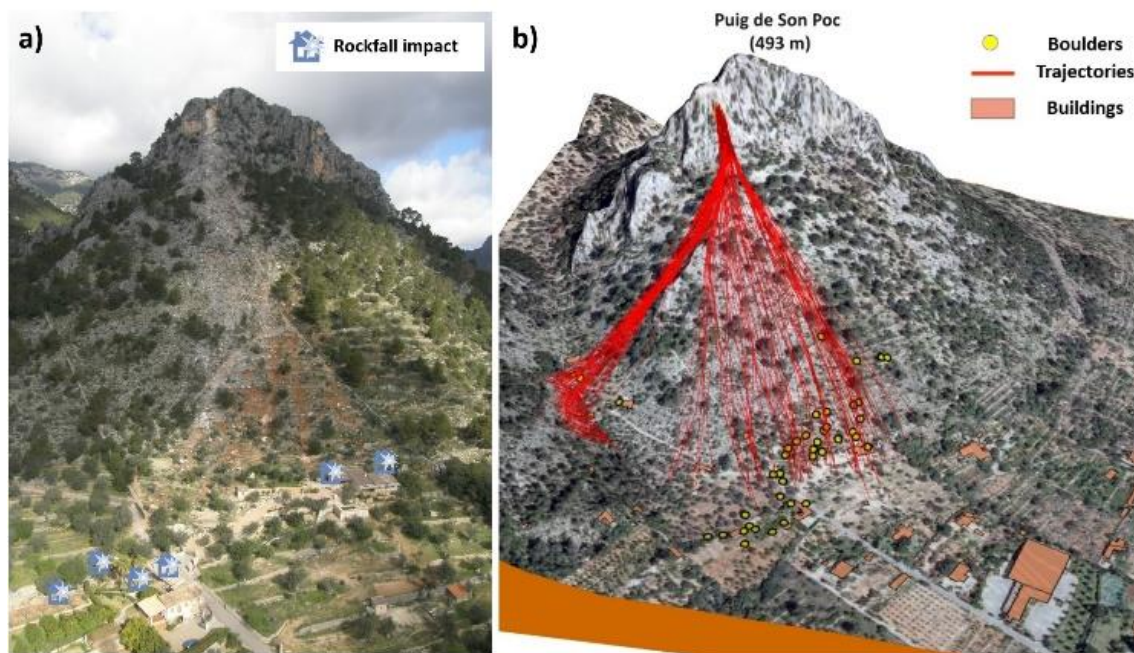


Figure 4. The Son Poc rockfall in March 2013 (Mallorca). Computed trajectories by RocPro3D (Sarro et al. 2014)

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## Palomares Fault: Geomorphological exploration and mapping, microtopographic analysis and classical trenching survey (NSOURCES PROJECT)

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### Abstract

Paleoseismological studies provide crucial information for Seismic Hazard Analysis. Determining the geometry and slip rates of the faults is essential for defining their seismogenic potential (magnitude and recurrence interval of the large earthquakes), especially in low-to-moderate activity areas.

The Palomares fault is one of the main structures of the Eastern Betic Shear Zone (EBSZ), a set of NE-SW active slow faults with long seismic loading cycles, which absorb part of the convergence between the Nubian and Eurasian plates (5-6 mm/yr) in the western Mediterranean under a transpressive regime. The faults that form this large crustal structure are the Carboneras, Palomares, Alhama de Murcia, Los Tollos, Carrascoy and the Bajo Segura faults, from south to north. The Palomares fault shows a northernmost orientation and a fault zone very wide. This is a geometry very different from the other faults. Another substantial difference is that the Palomares fault still remains largely unstudied from a paleoseismological point of view, representing a major knowledge gap in the EBSZ and so hindering the development of reliable fault-hazard models as the ones that have been recently carried out for the EBSZ based on magnitude-frequency distributions, transfer of Coulomb stress or earthquake simulators. In this context, the NSOURCES Project, awarded in the last R+D+i project call of the National Plan, proposes the Palomares fault as one of the case studies to develop new approaches to earthquake source characterization, in areas of low-to-intermediate activity of eastern Iberia, and their effective integration into fault-based seismic hazard models.

The main objectives of these studies are a) characterizing with precision the source parameters and the strain rates of the fault, b) redefining methodologies (as the geochronology) and c) reassessing the effect of introducing source parameters on a new probabilistic seismic hazard calculation. In order to achieve the first objective, it is proposed to make a detailed morphotectonic analysis of the most recent deformation band from DEMs, photogrammetric restitution of detailed locations, drainage network analysis at different scales and swath topographical profiles perpendicular to the fault zone. These preliminary works will provide a first approach for fault segmentation and to propose detailed study areas in which to carry out a paleoseismological trench survey.

## Integration of data acquired using SfM orthoimagery correlation techniques and satellite InSAR techniques for the calculation of 3D displacements in densely vegetated unstable slopes

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### Abstract

Detecting and monitoring slope movements is essential to better understand their causes and mitigate their adverse consequences. Satellite radar interferometry (InSAR) techniques allow to generate deformation maps at high resolution (both spatial and temporal), especially since 2014, when the European Space Agency's Sentinel-1 mission (6-day revisit frequency) became operational. The application of InSAR is, however, constrained by a number of limitations. The main one relates to the inability of the technique to measure rapid deformation phenomena. In the case of Sentinel-1, for example, the maximum measurable deformation rate (along the satellite line of sight) is about 0.85 m/year. In this context, the application of digital photogrammetry (SfM) orthoimagery correlation techniques constitutes a directly applicable alternative for the remote monitoring of rapid slope movements. Moreover, whereas the application of InSAR monitoring techniques in densely vegetated areas is often impractical given the decorrelation produced by strong changes in the vegetation cover, the application of SfM monitoring techniques allows more effective analyses to be conducted in areas with abundant vegetation.

In this work we present the results of a local-scale study carried out in El Feixolín (León), a former open-pit and underground mining area affected by a rapid (1.67 m/year according to in situ measurements) large slope movement. Results include data obtained using satellite InSAR techniques, SfM orthoimagery correlation techniques and DGNSS techniques. Further, this study provides as final result two datasets of 3D displacement values: (i) one calculated by integrating the InSAR monitoring data obtained in ascending (ASC) and descending (DES) geometry, with the SfM monitoring data obtained in north-south (NS) direction (InSAR 3D dataset); and (ii) another calculated by integrating the SfM monitoring data obtained in NS, east-west (EW) and up-down (UD) direction (SfM 3D dataset). Comparison of the results with the DGNSS data revealed relative errors (RMSE) of 6, 36, 12, 13, 24, 23 and 15%, respectively for the InSAR ASC, InSAR DES, SfM EW, SfM NS, SfM UD, InSAR 3D and SfM 3D datasets, highlighting the effectiveness of SfM for the monitoring of rapid slope instabilities in densely vegetated areas.

## Geological applications of the PRISMA hyperspectral mission. Canary Islands scenario

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### Abstract

PRISMA is a technology demonstration and pre-operational mission of the Italian Space Agency. The space segment is an Earth observation satellite with medium resolution hyperspectral and panchromatic instrumentation, which allows the recognition of the geometrical characteristics of the scenes together with their spectral properties along the VNIR and SWIR ranges of the electromagnetic spectrum.

This work explores the possibilities of this mission for the study of the eruptive episode that took place on La Palma (Canary Islands) between 19 September and 13 December 2021. The multi-temporal analysis of the PRISMA images allowed us to carry out analyses of changes in the active processes that take place during volcanic eruptions. Thus, the characteristic spectral features and their temporal variation of the different active elements that appear in this eruptive scenario have been explored, such as volcanic gases, the ash and pyroclast column, the ongoing lava flows and the new lava delta.

It has been possible to determine the influence of the presence of volcanic ash in these contexts, as well as the variations occurring in the lava delta. The analysis of CO<sub>2</sub> spectral features together with MODTRAN simulations also allows an estimation of the concentration and distribution of this gas.



## Seismogenic characterization of active faults in Colombia for seismic hazard assessment of the city of Bogotá: Formal agreement between the Colombian Geological Survey and the Centro Nacional Instituto Geológico y Minero de España (CSIC)

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### Abstract

The recent update of the Colombian seismic hazard model by Dirección de Geoamenazas of the Colombian Geological Survey (CGS), has identified the necessity of considering fault geological data in future successive updates of the hazard map. At the same time, the fault-based seismic hazard studies developed in the Centro Nacional IGME-CSIC have also identified the need of increasing the available knowledge on recent activity and paleoseismology of Spanish active faults in preparation for a future update of the national seismic hazard. In this frame, both CGS and IGME-CSIC, have formally agreed to collaborate in active faults research as well as their modelling for seismic hazard calculations to improve seismic risk provisions. It has been program firstly a pilot study in the transfer zone between the Algeciras and Guaicaramo faults (Colombia) that could also serve to provide the methodological framework for studying other faults in the country.

The Algeciras fault is a dextral strike-slip structure running through the Western Colombian Cordillera along for more than 250 km from Ecuador's border to approximately Mesetas (Meta, Colombia), where it finishes and presumably the Guaicaramo thrust system takes over controlling the cordillera mountain front and the pass to the Amazonía, a strip of land known as Borde Llanero. In this area, moderate to large magnitude earthquakes (Mw 5.0-7.0) have taken place and felt strong in the city of Bogotá (e.g., 1785, 1917, 1967, 2016).

This formal agreement aims at obtaining, eventually, a seismogenic model of the transfer zone from geological and geophysical data for its incorporation in a new seismic hazard assessment of the city of Bogotá. The agreement has a duration of 2 years, and could be further extended by mutual agreement of both parties. Working plan consists in three main phases, basically: office work, field work, and fault geomodelling. Personnel from both institutions participate in all phases of the project. Currently, phases 1 and 2 are taken place, the first field campaign have been already done in February 2022.

## Geological Extreme Events: analysis and mitigation at IGME-CSIC

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### Abstract

The analysis of extreme geological events and the proposal of mitigation measures to prevent the concomitant hazard and risk effects, especially on the natural and cultural heritage, are addressed from the IGME-CSIC research group on “Geological extreme events and Heritage”, by applying pioneer and innovative methodological approaches, including: geology applied to emergency situations; earthquake geology and archaeo-seismology; geological hazard assessment in volcanic islands; cataloguing and surveying mass movements; flood and paleo-flood hydrology and geomorphology; characterization and observation of geological events through UAS; education and training on geological risk; and citizen science. The main results achieved by the group components, along the last five years (2017-2021), amount to 400 high quality publications and the involvement in more than one hundred scientific projects (leading twenty of them); additionally to many contributions in congresses, meetings, conferences, research stays and social dissemination. Among the implementation fields of this research may be highlighted the territorial planning, emergency operations, and heritage management. It is the reason why many public administrations, private institutions, and social and commercial actors, are counted among the end users and the partners of this research group.

### Introduction

Although there is no general international agreement to define what extreme geological events are, they could be set as those phenomena, processes, or natural actions, whose occurrence and/or magnitude (energy release or mass movement) are plotted at the edges (tails) of the frequency distribution functions in time and space; and they also can be studied using Earth-science data sets and geoscience methodologies.

Among such phenomena, those related to internal geodynamics are included, like volcanic eruptions, earthquakes, tsunami-seaquakes, sudden halo-kinetic phenomena; and other properly associated to external geodynamic processes (landslides, rock falls, mudslides, terrain collapses, subsidence, expansibility...), snow avalanches, inland and coastal flooding, sudden littoral erosive-sedimentary events, etc. In order to study such processes and the mitigation of their damaging effects, natural data record (geological and biological) and cultural record (systematic instrumentation and historical documentation) are used. Very frequently, some specific methodologies are also applied like volcanology, petrology, geochemistry, geochronology, seismology, structural geology, tectonics, geophysics, geomorphology, hydrology, geotechnics, etc., but always in connection with other disciplines like archaeology, history, geography, meteorology, biology, sociology, psychology, economy, civil engineering, etc.

The Geological and Mining Institute of Spain (IGME; in present days constituted as a national center attached to the Spanish National Research Council, CSIC), since its very early origins in

1849, when was created as a “Commission appointed to develop the geological map of Madrid and the Spanish Kingdom”, already had among the tasks, to study the natural phenomena, and preferably the extreme geological events, like volcanic eruptions, high intensity earthquakes, catastrophic movements of the ground, and extraordinary floods (Díez Herrero y Laín, 1998; Llorente et al., 2006). Since the integration of IGME in CSIC, the research group on extreme geological events has been officially constituted; paying special attention to the connection with heritage in an ample sense, both cultural (archaeological, historical-artistic, ethnographical, immaterial...) and natural (geological and biological).

This communication compiles the goals, methodologies, results, implementations and the end users of the analysis and mitigation works that have been performed since last decades by the members of this research group on “Extreme geological events and Heritage” of IGME-CSIC.

### Goals

- Characterization, analysis, monitoring and modelling those active geological processes that generate natural hazards, as well as the vulnerability of the affected natural and anthropic systems.
- Development of innovative methodologies and techniques, to prevent the hazards and impacts of the extreme geological events, like earthquakes, tsunamis, volcanic episodes, flash floods, ground and mass movements, etc.
- To focus the interest and the attention of the hazard studies on both, the natural (geological and biological) and the cultural (historical-artistically, documental, ethnographical, immaterial...) heritage.
- Implementation of the acquired knowledge to take the optimal three predictive (early warning and alerts), preventive (structural and non-structural) and corrective measures, in areas like land planning and urbanistic management, risk education and communication, citizenship science, increase of the risk perception and protocols of action in emergency situations.

### Main research and methodological areas, and technological development

- *Emergency geology.* Integration of the acquired geological knowledge on geological hazards, to manage the emergency in catastrophic situations like volcanic eruptions, earthquakes, floods, seaquakes, ground movements and any other national interest contingencies related with earth science areas. The group crew have a high qualification and training on all kind of geological hazards to tackle it, as well as experience on working in real emergency situations with the Emergency Geological Response Unit (URGE).
- *Earthquake Geology.* A holistic view of the seismic phenomena, analyzing the geological record of earthquakes, the proper seismic event and the geological effects on the territory that affects the whole society (Silva and Rodríguez-Pascua, 2014).
- *Archaeoseismology.* Study of earthquakes happened in the past using architectural and archaeological heritage. Historical earthquakes and their effects on the heritage are studied. Documental-unrecorded earthquakes will be considered as well. This late may be useful to complete the seismic catalogue and the effects on the heritage. Own methodologies, created by the research group, will be used. Thanks to these studies it is possible to understand how the architectonic heritage behaved during an earthquake and how it will do in the future. This is key to take decisions and preventive measures too.
- *Geological hazard in volcanic islands.* This research is focused on lessen the geological hazards in volcanic islands (Galindo et al., 2013 and 2016), as well as working to ensure the

geological heritage since it is an up and coming value to develop a sustainable tourism, moreover when they are especially exposed to climatic global change.

- *Studying and cataloguing ground and mass movements.* This research field consist on carrying out integral studies of those ground movement events that are affecting or are susceptible of affect nearby facilities, towns and heritage. They encompass the detection, cause analysis, damage assessment, mapping and risk mitigation proposals (Ferrer Gijón and García López-Davalillo, 2009). It will also permit the continuous maintaining and upgrading of the National Database of Ground Movements (BD-MOVES).
- *Paleoflood hydrology.* It basically consists on the reconstruction of both, the frequency and the magnitude of past floods, as well as the effects produced on socioeconomic elements and heritage (natural and cultural), using natural data sources (geological, hydrological and biological) and the use of innovative methodologies (dendro-geomorphology, paleo-flood sedimentology, lichenometry...; Díez-Herrero et al., 2009). It will also allow the maintaining and upgrading of the National Database of PaleoFlood Events in the Natural Record (BD-PaleoRiada).
- *Observation and characterization of geological events by means of UAS (Unmanned Aircraft System).* Selective acquirement of high temporal and spatial resolution aerial information, to address an expert interpretation of images and physical parameters. It allows a real time observation and characterization of those potentially dangerous geological processes and their consequences.
- *Educational and training in risk.* Dissemination of knowledge, proceedings and attitudes to the population about geological hazards, in order to increase their resilience and reduce the vulnerability against natural disasters and catastrophic events.
- *Citizenship science:* Encourage the citizen engagement in the analysis and management of geological risks.

#### Obtained results by the research group during the last five years term (2017-2021)

The main results and outputs produced by this research group during the last five years period (2017-2021; Table 1), clearly show the high scientific and technical production and the prime quality of them as useful resources for both, the society and the science progress.

Table 1. Summary of the scientific and technical production of the research group during the last five years period (2017-2021).

Result, product or activity (2017-2021)		Number of items	
Publications	Papers (articles) in international peer reviewed journals (JCR-SCI WoS)	106	
	Papers (articles) in JCR-SCI WoS journals in the first quartile (Q1)	38	
	Papers (articles) in other prestigious international journals and books	66	
	Publications of chapters in books of international editions	194	
Projects	Research projects participation		95
	Research projects leading	European projects	1
		National Plan R+D+i	8
		Regional projects	2
		Other leading research projects	5
	International Cooperative projects		2
Other	Representations in international delegations		2
	Policy makers assessment reports and 3 geo-thematic cartographies		77
	Scientific-technical support to emergency managers during disasters		5

	Internships in foreign research centers	8
	Key abstracts in international congresses	183
	Oceanographic cruises	6
Academic Supervision	PhD Thesis	4
	Master Thesis	6
	Graduate Project	8
Dissemination	Organization of symposiums and international workshops,	8
	Invited talks, seminars and master courses	10
	Dedicated websites	4
	Social Media accounts (Twitter and Facebook)	7

## General and specific application areas of the research activities of this group

### General:

- Territory planning and management.
- Intervention during emergency geological situations (management, humanitarian aid).
- Guidance to public administrations and public/private entities.
- Preservation of the natural and socioeconomic heritage.
- Research and education.
- Scientific dissemination.

### Specific:

- Emergency Geology: emergency management; rescue teams in urban environments during natural disaster events; management and preservation of the cultural and natural heritage during natural disasters situations; research and educational actions.
- Studying and cataloguing ground movements: guiding the public administrations and entities in risk management and planning of hillside mass movements. Territorial planning, protection of facilities, preventive and alert systems design.
- Observation and characterization of geological events using UAS. Documentation of geological events, mapping, analysis of causes and modelling of processes, management of emergencies, damage evaluation, scientific dissemination.
- Paleo-flood hydrology: Long term territory planning and optimal location of critical and vulnerable facilities (nuclear power plants, large dams, industrial complexes, communication lines or energy transport-lines, redlines...); protection of critical and vulnerable infrastructures like nuclear power plants, industrial complexes and heritage elements (cultural and natural); designing and dimensioning the structural preventive measures of flood risk, like large capacity dams and their drainage elements; adaptation measures to the harmful effects of global and climatic change.
- Education and training in geological risks: school sector, from primary education to secondary and university as well as no formal education (camps, extracurricular activities); primary sector, training farmers, stockbreeders and forestall crews; business and industrial sectors; and service sector, in the areas of management and operation of natural and cultural heritage.

## End users and interested institutions in the activities of this research group

### General:

- National public administrations (central state, autonomic and local administrations); international (European Union, OECD, NATO, IEO, and United Nations, OIEA, UNESCO) and from other countries and continents (OAS...).
- Civil work companies, natural and cultural operation companies, engineering and environmental consultancies and insurance companies.



- Universities, high schools, elementary schools and other educational institutions like institutes and research departments.

*Specific:*

- Military Emergency Unit (UME).
- Directorate General of Civil Protection and Emergencies (DGPCE).
- Insurance Compensation Consortium (CCS).
- Directorate General on Arts (Ministry of Culture and Sports), including the Cultural Heritage Institute of Spain (IPCE).
- Directorate General on Water (DGA).
- Nuclear Safety Council (CSN)
- Centre for Public Works Studies and Experimentation (CEDEX).
- European Civil Protection.
- ECHO-ERCC Office: Directorate-General for European Civil Protection and Humanitarian Aid Operations, Emergency Response Coordination Centre.
- EuroGeoSurveys: European Geological Surveys.
- Association of Geological Surveys of Iberoamerica ASGMI.
- UNDAC: United Nations Disaster Assessment and Coordination, OCHA: Office for the Coordination of Humanitarian Affairs.
- Sustainable Tourism Sector.
- Official centers and companies on territory planning.
- Insurance and reinsurance companies.

## Conclusion

The research group on “Geological Extreme Events and Heritage” of the National Center Geological and Mining Institute of Spain (IGME, CSIC), has developed different research lines as well as some pioneering and innovative methodologies on extreme geological events analysis, focusing on the mitigation of the affections to the natural and cultural heritage elements. The scientific and technical production during the last five year term (2017-2021), shows well the great amount and high quality of the obtained results, which are demanded thanks to the multiple fields of application by many users and partners in both, the national and the international scene.

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## Research Group on Sedimentary Record of Climatic Changes– SERCC

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### Abstract

SERCC was created at the end of 2021 in response to the recent incorporation of the IGME as a National Centre of the Spanish Research Council (CSIC) and the need to converge to CSIC's research organization, which is structured on Research Groups as basic units. SERCC is composed of 11 persons (6 Staff Scientists – 3 of them recently promoted to Scientific Researchers, 4 Specialized Technicians and 1 Predoctoral Student), and focuses on the imprint of past climate changes on the characteristics and properties of the sedimentary record, accumulated both in marine and continental realms. The group follows a multidisciplinary approach based on the combination of geochronological tools, such as radiocarbon dating and chemo-, bio-, magneto- and cyclo-stratigraphy, with the development and application of a variety of stratigraphic, sedimentologic, mineralogic, micropaleontological, geochemical and geophysical proxies that provide complementary views on how climate change has impacted different sedimentary environments and their associated ecosystems. Our research is centred in the Iberian Peninsula and its surrounding areas of the North Atlantic, the Mediterranean Sea and North Africa, but includes also other areas of special interest such as the Pacific, the Arabian region and East Africa. The scientific objectives are centred on disentangling the timing, pace, and origin of climate variability undergone in the Iberian Peninsula and its surrounding areas in the past, at periods from the Mesozoic to the Holocene and timescales ranging from millions of years to multidecadal. A strong emphasis is placed on periods that, because of their characteristics (e.g., high CO<sub>2</sub> concentrations, high temperatures, extreme climate variability, enhanced marine productivity and export to the seafloor, impact on ecosystems) represent analogues of either global warming (Mesozoic marine anoxic events, Eocene, Miocene and Pliocene hyperthermals, Quaternary interglacials-interstadials) or periods of natural climate recovery (Mesozoic cold snaps, Heinrich cold events and interstadials). Special attention is also placed, for the most recent period, on disentangling the natural component of climate change in order to isolate the role of human activities on global warming. SERCC also focuses on other aspects of the sedimentary record pertinent to the Ecological Transition, such as the search for reservoir rocks, assessment of economically-important organogenic rocks, and monitoring pollution and erosion of soils, among others. We follow a perspective that combines: a) production of excellent science with an international impact that conveys the recommendations of the DORA declaration, b) publication of scientific documents and data in open access journals and institutional repositories, c) outreach and dissemination activities aiming at returning back to society the public resources invested in science, d) securement of funding in competitive calls, with an especial focus on European programs, e) recruitment and training of scientific and technical staff, and f) improvement of technical and laboratory facilities. In the long run, SERCC faces the

main challenges common to other research groups at the CISC and, overall, the Spanish Science and Technology System, namely: a) the reduced number of calls for recruiting and promoting young scientific talent; b) difficulty in acquisition of new equipment and space to develop both consolidated and emergent research lines; c) the heavy bureaucratic burden inherent to the management of research projects; and d) the unfavourable national context for the development of the scientific and technical (provided it is established) careers.



## Technical Vice Direction





## Geominero Museum: past, present and... the future?

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### Abstract

The Geominero Museum is a public museum that currently depends on the IGME - CSIC National Centre. A valuable geological heritage made up of more than 100,000 specimens of fossils, minerals and rocks is kept by the Museum, whose origin dates back to the second half of the 19th century. Its objectives are to conserve, disseminate and research the richness and diversity of the palaeontological, mineralogical and petrological heritage from all Spanish regions, as well as from former Spanish colonies and some representative sites of the geological record of the world. From the 1990s until 2021, the Museum has worked in three areas: research, curation-restoration and education-dissemination. A vocational and consolidated staff has achieved to position the Museo Geominero among the national and international distinguished geological museums. However, as of Royal Decree 202/2021, 30th March, the Museum missed one of its main roles: research. The reduction in Geominero Museum staff, therefore the capacities to take on museum objectives are also reduced (see the definition of a Museum by International Council of Museums, ICOM), the current weakness of the synergies previously created between researchers, curators and disseminators and a lack of expertise staff on educational and dissemination activities, have led the Museum to become a mere exhibition space for exhibiting specimens. It does not seem a very promising future for a Museum that has been a main window to the world for such an emblematic, prestigious and a long and fruitful history institution as the Spanish Geological and Mining Institute (IGME).

### Past

On 20th July 1849, Gaceta de Madrid published Royal Decree of 12 July establishing a "commission to create the geological map of Madrid and to gather and coordinate the data for the general map of the kingdom", known as the Commission for the Geological Map of Spain. It was divided into four sections (Geographical-Meteorological, Botanical, Zoological and Geological-Palaeontological) led by prestigious leaders, but its trajectory was brief: cuts in funding and competences (in 1852 the section in charge of the topographic map was created) were the cause of the disappearance of the Commission in 1859 (Rábano, 2012). The geological work was taken by Junta General de Estadística until 1870, when a new Royal Decree established a second Geological Map Commission. It was made up exclusively of mining engineers, whose mission was to make general and provincial geological maps and the geological maps of the most important mining districts of the time. In 1873, the commission was reinforced with more human and financial resources, which led it to follow the path of geological-mining research that continues today at the Spanish Geological and Mining Institute (Instituto Geológico y Minero de España).

The Geominero Museum was inaugurated by King Alfonso XIII on 24th May 1926 when the XIV International Geological Congress was held with a great success in Spain. 1150 participants (350 nationals and 800 foreigners representing 52 delegations) attended to the congress and 16

geological field guides of the field trips during the congress, were published. The showcases and collections were definitively placed in the Museum in 1927. The museography was designed by Primitivo Hernández Sampelayo, the first director of Geominero Museum.

IGME was an important geological research centre from its creation until the Spanish Civil War. The war interrupted the development of work in all Spanish scientific institutions, and many prestigious researchers disappeared or went into exile. The Geominero Museum, custodian of important collections collected by scientists such as Guillermo Schulz, Casiano de Prado and Lucas Mallada, was no exception. During the post-war period, it went through a dark time of suspension of research, plundering of samples and entire collections, loss of archives, of cartouches and documentation associated with the specimens, etc. Many of the collections and their data disappeared between 1960 and the end of the 1980s due to different remodelling works carried out at the headquarters hall of the museum. These works were much likely conducted by staff with no specific curatorial expertise that systematically eliminated those samples that were decontextualized due to a lack of provenance data or systematic classification, or that simply did not seem valuable from a scientific and/or aesthetic point of view. The last of these remodellings took place during the refurbishment of the Museum, which was completed in 1989, just as the elaboration of the general inventory was about to begin.

## Present

The modern stage of the Museum began in 1989 with the restoration and refurbishment of the main hall and the stained glass roof. On 2nd March 1989, the Museum was reinaugurated by King Juan Carlos I, taking the name of Museo Geominero since this time. Therefore, more than three decades ago, the Museum began a new journey, recovering its role as a research centre, enhancing its geological collections and reopening its doors to the visitors. Due to the lack of a museum register book and almost any other type of documentation, it was necessary to carry out a general inventory in order to be able to estimate the volume of items in the collection. The inventory is now complete: we now know that the Museum includes more than 40,000 minerals, about 67,000 macrofossils and more than 1,500 rocks. It also comprises a micropalaeontological collection estimated at around 100,000 specimens of foraminifera, characeae, ostracods, diatoms, conodonts, pollen grains, etc. Among all the elements that can be observed to the naked eye, approximately 17% (about 18,800) are exhibited in the permanent exhibition. The collections are distributed in more than 250 carved wooden and glass showcases located in the main hall and in the access corridors. Currently, visitors can visit the Mineral Systematics Collection, made up of minerals arranged according to crystallochemical criteria; Mineral Resources Collection, with a selection of substances of mineral interest; Collection of Minerals of the Autonomous Communities and Cities, made up of an extensive selection of specimens from Spanish deposits from historical mines and current exploitations; Collection of gems, with 159 gems exhibited, including rubies, sapphires, emeralds and aquamarines, as well as 14 replicas of famous diamonds; Basic collection of rocks, samples of the most common rocks in the lithosphere; Collection of special rocks, represented by meteorites, impact rocks and natural glass; Collection of systematic palaeontology of invertebrates, includes the main groups of fossil invertebrates, highlighting their most distinctive morphological characteristics; Collection of flora and fossil invertebrates, which represent the richness of palaeontological record of Spain following a chronostratigraphic order from the NeoProterozoic to the Pliocene; Collection of fossil vertebrates, which presents an evolutionary

order from fish to human fossil remains, and Collection of foreign fossils, made up of samples of historical interest from some classical or now extinct palaeontological sites.

In 1993 Isabel Rábano took over the direction of the Museum and was responsible for the definitive modernisation of the institution. Under her leadership, the permanent exhibition was remodelled, a travelling exhibition was created with more than 500 pieces and 30 panels, research projects and educational and teaching programmes were launched, a restoration laboratory was set up and, ultimately, a working team was formed and trained to articulate the three areas that had given coherence to the Project of the Museum to date: research, curation-restoration and education-dissemination. Thus structured, the Geominero Museum was situated among recognized national and international geological museums.

During this period, the Museum's **research** is carried out on three areas:

(1) *Palaeontology, Mineralogy and Petrology*

Palaeontology: study of past ecosystems, biodiversification events, extinction events, bioinclusions, palaeobiology, palaeobiogeography, taphonomy, biostratigraphy and movable palaeontological heritage.

Mineralogy and petrology: development of methodologies for the valuation of mineral deposits, mineralogical and petrological movable heritage, petrology of igneous materials (study and classification of meteorites), petrology of sedimentary materials (palaeoclimatic and geochemical studies in speleothems and geochemistry of cave waters), geochemistry of cretaceous amber and preparation of the Spanish Inventory of Places of Geological Interest (ELIG).

(2) *Curation-Restoration*

The tasks carried out by the technicians of the Museum in the area of curation include the management, classification, expansion, loan, updating and enhancement of the collections of the Museum. In general, the following activities are realised:

- Digital management of the information of the specimens of the collections (geolocation, cleaning, homogenisation and standardisation of data and refine the information of the institutional database).
- Classification and inventory of new samples (fossils, minerals and rocks) of the collections.
- Monitoring and renovation of the museography of the permanent exhibition.
- Field collection of samples of interest.
- Management of specimens donation to the Museum.
- Data extension of inventoried samples.
- Preparation of catalogues, brochures, publications, teaching sheets, etc.
- Management of sample loans to other institutions for temporary exhibitions.
- Identification, revision and catalogue of historical specimens.
- Organization and participation in mineral exchange roundtables.
- Mineral characterisation by electron microscopy, RX fluorescence and electron microprobe.
- Attention to specialists for checking and revision of specimens.
- Attention to public, teachers, private entities and the media.
- Advice on mineral nomenclature (participation in the Mineral Nomenclature Committee of the Spanish Mineralogical Society).
- Expertise and scientific-technical reports on geological heritage seized by Spanish authorities.

- Assessment on management, conservation and restoration of movable and immovable geological heritage for the National and Local Administration.

Regarding restoration, the following activities stand out:

- Preventive conservation of minerals, rocks, and fossils, avoiding inadequate exposures and the most sensitive samples.
- Monitoring of the state of conservation of the samples.
- Climate control of the Geominero Museum hall.
- Consolidations, adhesions and reintegrations, both material from the collections and that from field works.
- Cutting, mounting, polishing, and drawing of samples.
- Musealization of various sets of specimens, such as the showcase of the formation of amber or on the alterations of unstable minerals, both recently.
- Realization of molds and replicas from samples for educational workshops or weekend activities, molding and casting in the field of large format replicas (Cabañeros, Zumaia...) or to projects such as Soplao, etc., elaborate high quality replicas for holotypes or research, based on the invention patent owned by the IGME-Museo Geominero (2005-2025).
- New materials and new treatments research applied to conservation and restoration.
- Publication of the methodology and the results obtained in this kind of researching in specialized reviews, congresses, etc.
- Participation in postgraduate courses, master's degrees and collaborations with other museums and institutions.
- Consolidation and structural reinforcement of a "peel" of ash deposited during the eruption of the Cumbre Vieja volcano in La Palma, to allow its future exposure. In this peel, the complete stratigraphy of the ashes deposited from the beginning of the eruption until its end is collected.
- Study and evaluation of the possible musealization in situ of several points affected by the eruption of the volcano.

### (3) *Education-Dissemination*

The museum is visited by at about of 45,000 visitors a year. The museum organises different activities aimed at various visitors groups: guided visits, workshops, courses, conferences, etc. Museum also take part in regular events such as Science Week, the Science Fair, International Museum Day, Book Night, Researchers' Night, etc. The museum currently lacks expertise staff dedicated to these tasks.

The activities carried out are as follows:

- Visitor service (face-to-face, by telephone and online).
- Reception of scheduled visits.
- Email management.
- Supervision of maintenance and cleaning of the facilities of the museum.
- Management of the visits agenda and volunteer guides.
- Control of educational and audiovisual material.
- Development of educational and dissemination activities (outlined above).
- Production of audiovisual teaching material.
- Production of teaching material: classroom worksheets, teachers' guides, pupils booklets, etc.
- Management of social networks and website.

- Design and production of temporary exhibitions.
- Layout of catalogues and publications.
- High quality digital photography.
- Preparation of pictures, plates and graphs for scientific publications.
- Design and production of posters and brochures for the museum.

*Fardes River valley paleontological Station and Fonelas P-1 site (Lagerstätte Site, Granada).*

Currently depending on the Museum, the Fardes River Valley Paleontological Station is a field infrastructure owned by the Spanish Geological Survey (IGME-CSIC), where activities are organized around the large mammal site in Fonelas P-1 at the start of the Pleistocene. Its main function is study, research, dissemination and teaching activities, in the fields of paleontology, taphonomy, paleoecology, paleoclimatology, stratigraphy and sedimentology. The main objective is the Geoconservation of national paleontological heritage of international relevance, in a musealized space *insitu*. Fonelas P-1 is a key international Geosite of the Granada UGGp (UNESCO Global Geopark).

The most relevant activities are related to the study of Quaternary large mammals and paleontological heritage at the Guadix-Baza basin, the inventory and the conservation of natural heritage on the paleontological station (25 hectares), and the dissemination to a broad public and teaching.

Definitively opened to public in December 2016, the Fonelas P-1 paleontological Center has become a regional reference in paleontology and Earth Sciences teaching in the field, and in geological tourism. Until February 2022, the Center had carried out 110 educational activities involving 3,325 students and teachers of primary, secondary and university education. As for geo-tourism, 7,443 visitors from 29 countries have been received.

In 2007, Fonelas P-1 was listed as a Geosite (VP014; Global Geosites Project Spain; Natural Heritage and Biodiversity Law (Law 42/2007)), and in 2010, as a cultural geo-resource by the Regional Government of Andalusia (AND 303; Andalusian strategy for comprehensive management of geo-diversity). On 28 December 2010, IGME purchased the 25 ha where the site is located, thus affording it the highest level of protection. In September 2011 IGME approved funding for a new stage of research and publicity for the Fonelas P-1 site and the Fardes River Valley Palaeontological Station (Spanish acronym EPVRF) was established, with appropriate financial and technical support for diverse activities over the following years (IGME EPVRF Task Force), to develop the first stage of the scientific field work project: Fonelas P-1 Paleontological Center (CPFP-1).

The infrastructure created with a grant funding (applied for from the Granada Province Cooperation Group -Directorate General for Sustainable Rural Development-, in the category Protection and Conservation of Cultural Heritage and was co-funded by the European Regional Development Fund and the Regional Government of Andalusia), built during 2013, is the Fonelas P-1 Paleontological Center (a 1020 m<sup>2</sup> protected area, monitored and displayed). This enabled protection of the site from atmospheric and biological damage, and its paleontological heritage to be safeguarded. Systematic works then proceeded so that the fossils obtained could be analyzed *in situ*. Stratigraphic sections were conserved to enable appropriate 3D interpretation of the processes that formed the site, as well as to collect materials for research and display in a musealized space.

In 2014, IGME (EPVRF) selected, collected and funded items for display in the Paleontological Center, and the center was opened to the public by appointment. In 2016, Fonelas P-1 was listed



as a Granada Geopark LIG (GG-08), and in 2017, fieldwork staff was appointed (senior technical expert) and the Center opened to the public all year round. In 2020, Granada Geopark joined the UNESCO Global Geoparks Network.

### **And... the future?**

By Royal Decree 202/2021 of 30 March, IGME loses its competences as a Public Research Body and becomes part of CSIC. The organization changes to a dichotomical structure: scientific and technical, with research staff in a scientific Vice-Presidency and technical staff in technical Vice-Presidency. This imposition by the Ministry of Science and Innovation disarticulates and splits the Museum team: the researchers, despite their complaints and frontal opposition to this change, are forced to join a scientific department, and the rest of the museum staff, together with the Valle del Río Fardes Palaeontological Station (Fonelas, Granada) is integrated into a technical department. As a result of this situation, the Museum staff has been reduced by almost 50% (from 19 to 10) and the functions of the Geominero Museum have been limited considering that the currently most accepted definition of a museum contemplates the research as one of the required attributes. According to the ICOM Statutes, adopted by the 22nd General Assembly in Vienna, Austria, on 24 August 2007, the current museum definition is as follows: A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment.

On the other side, the Museum Public Programs have suffered significant cutbacks. These programs covered a variety of activities (workshops, trips, talks, temporary exhibitions, courses, educational kits, audio-visual resources, etc.) aiming to promote community literacy in Earth Sciences. And therefore a community who is able to know, preserve, value and enjoy its geological heritage. Some of these activities have been recognized with several awards in 2003, 2007, 2015 and, more recently, 2021. However, the Museum currently lacks the budget to develop these activities as well as the staff devoted exclusively to educational fields, so that its functions are even more limited, being reduced to preservation and restoration.

Until January 2022, the Museum had a perfectly articulated and consolidated work team. Its activities and awards in all areas (research, preservation and dissemination) gave visibility and prestige to the IGME. But since then we live times of uncertainty in which the future of the Museum seems to be at stake. We do not know if we are going to have the economic resources to carry out educational activities, nor the expert staff to design them. We have lost the support of researchers in most of our daily work. We do not know if some kind of general admission fee or activity fee will be charged in the future. But we do know that we are a public service that fulfils a social function and therefore should be regulated according to broader criteria than those merely economic.

We will continue working on the objectives that define the functioning of our Museum because these objectives were, are and will be the attributes that represent its uniqueness.

## The Geological repository of CN IGME

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### Abstract

This paper presents the meaning, content, future plan and viability of the geological repository of the IGME, which has been recently created after its incorporation to the CSIC. This area comes from a previous area called “special infrastructures, documentation and dissemination” that included the management and collection of documents and geological samples. The new geological repository area comprises, for now, two large and important collections of samples and documents: those from the exploration of the subsoil in the form of boreholes and cuttings located in the core-repository of Peñarroya (Córdoba), and the MAGNATECA, where the samples from the elaboration of the MAGNA are kept and curated. In addition, it aims to incorporate and integrate, the rest of the collections scattered in different IGME laboratories and offices. The geological repository will make available to the scientific community both samples/data of the largest institution in Earth Sciences of Spain, in the context of the Open Science international strategy.

### Introduction

Geological and scientific collections consist of physical objects that are preserved, cataloged, and managed by organizations for research and other purposes. Openly-accessible data contribute to scientific progress and international collaboration, and are a catalyst for innovation (IWGODSP report, 2016). A permanent, well-organized scientific collection clear benefits science and society for the following reasons:

- Geological samples are a testimony of earlier observations and a proof of theories already performed/published.
- Curation of geological samples, will allow verify, repeat it or apply new analytical techniques in the same sample, which will result in a save of time and money.
- They can be standards and repositories for rare or unique objects, a record of the geology or the geodiversity of a country, and can serve as a way to preserve the geological heritage, avoiding sampling critical points of geological interest.
- Finally, geological collections can be a source of ideas for education and training both for public, graduated or undergraduated students.

Scientific progress and collaboration benefit from an early and continuing commitment to the establishment, description, curation, maintenance, validation, discoverability, accessibility, and distribution of scientific data, therefore long-term scientific collections and scientific samples should be preserved to be used by a broader research community.

The CN IGME has a long and extensive tradition in the creation and maintenance of knowledge infrastructures. Throughout its history it has developed relevant scientific projects in the fields of geology, cartography, water-resources or mining, National Research Plan (I+D), ornamental rocks, biostratigraphy, etc. that have provided a large amount of data, documents and samples. In addition, it has an important legacy of donations from private companies or

individuals that have been incorporated to its patrimony. Some of these samples are spread and a new reorganization and vision is required. An adequate physical space is also necessary to create a geological repository and to house storage systems, compact cabinets, observation instruments and multipurpose working spaces.

### **Strategic and scientific objectives of the Geological Repository**

The creation of a Geological Repository by IGME-CSIC, aims to house, curate and maintain all the collections under a single unit (decentralized/in, at least, two locations) that will provide visibility, coherence and unity to the different CN IGME scientific geological collections. Therefore, it will merge and manage all CN IGME collections (except for the Museum), unifying criteria and databases, digitizing attached documentary collections and spreading their contents to the geological community at national and international level. This model is similar to the one followed by relevant institutions such as British Geological Survey, where under a common management, and placed in different locations, the samples resulting from geological research of the soil and subsoil, both on-shore and off-shore, are made available to society. The Geological Repository will be a national science facility of the CSIC, and will comprise the largest collection of geoscience samples from Spain. The location will be at Tres Cantos (Madrid) and Peñarroya (Córdoba).

As the principal benefits of the creation of the GR at CN IGME:

- It will curate and organize the samples obtained in the research projects, as well as all the scientific specific preparations (thin sections, concentrates, etc.), in order to save money and time in future research projects and analysis.
- It will make available to the scientific community both samples/data of the largest institution in Earth Sciences of Spain, in the context of the Open Science international strategy. This objective match with the European regulations on the data management plans at project initiation that considers the full data life cycle for scientific data.
- It will be designed as a place to be visited by the general public, where samples that may have been related to important scientific achievements or events (like La Palma volcanic eruption) or those that represent the geology of our country, can be seen at different scales. This fact will bring geology/science closer to society.

Because of the creation of the GR of Spain, and following the idea of the ICTs (Spain) and ESFRIS (EC), the geological-repository will be able to lead the integration of all public core repositories in Spain through the creation of a distributed network of core-repositories with full open access to samples, data and analytical facilities. It is therefore necessary to give a value to these collections, and to set a new concept for the use of geological samples that will allow a universal visualization and access based on FAIR principles, by means of standardizing, and harmonizing databases. This will be achieved by creating modern and versatile workspaces for the study and observation of the different collections (rocks, sediments, thin sections, etc.) and opening the samples from the geological record to the general audience/society.

### **Core-repository of Peñarroya-Pueblo Nuevo**

The IGME has a unique scientific infrastructure created in 1988 in the town of Peñarroya-Pueblonuevo (Córdoba), an area weighed down by the lack of investment and abandonment of mining and where thousands of meters of cores and samples from subsoil are located. The

Peñarroya core repository, the biggest and unique in its category in Spain, preserve, catalog and manage rock/sediment cores and cuttings, scientific collections of rock samples, including thin sections, foraminifera slides and drilling documentation. It contains approximately 13.075 cores that represent more than 250.000 m of continuous drilling cores and cuttings. The cores and samples were obtained through the research and exploration of geological resources (groundwater, mining, hydrocarbons, geothermal energy) and regional geology research. In addition, the core repository contains more than 250.000 geological samples. The Peñarroya core-repository also curates an extensive documentary archive (maps, cartographies, plans and other graphic documents of great historical and scientific interest) associated to underground exploration activities, exploitation of geological resources of Spain and mining. The most important collections are: The Peñarroya Metallurgical Mining Society (SMMP), the National Uranium Company S.A. (ENUSA), and the national company of mining research (ENADIMSA).



Figure 1. Main room of the Core repository of CN IGME

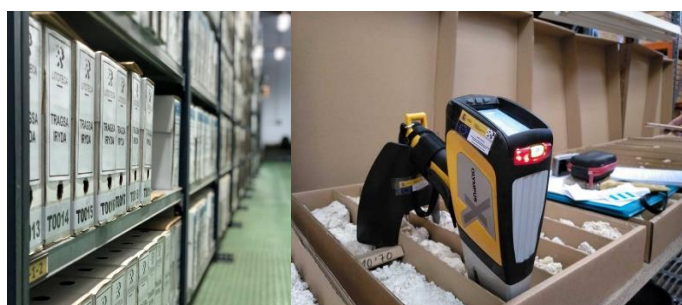


Figure 2. Left, documentary archive of the core-repository. Right: portable XRF analyzer.

The core-repository of Peñarroya is located in an area of 8.000 square meters with 5 warehouses where the core-collection are stored. It has a state of the art infrastructure for the study and sampling of cores and cuttings: a logging area, saw room, thin section cutting machines and petrographic and binocular microscopes. Advanced analytical infrastructures also



include a Color II DMT core-scanner with Digicore software, two handheld XRF analyzers for the non-destructively in situ chemical analysis. A new multisensory platform for non-destructive analysis for core and discrete samples (Boxscan by Geotek) is also available. There is also a large cool room (+ 4 °C) for the preservation of sediment cores. In order to give an international scope to the borehole repository, a series of improvements can be undertaken to allow the correct storage and curation of different types of boreholes and the easy access (presencial/virtual) in the aforementioned infrastructure.

### **MAGNATECA**

IGME has a unique collection of samples coming from the national cartography project at a scale of 1:50,000 (MAGNA). The Magnateca is made up of the collection of rock, sediment and fossil samples that were collected and studied for the preparation of the Geological Map of Spain at a scale of 1:50,000 (MAGNA), between 1971 and 2003. It has more than 260,000 petrological and paleontological samples from all over Spain, which makes it the most complete and representative archive of the geology of Spain. This collection is available for consultation and study by the scientific community, companies and the scientific community. The documentary information concerning this collection is available at the following address: <https://info.igme.es/cartografiadigital/geologica/Magna50.aspx> and the physical samples are curated in compact cabinets at the IGME headquarters in Tres Cantos (Madrid).

### **Other Available Facilities/scientific infrastructures of the geological repository**

The rest of the collections of CN IGME are scattered in several locations both in Madrid and Tres Cantos and also in the regional offices and laboratories. Therefore, a new inventory of sample collections is required.

### **Working Plan - Actions**

The necessary actions for the creation of a new scientific infrastructure would be:

- Compilation and inventory of all sample collections scattered in different locations.
- Review of the content of the databases and samples.
- Harmonization of the databases, with the creation of a new database, after observations of international metadata and standards.
- Fixing and setting the spaces necessary to house the revised collections.
- Organizing/classification of all the collections in the chosen spaces
- Creation of a new web site in order to show the Geological Repository and how to access to the different collections.
- Dissemination and outreach activities

In all cases, geological collections will offer services for research and study, and a center for scientists, companies, students and administrations. GR will provide help and technical advice for the study and sampling of these collections. The GR also aims to be a reference center for the dissemination, education and outreach activities accessible to research groups and institutions, in the field of geology, drilling exploration, geological resources, through the development of scientific outreach projects in these fields.



### **Impact on internationalization of the center**

As a general rule, science is increasingly collaborative and multi-disciplinary, and openly accessible scientific data can be powerful catalysts for international collaboration and the advancement of scientific research and innovation.

The core-repository is already an open-science infrastructure and serve as a research and study place for scientists, companies, students and administrations. In the near future (2022-2025), the repository plans to join other research infrastructures, RIs, both in the management and access to data, as well as in the shared-use of collections and facilities. Regarding the first point, the repository is now part of a Horizon European GEOINQUIRE project, (HORIZON-INFRA-2021-SERV-01-07), which will integrate core-data into a database available online under the FAIR principles for the international community. These data will be integrated into the main existing data platforms in Europe (EPOS and others), and therefore data will be available in open access. Following this strategy, the GR will be at the same level as other similar infrastructures at European/ world level, making easier to become part of international infrastructure/facilities networks in the frame of ESFRI.

The possibility of having an open and reference-scientific repository in Spain, including facilities, places the future NGR, as a possible candidate to be a reference repository for the international drilling programs as ICDP-IODP. Scientist of IGME are currently participating in international projects where once the cores are retrieved, may be deposited in the Córdoba core-repository. This type of international collaboration exponentially increases scientific results of the center.

### **Accessibility**

Access infrastructures to scientific collections should be set up under the principles of full open access free of charge. Some of the data will be available online without payment, and others will be obtained through on-site visits to the facilities while respecting the rules of use of the different collections. Modern analytical infrastructures will make it possible in the future to progressively scan the collections of the repository, so that they can be viewed online, prior to the visits. In the case of the MAGNATECA, much of this data is already now fully accessible online. A deep-review of scientific collections and the development of the corresponding databases will result in greater visibility of samples and scientific data to the rest of the scientific community.

## Two new techniques for non-destructive core analysis: Hyperspectral reflectance spectrometer and modular core scanning platform

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### Abstract

The IGME has recently acquired modern analytical infrastructures co-funded by the European Union NextGenerationEU for the Recovery and Resilience Mechanism (Project code C17.I7). These infrastructures allow obtaining a multitude of data at high spatial resolution without destroying the sample in a fast and relatively cheap way. We describe here the hyperspectral reflectance spectrometer and the multisensor platform located in Tres Cantos and Peñarroya core-repository respectively.

The hyperspectral infrared reflectance spectrometer allows the identification, quantification and mineral representation on the surface of geological materials by means of two cameras, SWIR-640 and VNIR-3000N by HySpex and the corresponding software. The novelty of this equipment is that the images are taken on the surface of sediment, rock or soil cores in sections up to 150 cm long, where a scanning stage is set. The lab rack includes a camera adjustment platform, to facilitate camera focus adjustment when using different close-up lenses. This analysis will provide important information in the study of core-samples, both for the prospecting of geological resources and other investigations as paleoclimate or environmental issues. This instrument has the advantage over other classical methods of determining mineralogical composition, being fast, non-destructive and almost continuous. It is the first equipment that will be able to perform hyperspectral analysis in CSIC on geological cores.

The Box Scan platform by Geotek, is a modular core scanning platform that allows users to choose the most fit-for-purpose multi-sensor suite for their project. It is composed of several sensors that will allow obtaining simultaneously along a core, chemical, mineralogical and structural composition, in a fast and non-destructive way in cores, soils or other geological samples. Box Scan avoids acquiring laborious handheld logging measurements using pXRF, NIR, cameras by delivering automated and simultaneous acquisition of geotechnical and geochemical parameters from one easy to use, core box scanning system. Only one technician is needed to operate BoxScan at lab, and up to 6 different datasets in the measurement can be obtained. The device is compact, field deployable and reinforced. It allows systematic work in the laboratory and is mainly oriented to geological repositories where the volume of samples to be analyzed is high. As the hyperspectral spectrometer, it is the first equipment in Spain that allows direct analysis in core boxes, either at laboratory, drilling points, mining, etc.

## Classification and review of boreholes and documentation of the Andalusian regional community by the CN IGME core-repository

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### Abstract

The recovering of exploration and research mining activity in Andalusia in the last years, has implied an increment in the telematic and personal requests from researchers, mining operators, technical offices, consultancies or free professionals that require drilling information of a specific area of Andalusia. Companies such as Pan Global Resources, Valoriza Minería, CRS Ingeniería, Minera Escacena, Cobre Las Cruces S.A.U., Geotrex Gestión Minera for Atalaya Mining, among others, visit the core repository to use both documentation and samples from drill holes for their projects and research. In order to attend these and other requests, the core-repository staff continues to review and enhance the collections present in the infrastructure.

This work presents the activity carried out in recent years at the IGME-CSIC core-repository related to the Autonomous Community of Andalusia. In the first place, the research project: observatory for the geo-economic valuation of the Iberian Pyrite Belt GEO\_FPI, funded by the INTERREG V-A Spain - Portugal (POCTEP) 2014-2020 program, created a public and updatable consultation network that concentrates the existing information of the Iberian pyrite belt (PI). After this important project, the core-repository has carried out an intense work within the framework of the Agreement with the Junta de Andalucía, where, among other aspects, it has been working on the updating and dissemination of the documentary and core collections related to Andalusia region.

This work consisted, on the one hand, in the geo-location of 825 cores present at the warehouses, using GIS software (Geographic Information Systems) based on the technical documentation where information related to their spatial location contained in old maps or approximate location was shown. On the other hand, the documentation of 1800 boreholes has been catalogued and 433 projects and reports of the extinct national company ADARO and documentation produced by TRAGSA based on their intense geological survey carried out in the community of Andalusia have been digitalized and archived. A total of 261 continuous cores/cuttings, making a total of 61,009 meters of core stored in the warehouse, have been reviewed and catalogued, becoming now part of the definitive collection that in a standardized way is stored and kept in the core repository, available for research and study.

## The General Laboratories of the Geological and Mining Institute of Spain, CSIC / Technical Vice-Directorate

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### Abstract

The General Laboratories of the Geological and Mining Institute of Spain, CSIC, is one of the CSIC laboratory centers that make up the Materials Science and Technology Area of the Higher Council for Scientific Research (CSIC). Its activity is based in giving support to research studies related to Earth Sciences materials as well as resources and environment.

The laboratory is assigned to the Technical Vice-Directorate of the IGME, CSIC and it is organized in four Laboratories (Water, Mineralurgy, Geochemistry and Technological Tests and Natural Stone) and an Applied Microscopy/Artificial Vision Tests unit.

This document summarizes the main lines of activity developed and the equipment available.

### The IGME General Laboratories

The IGME General Laboratories are a unit that provides specialized technical services. It provides experimental technical data in support of the research projects of the Organism itself and other Organisms and Entities, both public and private, testing a wide range of samples related to earth sciences, such as rocks, drilling cores, soils, sediments, water and leachate. The capacity to carry out analysis and testing covers the entire process, from the initial preparations of the different materials to their analysis or testing by different high precision and accuracy techniques required to identify and quantify basic elements in the evaluation of resources.

Other services provided include the management of laboratory equipment and instruments, technical advice on instruments, equipment and tested materials, support for the training of laboratory technical personnel through the provision of practices and waste management in accordance with current regulations.

Its headquarters are placed in Tres Cantos (Madrid). According to the organization chart, it is divided into four laboratories (Water, Geochemistry, Mineralurgy, and Technological Tests and Natural Stone) and an Applied Microscopy/Artificial Vision Unit, which are independent but complementary to each other and act in a coordinated manner.

The Laboratories have established a Quality Management System based on the requirements of the UNE-EN ISO/IEC 17025 Standard, managed through an application (SILAB) developed by the Area of Geoscientific Information Systems and Institutional Databases of the IGME itself, which promotes the organization and management of work in a computerized way. IGME General Laboratories are part of the Network of Laboratories of the Community of Madrid (RedLab 192) and have an ENAC accreditation to carry out physicochemical analysis of natural mineral waters, spring waters, mineral-medicinal waters, mineral-industrial and thermal waters.

To guarantee the quality of the analysis and test results, the General Laboratories participate in interlaboratory intercomparison tests, such as the AQUACHECK program on water samples, organized by LGC Standards, or those organized by the International Association of Geoanalysts (IAG) on solid samples.

The laboratories have provided, since their creation, infrastructural support to the activity carried out by the IGME in geological, hydrogeological, geotechnical and mining research studies and investigations. The experience acquired and the knowledge and handling of the different available technical equipment gives them a particular degree of distinction in carrying out analysis and testing materials related to Earth Sciences.

### Water Analysis Laboratory

Natural waters, both surface and groundwater, have certain characteristics. Its progressive contamination, due, among other things, to anthropogenic factors such as leaks or discharges, makes it necessary to establish an increasingly demanding level of control systems. Water quality control includes the establishment of physical control parameters (organoleptic characteristics, color, smell, suspended elements, temperature, conductivity, radioactivity), chemical (pH, organic matter, nitrogen and derived compounds, COD, phosphates, hydrocarbons, chlorine and chlorides, fluorides, sulfates and sulfides, phenols, cyanides, metals, pesticides, etc.) and dissolved gases.

In the Water Analysis Laboratory, the analysis are carried out in accordance with:

- RD 1798/2010, of December 30, which regulates the exploitation and commercialization of natural mineral waters and bottled spring waters for human consumption, because of the powers that the IGME has by the Mining Law regarding its statement;

- RD 140/2003, which establishes the health criteria for the quality of water for human consumption.

It has the necessary equipment and techniques to determine the parameters required by law. The most used techniques are gravimetric, volumetric, absorption and emission spectroscopy; electrometry techniques, low background and liquid scintillation counters, chromatographic techniques and combustion and infrared detection.

The Water Laboratory has been accredited by ENAC since 1994 according to the UNE-EN ISO/IEC 17025 standard for carrying out physicochemical tests on inland water and water for human consumption in the environmental sector, with accreditation No. 62/LE-169. Table 1 shows the main equipment available in the Water laboratory.

Table 1 Main equipment of the Water Laboratory

LABORATORY EQUIPMENT	COMMERCIAL BRAND	TEST
Atomic Absorption Spectrophotometer (AAS)	AGILENT TECHNOLOGIES	Determination of major and trace elements
Atomic Absorption by Graphite Chamber (GF-AAS)	SpectraAA 220 FS (VARIAN) +Agilent 240 SpectraAA	Metal determination
Organic Carbon Analyzer (TOC)	Shimadzu	Total Organic Carbon, Total Nitrogen
Molecular absorption in continuous flow	ALLIANCE-FUTURA	Anions, cations, cyanides and phenols
liquid scintillation counter	QUANTULUS TM	Tritium
Low background $\alpha/\beta$ proportional counter	BERTHOLD LB750L	Total alpha and beta activity
Gas Chromatograph GC/MS	VARIAN 4000	Volatile Organic Compounds (VOC)



LABORATORY EQUIPMENT	COMMERCIAL BRAND	TEST
Gas-Mass Chromatograph and triple quadrupole mass detector	Agilent 7000C	Pesticides and polycyclic aromatic hydrocarbons
Ion Chromatograph	881 Compact IC Pro Metrohm	Anions (Bromides, bromates, nitrites, nitrates, sulfates, fluorides, chlorides and phosphates)
UV/Visible Spectrophotometer	HANNA IRIS HI801-02	Color, turbidity, detergents

### Mineralurgy Laboratory

The mineralurgy laboratory performs a dual function. On the one hand, it is responsible for preparing the solid samples, by crushing and grinding, for their subsequent chemical analysis or for concentration processes.

On the other hand, in this laboratory mineral processing tests are carried out to support the investigation of new mineral treatment processes, both at laboratory and pilot plant scale, as well as the treatment of effluents for subsequent discharge and/or use. Basically, separation and concentration test, ore leaching, designed to obtain concentrates and/or marketable products from the raw material.

Sorting and concentration techniques are applied, using specific differences in physical or chemical properties between the valuable mineral and tailings. The tests are based on gravimetric methods (particle size classification, dense liquids, shaking tables), physicochemical methods (flotation), and magnetic, electrical and hydrometallurgical methods (leaching, solvent extraction). The main equipment of the Mineralurgy laboratory is showed in table 2.

Table 2 Main equipment of the Mineralurgy laboratory:

LABORATORY EQUIPMENT	COMMERCIAL BRAND	TEST
Jaw and mixed crushers	Humboldt-Wedag	Primary crushing by impact and crushing of the material
Roll mill	Humboldt-Wedag	
Tilting ball mill	--	
Ball mill (porcelain and steel)	Molyba	
Micromills (steel, widia and agate)	Siebtechnik	Grind to analysis size (<0.64 microns)
Elutriator	CYCLOSIZER	Wet sorting of <0.74 micron fraction with fraction collection.
Particle size analyzer	SEDIGRAPH III Plus	Particle size distribution
Helium pycnometer	ACCUPYC 1330	Determination of true and bulk density
Shaking tables	Wilfley	Gravimetric wet separation
UV/Visible Spectrophotometer	PERKIN ELMER	Color, turbidity, detergents
Magnetic separator	FRANTZ ISODYNAMIC	High and low intensity magnetic separation
High voltage electrostatic separator	CARPCO	Separation by electrical conductivity of the material
Flotation cells	DENVER	Concentration of ores by flotation
Pressure reactor	Autoclave Engineers Bolted Closure	High temperature and pressure leaching

### Geochemistry Laboratory

In this laboratory, analysis of major, trace and ultra-trace elements are carried out in solid, geological and non-geological materials, using spectroscopic techniques such as XRF, AAS, ICP-AES and ICP-MS. It assists the Water Laboratory in the determination of trace elements in natural waters. The laboratory also determines the chemical parameters of the soil and analyzes for the control of wastewater and mining tailings. It also has a unit for the characterization of mineral species by XRD, another for dating by the U-Pb method using isotopic dilution (ID) and TIMS mass spectrometry. It has a positive pressure clean room as a controlled environment work area for sample preparation with a water purification system and a sub-boiling distiller to obtain highly pure acids.

This laboratory regularly participates in intercomparison exercises of the International Association of Geoanalysts (IAG). Thanks to the good results obtained, it has been selected by the Central Geological Laboratory of Mongolia to participate in the Certification of Certified Reference Materials (CMR). The main equipment of the Geochemistry laboratory is shown in table 3.

Table 3 Main equipment of the Geochemistry laboratory

LABORATORY EQUIPMENT	COMMERCIAL BRAND	TEST
Thermoionization Mass Spectrometer (TIMS)	Thermo Triton	Geochronology (U-Th-Pb Method) and isotope analysis
X-Ray Diffractometer (XRD)	Panalytical Xpert pro MPD	Mineral characterization
Ray Fluorescence Spectrometer (XRF)	Panalytical Zetium	Determination of major and trace elements
Mass Spectrometer with Plasma source (ICP-MS)	Agilent 7500 ce	Determination of trace elements
ICP-AES Spectrometer	Varian Vista-MPX	Determination of major and trace elements
Atomic Absorption Spectrophotometer (AAS)	Varian SpectrAA 220 FS	Determination of major and trace elements
Atomic Absorption by Graphite Chamber (AAS-GF)	SpectraAA 220 FS (VARIAN) +Agilent 240 SpectrAA	Metal determination
Elemental analyzer	Leco CS-800	Determination of C and S

### Technological Tests and Natural Stone Laboratory

In this laboratory, geotechnical tests are carried out to characterize soils and rocks and it has a unit specialized in the characterization of non-destructive analysis of drilling cores.

Petrographic, hydric, mechanical, alteration and finished product characterization tests are carried out on natural stone.

In soils, geotechnical tests are carried out for its identification, for evaluation of its resistance and deformability characteristics, and its aggressiveness, with application to the calculation of foundations and retaining structures for buildings.

The Core testing Unit allows to obtain, in a quickly and non-destructively way, high-resolution geophysical and geochemical data in sediment and rock drilling cores, within the geological investigation. The facies classification obtained with these techniques allows better planning for the selection of areas of interest that require destructive analysis.

It has multiparametric geophysical testing techniques (determination of bulk density, porosity, magnetic susceptibility, and p-wave propagation velocity), semi-quantitative and continuous analysis of major and trace elements by XRF, and acquisition of linear mode images through the use of high quality and resolution scanning. The main equipment of the Technological Test and Natural Stone laboratory is shown in table 4.

Table 4 Main equipment of the Technological Test and Natural Stone laboratory

LABORATORY EQUIPMENT	COMMERCIAL BRAND	TEST
MSCL Geotek multiparameter tester	GEOTEK MD-81	Continuous geophysical testification of drill cores (sediments and rocks). Non destructive.
X-ray fluorescence scanner (MSCL-XRF)	GEOTEK XRF Core Scanner	Semi-quantitative and continuous determination of major and trace elements in drilling cores.
GEOTEK Spectrophotometer	CM 700D KONICA-MINOLTA	Measurement of the color and chromatic coordinates of the materials, in the field or in cores (coupled in XRF MSCL Geotek)
Geoscan IV High Resolution Scanner	GEOTEK	Capture of high resolution images and rgb coordinates in rock or sediment cores, whole or sectioned.
Adsorption isotherm analyzer	ASAP 2020 Micromeritics	Determination of the specific surface (BET area), volume and pore size distribution of solid material.
Mercury intrusion porosimetry	Autopore IV 9500	Calculation of the area, distribution of pore sizes, percentage of porosity of the material and real and apparent densities.
Presses	Multiple brands	Flexural and compressive strength for natural stone
Climatic chambers (frost, thermal shock, saline mist)	Dycometal, LCE	Simulation of accelerated aging processes in natural stone

#### Laboratory of Applied Microscopy/Artificial Vision/Autoclave Tests

The activity of this Laboratory is focused on basic and applied research for the numerical characterization and interpretation of petrographic characteristics (mineralogy, porous system, texture, anisotropy, etc.) of rocks and mineral ores. Rocks and mineral ores obtained in geological-geophysical prospecting for natural resources (oil-natural gas), rock masses, radioactive waste repositories and in advanced studies of materials. Also in the identification of geological formations that allow safe storage of CO<sub>2</sub>, the search for unconventional energy deposits and the prospecting of new sources of heavy metals.

It brings together in the same group all the services, from the preparation of thin sections and polished specimens, as well as the equipment for their study and description: scanning electron microscope, digital image analysis system, petrographic microscope, high-resolution scanner for reflected light, and binocular loupe among others. The main equipment of the Applied Microscopy/Artificial Vision/Autoclave Tests laboratory is shown in table 5.

Table 5 Main equipment of the Applied Microscopy/Artificial Vision/Autoclave Tests laboratory

LABORATORY EQUIPMENT	COMMERCIAL BRAND	TEST
Variable pressure Scanning Electron Microscope (SEM)	JEOL JSM -6010 LA PLUS	High-resolution images of the surface of a sample using electron-matter interactions.
Carbon coater	Cressington 108carbon/A	Sample preparation for SEM
Stereomicroscope	Nikon SMZ-745T	Visual characterization
Hyperbaric reactor	HEL. 6 litros: P. max 120 bar. T. Max 100 grados	Characterization of geological stores of CO <sub>2</sub> Evolution of the porous system of rocks exposed to SC CO <sub>2</sub>

The infrastructure of the laboratories has recently been increased with the incorporation of new equipment purchased with European funds, within the framework of the EU's Recovery, Transformation and Resilience Plan. They are part of the investment made to face the challenges related to the environment, climate change and renewable energy. This technical equipment will contribute to the development of an exclusive infrastructure in the field of Earth Sciences. They are the following:

- For the Water laboratory:
  - A total organic carbon analyzer (TOC), a combustion catalytic oxidation with a non-dispersive infrared detection (NDIR) method. It allows to determine water quality by measuring all carbon forms: TC (Total Carbon); IC (Inorganic Carbon); TOC (Total organic carbon by difference of TC and IC); NPOC (non purgeable organic carbon).
- For the Geochemistry laboratory:
  - A laser ablation system and an ICP-MS inductively coupled plasma mass spectrometry unit for the characterization and spatial distribution of trace elements and mineral deposits and for supporting dating in geochronological studies, in combination with precision dating by ID-TIMS, carried out in the geochronology laboratory of the IGME, CSIC.
  - An inductively coupled plasma atomic emission spectroscopy (ICP-AES) spectrometer for chemical characterization (major and trace elements) in water and solid samples. When elements cannot be determined directly by ICP-MS based on their content, the ICP-AES values are used.
  - An atomic absorption spectrophotometer for the chemical characterization of materials with a high content of total dissolved solids, samples dissolved in organic medium, acid mine drainage, determinations of exchange cations from extractions with ammonium acetate or determinations of polluting elements (mercury, arsenic).
  - An elemental analyzer of carbon, nitrogen and sulfur, which allows obtaining the C/N ratio of great interest in paleoclimatic or paleoceanographic investigations, as well as obtaining information on the sources of sedimentary organic matter and information on ecology, climate and oceanic circulation.
  - A lyophilizer, for continuous rocks and sediments cores samples preparation in a way to facilitate their handling and to increase the performance of subsequent analyses.
- For the core testing unit, two non-destructive techniques in analysis of test cores:

- An X-Ray Computerized Axial Tomograph, to obtain and analyze the internal image of soil, sediment and rock cores, capable of revealing their two-dimensional (2D) and three-dimensional (3D) internal structure through computerized images. Its operation is based on a fast, non-destructive and high-resolution X-ray transmission system, which collects images in a digital system. The advantage of this equipment is that it is designed for loose or fractured cores that cannot be rotated. The source and detector rotate around the core and the three-dimensional structures of the samples are recorded, whatever their state. It has CT reconstruction software that allows multiple sequential volumes to be joined to form a complete image.

- An hyperspectral camera, for the generation of continuous data on the surface of samples, cores or drilling debris, which will allow the identification, quantification and mapping of specific minerals, their chemical composition, alteration zones or the presence of hydrocarbons and contaminants;

For the Applied Microscopy and Artificial Vision laboratory:

- An Automated precision cutting and roughing equipment, to optimize the process of preparing thin sections and polished specimens.

- A vacuum impregnation unit. By embedding geological materials in resin using a vacuum, the process of filling pores and fractures is optimized, facilitating their subsequent study under a microscope.

- An adhesion system for thin sections, which allows continuous pressure to be applied on the sample, optimizing the process of gluing the sample blocks to the slides.

### Laboratories activity

In the last five years, 17.903 samples have been received and processed at the laboratories, 7.866 water samples and 10.037 solid samples and drilling cores. In turn, each one of these samples generated multiple subsamples for subsequent preparation, analysis and test in the different laboratories.

These samples managed, correspond to samples sent by other OPIs or external applicants, samples to research projects, agreements or infrastructural actions of the IGME, CSIC.

### Technical services catalog

Until their affiliation to the CSIC in March of 2021, the Laboratories had public prices, regulated by the Resolution of May 26, 2009 (BOE nº 144, of June 15, 2009). These prices are actually in the process of being reviewed in order to be included in the CSIC's catalog of technical services. This process is expected to be completed before the end of 2022.



## Geological Information System Division

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### Abstract

This paper aims to summarise the activities carried out in the Geological Information Systems Division. The activity of the Division focuses on the application of information technologies for the development of systems related to Earth Sciences. Its main objective is the design and implementation of systems that help researchers, technicians, companies, students and society, in general, to reuse available geoscientific information. This activity encompasses the modelling, capture, management and dissemination of this information, for which the Division builds maps, databases, repositories, applications, web sites and services and metadata, using the most appropriate available technology, both open source and commercial tools. Among the technologies used are Database Management Systems, GIS and ETL applications, Integrated Development Environments (IDEs) and Open Access, metadata and source code repositories. The area participates in funded projects with the aim of obtaining resources to enable the technological systems to be updated, as well as to advance in the knowledge of the continuous evolution of the technology necessary for its activities. It is currently actively participating in the development of the technological platform to build the future European Geological Survey

## IGME's Information Systems contribution to the European Geological Data Infrastructure (EGDI)

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### Abstract

The Geological Survey of Spain (IGME) is a founding member of EuroGeoSurveys (EGS). This non-governmental organisation brings together 38 National and regional Geological Organizations (NGOs), whose main objective is to provide the European Commission (EC) with Earth science knowledge to enable decision-making on environmental and energy policies. One of the central pillars of the EGS strategy is to provide harmonised data through the European Data Infrastructure (EGDI) to facilitate such decision-making.

In most EC-funded projects, accessing FAIR data plays a key role. Unfortunately, projects are limited in time and number of partners, resulting in poor pan-European coverage and harmonisation. In 2008 the OneGeology Europe project marked a first milestone with the participation of 20 NGOs and the implementation of standardised and harmonised geological web services data infrastructure. The ASIG (IGME's Geological Information Systems Division) not only harmonised and created the corresponding map and services for Spain, but it was also actively involved in the definition of the data model, incorporated into the mandatory INSPIRE geological data specification. In 2010, the EC focused its efforts on having an overview of raw material resources in Europe. Following OneGeology success, 27 NGOs started working through the Minerals4EU project to construct a harmonised INSPIRE-compliant raw materials database. ASIG is responsible for the WFS service that feeds this database with the most updated information from BDMIN. In 2016, the EGS Spatial Information Expert Group (SIEG) mobilised to launch the first version of EGDI, where the ASIG acted as a consultant for new functionalities. In 2018, in the framework GeoERA Information Platform Project (GIP-P), the ASIG was in charge of developing the EGDI search engine that facilitates users' discovery and access to more than 500 layers of information and more than 1000 documents safeguarded by EGDI. The division, in parallel, participated in the functional requirements analysis and the multilingual thesaurus development. In 2020, IGME became a partner of the EGDI consortium, where ASIG helps to support the essential operation and maintenance of EGDI together with six NGOs.

In the Geological Services for EU (GSEU) project 2022-2027, the ASIG takes up the challenge jointly with 50 partners to evolve EGDI from data infrastructure to a knowledge infrastructure connected to Destination Earth, EOSC and EPOS, among other infrastructures.

## EGDI Data Search. A web application to support geoscientific information discovery and access in Europe: Sistemas de Información Geológica

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### Abstract

There is a considerable amount of geoscientific information in Europe that is useful to tackle some of the problems modern society is facing, but also helping companies to provide derived products and services and, therefore, to stimulate the economy. This geoscientific information comes from European cross-border projects, but also includes maps and inventories that the geological surveys of the different countries or regions produce.

Most search engines use metadata to search for datasets and have difficulty finding the relevant datasets. On the one hand, sometimes the search text typed by the user is not found in the metadata. However, sometimes the text is present in the values from data-attributes and therefore the dataset should be in the results list. On the other hand, the search text often does not match the text that appears in the metadata or the data, either because another term is used or it is in another language.

IGME has developed a new web application that allows a very powerful data discovery and access and is now one of the main components of the European Geological Data Infrastructure (EGDI). This application, by searching both in data and metadata, using text and spatial delimitation, allows to obtain relevant results that could otherwise have been missed. One of the most outstanding features of the application is that it adds to the search, using a multilingual thesaurus, translations and terms with similar meanings to those typed by the user. In addition, full-text searches are performed, which allows the data discovery even if the search text is a variation of the text that appears in the metadata or the data. With all of the above, the system allows users to find datasets that do not contain exactly the terms they typed.

The system tries to determine the “best” results by calculating a rank calculated using many factors, including things such as the text matching with data or metadata, relevance of datasets, scale, etc. For each of the results listed, the system offers all the online accesses to the dataset: existing web applications to query, display and analyse the dataset; URLs to access the dataset in certain formats (e.g. CSV, SHP); services to display or query the dataset (e.g. WMS, WFS); metadata details (e.g. ISO 19115). In addition, it allows data to be displayed which facilitates its evaluation as sometimes metadata is not enough to know if a dataset is useful to a given need. Downloading selected records, on the basis of the selection criteria, from a dataset in different formats facilitates its re-use for a given need.

## SILAB IGME's laboratory information system and new applications for IGME's services management: Geoscientific Information Systems and Institutional Databases

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### Abstract

SILAB stands for "Laboratory Information System". It complies with the quality policy established in the laboratories. This policy establishes and maintains a high degree of quality in all testing activities performed, in order to ensure the reliability and objectivity of the results and services provided to its customers, while maintaining the confidentiality and security of the information obtained in the development of its activities. SILAB manages all laboratory workflows, from sample reception to quotation and invoicing. SILAB manages all samples, analyses and results. SILAB was conceived as a laboratory information management system to manage all the content and context of the IGME general laboratories. Despite the complexity of the quality procedures of IGME laboratories, SILAB was created as a web interface capable of managing workflows efficiently and completely.

SILAB is a continuously evolving project, new features are often added. The laboratory staff regularly feeds the development of new functionalities that make the application undergo a continuous maintenance. The main features of the application are: requests and quotations, sample reception, job description and execution, report generation and invoicing.

The recent merger of the IGME into the CSIC has led to the restructuring and offering of the new IGME service catalog. These services will be offered both internally (to CSIC researchers and institutes) and externally (to citizens and companies in general). New web applications are being created to manage the new catalog of services both internally and to society in general. These applications will allow the acquisition of these services and at the same time will be connected in a synchronized way with other applications such as SILAB or GESTEC (system that allows the technical and economic management of projects) that provide an organizational and economic management of these services.

## GESTEC, evolution and integration with IGAE tools: Geoscientific Information Systems and Institutional Databases

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### Abstract

GESTEC is a system that allows the technical and economic management of projects, as well as the budgetary management of the different departments of the organization and the institution. It is currently implemented in the national centers IGME-CSIC and INIA-CSIC. In GESTEC, users can request any type of project currently being developed at the National Center. The idea is to facilitate the task to all the personnel and centralize the basic information in a single place accessible to all the interested parties, as well as to the responsible and control units of the National Center. Avoiding redundant tasks of entering information in different systems permits to generate synergies, streamlining bureaucratic processes and minimizing errors that might happen in such data rewriting.

GESTEC allows the detailed cost control of a project. At the budgetary level of the organization, it facilitates the work of economic control to the higher management of the institution by escalating the information from the projects to the cost centers, then to the departments and then to the management of the organization itself.

The origin of GESTEC dates back to 2011 with the project and secondment modules. Progressively, different modules have been integrated which have allowed the management of expenditure files, project modifications, staff dedications, beginning proposals, agreements, documentation, queries and administration. The system development team is made up of a group of people who belong entirely to the IGME-CSIC National Center.

Currently, work is being carried out to integrate it with the tools developed by the IGAE (*Intervención General de la Administración del Estado*), such as CANOA and SOROLLA2, in order to introduce the information in a single system. The SOROLLA2 system is aimed at facilitating the economic-budgetary management carried out in the expenditure management centers of the General State Administration, its Autonomous Bodies and other public entities. The CANOA system is intended to implement an analytical accounting system for the State Administration and other public entities.

In 2016, GESTEC was recognized with the 'Second place award for Innovation in Management' of the Awards for Quality and Innovation in Public Management managed by AEVAL.



## IGME's UAVs in La Palma volcano: STA (IGME's Aerial Works Service)

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### Introduction

On 19 September 2021, started the eruption of the volcano in Cumbre Vieja on the island of La Palma, that lasted 3 months. The emergency response associated with the eruption has had an unprecedented deployment of aerial means (UAVs), among which the STA (IGME's Aerial Works Service) has stood out with its scientists - pilots and specialized aircrafts, as well as ground and cabinet personnel who have provided coverage to the STA at all times.

This eruption was the eighth in La Palma and the longest (85 days) since there are historical records. The eruption destroyed 2,988 buildings of all types and forced the evacuation of more than 7,000 people.



*Figure 1. Mavic 2 Enterprise Dual flying in formation on the way to the upper emission centers to verify the state of the eruption, from the area of Los Llanos del Jable viewpoint NE to SW perspectivefoto. Photo: Carlos Camuñas.*

The eruptive column had paralyzed air traffic for many days, due to the emission of pyroclasts, ashes and gases, as well as its height, up to 8500 meters. Thanks to the prevailing easterly wind (alíseo) in the area, during most of the days, the column was swept to the southwest (open sea), except when these prevailing wind conditions ceased. At these times, gas warnings were generated, which lasted several days, due to the poor quality of the air for breathing. In the meantime, ash continued to fall, covering absolutely everything.

Due to the accumulation of material coming out of the emission centers, a volcanic edifice has been created that is more than 200 meters high on the ground. It is located at a height above sea level of 1121 m, with dimensions of 1000 m east-west and 500 m north-south.

## Materials and methods

The STA (IGME's Aerial Work Service) is currently composed of 8 pilots, with different academic backgrounds, most of them geologists. It also has 8 drones at present, (7 multirotors + one fixed wing) and 3 more that were out of service during the eruption. These RPAs are equipped with different types of sensors: RGB, Thermal, Multispectral, etc.



*Figure 2. This image is taken from Montaña Cogote, from the southwest looking northeast, you can see the whole volcanic edifice and the lava flows that devastated El Paso, Los Llanos and Tazacorte. Photo: Ana María Cabrera.*

Among the works that the STA has been developing and making available to the IGME are:

- Rectified orthomosaics of aerial images, which are valid as a map for taking measurements and calculating areas.
- Digital terrain models in 3D, for dimension calculations, volumes, etc.
- 3D models of tesserae with real high resolution texturing. And documentary videos of them.
- Detailed aerial images, both zenithal and oblique.
- Aerial videos for documentation of different types of geological processes.
- Point cloud generation from photogrammetry. Operations with point clouds obtained on different dates, in which the temporal differences between them due to terrain modifications can be seen.
- R+D+i such as water sampling in dangerous and/or difficult to access places such as mining lakes with high concentration of harmful materials.

The STA has been in the field, unconditionally supported by the 112 GES of the Canary Islands, from days before the eruption, until several weeks after its end, providing an extra value based on the enormous previous experience in complex flights in geological emergency situations and that most of the pilots are geologists and have been able to use the drones from a scientific point of view, providing a specialized vision necessary and different from what could be seen in the media. Detailed photography, thermal imaging, photogrammetry and 3D modeling, scientific analysis of eruptive mechanisms, aerial videos and a huge dissemination of information

in national media and social networks and especially the advice, in real time, to PEVOLCA (Plan de Emergencias Volcánicas de Canarias) as emergency managers, for decision making.

The STA continues to develop field and cabinet work essential for the planning of the reconstruction after the eruption, such as the cooling maps of lava flows. The IGME has been recognized for all this work with the silver medal for civil merit with blue badge.

## Results

The roles of the STA in La Palma have been to SUPPORT EMERGENCY MANAGERS, TO RESEARCH IN ERUPTIVE MECHANISMS AND TO GIVE VISIBILITY TO IGME through the services offered and the data generated.

### EMERGENCY: "the eyes of the responders":

- We can see the importance of high resolution thermal cameras, since the information provided by the RGB sensors, in some cases was not enough, for example, the differences between an emission of ash and gases versus an emission of lava and incandescent pyroclasts are clearly seen, not being easy to differentiate with an RGB sensor.
- We have been able to see and document in detail eruptive processes such as explosions of gas pockets within the lava lakes that formed inside some of the craters.
- We have taken general shots of the flow of the lava flows along the slope of the volcanic edifice, and we have also taken particular shots of the places where the lava channels flow when applying the thermal camera.
- We documented outflows of lava from subway lava tubes and new entrances to the subway lava tube systems.
- We recorded lava channel overflows when the lava material input increased sharply, in many cases rupturing part of the volcanic edifice, which was carried away by the lava rivers in the form of house-sized "erratic blocks" floating in the surface channels.
- Approaches of the drones to the eruptive centers documenting eruptive processes and enduring very complicated flight conditions, such as heat (melted sensors in some of our drones), or impact of shock waves produced by the explosions (which displaced the drones abruptly several meters away), as well as the impact of ash and pyroclasts on the blades and rotors.

RESEARCH: Drones have helped us to document and study eruptive processes that we would not have been able to do otherwise:

- We have recorded some ephemeral formations such as the "Hornitos" of which we have even generated 3D models. At present they have mostly collapsed.
- We have been able to make 3D models of the volcanic edifice on successive dates in which the changes can be appreciated, and to make measurements of dimensions and volumes, as well as to see details of their masked morphologies during the eruption.
- We have documented with thermal cameras moments of unprecedented explosivity as freshly fallen bombs with sizes from 20 to 50 cm in diameter, in which we could measure temperature and make studies of spatial distribution and range in their fall.
- We have generated digital terrain model subtractions between the pre-eruption and post-eruption state, obtaining the heights of the lava flows.
- We have generated temperature maps of the lava flows serialized by dates for depths of 1 and 3 m, which serve as support to the management administrations when making decisions

in the reconstruction tasks. They show zones with a temperature associated with the depth at 1 or 3 m and for each specific date on the map. We have started from the digitalization of all the surface active channels monitored during all the days of the eruption and we have mathematically modeled the effects of the heat equation in the lava flows, obtaining two approximations depending on the behavior observed in the field, one for lava flows up to 6 meters thick and the other for those thicker than 6 meters, and joining them to obtain the final result.

#### VISIBILITY:

- The videos obtained by the URGE (Emergency Geological Response Unit) in which the STA is integrated, mostly aerial videos, published on the YouTube channel of the IGME, have been more than 500, amounting to more than 20.000.000 views, in addition to having been shown in the main audiovisual media in the country and internationally (news programs of the most important television channels).
- These images have been used for documentaries and reports.
- More than 800 interviews have been granted by IGME scientists for various media.
- More than 600 tweets have been published, increasing the number of followers on twitter to more than 100%, with more than 1.500.000 visits.

The IGME website dedicated to the eruption of La Palma has been viewed more than 2.500.000 times, due to the quantity and quality of the information displayed on it, from 2D and 3D viewers, to animations of the advance of the lava flows, through the incorporation of other sources of data from other official agencies.

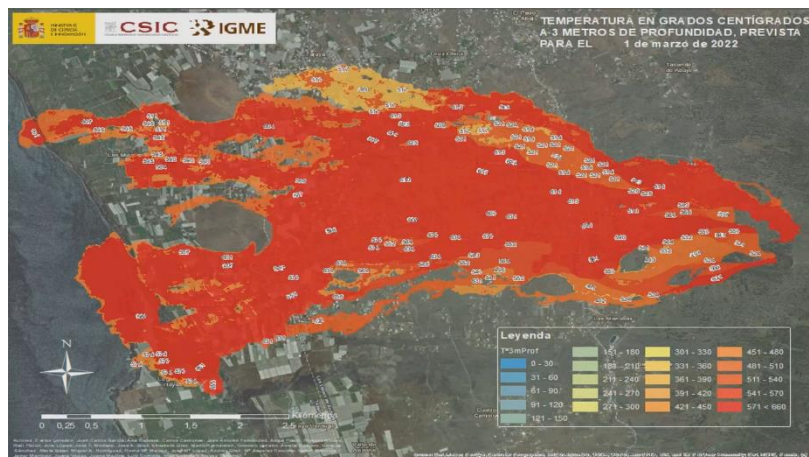


Figure 3. Time-series maps of the 1st day of each month of the year 2022 with temperatures at 1 m depth varying by color.

#### Conclusions

Drones have been an essential tool for emergency management and information gathering. They have made it possible to monitor the eruption in real time and to access places that otherwise could not have been visited.

The information obtained from the drones together with the monitoring campaigns of structural measurements, deformation, measurements of ash, gases, sample collection, etc. have made it possible to generate content for the web and social networks (especially YouTube)

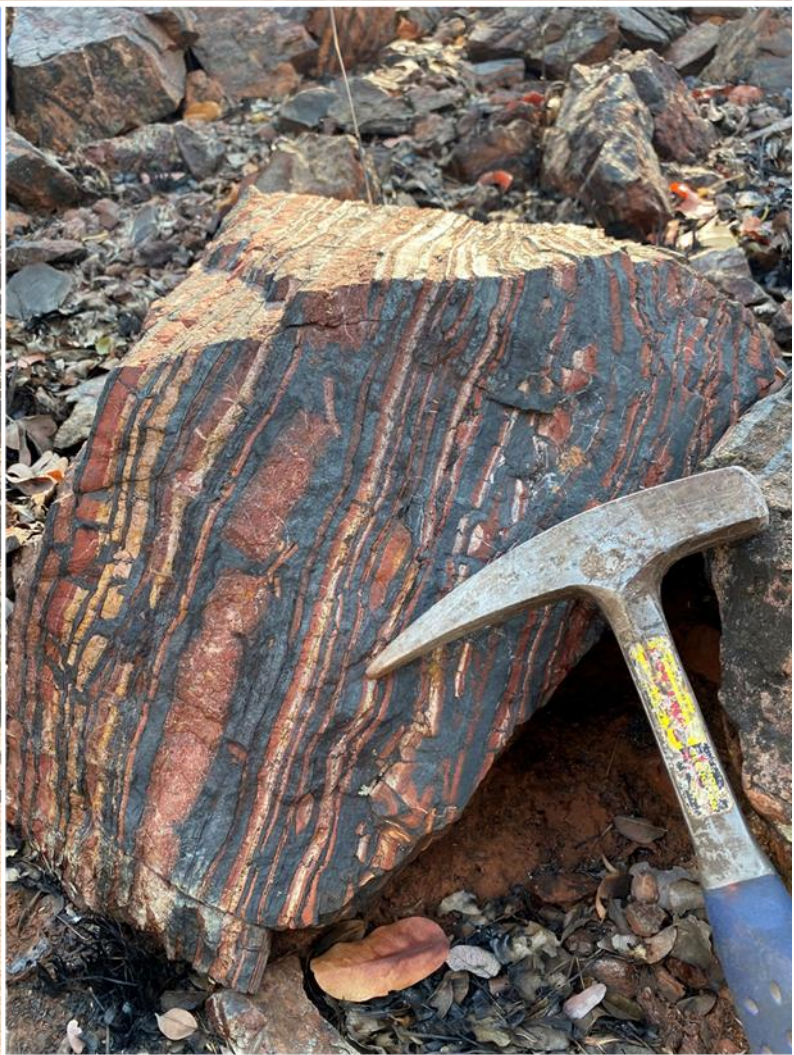
which together with the interviews granted have significantly improved the visibility of the IGME.

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## PLANAGEO Project





## UTE-PLANAGEO Project: national geology plan of Angola

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### Abstract

PLANAGEO was approved by the President of Angola in June 2009, awarded in 2013 to 3 international Consortiums, and started in 2014. It includes: (A) Regional aerial geophysical cartography (mag/rad) of the entire country, (B) Regional geological mapping at a scale of 1:250,000 for the entire country (with a selection of added sheets at a scale of 1:100,000 and 1:50,000), (C) Geochemistry campaigns, and (D) Specific studies.

PLANAGEO aims to provide better knowledge of the geological and mineral potential of Angola, to attract international investment and favor the development of the country, as well as strengthen the training of the staff of the Geological Institute of Angola (IGEO).

The IGME-CSIC National Center established in March 2013, together with the National Energy and Geology Laboratory of Portugal (LNEG) and the Spanish company IMPULSO Industrial Alternativo S.A. (IIA), a joint venture (UTE) for the development of the Geological, Geophysical and Geochemical Mapping Plan of Angola (PLANAGEO). It is the only public-private consortium of a Spanish OPI, constituted to date. Following an international tender, the Geological Institute of the Republic of Angola (IGEO, dependent on MIREMPET "Ministry of Mining and Petroleum Resources of Angola"), after a long and arduous negotiation lasting almost 3 years, awarded the IGME-LNEG-IIA UTE joint venture the execution of the PLANAGEO project in an approximate area of 480,000 km<sup>2</sup> (8 blocks in the South-West of Angola; a third of the country). The contract was signed in October 2013, amounting to 115,300,000 USD. Currently, UTE-PLANAGEO is almost finished (expected end date: May 2022). The results obtained by the UTE-PLANAGEO consortium led by IGME-CSIC have been:

- Regional aero-geophysical cartography (magnetic and radiometric maps, and interpretation of 480,000 km<sup>2</sup>).
- Mapping of: (A) 44 geological sheets at a scale of 1:250,000; (B) 15 geological sheets at a scale of 1:100,000; (C) 30 geological sheets at a scale of 1:50,000; (D) 8 geological sheets at a scale of 1:500,000, one per block; (E) 39 sheets of mining geochemistry at a scale of 1:50,000; (F) 10 sheets of regional geochemistry at a scale of 1:250,000; (G) 4 geological maps at a scale of 1:1,000,000 of the study zone.
- Hydrogeological mapping, by means of terrestrial geophysics and mechanical drilling, of the KOH-II aquifer of Angola-Namibia.
- More than 400 memories and reports of different kinds.

## Remote sensing applied to litho-structural and regolith mapping of the SW of Angola (PLANAGEO Project)

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### Abstract

IGEO (Geological Institute of Angola) has developed the so-called “PLAN NACIONAL DE GEOLOGIA DE ANGOLA” (PLANAGEO). Within this ambitious project, one of the basic subprograms was focused on the remote sensing survey of the country. The main objective of the study is the use of satellite Earth Observation data in order to support preliminary geological and regolith mapping. This allows us to obtain a first approximation to cartography 1:250.000. Litho-structural and regolith maps are elaborated over eight blocks, covering one-third of the country area and including different geological contexts.

For this purpose, multispectral scenes acquired by the Operational Land Imager (OLI) sensor of the Landsat 8 satellite were used. The scenes were selected during the dry season (which in the case of Angola corresponds to the southern winter) and with the lowest percentage of clouds as far as possible. The Landsat 8 images are geometrically corrected (Level 1 T- Land Correction). Image's pre-processing was carried out including: i) radiometric correction (conversion of original digital levels to physical parameters as radiance and top-of-atmosphere reflectance) and ii) atmospheric correction to reduce atmospheric and illumination effects on satellite image data to retrieve surface reflectance. Image processing techniques were applied to support the litho-structural and regolith interpretation.

The Litho-structural Interpretation Map differentiates types of lineaments and categorizes lithologies from photo-interpretation of Landsat 8 images and their derived products. The methodology used for the elaboration of this map is based on: i) data collection and analysis of the ancillary information, and ii) its integration into a GIS includes all the products obtained during the processing of Landsat 8 images, the digital model of elevations (MDE) and the data obtained in the airborne geophysical campaign (magnetic and gamma-ray radiometric data).

The Regolith Interpretation Map provides information on the nature and distribution of regolith deposits and the main geomorphological units. The methodology to characterise and map the different regolith units is based on: the integration of geomorphological and lithological features; the soil and climate characteristics; and the information from gamma-ray radiometry (in the form of U-K-Th ternary image) with Landsat 8 images processed by applying DPCA (Directed analysis of principal components) technique.

The result is a thematic series of litho-structural and regolith maps distributed into 1:250.000 sheets for the different studied blocks in the SW of Angola.

## Geological mapping and geochronology of Southern Angola

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### Abstract

The Temporary Union of Enterprises (UTE), integrated by the Centro Nacional Instituto Geológico y Minero de España (IGME-CSIC), the Laboratório Nacional de Energia e Geologia de Portugal (LNEG) and the company Impulso Industrial Alternativo S.A., was responsible for the Regional Geological Survey and Geological Mapping of southern Angola within the PLANAGEO Project (480.000Km<sup>2</sup>, 1/3 of the country).

In order to contribute to the sustainable development of Angola and the management of its mineral resources, 44 maps at scale 1:250.000 and 15 maps at scale 50.000 were performed, as well as other thematic maps at different scales.

In addition to the petrographic and structural information obtained in the field, the acquisition of radiometric ages was essential for the temporal organisation of the geological units, given the complex and wide (polycyclic) geological history that records the Angolan territory since Neoarchean times.

The acquired isotopic dataset (225 U-Pb zircon ages and 28 Ar-Ar ages in mineral concentrates, together with a large number (n=119) of whole-rock Rb-Sr and Sm-Nd isotope analyses), considerably increased the geological knowledge of the region, allowing the assessment of the tectono-metamorphic and magmatic events responsible for crustal generation and/or reworking, and the definition of the Geological Domains of southern Angola.

## Geographical Information System (GIS) and data base of Planageo Project

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### Abstract

The main objective of the PLANAGEO Project is to obtain continuous geological mapping at a scale of 1:250,000 for the entire Angolan territory, generating a systematic and homogeneous knowledge of the country. This geological information has been the basis for other specific works at different scales in areas of interest, such as the Regional Geochemical Map of Angola at a scale of 1:250,000, the Geological Map at a scale of 1:100,000, the Map of Metallic Resources and the Map of Industrial Rocks and Minerals (RMR), at a scale of 1:50,000.

To ensure the homogenisation and continuity of geological and geochemical data collected in the field, IGEO (Geological Institute of Angola) provided a specific Tablet App for each type of data, both with a public domain relational database management system (SQLite). This structure was modified and adapted for the smaller scale maps. The case of the RMR was different, using the ARMINA database (Archive of Industrial Rocks and Minerals of Angola) in the Access program.

These databases generate a double code, one that allows to unequivocally relate all the information associated by the geologist and another code associated to the physical sample, that provides confidentiality for its use in laboratories. They aim to establish a precise conceptual framework to provide the IGEO and users with the maximum amount of information generated by a multitude of specialists.

The GIS analysis and the generalisation of geological information has led to the production of other thematic cartographic products at a larger scale, such as the Geological, Hydrogeological and Intensive Survey Area Maps at a scale of 1:500,000 or the Geological, Hydrogeological, Tectonic and Metallogenetic Maps at a scale of 1:1,000,000.

All cartographic products generated by Planageo follow the standards of the ISO 19100 family, ensuring the interoperability of all its data, as well as a series of technical specifications provided and/or agreed with the client. These specifications comprise the map, sheet model and digital data structure of each cartographic product.

Even though each deliverable has a different database associated with it, they have extensive semantic support at all levels, from the designation and description of the phenomena to the designation and description of the values of lists of controlled terms. The latter play a particularly important role in the coherence of geological information, its understanding and quality.



## Gravimetric approach to the outstanding Kunene Complex (SW Angola): dimensions from modelling

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### Abstract

The Kunene Complex (KC) represents a large igneous body, mainly composed of anorthosites and gabbroic rocks, extending from the Quipungo region, SW Angola, to the Zebra Mountains of northwest Namibia. The exposed portion of the KC is about 18000 km<sup>2</sup>, being studied from a cartographic and geochemical point of view but little is known about its extension and its structure at depth below the sedimentary deposits of the Kalahari basin. We use available gravity data to estimate its extent and to understand the deep-crustal structure. The Bouguer anomaly map depicts a gravity gradient from W to E interrupted by the outcropping of KC. Five 2.5D gravity profiles have been modelled to investigate the unexposed eastern boundary, reconstructing the superficial crustal structure covered by the thin sedimentary cover of the Kalahari basin. The KC, emplaced during the Mesoproterozoic in the Upper Crust, extends in depth up to ca. 6 km, showing a lobular structure and conforming a large NE-SW to NNE-SSW-trending structure, presumably inherited from older Palaeoproterozoic structures. The lateral continuation of the KC, beneath the Kalahari sediments, suggests an overall size of at least twice the dimension (about 37500 km<sup>2</sup>) of the currently exposed materials, increasing its economic mineralization potential.

## Tectonostratigraphy of Benguela and Namibe sedimentary basins

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### Abstract

Benguela and Namibe coastal basins are located at the West Angolan passive margin, which formed during Gondwana fragmentation. Sedimentary records of these basins, as well as their conjugate Campos and Santos basins, are intimately related to rifting stages.

In order to discriminate autocyclical and allocyclical recorded events within the Benguela and Namibe basins, stratigraphical and sedimentological features were studied and then correlated to tectonic stages (Pre-rift, Syn-rift, Transitional and Post-rift).

Pre-rift to syn-rift cycle is characterized by flexural subsidence induced by the lithospheric stretching process followed by fracture, tilting and block rotation. The sedimentary record (Hauterivian-Barremian) in both Benguela and Namibe basins, reflects alternating stable fluvial systems interrupted by high-energy events and massive discharge related to tectonic reactivations. Thickness and geographical distribution of units within this cycle are very heterogeneous and closed associated to grabens and semigrabens fracturation and tilting.

Transitional cycle is represented by the onlapping deposition of lagoonal, gypsiferous and saline thick units of continental origin during Aptian. Transition from tectonic to thermal subsidence combined with an isolated paleogeography in an arid climate, allowed the precipitation of one of the world's largest sand layer.

Post-rift cycle (Early Albian to Present), dominated by thermal subsidence, is characterized by marine sedimentation.

Combination of all these criteria allowed grouping the sedimentary record into main megasequences that show local differences in facies associations, stratigraphical architecture and basins evolution within Benguela and Namibe basins.

## Mineral resources and geochemical exploration in PLANAGEO (Angola)

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### Abstract

PLANAGEO is an international Project developed by the Spanish Geological Survey (IGME), Portugal Geological Survey (LNEG) and Asturian company (IMPULSO) for 8 years (2014-2022) in the south part of Angola (476.500 Km<sup>2</sup>). This project has four main activities: 1) Aerogeophysical surveys, 2) Geological mapping, 3) Geochemical exploration and 4) Specific studies (Mineral resources exploration, hydrogeological studies and ornamental rock and industrial mineral exploration).

Mineral resource and geochemical exploration have been the last activities for this project carried on in two exploration campaigns between 2021 and 2022 in 39 different 1:50.000 geological sheets selected previously. Three different clusters have been defined in order to explore different raw materials, regarding their interest in mineral metallic resources: cluster 1 for gold and iron, cluster 2 for REE and niobium-tantalum and cluster 3 for base metals and platinum group elements. Geologists have taken direct measurements with XRF portable analyzers from approximately 140 different measurement points in each sheet, together with geological sampling of soils, rocks, stream sediments and heavy mineral concentrates for geochemical purposes.

A complete database with all analytical results, data from field campaigns and other outstanding geochemical and geophysical characteristics is being prepared for statistical computation. After that, univariate and multivariate statistical analysis and spatial distribution will be performed in order to show the single-element geochemical distribution, relationships and associations among the different elements with the distinct geological units found in southern Angola.

## Rocks and industrial minerals map of Angola (CARMINA)

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### Abstract

The Spanish Mining and Geology Institute (IGME) and the National Institute for Energy and Geology of Portugal (LNEG), have created 30 rocks and industrial minerals maps, on 1:50.000 scale, focused in the South of Angola, where the miner development can allow an important economic development.

It is set in the Rocks and Industrials minerals map of Angola (CARMINA), on 1:50.000 scale as a geological-miner map in which are combined the current knowledge of the rocks and industrial minerals and their potential, with the following target:

- To know the current situation of the rocks and minerals in Angola
- To enhance and dynamize the mine area
- To improve the knowledge and potential of the rocks and minerals resources
- To ensure the development of the country through the enhance of the mine area

The search of new resources leads increasingly more specialized reports and more complex databases. With this thematic cartography, it is intended to give a valuable tool for the use of mine knowledge by public and private institutions, to apply it to investigation, to the use of the mine resources and the spatial planning, in order to promote a sustainable development.

The results are very successful, especially in relation with the discovery and characterization of natural stone sites. Are highlighted the deposits of granite, anorthosites and marbles, and to a lesser degree of limestones, gabbros and quartz. In relation to the stones and minerals used with industrial purposes, are relevant the pegmatite sites located in Giraul. These pegmatites allow possibilities in relation to the use for high purity feldspars, fosfates and gemological purposes. The columbite minerals are not very abundant and poor in tantalus, therefore can only be used as a subproduct of the extraction of feldspar. The accumulation of quarry, can allow the extraction through mechanic means, to the production of high quality silicate products.

## Hydrogeological potential of the Kalahari basin in Angola

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### Abstract

The Kalahari Basin is the largest sandy basin of tectonic origin. Developed over the Congo Craton, it covers part of the national territories of Botswana, Namibia, Angola, Zambia, Zimbabwe and South Africa, approximately 2.5 million km<sup>2</sup>. The sedimentary fill comprises rocks and sediments from Upper Cretaceous to Quaternary age, which were deposited mainly during periods when the Basin was subject to extensive geodynamic regimes.

Recent BGR research in northern Namibia, near the Angolan border and within the Cuvelai-Etoshia basin, has identified 3 aquifer levels in the sedimentary fill of the Kalahari basin: 1) the shallow Ohangwena aquifer (KOH-0) (<40 m), which hosts lenses with limited and stationary water resources; 2) the intermediate, continuous, saline Ohangwena aquifer (KOH-I) located between 60 and 120 m depth, whose resources are not suitable for human use; and 3) a third deep Ohangwena aquifer (KOH-2) (roughly between 200 and 300 m) with semi-fossil water of good quality and high productivity. These KOH-I and KOH-II aquifers are likely to extend into Angolan territory.

From the climatic point of view, it is a semi-arid region, with evapotranspiration much higher than rainfall and with a very marked seasonality. Surface water resources are abundant due to the presence of the Cubango, Cunene and Cuvelai rivers, with a high and perennial flow. However, outside their banks, surface water resources are scarce, which partly explains the low population density and underdevelopment of the region. Therefore, in the Planageo Project, the verification and characterization of the extent of the Ohangwena aquifers in the Angolan territory have become one of the main objectives of the project. This poster describes the complementary and specific studies carried out to this purpose, without disclosing the main results obtained so far due to the confidentiality clause of the project contract.

Analysis of pre-independence Angolan hydrogeological information in the Cunene region, consisting of more than 400 Vertical Electrical Surveys (VESs) and an old extensive depth-limited drilling campaign, together with the 1:250,000 scale geological mapping carried out during the Planageo Project, and the associated passive seismic survey had made it possible to create a starting 3D geoelectric model of the basin. Based on this model, a TDEM (1D Time Domain Electromagnetic) campaign has been made, together with 5 deep hydrogeological boreholes (summing up about 1,500 meters of drilling) with subsequent logging studies that are being completed at present. The results allow to visualize the vertical succession and lateral extension of aquifer and aquitard formations, as well as to provide information on their salinity.







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