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Poročila in ostalo - Reports and More

Unveiling Portugal's Geothermal Landscape: Insights from the IGCP636 Annual Meeting 2023

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Introduction

The Geothermal Resources for Energy Transition project, identified by the acronym IGCP636, is a collaborative effort involving research institutes worldwide, supported by the International Geoscience Programme (IGCP) of UNESCO. The IGCP programme has partnered since 1972 with the International Union of Geological Sciences (IUGS) and, since 2018, with the Jeju Province Development Corporation (JPDC) of the Republic of Korea.

The main goal of the UNESCO IGCP636 Project is to strengthen scientific to promote the use of geothermal resources as a clean, low-carbon, baseload, and renewable energy. The project has three main targets: increasing knowledge and understanding of deep geothermal reservoirs; conducting outreach activities with focus groups and communities; promoting the installation of geothermal heat pumps. The activities proposed by this research team include engaging local authorities, civil society, and other stakeholders, paying attention to local needs and concerns, enabling co-design of new strategies and measures for the development of green energy solutions.

Alongside the IGCP636 research team, students from the Geothermal Research Group at the *Institut national de la recherche scientifique* (INRS) in Quebec City, Canada, organized a research expedition in Portugal mainland and in Azores from October 21st to November 1st 2023. The primary aim of this expedition was to offer an enriching educational experience, particularly for graduate students specializing in geothermal energy, within the occasion of the annual meeting for the IGCP636 project. The focus was on providing the participants with insights into the utilization of geothermal resources in Portugal, along with attending the annual group meeting at the University of Coimbra (UNESCO World Heritage Site).

The INRS students wrote an itinerary guidebook[1], providing information to enrich the exploration of the visited sites. The guidebook offers in-depth insights into the geological features of Portugal and provides information about the geothermal energy exploration in the visited sites.

Additionally, it included details about the local culture, history, and attractions, widening the overall experience for the participants. This fieldtrip not only enhanced the overall group dynamics, but also provided the students and researchers (around 20 participants) with a unique opportunity to gain insights into geothermal resources in Portugal.

Geological context of Portugal

Portugal's continental territory is located in the Iberian Peninsula, where 63 % of the total geothermal occurrences are linked to the Central-Iberian Zone, associated with the *Variscan* granitic units and large deep regional faults and their conjugates; mainly the *Penacova-Regua-Verin* and *Manteigas-Vilarica-Bragança* fault systems in the north of the country (Julivert et al., 1980). In the West-

ern Meso-Cenozoic margin, geothermal occurrences are associated with faulting and diapirism, most importantly around the *Nazare-Caldas da Rainha-Vimeiro* fault; and detrital sedimentary aquifers, such as the lower Cretaceous aquifer in the Lisbon region. Finally, a small number of occurrences can be seen in the *Ossa-Morena* and *South-Portuguese* zones and the *Algarve* basin (Fig. 1). There are, in total, 30 low-enthalpy geothermal occurrences, with temperatures between 30 and 76 °C; 36 very-low enthalpy geothermal occurrences, temperatures between 20 and 29 °C; and 24 springs, officially used in balneotherapy, with temperatures from 25 to 76 °C (DGEG, 2020).

Itinerary and visited sites

Alfama Springs

The very first activity on the itinerary was organized at *Alfama* Springs, now a recognized cultural geoheritage site in Lisbon, served multiple purposes for locals, including bathing and water provisioning. Lisbon is situated in the Lusitanian Basin, characterized by Mesozoic and Cenozoic sediments, including aquifer formations. Consequently, Alfama Springs exhibit hydrochemical facies indicating low salinity and temperatures between 24 and 34 °C, with geothermometers suggesting groundwater rises quickly from depths

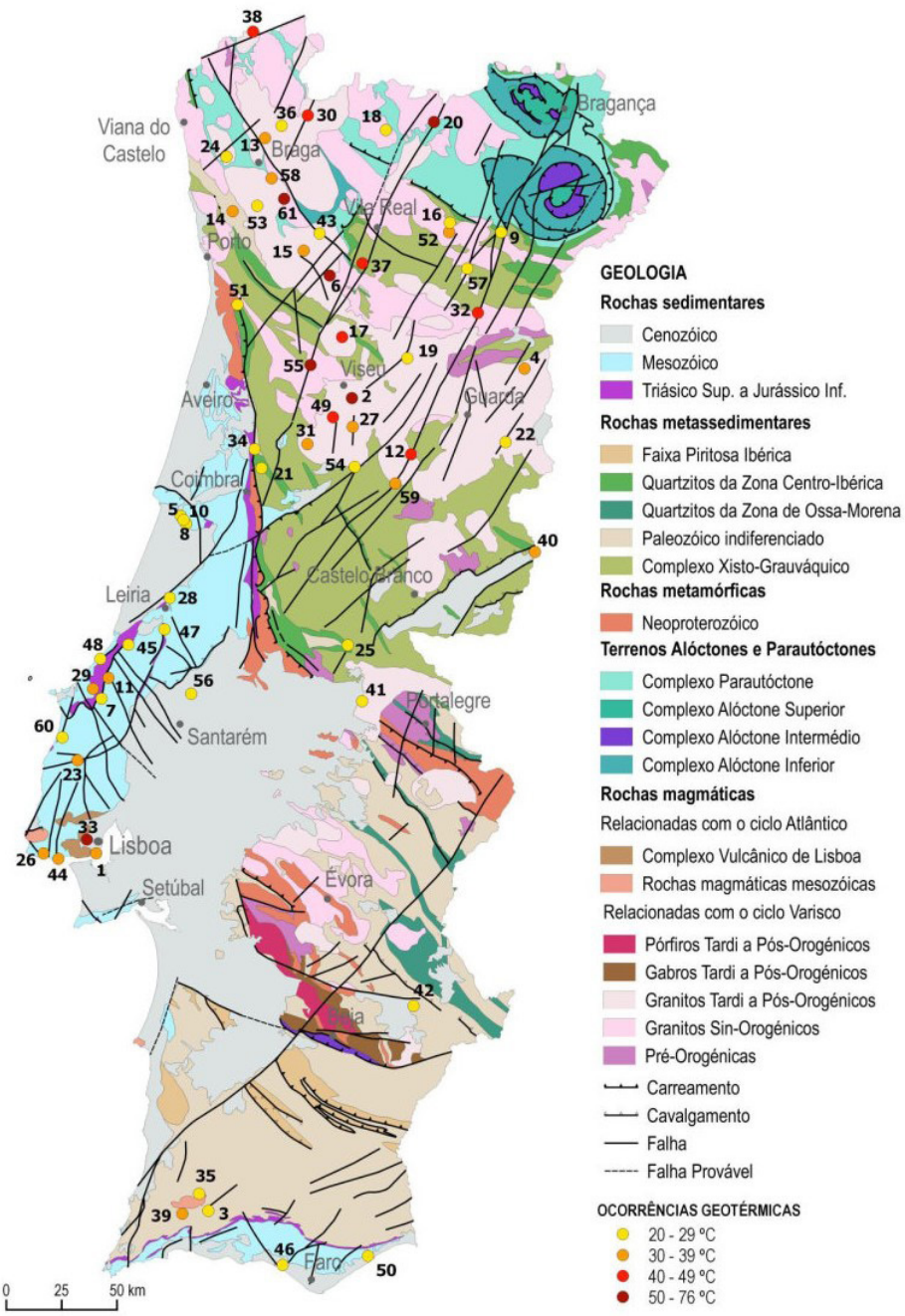

Fig. 1. Geological map of Portugal Mainland and thermal occurrences (DGEG, 2020).

of 565 to 2957 m, showing significant geothermal energy potential influenced by the Alfama fault (Ramalho et al., 2020; Marrero-Diaz et al., 2021).

This site was chosen as the first day visit because it represents a significant case study for geothermal energy. The analysis enhances the understanding of water temperature at depth and the reservoir depth in the Alfama Springs region, providing valuable insights into the geothermal potential of this historical site.

Vila Velha de Rodão

After Lisbon, the group drove to *Vila Velha de Rodão* for a guided visit of the region consisting of a field trip to recognize the geomorphological features of the *Naturtejo* Geopark and its relation to the Tagus River, as well as a visit to historical sites seeing prehistoric engravings and ancient roman olive oil production. During the day, the main sighting was the imponent *Portas de Ródão*, a gorge formed by the Tagus River in the quartzite crest of the *Perdigão* mountain range, featuring a 45-meter-wide bottleneck, and where Pleistocene terraces to the sides, comprising conglomeratic and silty sediments, showcase the fluvial evolution of the Tagus River over 2-3 million years, highlighting various stages of settlement.

Fronteira

On October 23rd, the itinerary continued towards the municipality of *Fronteira*, including the villages of *Cabeço de Vide* and *Alter do Chão*. Starting in Fronteira's cultural center, Dr. Carla Rocha presented the local geothermal occurrences, highlighting the local hydrogeological conditions, where mineral waters emerge from boreholes and natural springs located at the junction of the Alter do Chão pluton and Cambrian carbonate metasediments of Elvas, as part of the prior mentioned Ossa Morena zone. She also showed practical examples for methods used to quickly assess the geochemical composition of the water (Fig. 2). The thermal waters in Cabeço do Vide have been used since 119 B.C. for medicinal purposes and are used nowadays in the Termas da Sulfúrea balneary. They have a unique geochemical composition with a pH of 11.55 and being sulfuric, hyposaline, and hyperalkaline with sodium and calcium, oxidized. No other water in the country is simultaneously oxidized and hyposaline. The group was able to explore the surroundings of the thermal baths and observe the extraction wells and learn more about the functioning of the balneary and its relation to the geological and tectonic context.

Fig. 2. Application of experimental methods to local groundwater samples.

A visit to Alter do Chão was done after the thermal baths to learn about the history of the town and the region, given by a guided tour through the Casa do Álamo and to the Casa da Medusa museums.

To finish the day, a trip was done to the Alter Pedroso castle (Fig. 3) to learn about the 120 history of the Alentejo region and its importance in the Portuguese restoration war.

Fig. 3. Group picture in front of the Alter Pedroso castle.

Castelo de Vide

On October 24th, the group moved towards the municipality of *Castelo de Vide*. The historical relation between water and local Jewish ancestry since the 13th century and how the groundwater and thermal springs helped shape the town's rich history and culture were explained.

A short drive then took the group to the town of Marvão, located on a ridge of the Serra de Sã Mamede mountain range, to take a better look at the geological context of the region, where the ridge

is part of a synclinal structure with local quartzite and dolomite series. The day was finished with a visit to the municipality of Nisa, where the local tourism office presented their unique pottery techniques using quartz fragments, with a demonstration by local craftsmen and craftswomen, before heading to the city of Coimbra.

Coimbra: Annual IGCP636 Meeting 2023

The Earth Science Department and the Geosciences Center from the University of Coimbra, which is a UNESCO World Heritage Site, hosted the IGCP636 Annual Group Meeting on October 25th. The morning session was committed to introducing the IGCP636 project, featuring keynote talks on geothermal resources and case studies in Portugal. These talks were led by representatives from various pertinent institutions, including the Earth Science Department; Portugal's General Directorate of Energy and Geology, presenting the current state of geothermal energy use throughout the country; *SYNEGE,* showcasing different-scale projects for low to medium enthalpy geothermal applications; and the National Laboratory of Energy and Geology, introducing their work regarding research on new resources and the collaboration to unify geological data with multiple European geological surveys. In the afternoon, presentations were delivered by representatives from the Bureau of Economic Development, U.S.A., the Geological Survey of Slovenia, and Canada's National Institute for Scientific Research (Fig. 4).

Posters, listed in Table 1, were also presented after the meeting, where students and collaborators from the INRS exhibited their most recent research work in the field of geothermal energy.

São Pedro do Sul

São Pedro do Sul Hydromineral and Geothermal Field consists of two main zones: the *Termas* and *Vau* poles, both within the junction of São Pedro do Sul-Ribamá Fault, Termas Fault, and Fataunços Fault, in highly fractured granite and metasedimentary aquifers, and separated by approximately 1.2 km (Almeida et al., 2022). As a place of great interest for its hydrothermal activity, the group arrived at Rainha D. Amélia thermal bath where they had the opportunity

Fig. 4. Annual meeting at University of Coimbra.

Table 1. Works presented during the poster session at IGCP636 Annual Meeting in University of Coimbra.

Chapman, F.M., Klepikova, M., Bour, O., Soucy La Roche, R., & Raymond, J., 2023. Heat flow assessments in southwestern Yukon using fibre-optics.
Gasguel, V., Raymond, J. & Rivard, C. 2023. Repurposing idle wells for the heat transition: Dynamic modelling of a deep borehole heat exchanger system.
Goldoni de Souza, M., Bordeleau, G., Lacombe, S., Raymond, J. & Comeau, F. A., 2023. Geothermal and geochemical considerations in open-loop systems in Quebec's former open-pitmines.
Thibault, M., Rajaobelison, M. M., Comeau, F. A., Raymond, J., Terklay, V. & Newson, J. 2023. Geothermal potential of the South Slave Region, Northwest Territories, Canada.
Gold, A., Miranda, M.M., Raymond, J., & Asbjornsson, E.J., 2023. Minimiser le dégel du pergélisol et maximiser le stockage souterrain de la chaleur à Baker Lake (Nunavut).
Lee, V., Raymond, J., Rivard, C., Parent, M., Comeau, F.-A., & Newson, J., 2023. The potential of groundwater heat pump systems for urban heat island mitigation: aquifer suitability assessmentin Canada's major cities.
Thomas, G., Rajaobelison, M. M., Comeau, F. A. & Raymond, J. 2023. Geothermal Reservoir Analysis of the Fort Liard region, Northwest Territories, Canada.

to observe the exploitation network for the thermal waters. Both an artesian thermal spring and a 500 m deep artesian well are used to feed the direct geothermal systems in place. They have a flowrate of 10 l/s and outflow temperatures of 68.7 °C and 69 °C respectively, being bicarbonated, carbonated, fluoridated, sulfhydrated, sodic and strongly silicate waters, although weakly mineralized, with around 300 mg/L (Almeida et al., 2022). After the technical visit, the group spent the afternoon visiting the ancient roman baths and museum, learning about the historical importance of thermal waters in the region, concluded by paying a last visit to the thermal baths in the hotel to enjoy their health benefits.

Guimarães

The visit of Guimarães started at the Laboratório da Paisagem, where sustainability projects are proposed to promote and innovate in environmental and territorial practices, and where the group got to see first-hand many projects implemented in the city. Later, a trip to the Taipas Termal thermal baths was made to learn more about the local hydrogeological conditions and how the heat has been used since Roman times for balneotherapy. Within mostly granitic lithology, the hydrothermal waters are weakly mineralized and with low temperatures of around 32 °C (Fig. 5), where the exploitation well for the thermal baths was drilled on a fault and to a depth of less than 200 m, to get better temperatures and a pumping rate of 7.3 l/s. The afternoon consisted in a guided tour around the city's historical center to learn more about the importance of the city in Portugal's national history as a republic, followed by a visit to the Gimnastics Academy, where the coupled use of low-enthalpy groundwater, surface water, air, photovoltaic, thermal and passive solar, and adequate construction materials (special concrete, cork, etc.) contribute to a energy efficient and architecturally beautiful building. This building, during parts of the year, is a net producer of electricity to the grid, thus making a positive energy balance from sustainable practices.

Fig. 5. Temperature measurement at a thermal water outlet in the Taipas Thermal baths.

Porto to Lisbon

On October 28th, a road trip back to Lisbon from Porto was planned to prepare for the upcoming flight to the Azores Islands the next day, but not before a stop at the city of Nazaré, on the western coast, to see the very notable sedimentary cliffs and the enormous waves generated by Nazaré's undersea canyons, place that serves as one of the main spots worldwide for big-wave surfing competitions

Azores - São Miguel Island

The Azores archipelago consists of nine volcanic islands located in the North Atlantic. São Miguel, the largest island, is the most volcanically active with three dormant volcanoes: Sete Cidades, Fogo, and Furnas, and numerous scoria cones, given the location of the island on the mid-Atlantic ridge are where the Eurasian, African (Nubian), and North American lithospheric plates meet, resulting also in significant seismic activity. After landing on Ponta Delgada, São Miguel Island, on October 29th, the group immediately proceeded to visit one of the main dormant volcanic complexes, Sete Cidades. This site es most active volcano in the archipelago, with 17 explosive eruptions that displayed predominantly hydromagmatic character (Queiroz et al., 2015). A short hike was done through Grota Do Inferno to the panoramic view of the ancient calderas in the zone. A small discussion about the local geomorphology took place regarding the evolution of the volcano, its features, and their relation to the tectonic context. To continue learning more about the influence of volcanic activity on the morphology of the island, the group drove to the *Escalvado* viewpoint to observe the pumice, tuff, and other pyroclastic deposits that originated from ancient eruptions.

The next day, the University of Azores and its volcanology center received the group for a guided visit, to show their research work and laboratories around understanding of volcanic processes in the island and identifying possible threats to the population related to seismicity and eruptions. Hydrochemistry, petrology, meteorology, seismicity, and cartography are the main topics investigated. In the afternoon, the group moved towards the *Pico Vermelho* Geothermal Power Station, located

on the Ribeira Grande geothermal field, which, together with the *Ribeira Grande* Geothermal plant, provides around 44 % of the electricity needs of São Miguel Island, 23 Mwe net. The field is located in the northern flank of Fogo Volcano, the largest among the three dormant stratovolcanoes of the island, characterized as a 245 °C two-phase reservoir hosted in volcanic rocks intersected by 1 to 1.5 km deep wells. A guided visit through the installations was made (Fig. 6) and the operation team explained the details of the exploitation system, both advantages and challenges presented along the history of the plant. Currently, the operation runs five producing and three reinjecting wells, working with a fluid at 161 °C and 5 bar, with an installed production capacity of 10 MW with a binary ORC plant. Residual heat from the operation is not used for any other application, although the 90 °C reinjection temperatures could represent an interesting opportunity for low to intermediate enthalpy geothermal applications.

Fig. 6. Visit to the Pico Vermelho powerplant's installations (São Miguel Island).

Back to the University of Azores, the Geotalk workshop took place with the help of Department of Volcanology. The researchers presented their most recent work and a brief overview of the status of geothermal energy in their respective countries. The event was concluded by a discussion about the newest challenges geothermal energy is facing as an emerging renewable source and getting insights from recent experiences.

On October 31st, the day started with a visit to the *Gorreana* tea factory, known to be the oldest in Europe, and of significant importance in the economy of the island. Later, a series of sightseeing stops were included in the fieldtrip, to look at the region around the Furnas volcano, which has had 10 moderately explosive trachytic eruptions of sub-Plinian character. Two of these have taken place since the island was settled in the mid-fifteenth century, and where several craters, domes, maars, and pumice cones can be observed. The group then headed to the *Terra Nostra* park, located next to the Furnas Lake and inside the ancient caldera, where fumarole fields and hot springs can be seen (Fig. 7). A local dish is prepared here by burying a hot pot in the ground to let the high temperature fluids cook the meat and vegetables at temperatures from 66 °C to 93°, for 6 to 8 hours. There are also thermal baths, which are characterized by temperatures around 40°C, and high iron content.

Fig. 7. Visit to the Furnas volcano's fumaroles in Terra Nostra park.

The final day in Sao Miguel of Azores was spent visiting the rest of the island, diving the group in two teams: one that went to the *Salto Do Cabrito* trail, near the *Ribeira Grande* area to better observe the surrounding features of Fogo volcano; and the other team headed to see the impressive cliffs made from mafic pyroclastic rocks and thermal water discharging in the sea at *Ponta da Ferraria,* on the western most point of the island.

Main Results and Outcome of Annual Meeting 2023

A relevant involvement of graduate students at Master and Doctorate level (half of the group) was achieved: they gave more than 10 talks. They also presented posters (Table 1) and wrote a field guidebook for all planned activities with all due technical, scientific, and logistical aspects (Miranda et al., 2023).

The activities benefited from the contribution of local experts in geothermal energy (e.g.: Direção de Serviços de Recursos Hidrogeológicos e Geotérmicos, Synege and TARH companies) and the new contacts with professors and researchers from the Research Institute for Volcanology and Risk Assessment of the University of Azores.

It is worth mentioning the participation of professionals from Geothermal Canada, as well as the visibility of the IGCP636 activities in international bulletins (Cariaga, 2024).

The Annual Meeting and the fieldtrip were an excellent opportunity to strengthen and create collaborations between researchers, to encourage the participation of graduate students, and to lay the foundations for future joint research activities, while continuing to comply with the IGCP program mission.

Conclusion

Exploring Portugal's geothermal resources proved to be an enriching educational journey, marking yet another successful chapter for the IGCP636 Geothermal Resources for Energy Transition research group. The most important experiences in the immersion of young researchers, both from the INRS and the IGCP636 groups, was the opportunity to get into networking and the sharing of knowledge, having academic discussions with professionals in geothermics, and presenting their work to the universities of Coimbra, Azores, and governmental institutions interested in their research. As part of the third objective of the IGCP636 project, based on promoting educational resources and outreach around geothermal energy, the experience from the joint annual meeting and academic expedition proved to be a highly successful activity that can be taken as an example for further geosciences related events.

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