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Institut national
de la recherche
scientifique



IGCP 636 & INRS DISCOVER PORTUGAL GUIDE



We are thrilled to have you join us for 12 days of jam-packed geothermal-related adventures. In our time here, we will be visiting geothermal attractions across northwest Portugal, hosting the IGCP 636: Geothermal Resources for Energy Transition annual meeting at the University of Coimbra (UNESCO World Heritage Site), traveling to the geothermal power plant on São Miguel, and much more!

SPONSORS

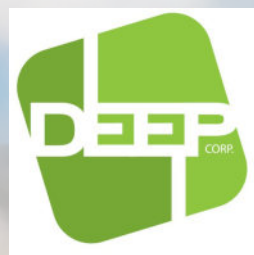
This field excursion would not have been possible without the generous contributions from our sponsors and support from local municipalities.



Volcanoes – Municipality & Institutional support



Geysers – \$250 to \$500



Hot Springs – Up to \$250



Special thanks to: Yolande Roy, Sébastien Castonguay, Monique Lacombe, Francine Davis, Daniela Goldoni, Cynthia Lee, Chantal Pelland, Michel Malo, Jasmin Raymond, and Christine Rivard for their individual donations.



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TRIP OVERVIEW

MAINLAND

TIME	OCTOBER 21	OCTOBER 22	OCTOBER 23	OCTOBER 24	OCTOBER 25	OCTOBER 26	OCTOBER 27	OCTOBER 28
06:00	Arrival Lisbon airport	---	---	---	---	---	---	---
07:00		---	---	---	---	---	---	---
08:00		Drive Vila Velha de Rodao	Drive Fronreira	Drive Castelo de Vide	---	Drive São Pedro do Sul	---	---
09:00		---	---	---	---	---	---	---
10:00	Arrival Lisbon airport	Geonatour activity guided hike lunch guided museum visit boat tour COST 150EUR/person	Fronteira <i>organized with the support of the municipality</i> guided tour to the Battle of Atoleiros, Interpretation centre, visit to Fronreira graveyard (built due to the 1755 earthquake that destroyed Lisbon)	Castelo de Vide <i>organized with the support of the municipality</i> visit to the thermal bath	IGCP636 annual meeting lunch at the cafeteria (+/- 8 EUR/person - buffet style)	S. Pedro do Sul thermal bath <i>organized with the support of the Spa technical director, Luis Gomes</i> 10AM – meeting point Rainha D. Amelia thermal bath Reception brief explanation of the thermal bath history, visit to the installation visit to the Roman thermal bath	Guimaraes <i>organized with the support of the municipality; bus will be provided</i> 09h00 - Visit begins 09h30 - Welcome and visit to the Landscape Laboratory 10h30 - Visit to the Caldas das Taipas Thermal Spa - Taipas Termal 13h00 - Lunch 14h00 - Cultural Visit - Park 2 National Monuments National Monuments Guimarães Castle + Palace of the Dukes of Bragança 16h00 - Visit to the Guimarães Gymnastics Academy	Drive from Porto to Lisbon with stops
11:00								
12:00			Cabeco de Vide <i>organized with the support of the municipality</i> guided visit to Cabeco de Vide thermal bath and explanations about the geology, hydrology, chemical composition and history of the thermal baths					
13:00								
14:00	Alfama Springs guided tour		Alter do Chao e Alter Pedroso <i>organized with the support of the municipalities</i> visit to the castle, to the museum Casa do Álamo and to the museum Casa da Medusa	Marvão visit to the castle		Drive Guimaraes		
15:00								
16:00				Stop in Nisa portuguese pottery				
17:00								
18:00	Hotel & dinner - Lisbon	Hotel & dinner Vila Velha de Rodao (included)	Hotel & dinner Fronreira (included)	Drive Coimbra	Hotel & dinner Coimbra	Hotel & dinner Guimaraes	Drive Porto	Hotel & dinner Lisbon
19:00								
20:00								
21:00				Hotel & dinner Coimbra			Hotel & dinner Porto	
22:00								
23:00								

TRIP OVERVIEW

AZORES

TIME	OCTOBER 29	OCTOBER 30	OCTOBER 31	NOVEMBER 1	
06:00	Flight Ponta Delgada	---	---	---	
07:00					
08:00					
09:00					
10:00		Visit to the volcanology center in the University of Azores	Miradouro St. Iria	Trail Salto do Cabrito (8.5 km) Visit to Caldeira da Ribeira Grande and Caldeira Velha	
11:00			Gorreana Tea Factory		
12:00	Option #1: Visit to Lagoa das Sete Cidades and other sites in the western part of the Island Option #2: 14:30 Miradouro do Pico Carvão 15:10 Miradouro da Vista do Rei 15:50 Miradouro da Lagoa de Santiago 16:30 Túnel de água 17:10 Miradouro da Lomba do Vasco	Lunch University of Azores 5 EUR/person	Bathing in thermal waters		
13:00		Drive Geothermal power plant	Lunch Visit to Terra Nostra Park		
14:00		Visit to the geothermal power plant	Visit to Fumarolas da Vila das Furnas		
15:00			Visit to Fumarolas da Lagoa das Furnas		
16:00					
17:00					
18:00		Conference University of Azores	Hotel & dinner Ponta Delgada		Flight Lisbon
19:00					
20:00					
21:00	Hotel & dinner Ponta Delgada	Hotel & dinner Ponta Delgada			
22:00					
23:00					



TRIP OVERVIEW

LOGISTICS

Car Rental:

- Car rental will be funded by IGCP 636 for all participants.
- Each car will have one driver insured.
- Drivers must be comfortable driving a manual car.
- All participants travelling together must stick to the same itinerary to ensure the trip runs smoothly.



Accommodation:

- Individuals are responsible for their own accommodations.
- Accommodations MUST be within walking distance of the student accommodation list provided.
- Morning meeting location and evening drop-off will occur at the student accommodations. The addresses are included in the daily itinerary.

Food:

- Please ensure that you always have one breakfast and one lunch to-go. We may not always be able to stop to buy breakfast/lunch during our activities.



Azores:

- Please be sure to take the 6 am flight from Lisbon to Ponta Delgada on October 29th.
- We will meet at the gate. Participants will be responsible for getting to the gate on time.



MAINLAND PART 1

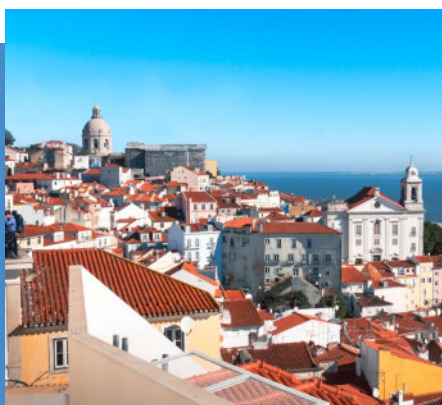




SAT. OCT. 21ST

ALFAMA SPRINGS

Maria do Rosário Carvalho, hydrogeology professor at University of Lisbon, will join us in Lisbon to give us a tour to the Alfama Springs, a cultural geoheritage site in the heart of the capital. **Meet @ Lisbon Cathedral (1:30 pm).**
Largo da Sé 1, 1100-585 Lisboa, Portugal.



ALFAMA SPRINGS

Alfama Springs, nestled in Lisbon's historic Alfama district, offer a serene escape. These natural springs are a hidden gem, surrounded by centuries-old architecture and charming alleyways, providing a tranquil oasis in the heart of the city.



LISBON

Lisbon, Portugal's vibrant capital, captivates visitors with historic charm and modern energy. Cobblestone streets wind through colorful neighborhoods, leading to stunning viewpoints like São Jorge Castle. Savor delectable pastries, explore iconic districts like Alfama, and soak in the Fado music culture. Lisbon offers an unforgettable blend of old-world and contemporary allure.

MEALS

Breakfast: In flight

Lunch: Independent before Guided Tour

Dinner: Independent (Lisbon)

ACCOMMODATION

Lisbon Chillout Hostel

R. Nogueira e Sousa 8, 1150-237 Lisboa, Portugal

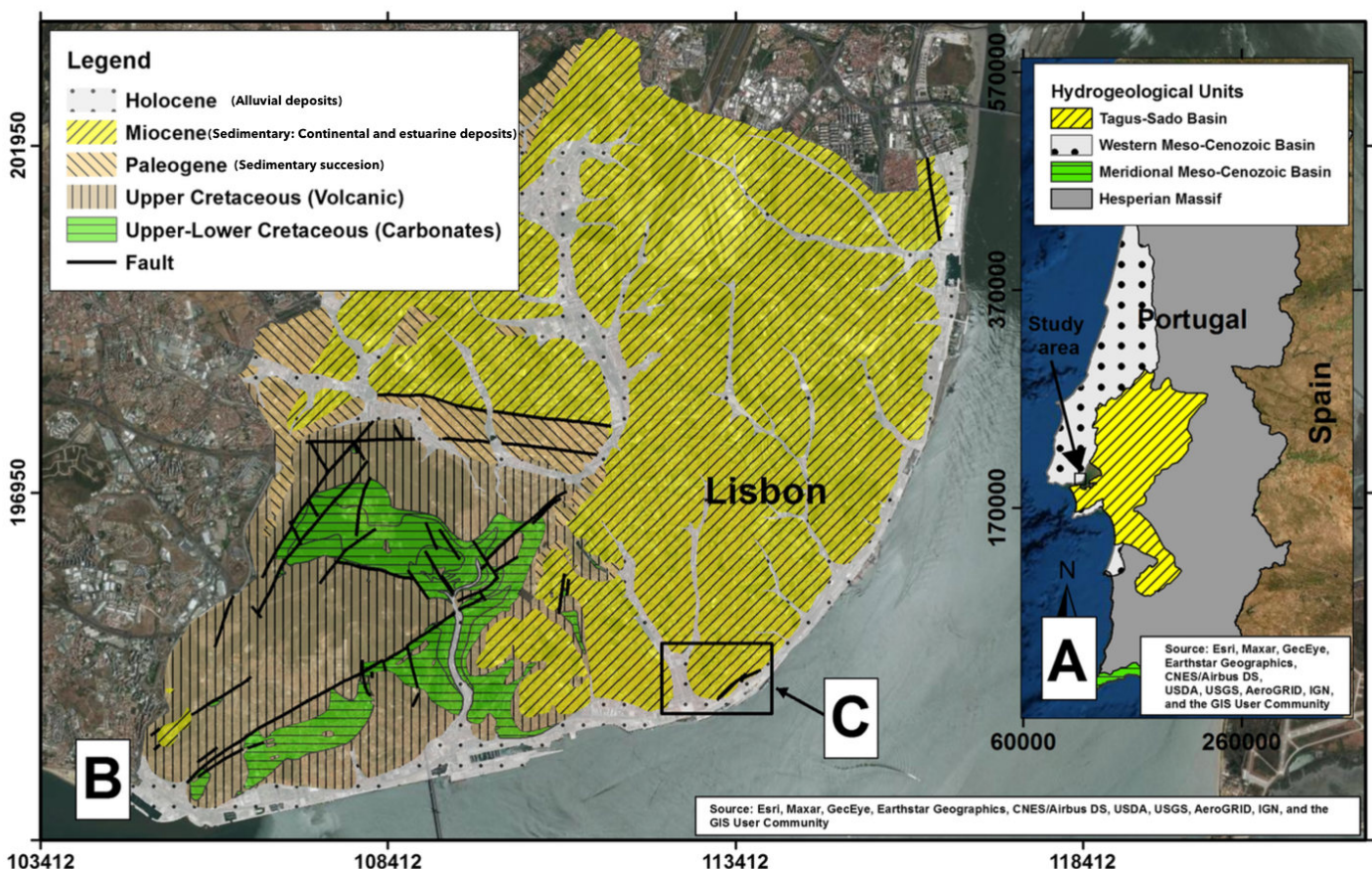
Lisboa Central Hostel

R. Rodrigues Sampaio 160, 1150-282 Lisboa, Portugal

GEOLOGY

ALFAMA SPRINGS

Alfama springs are an important part of the historical and cultural heritage of the Alfama district of Lisbon. They are a cultural geoheritage that now lies underground and can no longer be seen from the surface. Historically, they have been used by the locals for bathing, water provisioning, laundry, wool washing and leather tanning. Due to persistent degradation of the springs, the last balneotherapy facility was abandoned and sealed more than 40 years ago. Some of these Springs reached temperatures up to **34°C** with significant flow rates (several liters per second).



Modified from Ramalho et al., 2020, A: Main hydrogeological units of Portugal. B: Simplified geology of Lisbon County. C: Alfama Springs location

GEOLOGY

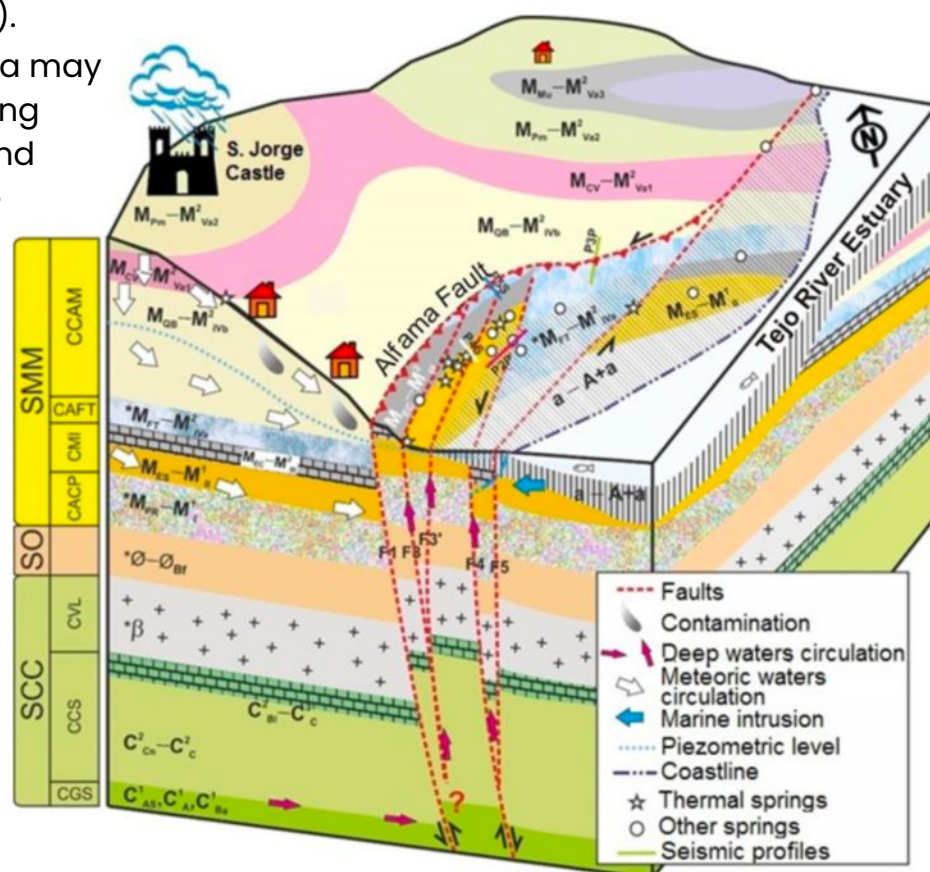
ALFAMA SPRINGS

Lisbon is situated in the southern sector of the Western Mesozoic and Cenozoic Basins, with its geological formations integrated in the **Lusitanian Basin** and partially overlain by **Lower Tagus Basin** Cenozoic deposits. The Lusitanian Basin is made up of Mesozoic detrital and carbonate deposits that are over 3 km thick. Since the Paleogene, a sedimentary sequence of roughly 1.2 km thickness has accumulated, comprising predominantly Miocene continental and estuarine deposits, but Holocene alluvial deposits also occupied the Lower Tagus Basin (Ramalho et al. 2020).

Groundwater circulation at Alfama may be facilitated by the accompanying complex of left strike-slip faults and inverse movement caused by the Alfama fault.

Several projects that revolve around harvesting this thermal resource are currently being considered. In the near future, wells could be drilled for several applications, such as balneotherapy and urban heating, renewing the prolific geoheritage of the Alfama Springs.

From Ramalho et al., 2020. Conceptual hydrogeological 3D model of Alfama region.



References :

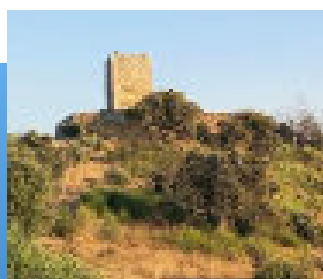
Marrero-Díaz, R., Ramalho, E. C., Carvalho, J., Dias, R., Ramada, A., & Pinto, C. (2021). 3D Modelling of a Hydrothermal System in a Densely Populated Urban Area—the Alfama Springs Case-Study (Lisbon, Portugal).

Ramalho, E. C., Marrero-Díaz, R., Leitao, M., Dias, R., Ramada, A., & Pinto, C. (2020). Alfama springs, Lisbon, Portugal: Cultural geoheritage throughout the centuries. *Geoheritage*, 12, 1–14.

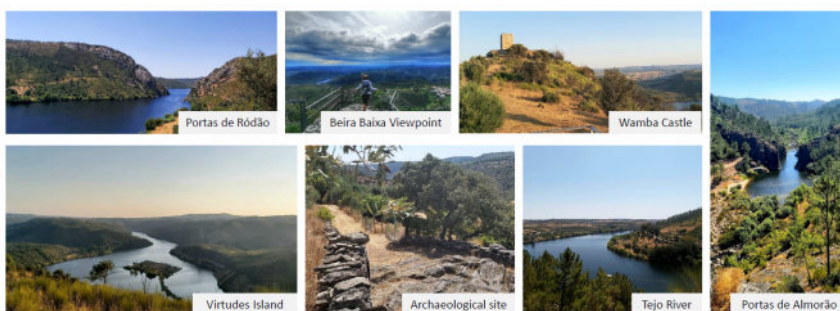
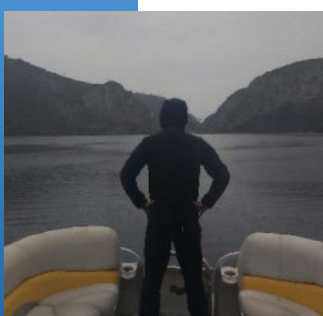
SUN. OCT. 22ND

GEONATOUR

We will participate in a fully guided day organized by Geonatour: 'Dive' in the Doors of Portugal. **Meet @ Lisbon Chillout Hostel (7:45 am).**
Please bring 150€ (cash preferred).



VILA VELHA DE RODÃO



PORTAS DE RODÃO BOAT TOUR

Explore Portas de Ródão by boat, Portugal's stunning natural monument. Sail through the towering quartzite pillars along the Tagus River and immerse yourself in ancient geological wonders and breathtaking landscapes.

PORTAS DO ALMOURÃO

Portas do Almourão, a natural wonder in Portugal, features towering quartzite formations sculpted by time. Explore this geological marvel, where ancient history is etched in stone, amidst the captivating beauty of nature.

MEALS

Breakfast: Independent

Lunch: Restaurant da Vila Portuguesa
(not included; 20/25 EUR/person)

Dinner: ~~Independent~~

ACCOMMODATION

Hotel organized by GeoNatour
(cost included in activities)

DRIVING TIME

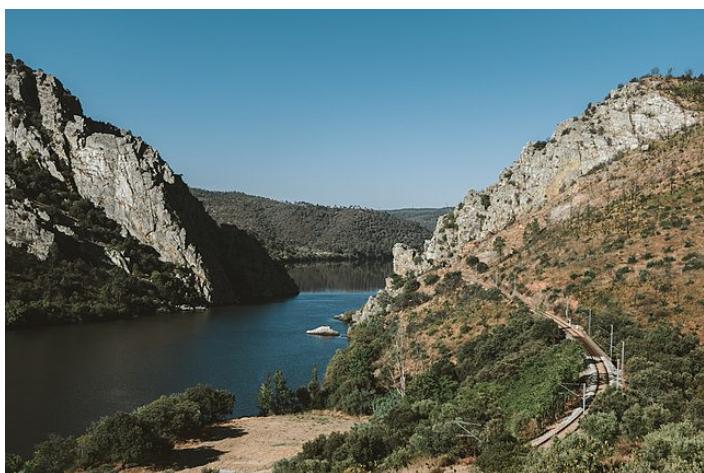
Morning: 2h15min

GEOLOGY

VILA VELHA DE RODÃO

Vila Velha de Ródão is a Portuguese village in the district of Castelo Branco.

The territory full of history written on the leaves of schist and quartzite blocks. The landscape is mainly shaped by the curves of the Tagus River and the imposing Portas de Ródão, the ex-libris of this region, which is classified as a Natural Monument and geosite of the Naturtejo Geopark.



The presence of these two natural elements enabled the establishment of prosperous ancestral human communities, as shown by the greater concentration of **prehistoric rock engravings** on the Iberian Peninsula, dispersed on the two banks of the Tagus River.



The **Portas de Ródão** is an imposing gorge carved out by the Tagus River in the quartzite crest of the Perdigão mountain range, which created a 45-meter-wide bottleneck in the watercourse. The quartzite ridges belong to the **Armorican Quartzite Formation** (dated from the Ordovician). The ridges stand out from the levels of phyllites and metagreywacke that make up the Beiras Group (upper Proterozoic) and the Cécemes Group (phyllite, Ordovician).

In addition to these geomorphological characteristics, it is possible to find conglomeratic and silty sediments corresponding to Pleistocene terraces. These terraces characterize several stages of the evolution of the **fluvial settlement of the Tagus River**, which occurred over the course of 2-3 million years.

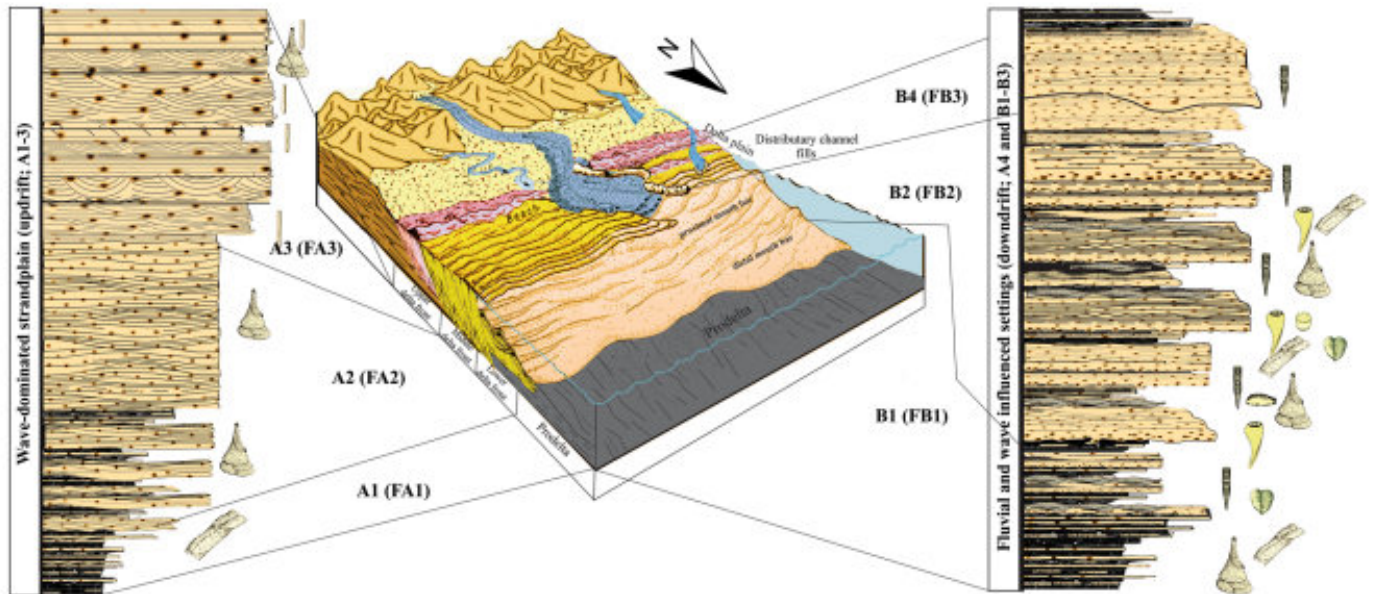


Fig. 3 Schematic sedimentological models of the Armorican Quartzite deposits in the study area (Penha Garcia Formation), showing a mixed river-influenced and wave-influenced asymmetrical delta with

a trend of along-strike variations between wave-dominated strandplain (updrift; FA1–FA3) and river-dominated deltaic settings (down-drift; FA4 and FB1–FB3)

MON. OCT. 23RD

FRONTEIRA

Today's activities are graciously supported by the municipalities of Fronteira, Cabeço de Vide, Alter do Chão, and Alter Pedroso. Carla Rocha, a PhD student at Instituto Superior Técnico (ULisboa), will be our guide. **Meet @ Hotel Entrance (7:45 am).**

FRONTEIRA

Guided tour to the Battle of Atoleiros Interpretation centre:
The Battle of Atoleiros was fought on April 6, 1384 between Portuguese forces commanded by Nuno Álvares Pereira and a Castilian punitive expedition sent by João I of Castile. It was the first battle during the crisis of 1383-1385 and the first victory won by the Portuguese general.



CABEÇO DE VIDE THERMAL BATH

Guided visit to Cabeço de Vide thermal bath. Cabeço de Vide, best known as Termas da Sulfúrea, represents the remains of an ancient Roman bathhouse that dates from the time of Augustus Caesar (119 BC). The healing properties of these waters have been used for about 4,000 years, and are recommended for the treatment of osteo-articular conditions, respiratory problems and skin diseases.



ALTER DO CHÃO E ALTER PEDROSO

Visit to the castle, to the museum Casa do Álamo and to the museum Casa da Medusa.



MEALS

Breakfast: Independent

Lunch: Organized by the municipality of Fronteira

Dinner: Organized by the municipality of Fronteira

ACCOMMODATION

Organized by the municipality

DRIVING TIME

Morning: 1h 15min





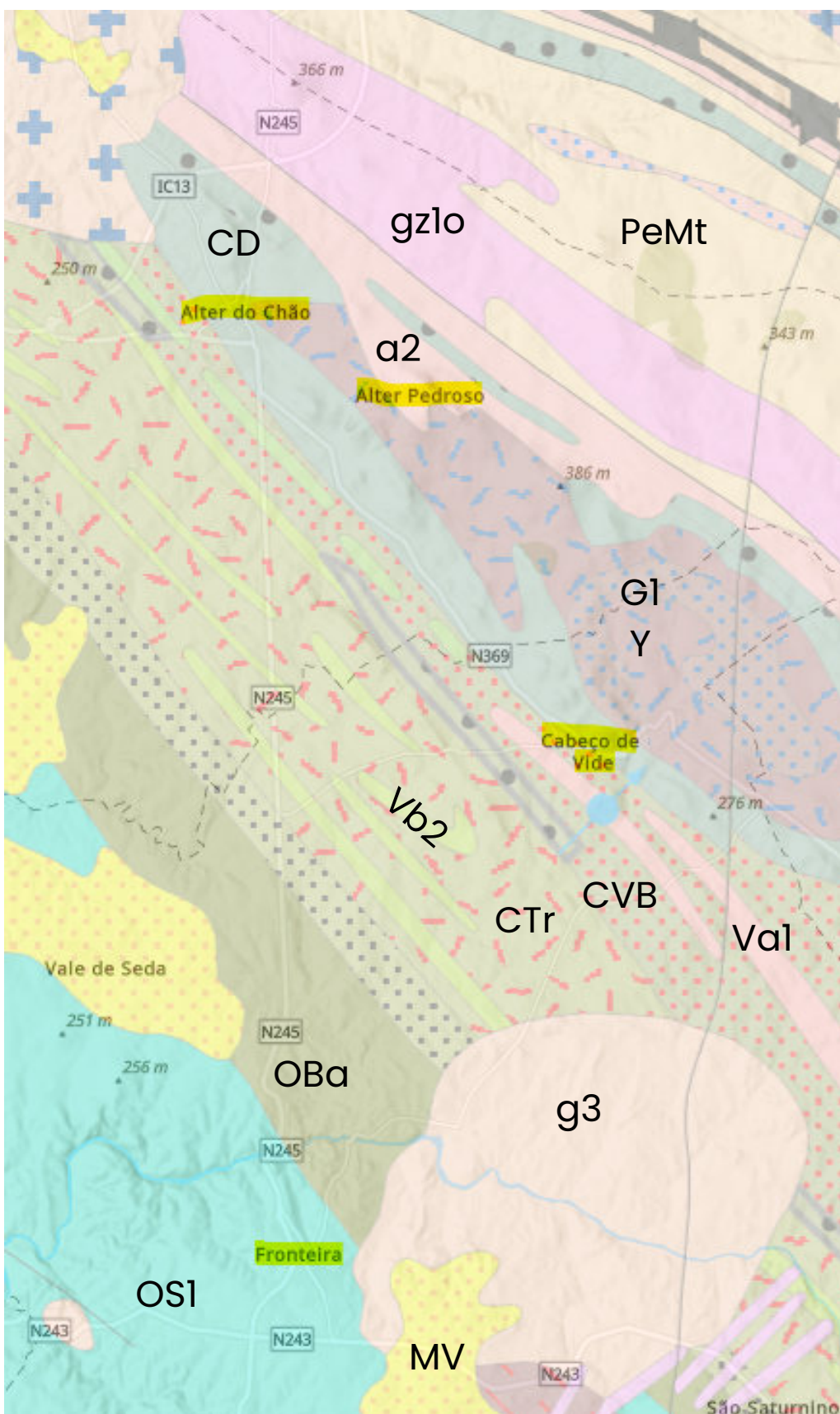
GEOLOGY

FRONTEIRA, CABEÇO DE VIDE & ALTER DO CHÃO

The geology of Fronteira, Cabeço de Vide, and Alter de Chão is influenced by their location within the **Ossa Morena zone**, a tectonic region in Portugal. Here, mineral waters emanate from boreholes and natural springs situated at the junction of the Alter do Chão pluton and the Cambrian **carbonate metasediments** of Elvas.

The **Alter do Chão pluton**, an elongated structure following the Variscan orientation, constitutes a ring-like intrusion with mafic rocks enveloping the ultramafic core. This pluton, originating from the Ordovician era, displays a cumulate-type structure, comprised of **ultramafic** (dunites, serpentized dunites, serpentinites, and peridotites) and **mafic** rocks (mostly gabbros).

The presence of serpentized peridotites, extending vertically to considerable depths, is indicative of geological processes that have shaped the Ossa Morena zone over time. This distinctive geology has left a significant imprint on the landscape of the region (Etiope et al., 2013).



(PeMt) Formação de Mosteiros: xistos, grauvaques, chertes negras, anfibolitos e calcários

(gz1o) Ortognaisses

(CD) Calcários dolomíticos; mármore

(a2) Rochas peralcalinas

(G1) Gabros anortosíticos

psi (Y) Peridotitos

(CVB) Formação Vila Boim: xistos e arenitos

(Va1) Formação Vila Boim: vulcanitos ácidos

(CTr) Xistos (C.V.S. Terrugem)

(Vb2) Vulcanitos básicos (C.V.S. Terrugem)

(OBa) Formação de Barrancos: xistos cinzentos esverdeados e roxos, psamitos.; Arenitos e conglomerados na base no Alto Alentejo

(g3) Granitos biotíticos

(MV) Formação de Vale do Guiso

(OS1) Xistos negros e liditos (Silúrico); Xistos cinzentos e psamitos (Ordovício) não diferenciados

Geological Map of Fronteira, Cabeço de Vide & Alter de Chão (GeoPortal LNEG)

Fun fact

In October 2012, NASA scientist Steve Vance was in Cabeço de Vide to validate a geological analysis method that would be used on probes sent to Mars. Mars was announced in various media as the place where life could have begun, perhaps mistakenly; so to test that theory, the thermal waters were chosen for the study because they are possibly equivalent to those found on planet Earth when the first living organisms were generated.

It all started in 2008, when Steve Vance discovered that Portuguese professor and researcher José Manuel Marques, from the Instituto Superior Técnico, had studied the type of active geology found in that region of the Alentejo, where water interacts with the rock in an unusual way.

The aim of the work was to define more precise parameters in order to be able to identify signs of life from geological and hydrogeological analyses. The researcher was trying to demonstrate that he could use a spectrometer identical to the one on board Curiosity to look for signs of active geological processes.

When gases such as methane, for example, are detected in a particular environment, it is difficult to tell with the naked eye if the gases were produced by living organisms or if they are the result of geological processes. More measurements are needed. And it is this phase of the analysis that Steve Vance wants to refine.

The samples collected in Cabeço de Vide were analysed in the field and the preliminary results seem to indicate the presence of methane and ethane in the samples. Now it's a question of going a little further and try to understand whether the origin of these gases is produced by living organisms or just a result of active geology.

TUES. OCT. 24TH

CASTELO DE VIDE

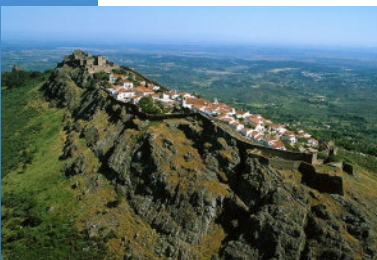
The first activity is graciously supported by the municipality of Castelo de Vide. The rest of the day will be guided by Carla Rocha.

Meet @ Municipality Accommodation Entrance (7:45 am).



CASTELO DE VIDE THERMAL BATH

Guided tour by Carolino Tapadejo (municipality of Castelo de Vide) to the ancient thermal baths.



MARVÃO

Guided tour to the castle.

Perched atop granite cliffs, this medieval fortress offers panoramic views, rich history, and an authentic step back in time.

"De Marvão avista-se toda a terra ... É compreensível que deste sítio, no alto da torre de menagem do Castelo de Marvão, o visitante murmure respeitosamente: "Como é grande o mundo".

José Saramago, Nobel Prize-winning author



NISA (PORTUGUESE POTTERY)

Quick stop to visit the town and browse the traditional Portuguese pottery.

MEALS

Breakfast: Pack a breakfast!

Lunch: Pack a lunch!

Dinner: Independent in Coimbra

DRIVING TIME

Morning: 1h

Evening: 2h

ACCOMMODATION

Penedo da Saudade Suites & Hostel

Av. Dr. Av. Marnoco e Sousa 18B, 3000-271 Coimbra, Portugal

Hotel Botanico de Coimbra

(ao cimo da Rua dos Combatentes da Grande Guerra), Bairro São José, Coimbra, Portugal

Change the world hostels - Coimbra - Almedina

R. de Fernandes Thomas 11, 3000-168 Coimbra, Portugal

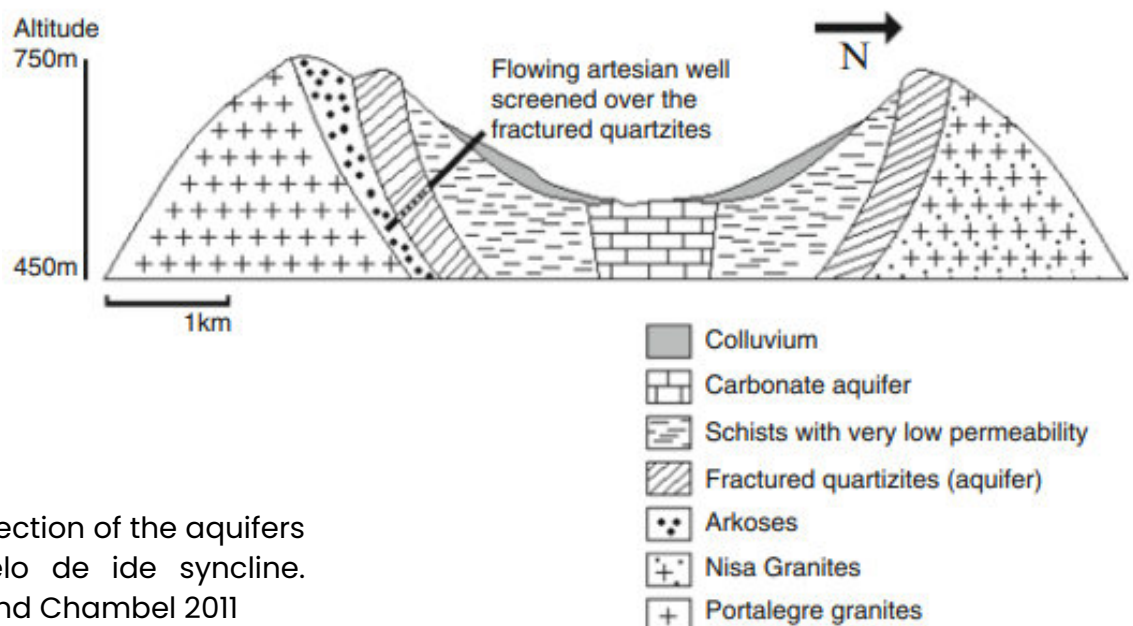
GEOLOGY

CASTELO DE VIDE

Castelo de Vide is a Portuguese village in the district of Portalegre.

This site is located in a transpressional shear zone of the SW Iberian Massif, in a 40 km long syncline that has a NW-SE axis and a maximum width of 10 km perpendicular to its axis.

This syncline contains several aquifer units. The contact of the syncline with the surrounding granites (Nisa granites to the NE and Portalegre granites to the SW) is marked by Ordovician quartzites. These quartzites are highly fractured, forming the first semi-confined aquifer. The quartzite layer is covered by a very-low permeability schist unit. On top of the schists, a 200m thick carbonate unit located near the center of the syncline acts as the second aquifer, named the Escusa aquifer. This predominantly dolomitic unit is karstified, with field-scale evidence of karstic process such as lapiaz, shallow holes and sinking streams. The expanse of this carbonate formation is covered by terra Rossa and colluvium deposits, formed by the weathering of carbonate rocks and surrounding crystalline rocks (Monteiro and Chambel 2011).



Schematic N-S cross section of the aquifers present in the Castelo de Vide syncline. Taken from Monteiro and Chambel 2011

A particularity in Castelo de Vide history was the presence of a Jewish community throughout the 14th and 15th centuries. The Jewish quarter (known as Judiaria) in Castelo de Vide is one of the most important examples of the Jewish presence in Portugal, dating back to the time of D. Dinis in the thirteenth century. Here is to be found one of the best preserved Jewish areas in Portugal, and for some years now it has been part of a detailed plan for the recovery and revitalisation of local buildings.



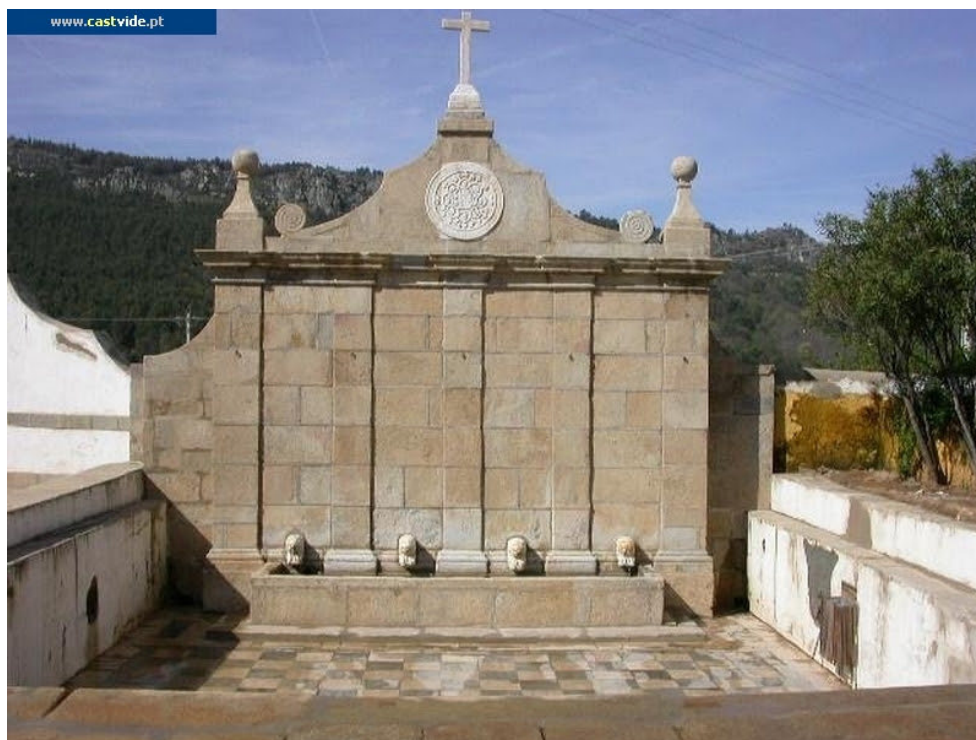
Synagogue of Castelo de Vide

The 14th-century Synagogue of Castelo de Vide in Santa Maria da Devesa still stands, and despite Portugal's expulsion of Jews in 1496 was used by Marranos as a religious sanctuary and school until the 16th century. Today it houses a small museum dedicated to Castelo de Vide's historical Jewish community.



Old Jewish quarter of Castelo de Vide

Castelo de Vide has always been known for its rich natural resources, particularly its hot springs, whose waters are said to have great healing properties. Several fountains can be found here, with the Fonte da Vila and the Fonte da Mealhada being perhaps the best known. Just one word of warning, however. If you believe in popular sayings, you should perhaps bear in mind that it is believed that anybody drinking water from the Fonte da Mealhada will one day return to Castelo de Vide to get married.



Fonte da Mealhada

GEOLOGY

MARVÃO

Marvão, the “Mui Nobre e Sempre Leal” village, got its name from Queen Maria II. It is located between the village of Castelo de Vide and the city of Portalegre, well within the borders of Parque Natural da Serra de S. Mamede.



Marvão and Serra de S. Mamede on the background.

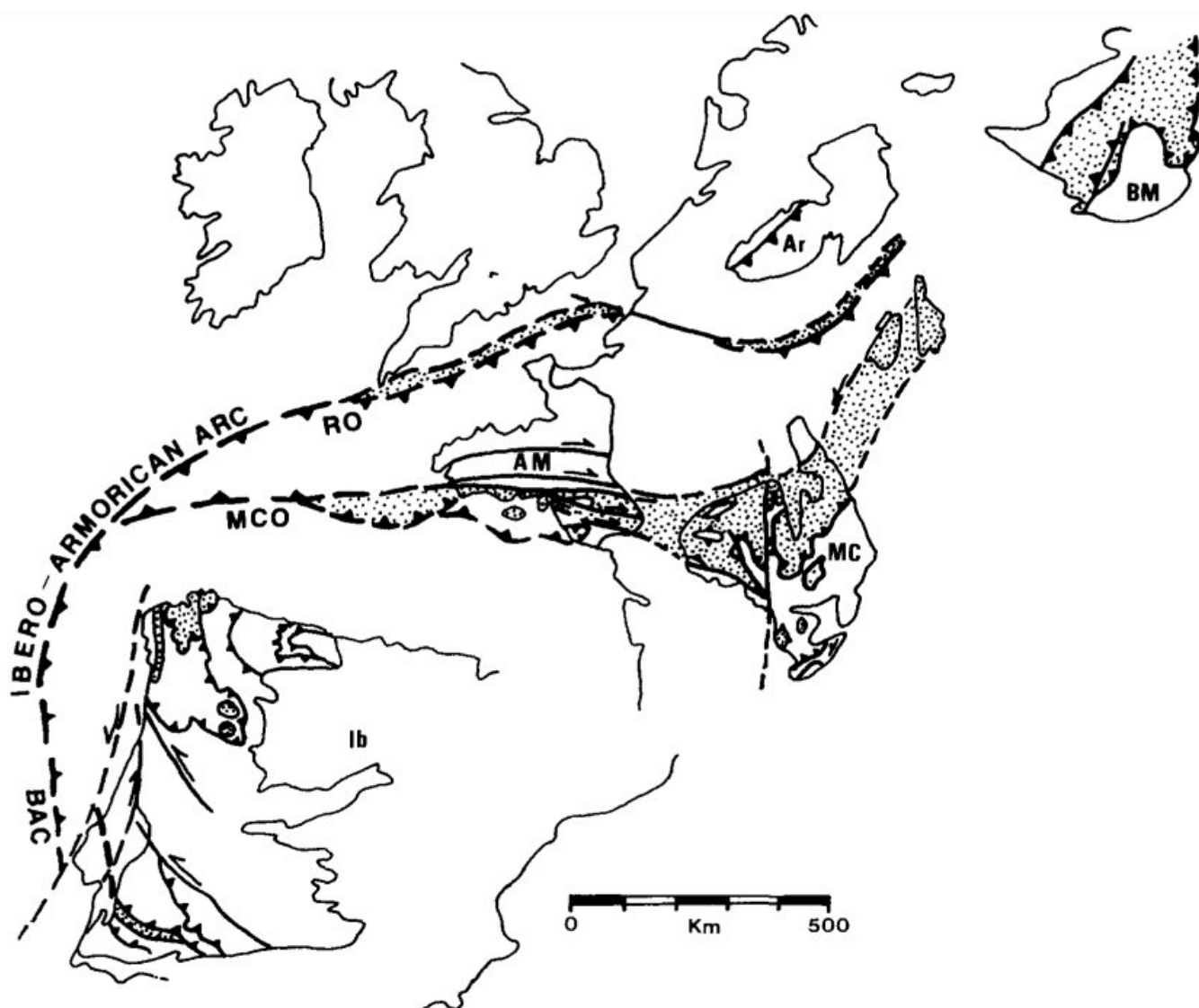


Serra de São Mamede is a mountain range in Portalegre District, one of the few places in the Alentejo region where there might be snow in the winter. This range is part of the western end of the greater Montes de Toledo, which is one of the main mountain ranges of the Iberian Peninsula. This range stretches for about 25 km in a NE-SW direction between Castelo de Vide and La Rabaza, Cáceres Province, Extremadura, at the border of Spain. The highest peak is Pico de São Mamede (1,025 m), which is also the highest summit in Portugal south of the Tagus river.

The Serra de São Mamede separates the drainage basin of the Tagus river to the north and the Guadiana river to the south. The main rivers that have their sources in this mountain range are the Sever and Nisa, which flow towards the Tagus, and the Caia and Arronches, which flow towards the Guadiana.

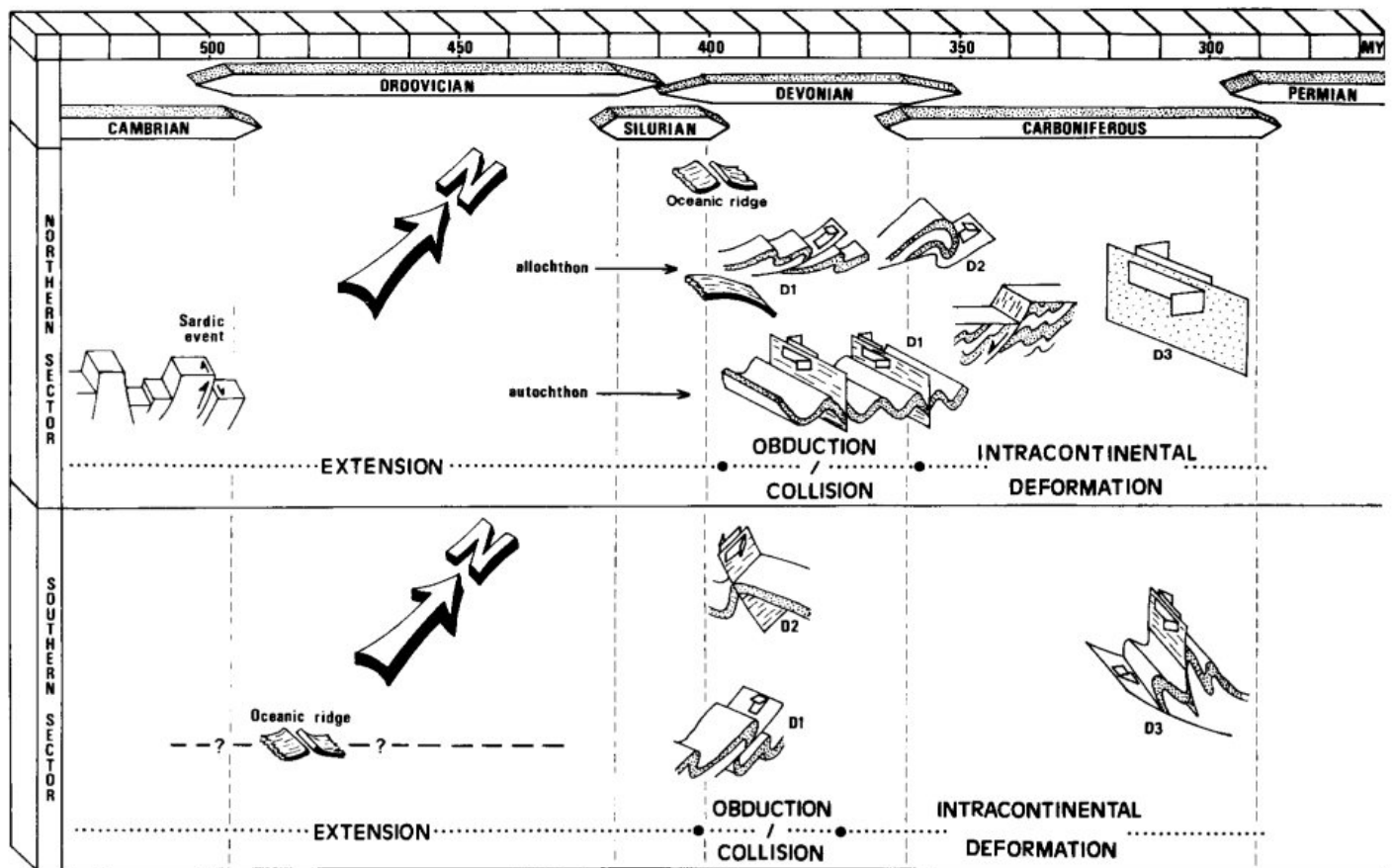
The Serra de São Mamede Natural Park is a protected area located within the limits of the range. The park features one of the largest bat colonies in Europe. The griffon vulture and Bonelli's eagle are also known to nest in the range.

Quartzite and dolomite are predominant, especially in the higher levels of the range. Granite is present in the southwestern expanse of the mountains between Portalegre and Fortios. The synclinal structure of the Serra de São Mamede mountain range's origin is associated with the formation of the Armorican Arch.

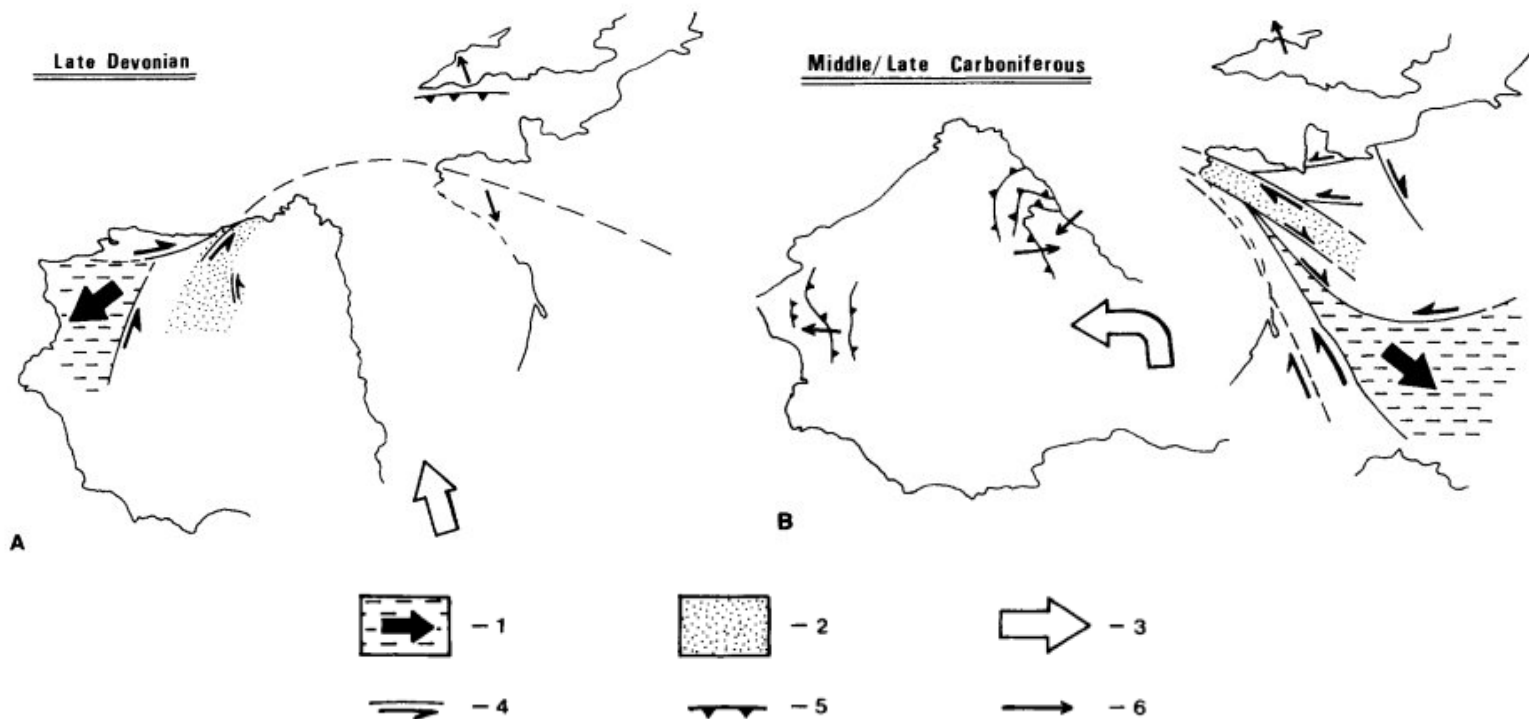


Correlation between the Variscan sutures in western Europe. The stippled areas correspond to the innermost crystalline nappes with horizontal foliations, ophiolitic remnants and related root sutures. RO = Rheic Ocean; MCO = Massif Central Ocean; BAO = Beja-Acebuches Ocean; Ib ~ Iberia; AM = Armorican Massif; SE = southwest England; MC = Massif Central; AR = Ardenne; BM = Bohemian Massif (Dias and Ribeiro, 1995).

The Ibero-Armorican Arc is the main Variscan macrostructure in western Europe. Although its genesis is still debatable, most scholars agree on the general geodynamic evolution of this virgation (i.e., a branching arrangement of fault lines) in both branches. In the Middle to Late Devonian, Iberia was deformed by a sinistral transpressive regime, while in the northern branch thrusting events were predominant. In the Carboniferous, a dextral transposition begins to predominate in the Armorican branch, while the southern branch was deformed by southward thrusting. In an attempt to correlate these events, Dias and Ribeiro (1995) propose that during the Late Devonian a Cantabrian indenter moved northward, producing the oblique closure of the southern part of the Rheic Ocean and an almost orthogonal closure in central Europe. In the Carboniferous, the collision with the irregular margin of Laurasia induced a rotation of the indenter; the intracontinental deformation was then achieved by dextral transposition in the northern branch and thrusting in the southern one.



Timing of the main deformation events in the Iberian Peninsula during the Variscan cycle (Dias and Ribeiro, 1995).



Sketch of the geodynamic evolution of the Ibero-Armorican Arc. (A) Late Devonian. (B) Middle/Late Carboniferous (adapted from Matte, 1986a,b). 1 = lateral escape; 2 = transpressive regime predominant; 3 = movement of the Cantabrian indenter; 4 = main strike-slip faults; 5 = main thrusts; 6 = facing and sense of movement in nappes (Dias and Ribeiro, 1995).

Marvão and its role in the history of Portugal

The town of Marvão is an ancient, fortified town located on a ridge of the Serra de São Mamede mountain range. Its emblematic castle is an archetype of medieval architecture. It dates back to the times of the Reconquista, the reconquest of the Iberian Peninsula from the Moors (a term used by Christian Europeans to designate a label for the Muslim populations of the Maghreb, al-Andalus (Iberian Peninsula), Sicily and Malta during the Middle Ages).

Marvão was once conquered by King Afonso Henriques of the Moors. Later, in 1190, the people of Marvão re-conquered the town. But, in the year of 1226, King Sancho II imposed one of the first royal charters in Alentejo on the population. This was followed by the final regain of Marvão castle, three years later, in 1229.

Because Marvão lies further up in Serra de S. Mamede, enemies did not have the easiest access. The town's locale provided a great advantage to those housed inside its walls historically, since its natural defenses prevented enemy access. Defensive reasons were, of course, at the root of its birth.

Marvão was the only Portuguese fortification with a strategic purpose until the 19th century. It was part of the first defensive line of the territory and it is still the richest in historical and military heritage. Here, people fought and won both physical and political battles against their external opponents.



Marvão – heritage and monuments

South of Marvão Castle slope, in the center of Parque Natural da Serra de S. Mamede, it is possible to observe the ruins of the Roman city Ammaia. Builders took many stones from the ruins to aid the construction of Marvão walls and other edifications. Only a few old, abandoned walls were left standing because their materials were not important.

Legend says that dirt swallowed Ammaia after an earthquake. But this is only one of the many stories told to justify the disappearance of the city. What is left of it, the ruins and the museum, deserve a visit. After being studied and identified, these ruins were considered a National Monument in 1949.

In Marvão Castle, the 13th and 17th century walls protect the village and embrace the houses inside. Raised up high, it shows itself to everybody with its winding narrow streets and houses painted in the white, Alentejo style.



The walls in Marvão are a monument that we won't forget for their greatness but the village is not just all about walls. Marvão is also historically rich in the 15th-century Igreja Matriz and the old Igreja de Santa Maria (churches). Today, the last one has become the Municipal Museum. Here, it is possible to admire local ethnological and archeological collections (menhirs, dolmens and a Roman fountain), as well as remains of thousands of years of people living here. In fact, the most ancient historical remains dating back to Paleolithic and Neolithic times are exhibited in the Museu Municipal.



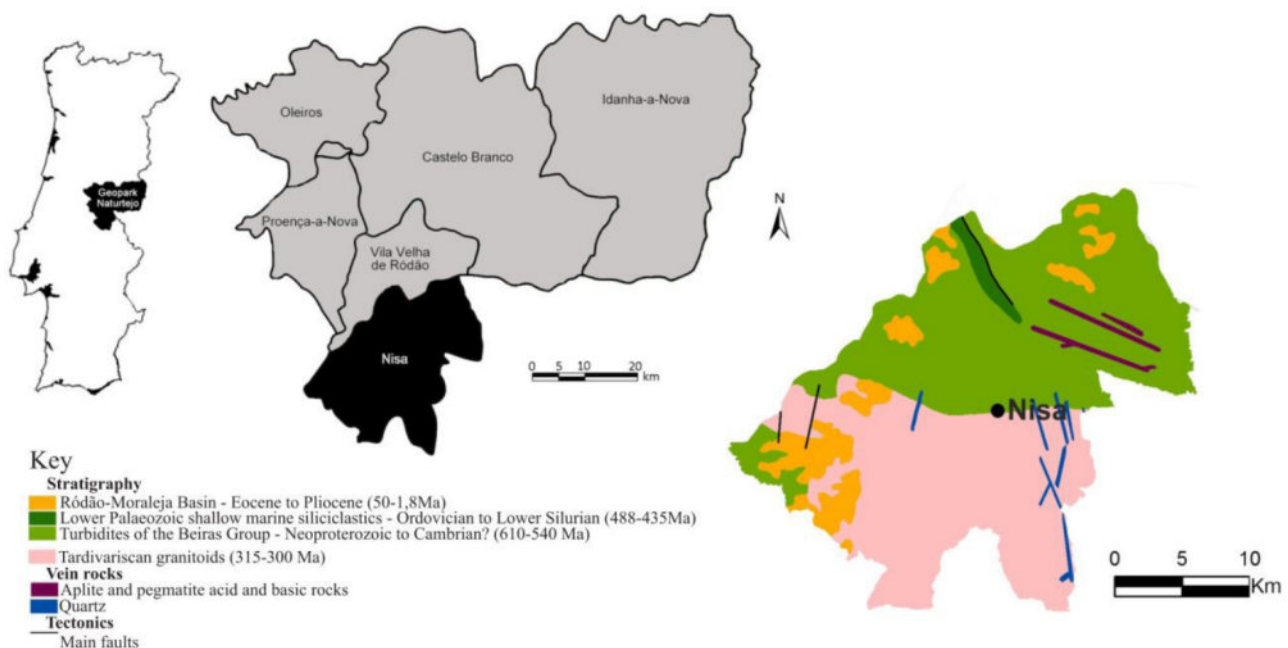
GEOLOGY

NISA

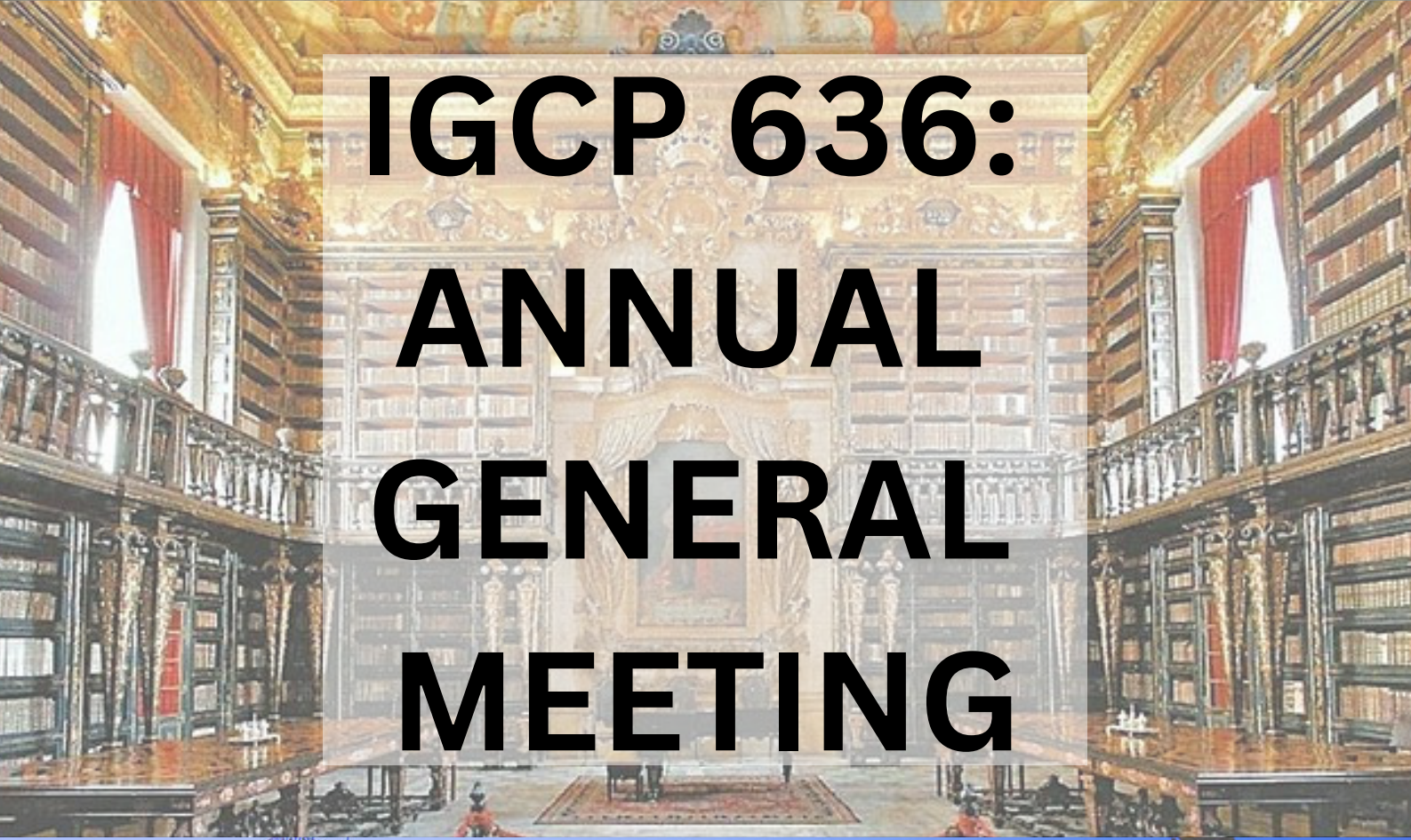
Nisa is located to the northwest of Castelo de Vide. It is part of the Southern Meseta Naturtejo Geopark since 2006 (Neto de Carvalho et al. 2014).

The pre-Ordovician Beira Schist formation, with outcrops over large parts of Western Iberia, forms the northern part of the Nisa region (Deekers et al. 1989). Phyllites and quartzphyllites with minor intercalations of more Ca-rich rocks are typical.

The southern side of the Nisa region is formed by a Paleozoic rock outcrop of Ordovician to Middle Devonian age (Peireira et al. 2015). It is mainly composed of quartzites, coarse sandstones and slates. These rocks were intruded during the Hercinian orogeny by acidic magmatic intrusions and plutons of coarse to very coarse-grained porphyritic biotite granites. Intrusion of this hot magma formed a 2 km wide thermal aureole in the nearby metasedimentary rocks. Uranium phosphates and oxides have been identified in the metamorphic contact zone between the Neoproterozoic turbidites of the Beiras Group and the Nisa Granite.



Location of the municipality of Nisa in the Naturtejo Global Geopark territory and the simplified geological map. (Neto de Carvalho et al. 2014)

A photograph of the interior of the University of Coimbra Library (Biblioteca da Universidade de Coimbra). The room is grand, with high ceilings, ornate wooden bookshelves filled with books, and a large, ornate wooden table in the center. The walls are decorated with murals and frescoes. The text "IGCP 636: ANNUAL GENERAL MEETING" is overlaid in large, bold, black letters on a semi-transparent white background.

IGCP 636: ANNUAL GENERAL MEETING





WED. OCT. 25TH

MEETING

The University of Coimbra Earth Science department and the Geosciences Center will be hosting the IGCP636 Group meeting.
Meet @ Earth Science Building Entrance (7:45 am).

University of Coimbra - history:

Founded in 1290 by King Dinis, the University of Coimbra (UC) is one of the oldest universities in the world and the oldest in all of Portugal. Having existed for over seven centuries, the University of Coimbra has a unique heritage, is a keystone in the scientific culture of Europe, and was coined a UNESCO World Heritage Site in 2013.

Keynotes:

- (1) GEOTHERMAL RESOURCES IN PORTUGAL - DGEG
- (2) CASE STUDIES IN LOW-ENTHALPY GEOTHERMY IN PORTUGAL: LARGE AND SMALL PROJECTS - SYNEGE
- (4) LNEG'S ROLE IN GEOTHERMAL RESOURCES RESEARCH - LNEG
- (3) THE CHAVES GEOTHERMAL PROJECT - TBD

MEALS

Breakfast: Independent

Lunch: University Cafeteria (8 EUR)

Dinner: Group dinner in Coimbra - Cervejaria Praxis

<https://linktr.ee/beerpraxis>

ACCOMMODATION

Penêdo da Saudade Suites & Hostel

Av. Dr. Av. Marnoco e Sousa 18B, 3000-271 Coimbra, Portugal

Hotel Botanico de Coimbra

(ao cimo da Rua dos Combatentes da Grande Guerra), Bairro Săo Jos , Coimbra, Portugal

Change the world hostels - Coimbra - Almedina

R. de Fernandes Thomas 11, 3000-168 Coimbra, Portugal



Grupo Português da
Associação
Internacional de
Hidrogeólogos





AGENDA

08h00 – Reception

09h00 – Welcome words

Pedro Dinis (DCT) and Maria Helena Henriques (CGeo)

09h15 – IGCP 636 Introduction

Daniela Blessent (Universidad de Medellin)

09h30 – Keynote Talk: Geothermal resources in Portugal

Carla Lourenço and *Luis Duarte Silva* (DGEG)

10h00 – Coffee Break

10h15 – Keynote Talk: Case studies in low-enthalpy geothermy in Portugal

Pedro Madureira (SYNEGE)

10h45 – Keynote Talk: LNEG's role in geothermal resources research as a national and European geological service

Elsa Ramalho (LNEG)

11h15 – Coffee Break

11h30 – Keynote Talk: The Chaves Geothermal Project

TBD

12h00 – Lunch – Centro Cultural Casa da Pedra (UC)

13h30 – Geothermal activities at B.E.D. & Project InnerSpace

Jackson Grimes (Bureau of Economic Development, U.S.A.)

13h45 – Preparing a one-stop shop for geothermal in Slovenia

Nina Rman (Geological Survey of Slovenia)

14h00 – Geothermal exploration in Northern Canada

Jasmin Raymond (INRS)

14h15 – Coffee Break

14h30 – IGCP meeting

15h00 – Coffee Break, Poster Session & Laboratories Visit

17h00 – Tour at the Old University (optional)

20h00 – Group Dinner at restaurant – Cervejaria Praxis (\$\$)



Grupo Português da
Associação
Internacional de
Hidrogeólogos



UNIVERSIDADE DE
COIMBRA



POSTERS

Institut national de la recherche scientifique (Canada)



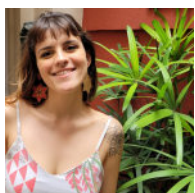
Garen Thomas

Geothermal Reservoir Analysis of the Fort Liard region, Northwest Territories, Canada



Michael Thibault

Geothermal potential of the South Slave Region, Northwest Territories, Canada.



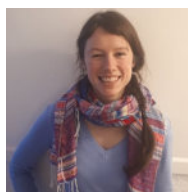
Mariana Goldoni

Geothermal and geochemical considerations in open-loop systems in Quebec's former open-pit mines



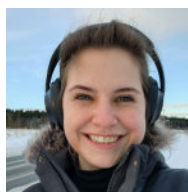
Fiona Chapman

Heat Flow Assessments in southwestern Yukon using Fibre-Optics.



Violaine Gasquel

Repurposing idle wells for the heat transition: Dynamic modelling of a deep borehole heat exchanger system



Abra Gold

Minimize permafrost thaw and maximize underground thermal energy storage



Victoria Lee

The potential of groundwater heat pump systems for urban heat island mitigation: aquifer suitability assessment in Canada's major cities

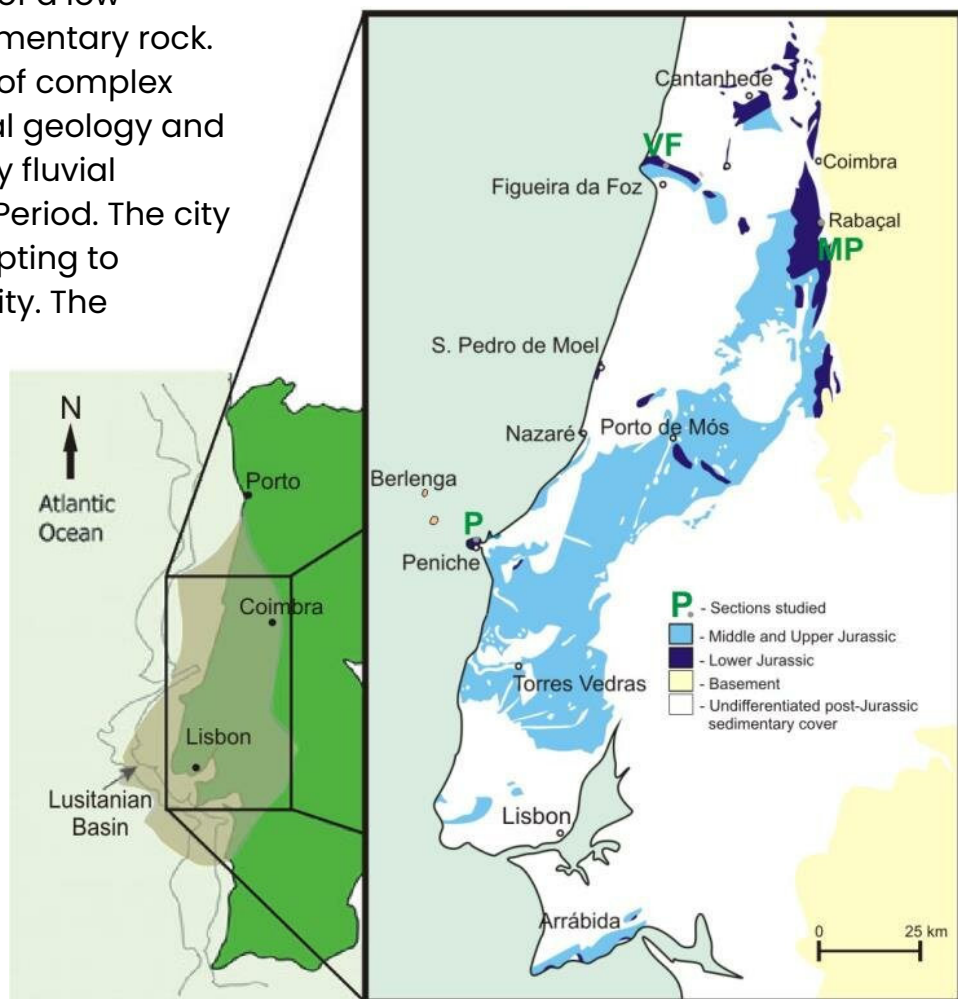
GEOLOGY

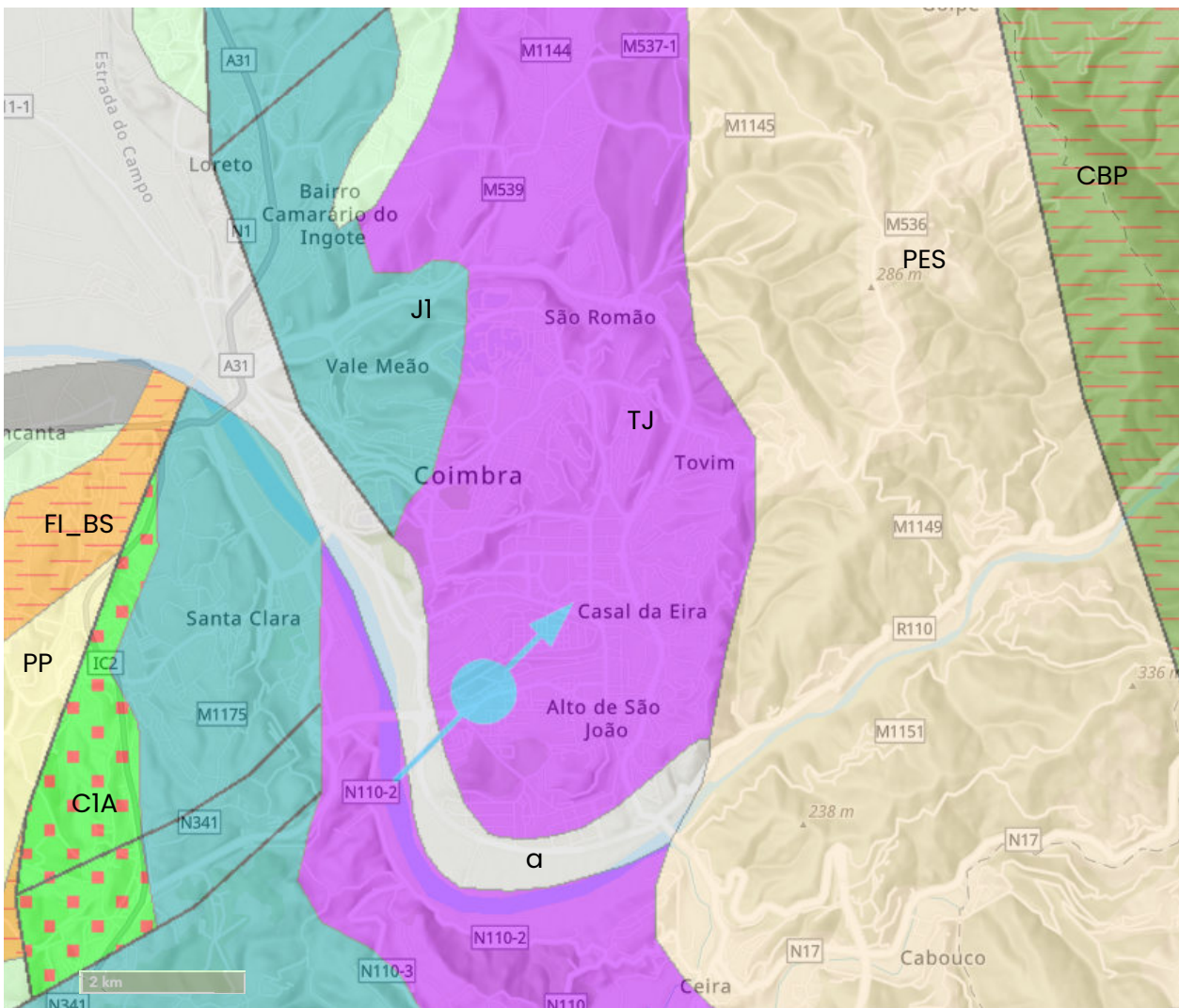
COIMBRA

Geological setting

Located in the **transition** between the **Old Massif** and the **Western Meso-Cenozoic Border**, its territory has a morphostructural base. The western and central sectors are made up of sedimentary materials within the marly limestone hills and the alluvial plain of the Mondego River. The eastern sector consists of a low mountain developed in metasedimentary rock. This mountain formed as a result of complex relationships between the regional geology and tectonics and was later shaped by fluvial dynamics during the Quaternary Period. The city developed and expanded by adapting to morphological and lithic complexity. The tectonic step that forms the edge of the eastern mountainous terrain contrasts with the level planes of the limestones and (very compact) Mesozoic sandstones. It also contrasts with the valley bottoms (those in the Mondego plain, as well as those in the fingers of its affluents), offering very unique transient conditions for the installation and development of the city.

The location and geological setting of the Lusitanian Basin of western Portugal





Geological Map of Coimbra (GeoPortal LNEG)

CBP: Central Iberian Zone (basement)

- Schist-Grauvache Complex, Beiras Group
- Perais Formation: turbidites

TJ: Orla Ocidental (Lusitanian Basin)

- Triassic-Jurassic of the Orla Ocidental
- Dagorda (pelites and evaporites), Pereiros (carbonates) and Silves (sandstones) formations

C1A: Orla Ocidental (Lusitanian Basin)

- Lower Cretaceous of the Orla Ocidental
- Torres Vedras Sandstone; Almargem Sandstone; Carrascal Sandstone; Palhaça and Requeixo Sandstones

PP: Cobertura Cenozóica (overburden)

- Pliocene deposits of Minho, Trás-os-Montes, Beira Alta and Beira Litoral
- Aguada and Barracão formations; Carnide, Pombal, Águas Santas and S. Pedro de Muel deposits

PES: Ossa Morena Zone (basement)

- Proterozoic of the Northwest Edge of the Ossa Morena Zone
- Shales, grauvaques, black cherts and acid volcanites

JI: Orla Ocidental (Lusitanian Basin)

- Triassic-Jurassic of the Orla Ocidental
- - Dagorda (pelites and evaporites), Pereiros (carbonates) and Silves (sandstones) formations

FI_BS: Cobertura Cenozóica (overburden)

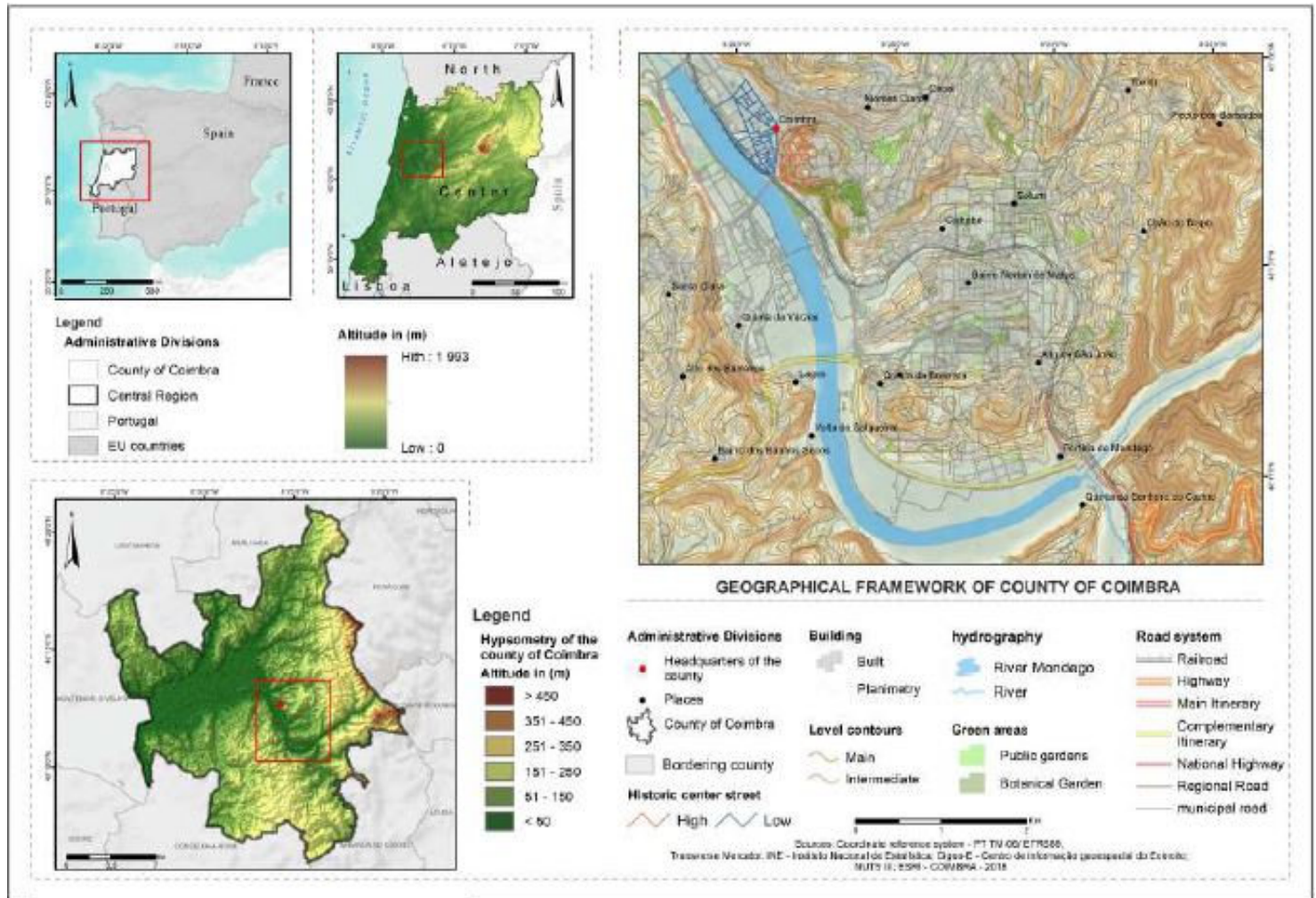
- Paleogene deposits of Minho, Trás-os-Montes, Beira Alta and Beira Litoral
- Bom Sucesso Formation

a: Cobertura Cenozóica (overburden)

- Overburden deposits
- Alluvial sediments

Coimbra's regional geographical setting in the Iberian Peninsula

From antiquity Coimbra has enjoyed a strong geostrategic position in the western sector of the Iberian Peninsula. Coimbra, located in a central coastal region of Portugal has long been an important node in the network of north/south connections and coastal/interior communications (with the Mondego River serving as a waterway). Coimbra became the **capital of the Kingdom of Portugal**, even before 1179 (the year of Papal recognition), a status it kept until 1255.



Geographical setting of the city of Coimbra on the Iberian Peninsula, in the Central Region of Portugal, municipality of Coimbra (Cordeiro, 2021).

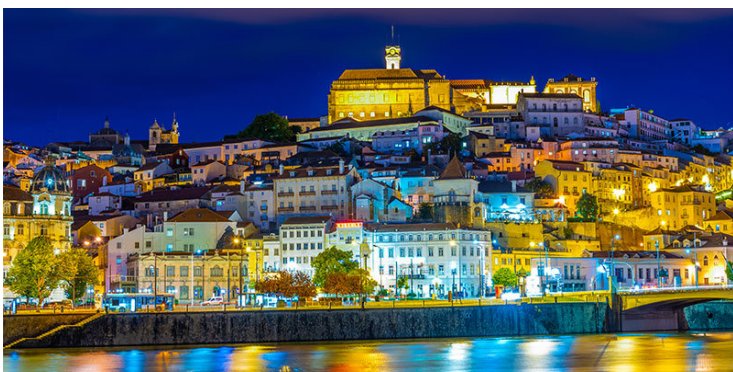
The perfect adaptation of the historic city to the morphological system

Coimbra's defensible territorial position was clearly taken advantage of from the time it was founded up to border consolidation of the Kingdom of Portugal. The position, morphological, and lithological features all influenced the **medieval urban design** of Coimbra.

The **“hill city”**, very closely associated with the function of power and defense, was initially developed on a hill of compact Jurassic limestone, on which successive “layers” of civilizations were built —Roman, Mozarabs and Medieval. The medieval “suburbs” grew up in the shadow of the protective castle, on a plain made up of alluvia (clays and silts) that reaches depths over 60 meters. The urban expansion both during and after the 11th century —mostly due to the borders of the Portuguese Kingdom moving southward as a result of the Christian reconquest — led to the expansion of the “suburbs” in the direction of the Mondego River. This created an urban design quite different from the one previously adapted to the limestone hill on which the castle had been set up. The castle’s defensive function lost its importance when the city changed from a border city to a crossroad city.

At the beginning of the 20th century, technological transformations brought communications and transportation structures, offering a way to advance the expansion beyond the medieval and 19th-century axis. The setting up of different electric tram lines, especially on the level ground of consolidated sandstone and limestone, enabled connections with new outlying neighbourhoods. There was a growing urban development in formerly rural territories during this time: Cumeada, Montes Claros, Conchada, Calhabé (the latter in the area southeast of the old town centre), and Tovim, thus increasing the city’s population.

The progress of the city of Coimbra up to the beginning of the 20th century was associated with its medieval heritage, but the urban expansion of the first half of this century is a direct reflection of local morphology. The city grew on the level ground surrounding the “Ribela” during this stage. This level ground consists of very hard rock, highly consolidated sandstone and slightly marly limestone and allowed for electric tram tracks to be laid.







THURS. OCT. 26TH

S. PEDRO DO SUL

Today's visit is organized with the support of Luís Gomes, the spa technical director, and Fátima Saraiva, the spa PR. We will drive from Coimbra to S. Pedro do Sul in the morning. Rendez-vous at Rainha D. Amélia thermal bath at 10 am.

Meet @ Penedo da Saudade Suites & Hostel – Coimbra (7:45 am).

10AM – Meet at Rainha D. Amélia thermal bath reception.

- Brief explanation of the thermal bath history and technical video
- Tour of the facilities led by our Technical Director, Professor Luís Ferreira Gomes:
 - Water catchment area
 - Geothermal Centre
- Visit to the Roman thermal bath (11 am to 2 pm)



Drive to Guimarães before dinner

MEALS

Breakfast: Independent (Coimbra)

Lunch: Please pack a lunch!

Dinner: Independent (Guimarães)

DRIVING TIME

Morning: 1h30

Evening: 2h

ACCOMMODATION

Student accommodation provided by the municipality of Guimarães



HI Guimarães – Pousada de Juventude

Complexo Multifuncional de Couros, Largo da Cidade, 8, 4810-430 Guimarães, Portugal

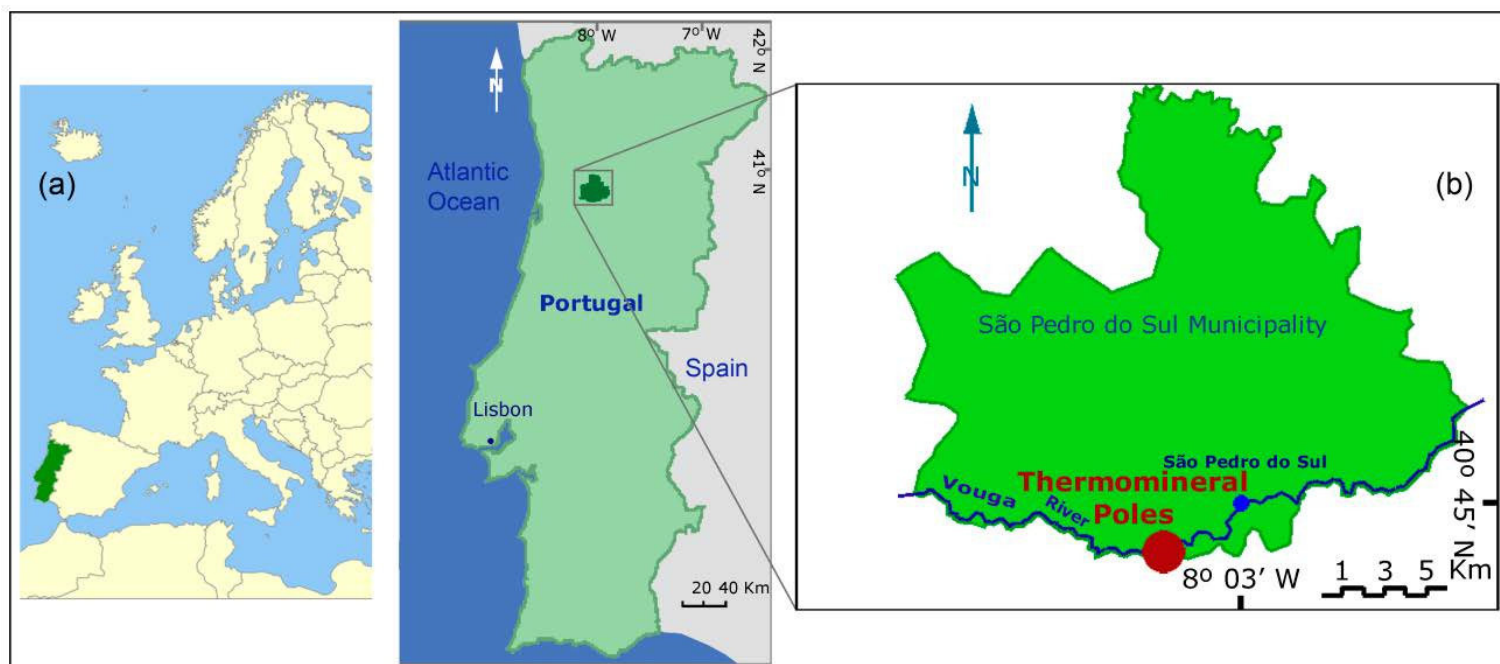
Trovador City Guest House

Largo do Trovador nº 20, 4810-451 Guimarães, Portugal

GEOLOGY

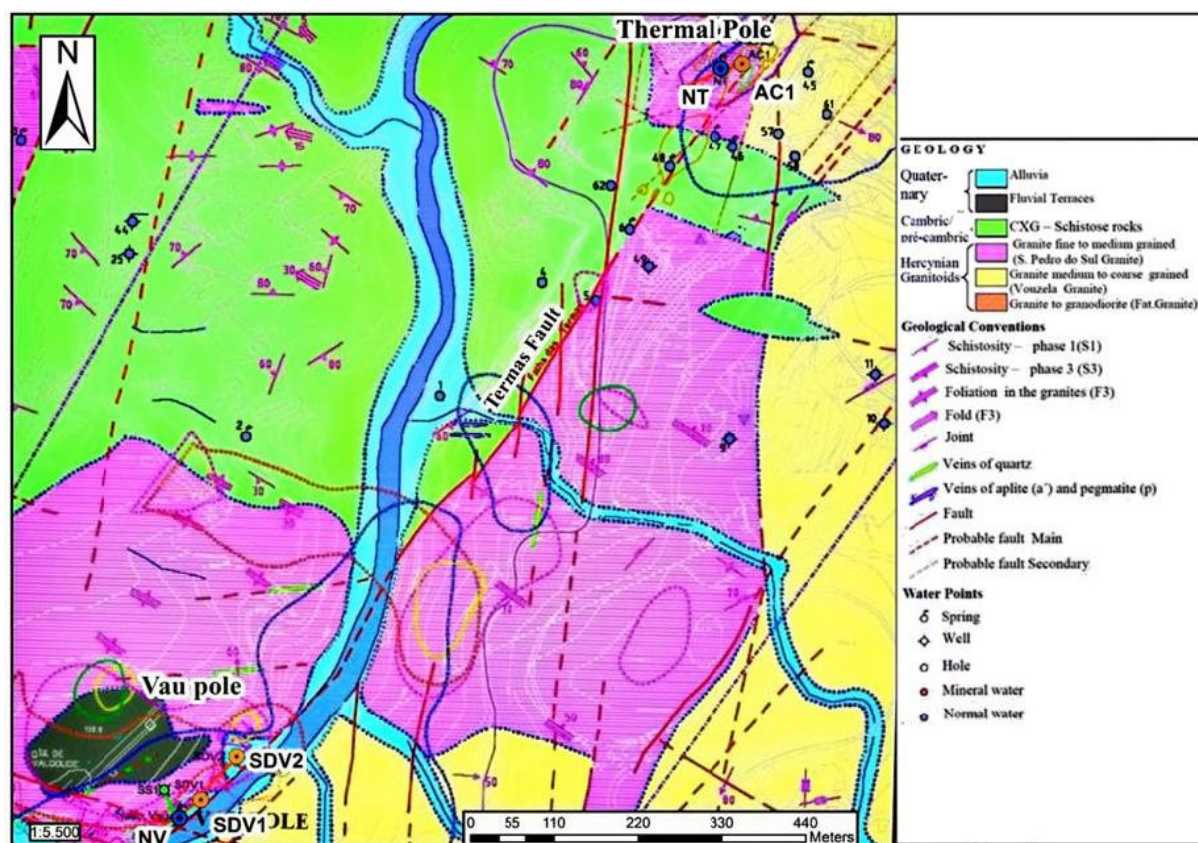
S. PEDRO DO SUL

The **São Pedro do Sul Hydromineral and Geothermal Field** (SPSHGF) is located along the course of Vouga River in the south-central section of São Pedro do Sul municipality. The SPSHGF is characterized by an area of approximately 1.5 km² and consists of the Termas Pole and Vau Pole. The poles or zones are separated by a distance of approximately 1.2 km (Ferreira Gomes et al., 2017; Almeida et al., 2022).



(a) Geographic location of Portugal (b) Geographic sketch of São Pedro do Sul municipality and thermomineral poles (obtained from Almeida et al., 2022).

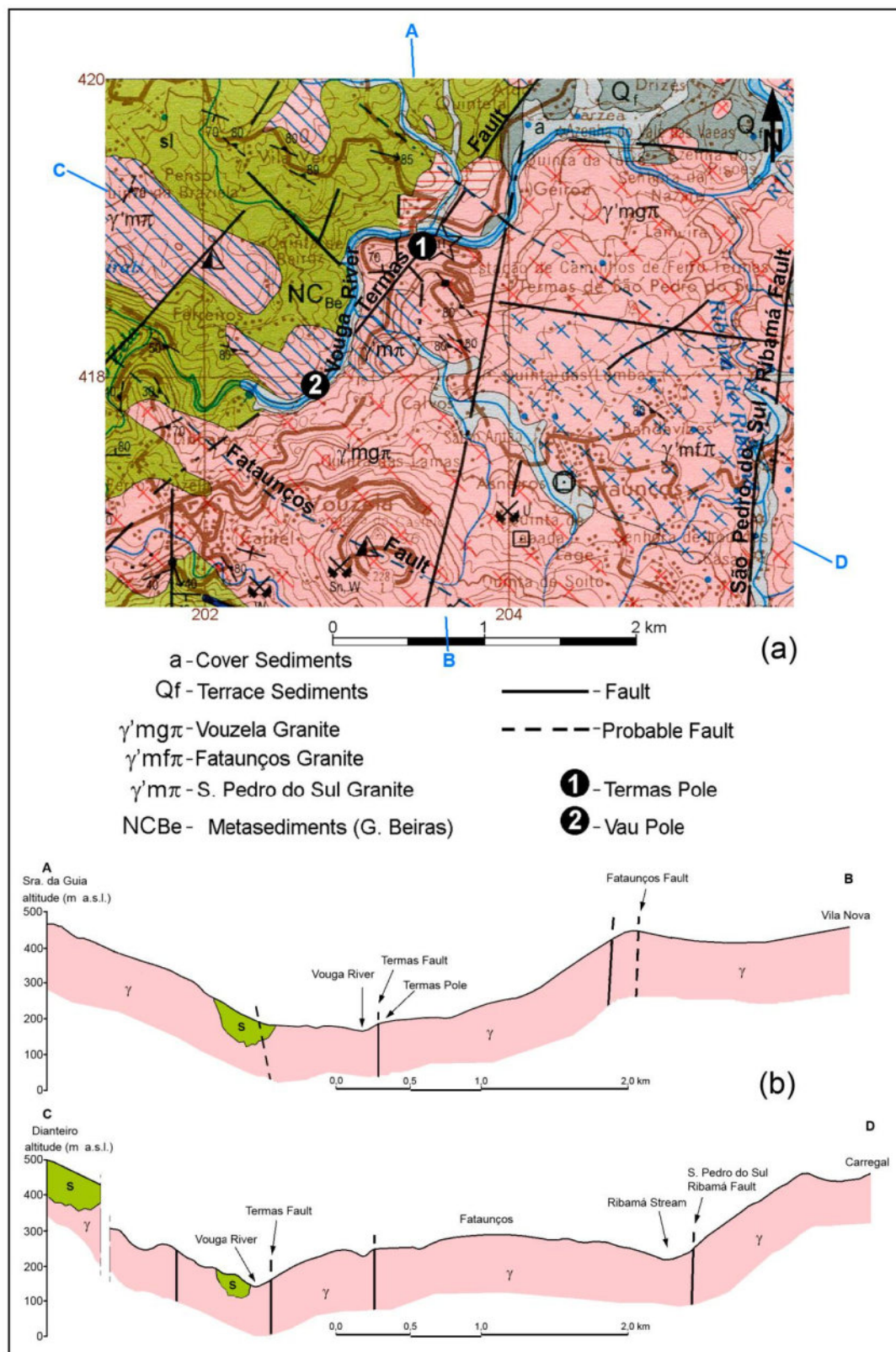
The poles or zones were developed for different purposes and each have a thermomineral spring. Production wells SDV1 and SDV2 at Vau Pole were used for the cultivation of bananas and pineapples in greenhouses until a few years ago. A water flow rate of 1.5 L/s at 67°C was mainly produced from SDV1. The SDV1 and SDV2 wells were drilled to depths of 216 m and 151 m, respectively. There have been discussions to drill a deeper well to utilize fluid temperature of approximately 75°C, but drilling has not commenced yet. The Termas Pole AC1 production well was drilled to a depth of 500 m. This borehole along with the Traditional Spring - NT supplies a flow rate of 18 L/s at 67.6°C for a District Heating System, hydro medicinal treatment, and the Medical SPA of S. Pedro do Sul. The spa consists of two bathhouses: King D. Afonso Henriques Building and the Queen Dona Amélia Building (Ferreira Gomes et al., 2017; Almeida et al., 2022).



Tectonic and geological setting of SPSHGF along wells and springs (obtained from Ferreira et al., 2017).

Thermal water within the SPSHGF is extensively impacted by **Hercynian granitoids**, which were emplaced 290 to 321 million years ago during the late Paleozoic era. These hercynic granites were part of the third phase of the Variscan deformation and have been subdivided into two outcrops: syn-tectonic granites and post-tectonic granites. The syn-tectonic granites are linked to two mica granites, whereas the post-tectonic granites are correlated with porphyroid granites (Ferreira Gomes et al., 2017; Almeida et al., 2022).

Active hercynian faults within the São Pedro do Sul region are represented by three main faults: **São Pedro do Sul-Ribamá Fault**, **Termas Fault**, and **Fataunços Fault**. The local fracture networks of these fault systems are enhanced by two varieties of aquifer systems of fractured granites and metasedimentary rocks. Moderately mineralized water is associated with shallow cold aquifer systems. In comparison, heavily mineralized water stems from a deeper aquifer system with a higher temperature (Almeida et al., 2022).



(a) Extract from the geologic map of Portugal, 17-A sheet (Viseu), 1:50,000 scale, with the localization of the São Pedro do Sul thermomineral poles (b) A-B and C-D cross sections (obtained from Almeida et al., 2022).

Ferreira Gomes, L.M., Neves Trota, A.P., Sousa Oliveira, A., and Soares Almeida, S.M., 2017. Reservoir Considerations and Direct Uses of São Pedro do Sul Hydromineral and Geothermal Field, Northern Portugal; World Multidisciplinary Earth Sciences Symposium (WMES 2017), IOP Conf. Series: Earth and Environmental Science 95 (2017) 022018. <https://doi.org/10.1088/1755-1315/95/2/022018>

Almeida, S., Gomes, L., Oliveira, A., Carreira, P., 2022. Contributions for the Understanding of the São Pedro do Sul (North of Portugal) Geohydraulic and Thermomineral System: Hydrochemistry and Stable Isotopes Studies. *Geosciences* 2022, 12, 84. <https://doi.org/10.3390/geosciences12020084>



FRI. OCT. 27TH

GUIMARÃES

Today is a guided tour of Guimarães graciously supported by the Municipality.

Meet @ Accommodation Entrance (8 am)

09h00 – Início da Visita
Visit begins

09h30 – Acolhimento e Visita ao Laboratório da Paisagem
Welcome and visit to the Landscape Laboratory

10h30 – Visita às Termas de Caldas das Taipas – Taipas Thermal
Visit to the Caldas das Taipas Thermal Spa

13h00 – Almoço
Lunch

14h00 – Visita Cultural – Parque 2 | Monumentos Nacionais
Castelo de Guimarães + Paço dos Duques de Bragança
*Cultural Visit – Park 2 | National Monuments Guimarães Castle
+ Palace of the Dukes of Bragança*

16h00 – Visita à Academia de Ginástica de Guimarães
Visit to the Guimarães Gymnastics Academy

17h30 – Fim da Visita
End of tour



MEALS

Breakfast: Independent

Lunch: Included in the activity

Dinner: Independent (Porto)

<https://www.timeout.com/porto/restaurants/the-best-francesinhas-in-porto>

ACCOMMODATION

Bragança Oporto Hotel

R. Arquitecto Nicolau Nasoni 12, Porto, Portugal

The Passenger Hostel

Estação São Bento, Praça Almeida Garrett, 4000-069 Porto, Portugal

DRIVING TIME

Evening: 1h

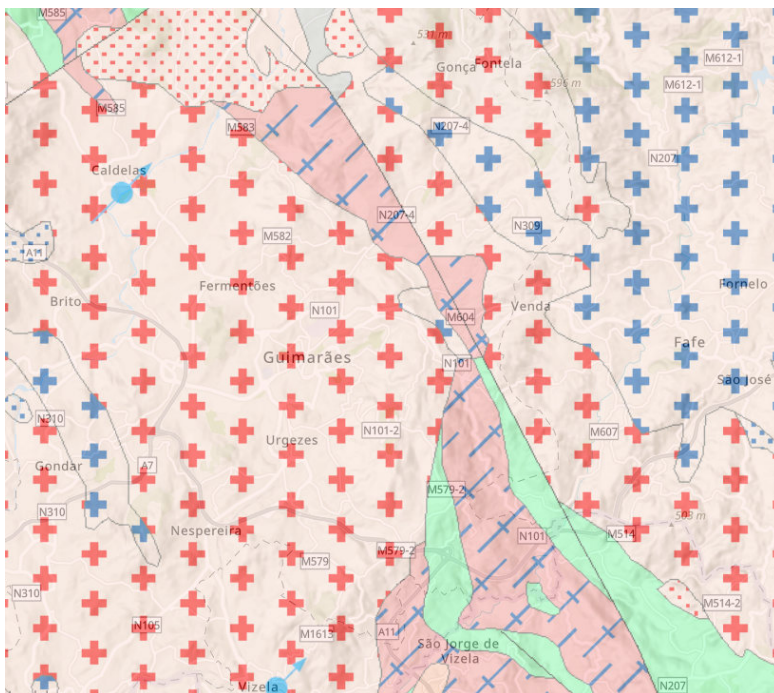
GEOLOGY

GUIMARÃES

Guimarães is a municipality located in northern Portugal. Its historic town centre has been listed as a **UNESCO World Heritage Site** since 2001, in recognition for being an "exceptionally well-preserved and authentic example of the evolution of a medieval settlement into a modern town" in Europe.

The History of Guimarães is associated with the foundation and identity of the Portuguese nationality. Guimarães, as well as other settlements, precedes the foundation of Portugal and because of its role in the foundation of the country it is known as the "cradle of the Portuguese nationality". In 1128, major political and military events that would lead to the independence and the birth of a new nation took place in Guimarães. For this reason, in one of the old towers of the city's old wall it is written "**Aqui nasceu Portugal**" (Portugal was born here).

Historic Centre of Guimarães: <https://whc.unesco.org/en/list/1031/>



Geological Map of Guimarães (GeoPortal LNEG)

Granite rock formations occupy the majority of the municipality, but **schist** rocks can also be found in certain zones in the northwest of the municipality. On the southeast, clay can be found in stream bed of the Ave, Vizela and Selho rivers.

SAT. OCT. 28TH (1)

PORTO - LISBON

We're driving down the coast! Today we make our way to Lisbon. INRS students have identified some areas of interest along the way and will describe the geothermal or geological significance of these sites. **Meet @ Bragança Oporto Hotel Entrance (7:45 am).**



PORTO - 8 AM

Complex Metamorphic of Foz do Douro - Upper Neoproterozoic of the Central Iberian Zone. Porto's Granite - Pre-Mesozoic Granitoids
Lavadores beach - Pre-Mesozoic Granitoids

AVEIRO - 9:30 AM

Composition of several river islands in the Ria de Aveiro and a portion of the coastal peninsula with colorful boats and houses



FIGUEIRA DA FOZ - 10:15 AM

Natural Monument of Cabo Mondego - Jurassic record in the Lusitanian Basin. Quiaios Fault - Neotectonics in continental Portugal

MARINHA GRANDE - 11:45 AM

São Pedro de Moel - Jurassic Record in the Lusitanian Basin

ALCOBAÇA - PATAIAS

Cliff of Sra. da Vitória Beach - Neotectonics in Continental Portugal



NAZARÉ - 12:30 PM

Nazareth Site - Cretaceous Sediments in the Lusitanian Basin

SAT. OCT. 28TH (2)

PORTO - LISBON

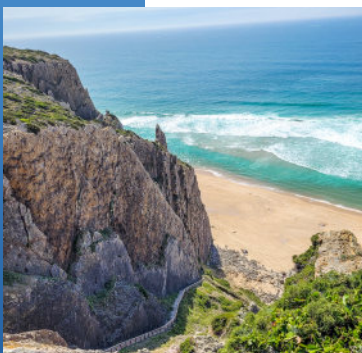


S. MARTINHO DO PORTO - 01:30 PM

The region formed by Pescaria Mountain and Bouro Mountain was once a single island in geological times. It divided, giving rise to the São Martinho do Porto bay.

ÓBIDOS - 02:15 PM

Syn-Sedimentary Deformation in the Upper Jurassic of the Lusitanian Basin – Meso-Cenozoic Tectonic Evolution of the Iberian Western Margin



PENICHE - 03:00 PM

TORRES VEDRAS - 04:00 PM

Re-structuring of the Lusitanian Basin in the Upper Jurassic – Meso-Cenozoic Tectonic Evolution of the Iberian Western Margin
Maceira Typhonic Valley – Diapiric Tectonics



SINTRA - 06:30 PM

Adraga and Alvidrar Caves – Karst Systems: a set of cavities formed by the action of the sea, combining karstic erosion with differential erosion due to the presence of volcanic rocks intruded into the limestone

PRAIA GRANDE - 07:00 PM

Sintra-Cascais Natural Park – Lower Cretaceous Dinosaur Footprints

CASCAIS - 07:30 PM

MEALS

Breakfast: Independent (Porto)

Lunch: Please, pack a lunch (Nazare)

Dinner: Independent (Lisbon)

ACCOMMODATION

Airport hotel accommodation

DRIVING TIME

Throughout the Day: 9-10 h

GEOLOGY

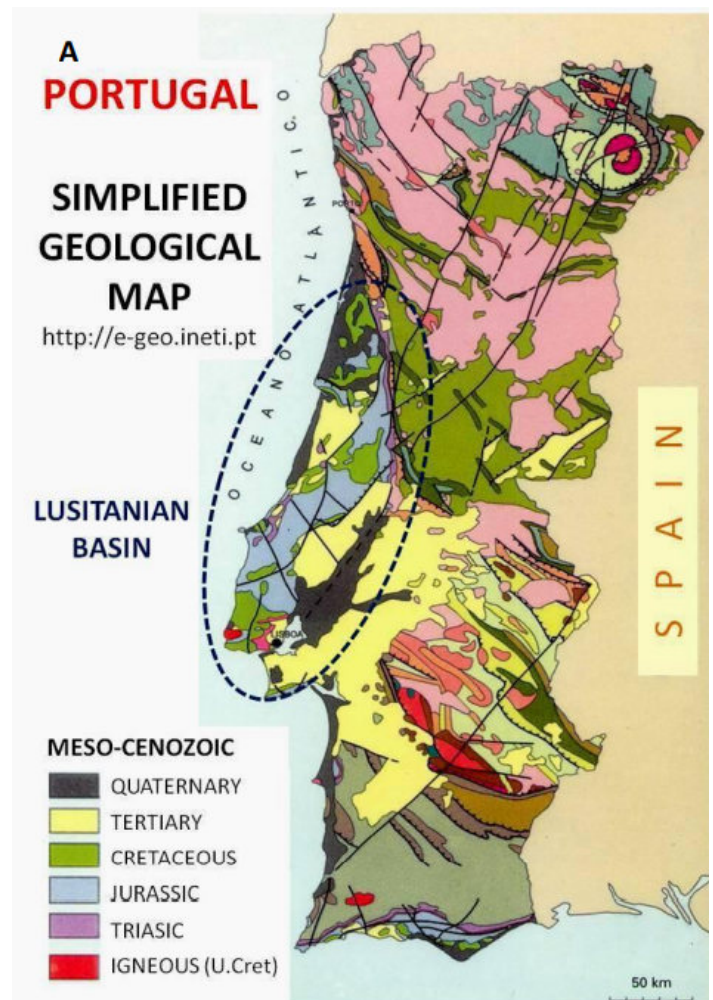
PORTO - LISBON

The geological evolution of continental Portugal, within the stretch between Porto and Lisbon, is a captivating chronicle of geological forces and processes spanning millions of years.

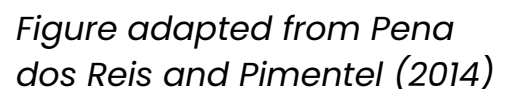
Within this expanse lies the **Lusitania Basin**, a rift valley housing a stratigraphic sequence primarily dominated by Paleozoic to Mesozoic sedimentary rocks. Beneath this lies the ancient **Precambrian basement**, composed of schists and gneisses. Stretching from Porto to Lisbon in a north-south orientation, the Lusitania Basin reaches its southern convergence point where the Alentejo and Algarve basins merge. Moving northward, the basin connects with the Porto Basin and the Galicia Basin via a submarine ridge.

The Paleozoic era witnessed tectonic forces, resulting in super-continental amalgamation combined with eventual fragmentation. Meanwhile, the Mesozoic era unfolded with sedimentation along the coastal expanse from Porto to Lisbon, depositing limestones and sandstones.

Within these formations – such as Lourinha, Alcobaça, Montejunto of the Late Jurassic, and the Papo Seco formation of the Cretaceous – a very rich collection of Jurassic mammal and dinosaur bones and footprints. These fossils offer insights into the environmental dynamics of intertidal coastlines, particularly characterized by the abundant trails of sauropods, for example.



PORTO - LISBON



In the Cenozoic era, marked by subdued tectonic activity, these landscapes underwent a process of settling and diversification. This dynamic past has shaped the diverse geological composition of the Lusitanian Basin, standing as a testament to the Earth's continuous transformation.



AZORES: PONTA DELGADA





SUN. OCT. 29TH

AZORES: LAGOA DAS SETE CIDADES

We have an early flight to catch and then we're heading to Ponta Delgada, Azores!
Meet @ Gate for the flight (6 am departure)



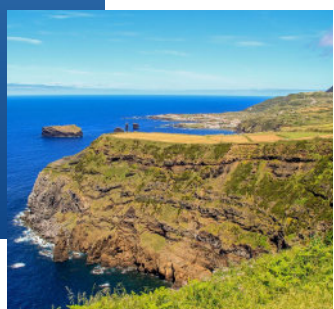
LAGOA DAS SETE CIDADES

This trail starts at Vista do Rei viewpoint, goes through the southwest slope of the Sete Cidades ridges and ends inside the village. Throughout the walk it is possible to observe the interior of the crater with its different lakes and volcanic formations.



GROTA DO INFERNO

The inhabitants of Santo António use the Canário Forest Park for nature walks and also because it's the closest access from that parish to Sete Cidades. In this park, you will find variety and abundance of flora, including the predominant endemic flora of Macaronesia. Besides the Park itself, there is a viewpoint that offers a superb view of the Sete Cidades caldera: Grota do Inferno.



ESCALVADO

The Escalvado viewpoint, at an altitude of 238m, is located at Rua da Carreira, parish of Ginetes, municipality of Ponta Delgada. From this viewpoint, you can sight the lava "fajãs" of Ferraria and Mosteiros and the four islets. There is a parking lot.

MEALS

Breakfast: Independent (Airport)

Lunch: Please pack a lunch!

Dinner: Independent (Ponta Delgada)

ACCOMMODATION

Change the World Hostels - Ponta Delgada

1ª R. de Santa Clara 178, 9500-241 Ponta Delgada
Portugal

DRIVING TIME

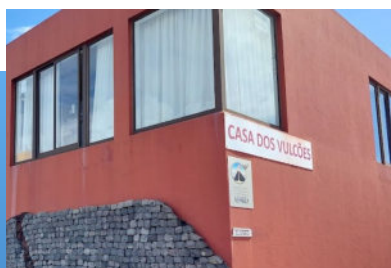
Throughout the day: 2-3 h

MON. OCT. 30TH

AZORES: UNIVERSITY & POWER PLANT

Today we will be hosted by University of Azores.

Meet @ Change the World Hostels Entrance (9:15 am).



UNIVERSITY OF AZORES: VOLCANOLOGY CENTER



UAc
UNIVERSIDADE
DOS AÇORES



Visit to the University of Azores and volcanology center.



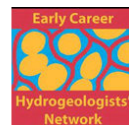
GEOHERMAL POWER PLANT

Visit to the Pico Vermelho Geothermal Power Plant of the Ribeira Grande Field.



UNIVERSITY OF AZORES: CONFERENCE (6 PM TO 7:30 PM)

GeoTalk: Short presentations about geothermal energy from international researchers followed by a discussion period.



MEALS

Breakfast: Independent

Lunch: University Cafeteria (5 EUR)

Dinner: Independent (Ponta Delgada)

ACCOMMODATION

Change the World Hostels - Ponta Delgada

1ª R. de Santa Clara 178, 9500-241 Ponta Delgada, Portugal

DRIVING TIME

Throughout the Day: 1 h

MON. OCT. 30TH

GEOTALK

Each presenter will have **10 minutes** to present the geothermal research in their region. These presentations will be followed by a **discussion period** during which researchers from around the world will be able to talk about advancements in the understanding and applications of geothermal energy.



Francisco Porturas
(**Peruvian Geothermal Association**)
Current status and plans towards 2030 and beyond: Stay HOT with geothermal in Peru



Nina Rman
(**Geological Survey of Slovenia**)
The first geothermal power plant in Slovenia and further plans



Emily Smejkal
(**Terrapin Geothermics, Canada**)
The Dehcho geothermal project (Northwest Territories, Canada)



Anna Kurek
(**Czech University of Life Sciences**)
Presentation about the Czech University and geothermal engagement



Jasmin Raymond
(**INRS, Canada**)
Geothermal energy in northern Canada



Daniela Blessent & Jacqueline Lopez
(**Universidad de Medellin**)
Presentation about the geothermal activities at the Universidad de Medellin



Jackson Grimes
(**Bureau of Economy Geology, U.S.A.**) Presentation about the Bureau of Economy Geology activities and the Project InnerSpace





TUES. OCT. 31ST

AZORES: FURNAS

Today we will be hosted by Prof. António Trota and spouse (Maria João Trota) and includes a presentation about the island with sightseeing, a visit to the Tea Factory, bathing in the thermal waters, and strolling through the Terra Nostra Park.

Meet @ Change the World Hostels Entrance (8:15 am).



GORREANA TEA FACTORY

Welcome to Gorreana ...

... The oldest tea plantation in Europe. We cultivate this wonderful product that is tea since 1883, keeping, since then, the original traditions of the Orient as well as the ancient qualities that have been in our family for five generations.

FURNAS

Visit of the Terra Nostra Park.

Possibility to take a swim in thermal waters.

A site of volcanic activity for more than 100,000 years, the village of Furnas is a thermal hotbed, home to geysers, hot springs, even volcanic steam-powered ovens (called cozidos). Located on the island of São Miguel, Furnas' springs and mud baths are said to have therapeutic properties, while nearby Furnas Lake offers tranquil views.

<https://www.viator.com/Azores-attractions/Furnas/overview/d22379-a20431>

MEALS

Breakfast:

Lunch: Terra Nostra restaurant

Dinner: Independent (Ponta Delgada)

ACCOMMODATION

Change the World Hostels - Ponta Delgada

1ª R. de Santa Clara 178, 9500-241 Ponta Delgada, Portugal

DRIVING TIME

Mid-morning: 1 h

Late-afternoon: 1 h

WED. NOV. 1ST

AZORES: TRAIL SALTO DO CABRITO

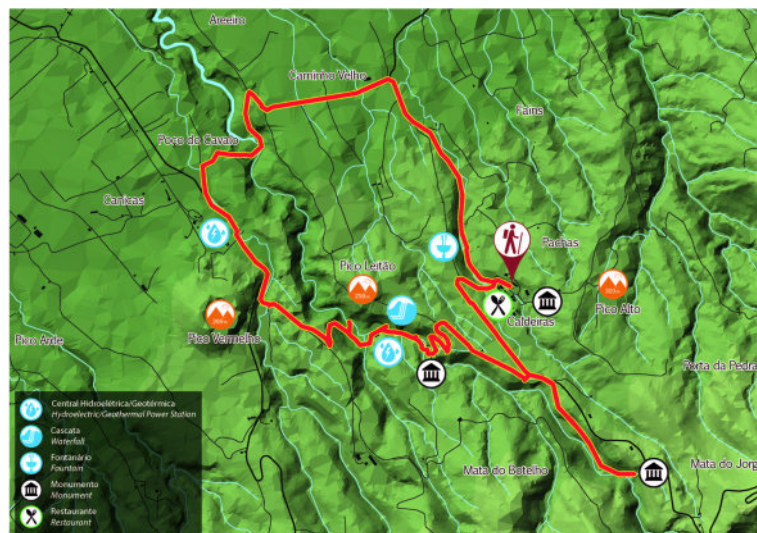
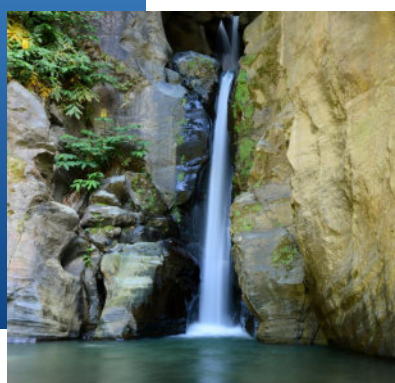
It's our last day! We will make the most of today by hiking along a local trail to visit Caldeira da Ribeira Grande and Caldeira Velha. In the afternoon, we will head to the airport to return the rental cars and spend our last night in Lisbon.

Meet @ Change the World Hostels Entrance (8:15 am).

SALTO DO CABRITO

Trail Salto do Cabrito (8.5 km)

Visit to Caldeira da Ribeira Grande and Caldeira Velha, where you can enjoy hot springs, waterfalls, and the option to swim if weather allows.



[https://trails.vi
sitazores.com/
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es/trails/sao-
miguel/prc29-
smi-2632.jpg](https://trails.vi
sitazores.com/
sites/default/fil
es/trails/sao-
miguel/prc29-
smi-2632.jpg)

We MUST be at the airport to return cars by 3 pm.

MEALS

Breakfast: Independent

Lunch: Please pack a lunch!

Dinner: Independent (Ponta Delgada)

ACCOMMODATION

This marks the end of our trip! Any further accommodation should be organized on an individual basis.

GEOLOGY

AZORES

The Azores archipelago is composed of nine volcanic islands located in the North Atlantic Ocean, about 1600 km from Portugal mainland. The islands are dispersed along a general WNW–ESE trend (600 km long and 200 km wide) crossing the Mid-Atlantic Ridge in the area where the Eurasian, African and North American lithospheric plates meet. While Corvo and Flores lie to the west of the Mid-Atlantic Ridge and emerge from a present-day relatively stable geological setting, the other islands are located in an important seismic and volcanically active zone corresponding to the boundary between the Eurasian and African tectonic plates.

São Miguel is the largest and most volcanically active island of the archipelago, resulting from the merge of several volcanoes. It includes three currently quiet volcanoes with summit calderas (Sete Cidades, Fogo and Furnas) linked by two basaltic rift zones with numerous scoria cones (Picos and Congro Fissural Volcanic Systems). Sete Cidades Volcano forms the western end of the island and last erupted 600 years ago, Fogo in 1563, and Furnas in 1630. The most recent eruption happened in 1652 in the Picos Fissural Volcanic System. The eastern part of the island is formed by the older and inactive volcanic systems of Povoação and Nordeste, ranging in age from 100 ka to over 4 Ma.

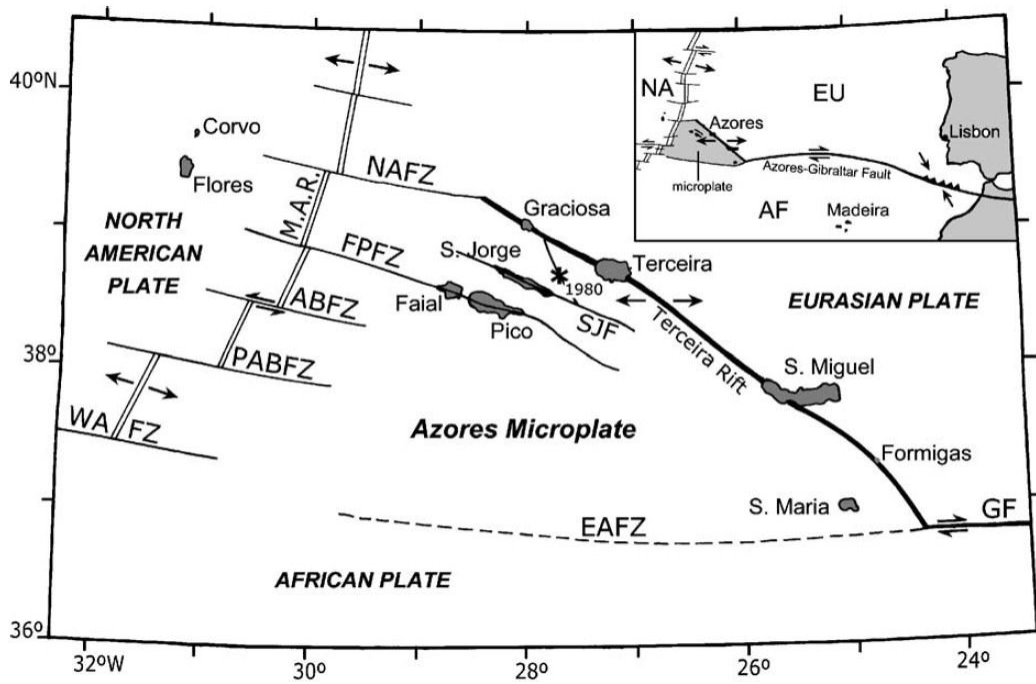


Volcanic systems of São Miguel Island

1, Sete Cidades Volcano; 2, Picos Fissural Volcanic System; 3, Fogo Volcano; 4, Congro Fissural Volcanic System; 5, Furnas Volcano; 6, Povoação Volcano; 7, Nordeste Volcanic System.

From Carmo et al., 2015. *Volcano-tectonic structures of São Miguel Island, Azores*. In *Volcanic Geology of São Miguel Island (Azores Archipelago)*, Edited by Gaspar et al., Geological Society, London, Memoirs 44 (1): 65–86.

<https://doi.org/10.1144/M44.6>

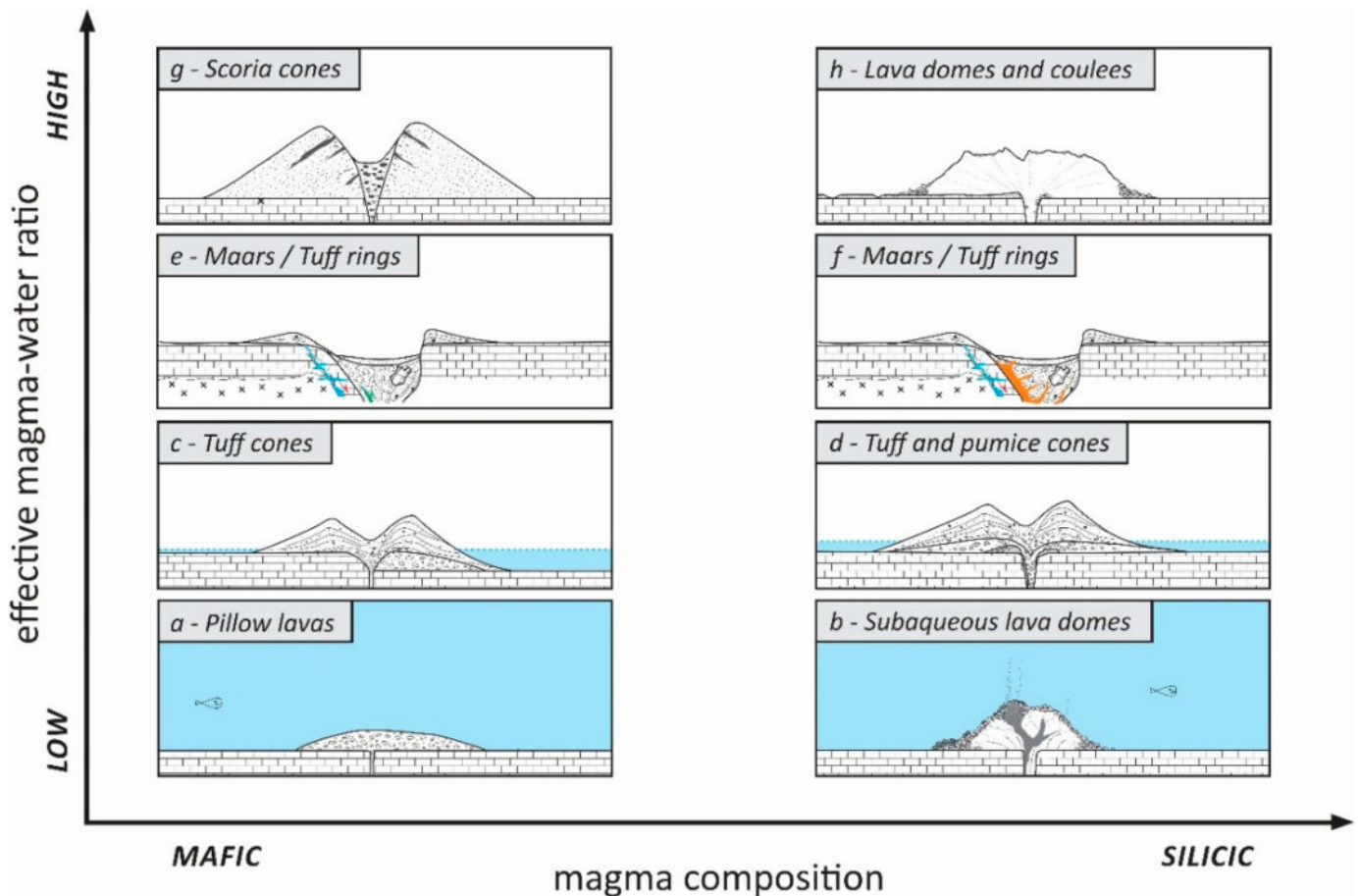


General tectonic framework of the Azores archipelago

MAR = Mid-Atlantic Ridge; EAFZ = East Azores Fracture Zone; WAFZ = West Azores Fracture Zone; NAFZ = North Azores Fracture Zone; FPFZ = Faial-Pico Fracture Zone; ABFZ = Açor Bank Fracture Zone; PABFZ = Princess Alice Bank Fracture Zone; GF = GLORIA Fault; SJF = São Jorge Fault; EU = Eurasian Plate; AF = African Plate; NA = North American Plate.

From Nunes et al., 2006. Gravity anomalies and crustal signature of volcano-tectonic structures of Pico Island (Azores). *Journal of Volcanology and Geothermal Research* 156(1-2): 55-70.

<https://doi.org/10.1016/j.jvolgeores.2006.03.023>

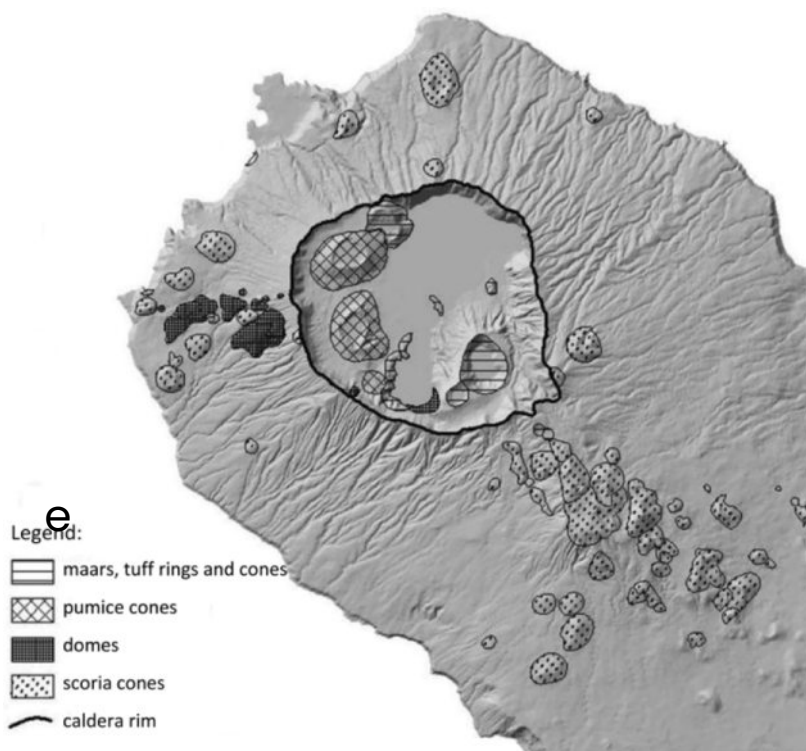


Typical architecture of mafic and silicic small-volume volcanic edifices formed within deep subaqueous to subaerial environments and resulting different effective magma-water ratios

From Németh and Kósik, 2020. *Review of Explosive Hydrovolcanism. Geosciences* 10(2): 44. <https://doi.org/10.3390/geosciences10020044>

Sete Cidades Volcano

The Geological record reveals that subaerial activity began 250 ka ago, and stratigraphic units reflect major events that occurred throughout the volcano's history. Caldera formation resulted from three major events (36, 29 and 16 ka ago). Effusive or moderately explosive eruptions were located on the slopes of the central volcano. Trachytic explosive activity is mostly centered inside the caldera involving, in the first stage, a dominant hydro-magmatic style starting ~5 ka ago. Trachytic effusive eruptions are represented by domes and associated lava flows that crop out in the inner caldera walls and on the western slopes of the volcano. Offshore sub-marine activity is represented by the historic eruptions of 1638 and 1811. In the last 5 ka, Sete Cidades was the most active volcano in Azores with 17 explosive eruptions that displayed predominantly hydromagmatic character.



Main volcanic structures of Sete Cidades

From Queiroz et al., 2015. Eruptive history and evolution of Sete Cidades Volcano, São Miguel Island, Azores. In *Volcanic Geology of São Miguel Island (Azores Archipelago)*, Edited by Gaspar et al., Geological Society, London, Memoirs 44 (1): 87-104. <https://doi.org/10.1144/M44.7>



Ribeira Grande Geothermal Field

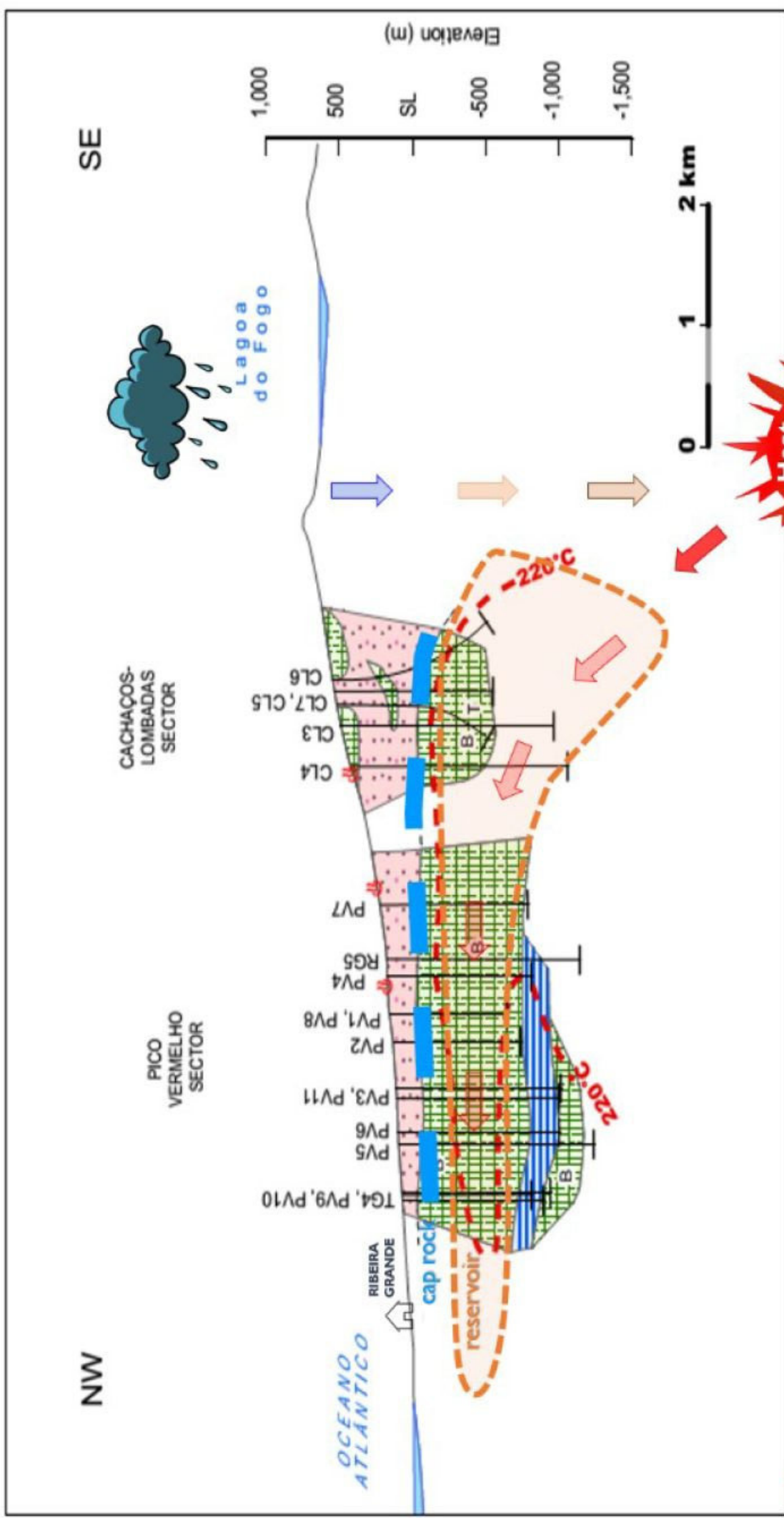
Geothermal power generation has four decades of history in the Ribeira Grande field, where the combined production from the Ribeira Grande and Pico Vermelho plants (23 MWe net) has been providing up to 44% of the electricity needs of São Miguel Island.

The Ribeira Grande geothermal field is in the northern flank of Fogo Volcano, the largest among the three active (dormant) stratovolcanoes of São Miguel Island. The geothermal system is characterized as a 245°C two-phase fluid-dominated reservoir hosted in volcanic rocks that may be intersected by relatively shallow wells (1 to 1,5 km wells).

In the central part of the volcano, meteoric water seeps downwards and is heated conductively by a deep magma chamber, or a young intrusion, associated with the activity of Fogo Volcano. The upflow of geothermal fluid is inferred to be in the southern part of the field, to the southeast of current project development. The fluids are transported northwest, following the structure of Fogo volcano and probably controlled to some degree by the faults and associated fractured zones of the NW-SE graben of Ribeira Grande (See Figure on next page). The outflow discharges offshore from the city of Ribeira Grande, along a narrow zone and within a thin interval (only 200-300 meters thick), and is apparently controlled by the NW-SE eruptive fissure that originated the Pico das Freiras scoria cone.

The Ribeira Grande project is divided into three sectors. The high-temperature reservoir has no boundaries limiting these sectors, and this project separation is primarily caused by the topography. The Cachaços-Lombadas (CL) sector is in the southern part of the field at a higher elevation; the Pico Vermelho (PV) sector is in the northern part of the field at a lower elevation; and the Caldeiras sector is in the eastern part of the field, which is separated from the other two sectors of the field by a deep river canyon. Geothermal exploitation has been in progress for several years in the PV and CL sectors, whereas the Caldeiras sector has been explored via geophysical survey (AMT) and deep drillings, which have confirmed the extension of the high-temperature reservoir towards the east.

Field development has adopted a stepwise strategy over time. The first step of exploration occurred in the Ribeira Grande field. This exploration was carried out in the late 1970s and led to the installation of a small pilot plant (3 MWe) in the Pico Vermelho area (1980). This was an important geothermal experiment for Azores, and it supported the next stages of development. Commercial operations began in the 1990s when the 13 MWe Ribeira Grande ORC binary power plant was built, which was established over the course of two stages in the southern part of the field (5 MWe in 1994; +8 MWe in 1998). In 2005 and 2006, the pilot plant was dismantled and replaced by a new 10 MW ORC binary plant in the Pico Vermelho area. Over the past decade, the Ribeira Grande and Pico Vermelho plants have been providing up to 44% of the electricity demand on São Miguel Island.



Vertical Exaggeration 1.4X
January 13, 2016

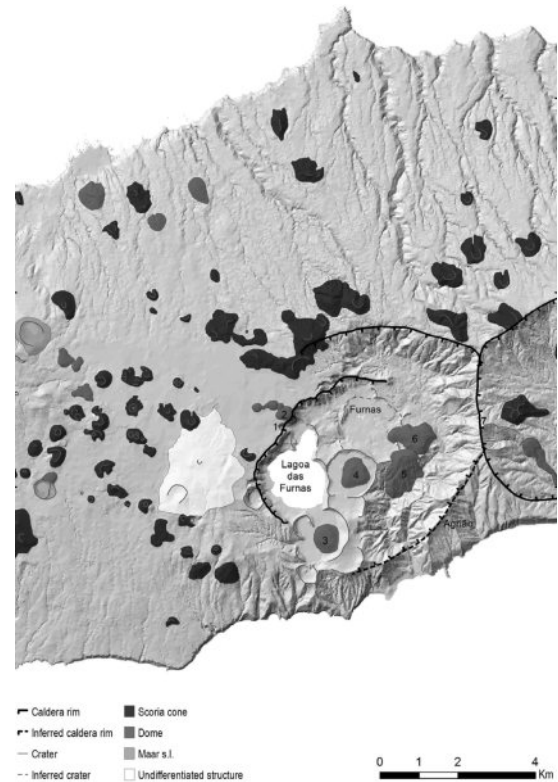
GeothermEx
A Schlumberger Company

Conceptual model of Ribeira Grande geothermal system

From Franco et al., 2021. Forty Years of Power Generation at the Ribeira Grande Geothermal Field, Azores. Proceedings World Geothermal Congress 2020+1 Reykjavik, Iceland, April - October 2021. <https://doi.org/10.3390/geosciences10020044>

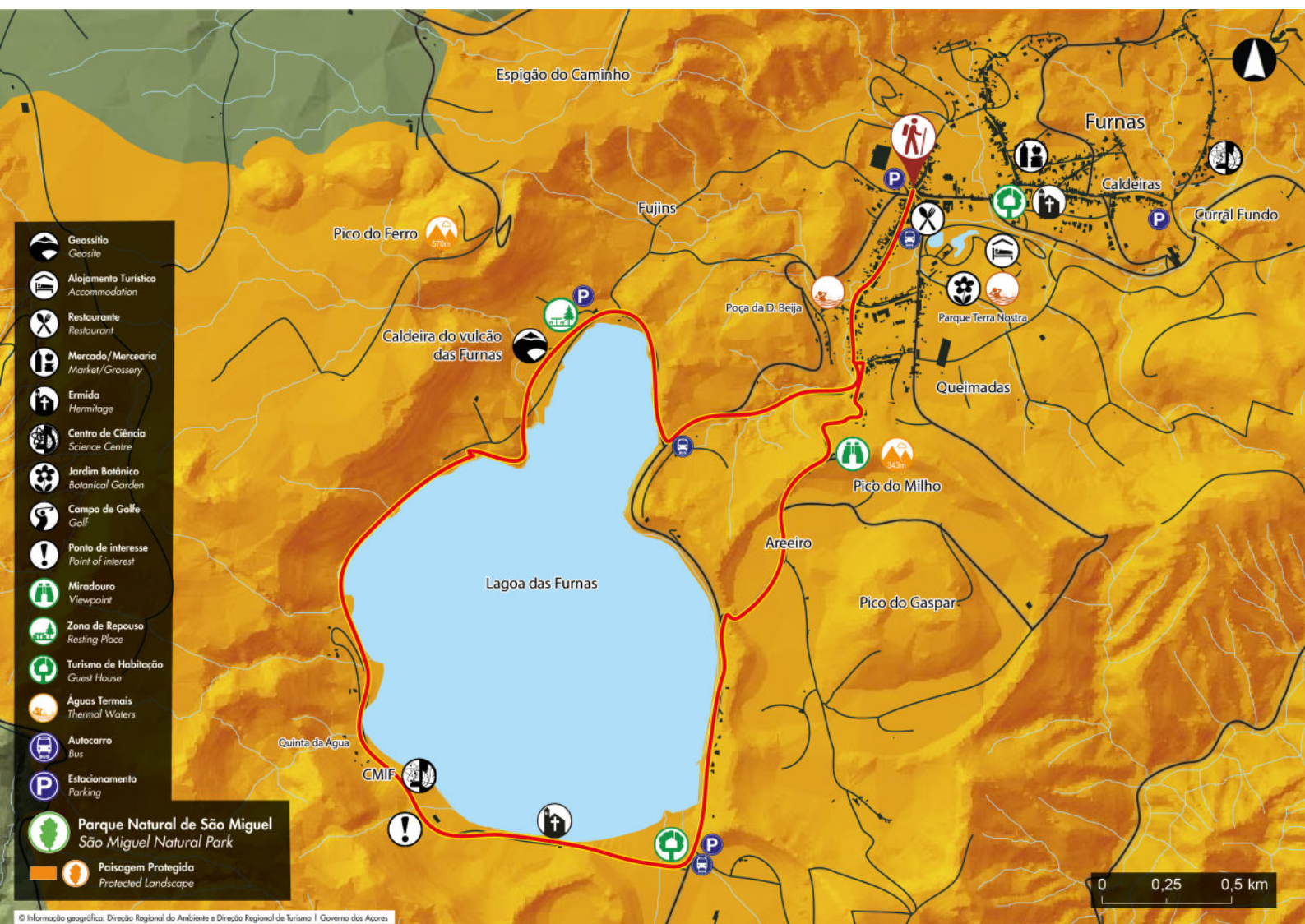
Furnas Volcano

Furnas is the easternmost of the trachytic active central volcanoes of São Miguel Island. Unlike the other central volcanoes, Sete Cidades and Fogo, Furnas does not have a substantial edifice built up above sea-level. Although not as dominant as the other two volcanoes, Furnas does, however, have an edifice rising from the basal basaltic lavas exposed on the north coast to around 600 m on the northern rim of the main caldera. In common with Sete Cidades and Fogo, Furnas had major trachytic explosive eruptions in its volcanic history that emplaced welded ignimbrites. In the last 5 ka, Furnas 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. A future eruption of sub-Plinian magnitude is a major hazard posed by Furnas Volcano. Even when not in eruption, Furnas is a hazardous environment. Its fumarolic fields discharge high levels of CO₂ and concentrations in some area of Furnas village present a risk to health. The steep slopes and poorly consolidated volcanic materials are prone to landslides, in particular when triggered by earthquakes or following heavy rain, as was the case in 1997, when landslides caused severe damage and casualties in Ribeira Quente.



Map showing principal volcanological features of Furnas Volcano

From Guest et al., 2015. *The volcanic history of Furnas Volcano, São Miguel, Azores*. In *Volcanic Geology of São Miguel Island (Azores Archipelago)*, Edited by Gaspar et al., Geological Society, London, Memoirs 44 (1): 125-134. <https://doi.org/10.1144/M44.9>

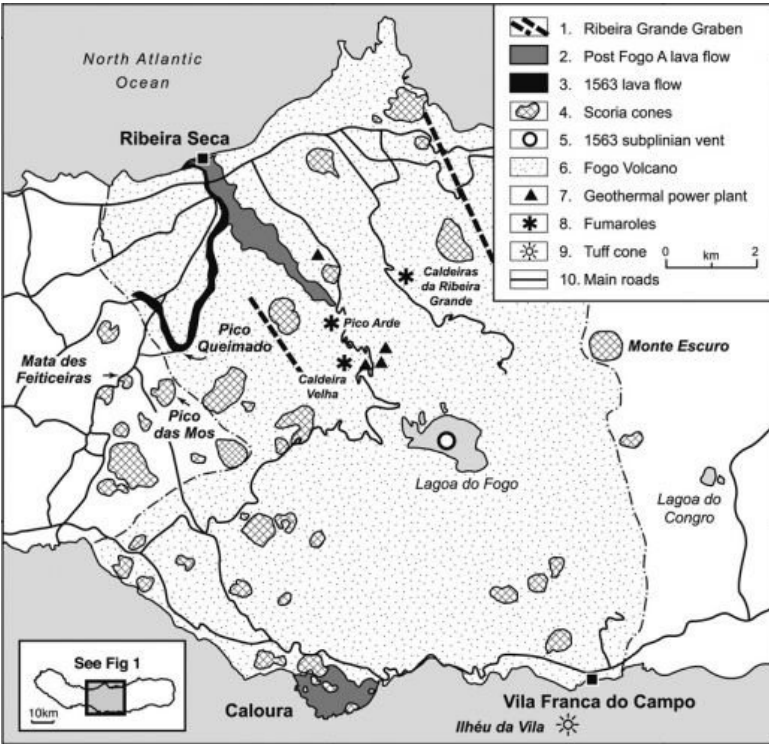


Salto do Cabrito Trail

The walking trail of Salto do Cabrito is a small circular route beginning and ending in the Caldeiras of Ribeira Grande area.

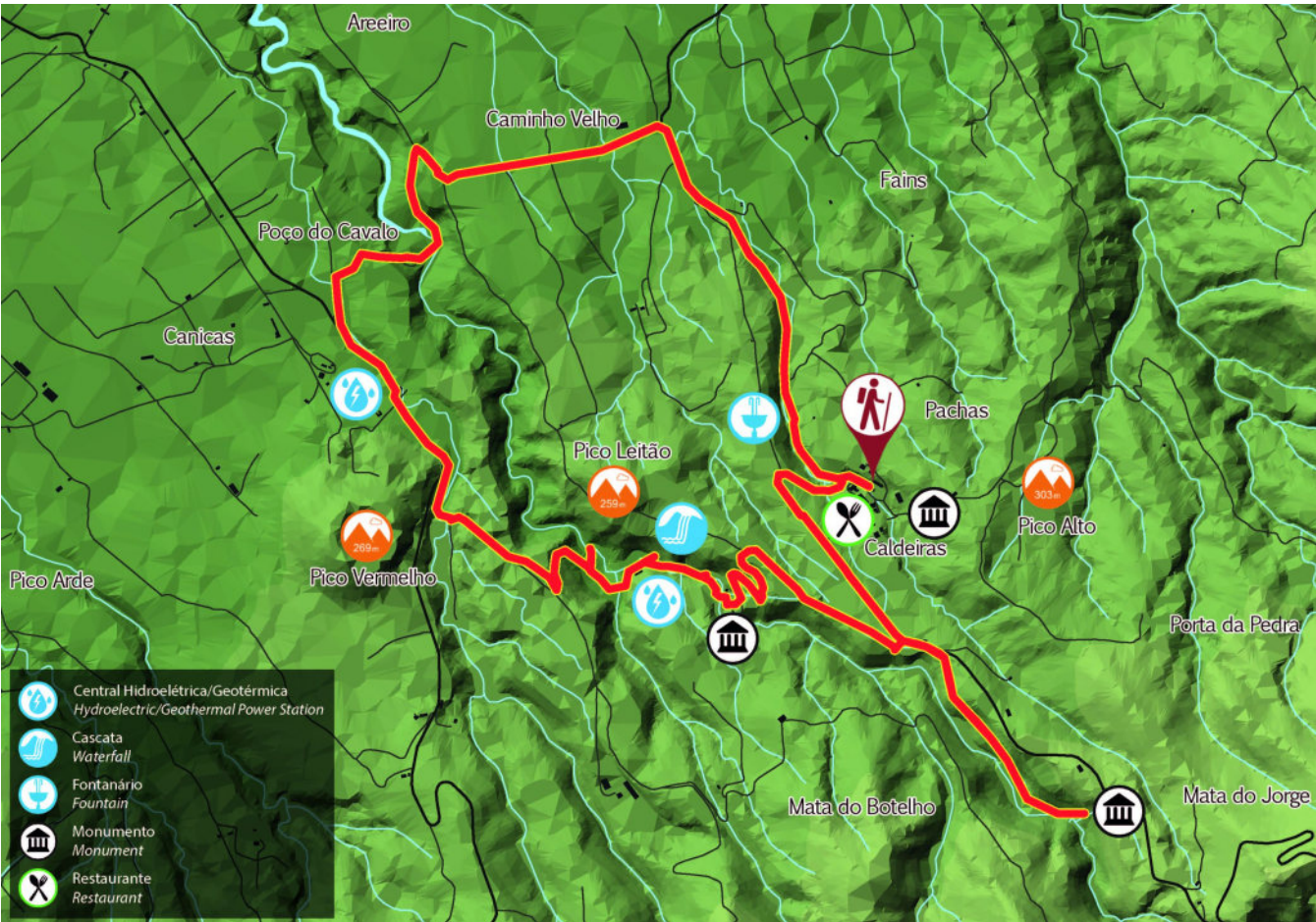
Fogo volcano, the highest of the three central volcanoes of São Miguel, rises to an altitude of almost 1000 m with a summit caldera that is partially occupied by Fogo Lake. Its caldera formed from numerous collapses and explosions. The most recent implosions occurred during the sub-plinian eruption of 1563 and the hydromagmatic explosive event of 1564. The northern and southern flanks of the volcano have been extensively carved by deep valleys that reach the coast, whilst to the north the volcano has been downthrown by a NW-SE trending graben. There are also surficial expressions locally exhibited by the hydrothermal system. Fumaroles at Caldeira Velha, Pico Vermelho and Caldeiras da Ribeira Grande are associated with the distensive NW-SE faults of the northern flank. At Caldeiras da Ribeira Grande a small spa has been developed.

Fogo is of great significance because it provides researchers an opportunity to observe and understand trachytic volcanism. Alternatively, the volcano is known for the dangers it poses to the population of São Miguel. Even when dormant, Fogo and the neighboring Congro Fissural Volcanic System exhibit frequent seismic swarms.

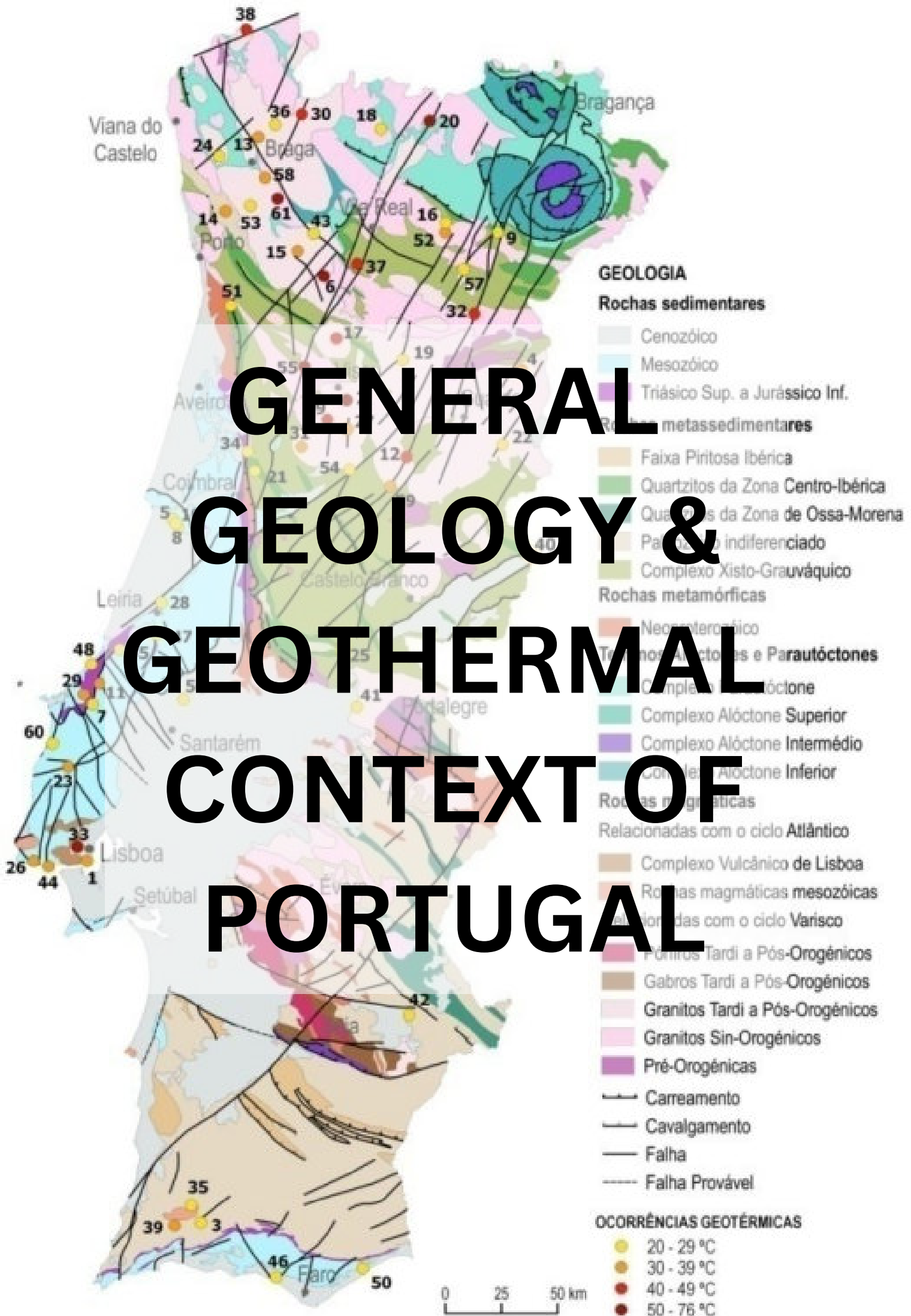


Fogo volcano: a morphostructural sketch

From Wallenstein et al., 2007. Fogo Volcano (São Miguel, Azores): a hazardous edifice. *Géomorphologie* 13(3): 259-270. <https://doi.org/10.4000/geomorphologie.2853>



GENERAL GEOLOGY & GEOTHERMAL CONTEXT OF PORTUGAL



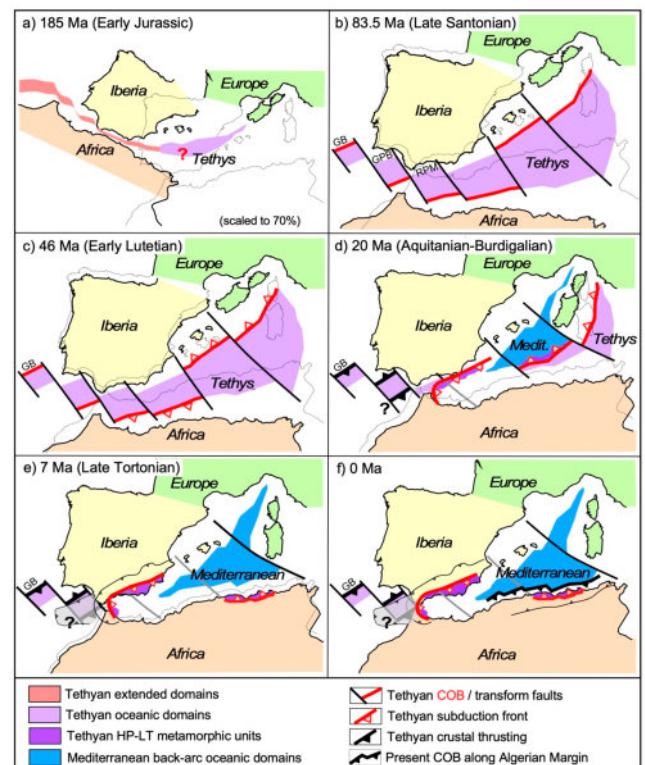
GEOLOGY

PORTUGAL

Located in the southwestern corner of Europe, Portugal's geological evolution has been shaped by a complex sequence of events of plate tectonics, sedimentation, and volcanic activity over millions of years.

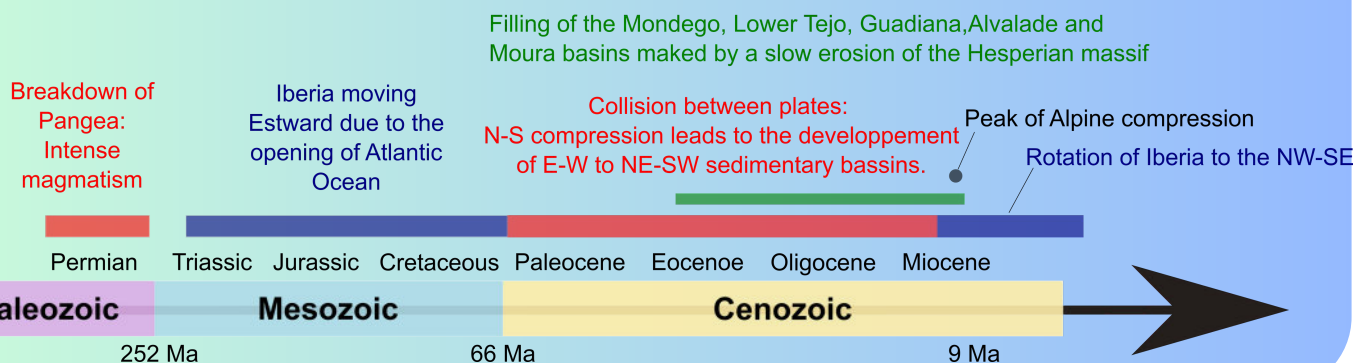
Portugal is situated within the Iberian Plate, a major tectonic entity that has been influenced by the interaction of several other plates. The formation of the Iberian Peninsula was a result of the collision between the Eurasian Plate and the African Plate during the Alpine orogeny. This prolonged tectonic event, spanning from the Late Cretaceous to the Cenozoic era, led to the uplift of the Pyrenees and the creation of the peninsula.

Portugal's position along the western edge of the Iberian Plate exposes it to the influences of both the Atlantic Ocean and the remnants of the ancient Tethys Ocean, which once separated the Eurasian Plate from the African Plate.



Fernández, M., Torne, M., Vergés, J., Casciello, E., & Macchiavelli, C. (2019). Evidence of Segmentation in the Iberia–Africa Plate Boundary: A Jurassic Heritage? *Geosciences*, 9(8), Article 8.

Major events influencing the geology of Portugal



GEOLOGY

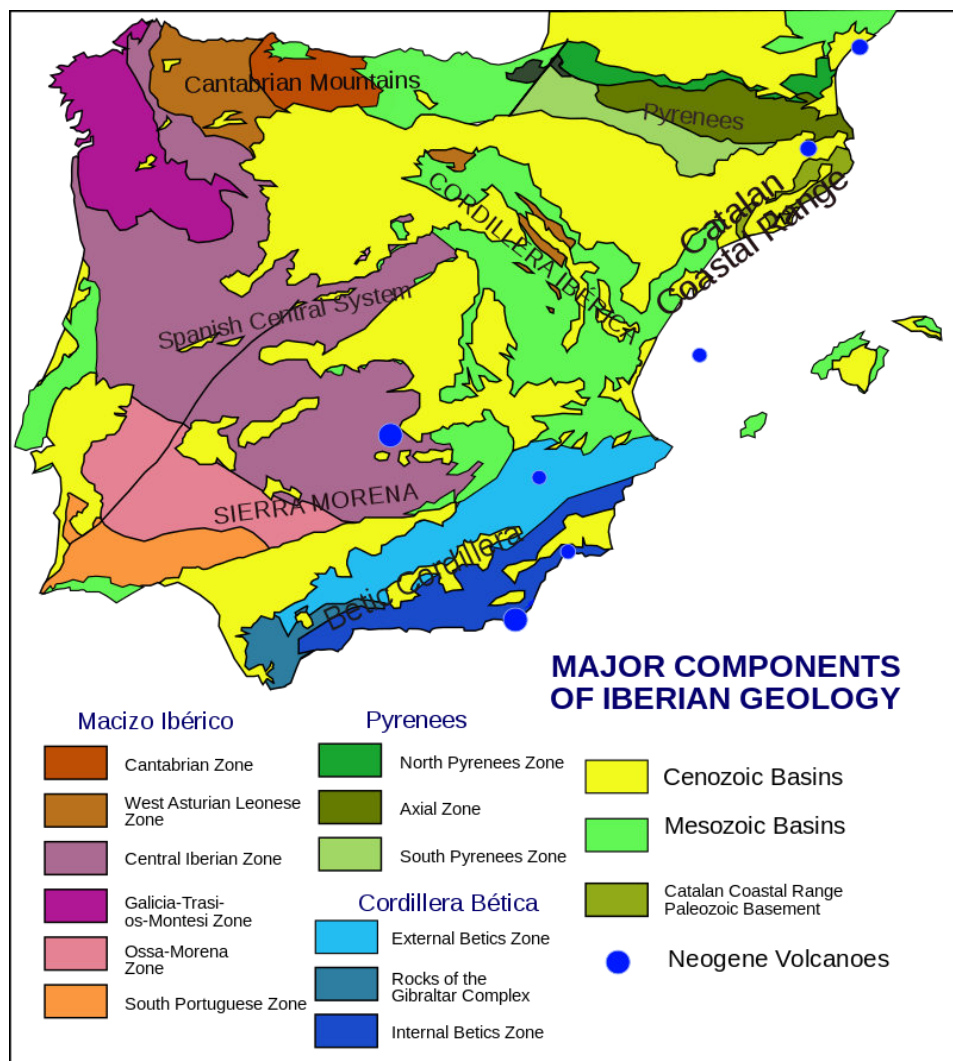
IBERIA

The core of the **Iberian Peninsula** consists of a Hercynian cratonic block known as the **Iberian Massif**. In the northeast, the Massif is bounded by the Pyrenean fold belt, and in the southeast it is bounded by the Betic fold mountain chain. These two mountain chains are part of the Alpine belt. To the west, the peninsula is delimited by the continental boundary formed by the currently expanding Atlantic Ocean. The Hercynian fold belt is mostly buried by Mesozoic and Cenozoic overburden in the east.

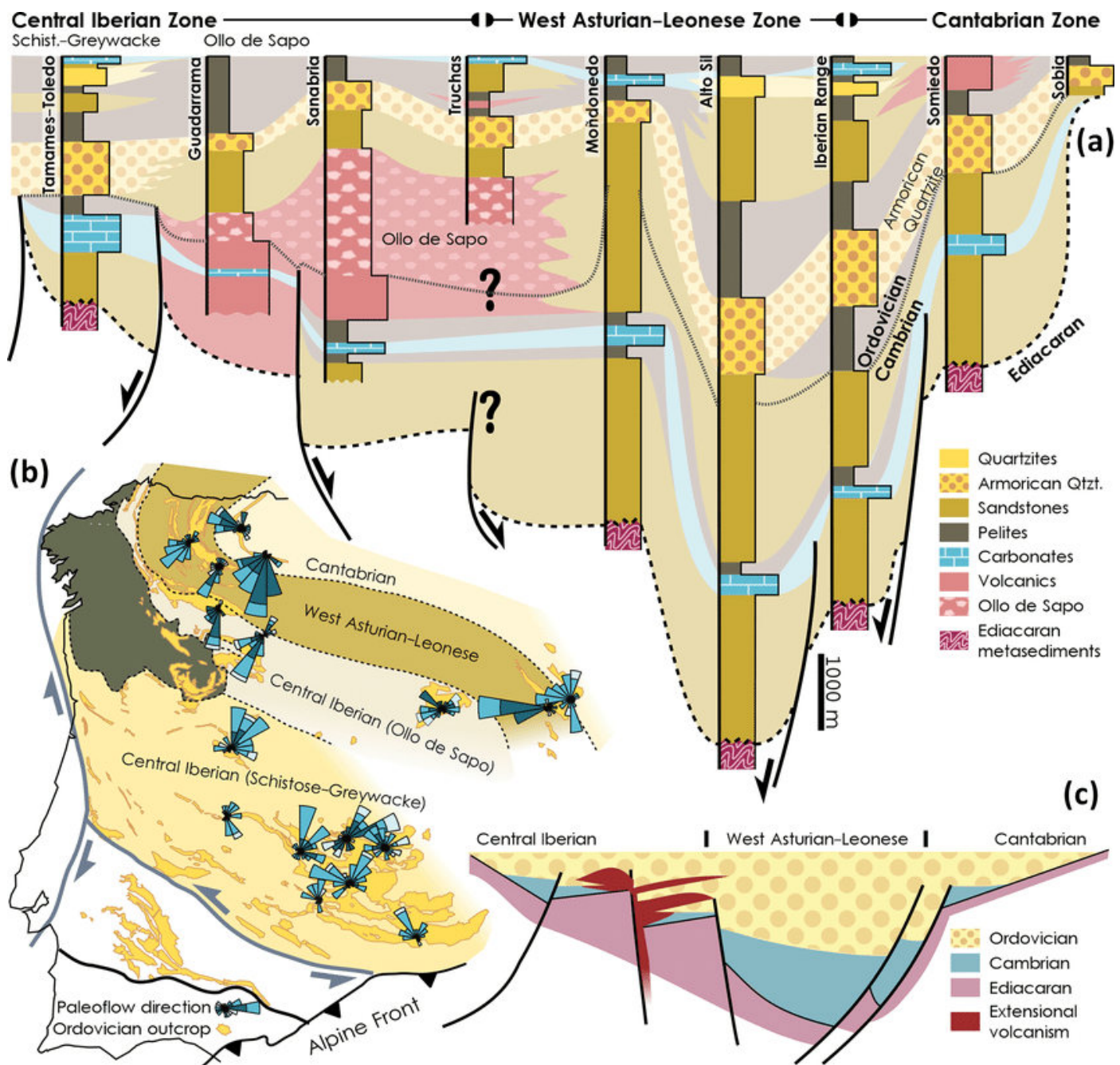
Iberian Massif

The Iberian Massif consists of rocks from the Paleozoic Era. It was assembled at ~310 Ma. The Iberian Massif is composed by several blocks assembled during the Variscan/Hercynian orogeny:

- **Cantabrian Zone**, on the north coast of Spain
- **Asturian-Leonese Zone** to the west
- **Central Iberian Zone**, which spans the north of Portugal and central Spain
- **Ossa-Morena Zone**, which outcrops to the east of Lisbon.
- The furthest southern part of the Iberian Massif is the **South-Portuguese Zone**.



M. Julivert; F. J. Martinez; A. Ribeiro (1980). "The Iberian segment of the European Hercynian foldbelt". *Geology of Europe from Precambrian to the post-Hercynian sedimentary basins*. Bureau de Recherches Géologiques et Minières Société Géologique du Nord. pp. 132–158.



(a) Stratigraphic synthesis of the Gondwanan platform series in northwestern Iberia. (b) Ordovician paleocurrent orientations. (c) Schematic basin architecture inferred from the stratigraphic compilation.

Pastor-Galán, D., Gutiérrez-Alonso, G., & Weil, A. B. (2020a). The enigmatic curvature of Central Iberia and its puzzling kinematics. *Solid Earth*, 11(4), 1247–1273. <https://doi.org/10.5194/se-11-1247-2020>

The **Variscan/Hercynian Orogeny** was a geologic mountain-building event caused by Late Paleozoic continental collision between Laurussia and Gondwana to form the Supercontinent Pangea. In Iberia, this event took place during the pre-Stephanian Carboniferous.

Central Iberian Zone

The Central Iberian Zone covers the middle part of the west side of the peninsula, including north and central Portugal. The top north-west corner has been replaced with the Galicia-Tras-Os-Montes Zone. The constituent rocks are metamorphosed sediments.

The oldest rocks are Proterozoic, metamorphosed sediments. They have been deformed by the **Cadomian Orogeny**. Volcanics and sediments from the end of the Ediacaran and Cambrian periods are also present.

Before the Carboniferous, the Central Iberian Zone was deformed in a northeast direction with thrusts and folds. The oldest rocks are from the Cambrian, possibly the Precambrian, and are orthogneiss and paragneiss. These are found near Foz do Douro and Miranda do Douro. Above the gneissic units are schists or shales with beds of turbidites or limestone interleaved. The stratigraphic sequence can also be observed southwest of Salamanca in the **Tamames Syncline**, and in the **Montes de Toledo**. The schists and shales are followed by an unconformity. Above the unconformity are reddish-sandstone, shale, and conglomerate of Tremadocian age, spanning up to 1 km in thickness. An overlying Arenigian-age quartzite formation is known as American Quartzite. Then there is black shale or slate matching the Lueza Slate of Llanvirn to Llandeilo Age. On top of this is the Botella or Cantera Quartzite, 0.1 km thick of Llandeilian to Caradocian Age.

Above this is a lenticular limestone called **Urbana Limestone**, with shale and sandstone of Caradocian to Asghilian Age. Then comes the **Criadero Quartzite** in the Almaden area at the base of the Silurian Period. Black graptolytic shale and basic volcanic rocks overlay this unit. Granite appeared with the **Variscan Orogeny**. Devonian age terrigenous deposits up to 2 km thick occur in the south of the zone. There is a large amount of volcanic rock in the **Almaden Syncline**.

The lower Carboniferous has a flysch facies along the southern boundary of the zone, and also in the San Vitero area and around the Morais and Bragança Massifs.



Criadero Quartzite with the cinnabar mineralization.

Higueras, Pablo & Mansilla, L. & Lorenzo Álvarez, Saturnino & Víctor, José & Esbrí, José. (2011). The Almadén mercury mining district. CUADERNOS DEL MUSEO GEOMINERO. 13. 75-88.

Jensen, S., & Palacios, T.A. (2016). The Ediacaran-Cambrian trace fossil record in the Central Iberian Zone, Iberian Peninsula
O registo icnológico do Ediacariano-Câmbrico da Zona Centro-Ibérica, Península Ibérica.

Galicia-Trás-os-Montes Zone

The Galicia-Trás-os-Montes Zone is a bean-shaped tectonic unit in the northwest corner of Spain and northeast Portugal (Trás-os-Montes). It has also been called the **allochthonous complexes**. The zone consists of a nappe stack which is highly metamorphosed. It was formed by the collision of the **Iberian Plate** with a thinned piece of crust from another continent called the **Meguma terrane**. There are five units in the stack:

1. Lowest-level high pressure, low temperature **metamorphosed rocks**.
2. **Ophiolite**.
3. Lower part of a continental crust which has been **metamorphosed** to high temperature with high pressure.
4. Layer of **sediments** exhibiting weathering and low-grade metamorphism. There is also an underlying Ediacaran and early Paleozoic layer called the **autochthonous sequence**. Metamorphism of the allochthonous nappe occurred 390–380 Ma in the mid-Devonian. The nappe is possibly from the Rheic Ocean.
5. Above this are other schists called the **schistose domain** of Galicia-Trás-os-Montes or Para-autochthonous.

There are five oval shaped masses of mafic to ultramafic rocks making up the ophiolite: the Cabo Ortegal, Ordes, Lalín, Bragança and Morais Massifs. Each of these Massifs are in a syncline and are surrounded by Silurian metamorphic rocks with an inward-dipping thrust zone forming the boundary. The kinds of rock in the mafic massifs are schists, gneiss, amphibolite, metagabbro, granulite, eclogite, and serpentine. The Ordes Massif dates from 380 to 390 Ma, and represents part of the Rheno-Hercynian Ocean as part of an accretionary wedge. It was joined to the European Hunic Terrane between the Channel Block and the allochthonous nappe. It has a corresponding block, the Lizard complex in southwest England. Finally, the Cabo Ortegal complex is dated to approximately 345–340 Ma and is thought to be the remains of a Paleo-Tethys Ocean mid-oceanic ridge.

The **Malpica-Lamego line** is a shear zone linearly expanding N-S on the west side of the Galicia-Trás-os-Montes Zone. It is 275 km long and associated with intrusions of **granodiorite**. There is over 10 km of vertical offset along the shear zone.



Tras-os-Montes Wine Region as a result of local geology.

<https://www.winetourismportugal.com/en/regions/tras-os-montes/>

<https://www.portugalvisitor.com/portugal-city-guides/tras-os-montes>
<https://www.portugalvisitor.com/portugal-city-guides/tras-os-montes>

Ossa Morena Zone

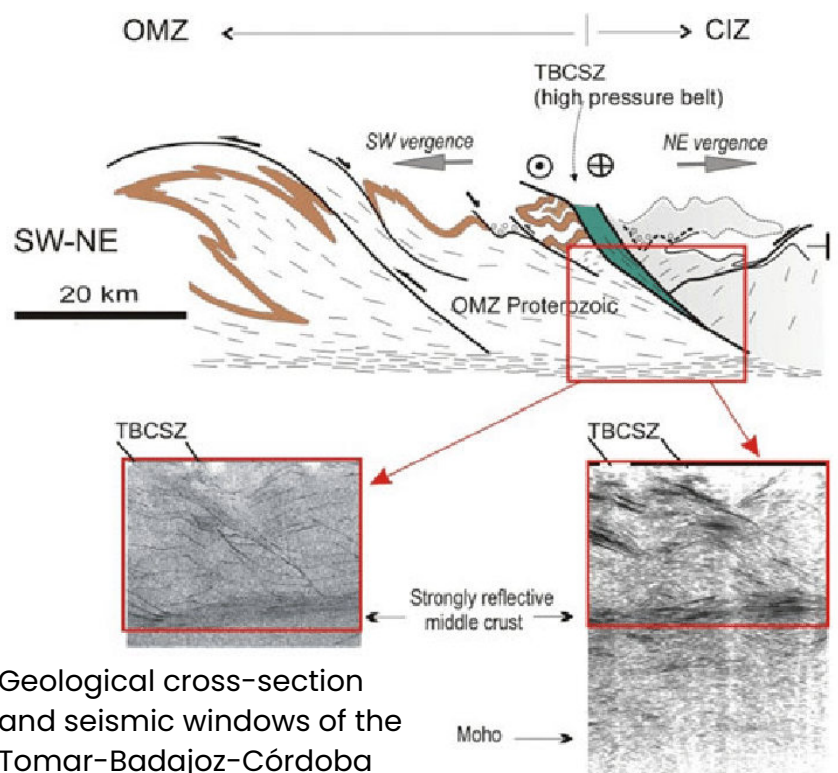
The Ossa Morena Zone forms a band in the southern part of Portugal and the southwest corner of Spain. The oldest rocks are **Precambrian**, forming bands in two **elongated anticlines** between Córdoba and Abrantes. The Cambrian rocks start with conglomerate and have shallow water deposits as well as limestone. The Ordovician Period is represented by pelitic facies. In the Late Ordovician, syenite and alkaline granite intrusions rose along the Córdoba Abrantes belt. The Silurian Period contains both acidic and basic volcanic rocks alongside pelitic deposits. The Devonian units formed in shallow water and is composed of flysch.

The Carboniferous begins with a **turbidite sequence** containing basic volcanics. This is about 200 meters thick. Above this are coal-bearing layers, implying that orogenic forces took over by this point. In the Westphalian age, the coal unit was deposited in lakes lying between mountain ranges. In the Stephanian age, molasse propagates.

The Ossa-Morena Zone was transform-faulted alongside the Central Iberian Zone. As it slid past (200 km horizontally to the south-east and 10 km vertically), it formed the **Peñarroya Basin** during the late Langsettian and early Duckmantian part of Carboniferous. The basin is about 50 km long and 1 km wide.

The **Tomar-Badajoz-Córdoba Shear Zone** (TBCZ) consists of rock that has been ductile-sheared in the left lateral direction. It is 350 km long and from 2 to 15 km wide. Granite from the Cambrian and Ordovician has metamorphosed into orthogneiss. Migmatites and metamorphosed sediments constitute the bulk units of the zone. There are also lens-shaped bodies consisting of eclogite and garnet amphibolite. Shearing occurred from the end of the Devonian to the Carboniferous. The zone is a boundary between different terranes (Central Iberian and Ossa Morena Zone) making up the Iberian Massif.

The boundary between the Ossa Morena and South Portuguese Zones is formed by an ophiolite: otherwise titled the Beja-Acebuches Ophiolite Complex (BAOC). The BAOCC consists of highly pressurized metamorphic rocks, eclogite and blueschist. Thrusting in the southwest direction over the top of the rock from the south is also present.



Geological cross-section and seismic windows of the Tomar-Badajoz-Córdoba Shear Zone.

Azor, A., Dias da Silva, I., Gómez Barreiro, J. [...] & Porcar, Aina. (2019). Deformation and Structure. 10.1007/978-3-030-10519-8_10.

South Portuguese Zone

The South Portuguese Zone is an exotic terrane merging from a different continent to the northern parts of the Iberian Plate. Prior to 380 Ma, the South Portuguese Zone existed as part of Laurasia and adjacently attached to what later became the Grand Banks. This continent was previously to the north of Iberia, which at the time was considered part of the European Hunic Terrane (EHT). At 380 Ma the South Portuguese Zone impacted the EHT between allochthonous units of the Galicia-Tras-Os-Montes Zone and Meseta. At about 320 Ma, the South Portuguese Zone migrated southward and slid past the west side of the Ossa Morena Zone.

The South Portuguese Zone now forms a thin triangle at the south end of Portugal. Only rocks from the Upper Devonian to Carboniferous are found in this zone. The Late Devonian is represented by phyllite and quartzite beds with graded bedding. Volcanic rocks from Tournaisian and Lower Visean contain manganese, zinc and pyrite ores, which is otherwise known as the Iberian Pyrite Belt. The belt is believed to be the remnants of seafloor hydrothermal vents. The majority of the zone is covered by Late Visean turbidite sequences several kilometers thick.

Intrusions

During the Hercynian cycle, plutons formed in the peninsula. Gabbro was exhumed from the subsurface in northwest Galicia as Monte Castelo Gabbro, and also at Beja in Portugal. Two different kinds of granite occur: one type evolves from the middle crust and is high in felspar and low in calcium; the other kind emerges from the lower crust, is mixed with mantle magma, and is calc-alkaline in composition.

The first kind of granite is subdivided into granodiorite and muscovite-biotite leucogranite (two-mica granite). Most of the granites are 318 Ma to 319 Ma, but some are from 340 Ma. The calc-alkaline granites intruded at two times: older plutons consist of granodiorite and adamellite with inclusions of tonalite, diorite, and gabbro. In western Galicia they are 316 Ma.

The younger calc-alkaline plutons mostly have coarse crystals and are biotite-hornblende granodiorites. They intruded later than the two-mica granite and are frequently found in northern and central Portugal. The radiometric age is dated to approximately 300 Ma.

Lusitanian Basin (Mesozoic basin)

The Lusitanian Basin stretches along the mid Portuguese coast, partially on land and partially offshore. Sinemurian–Callovian layers of thick carbonates were deposited 196 to 162 ma. Off the northern coast of Portugal is the Porto Basin, which has been elongated in the north–south direction. Further offshore from this, and offshore from the west coast of Spain is the Galicia Interior Basin. This basin was formed by rifting in the Late Triassic (220 to 195 ma). Off the west coast of Spain, and further out to sea, is the Galicia Bank, which consists of continental crust. The Galicia Bank was formerly attached to the Flemish Cap; it has limestone and marl constituents that were deposited in shallow water in the Tithonian age. These units are capped by dolomite from the Berriasian age (143 ma).

From Tithonian–Berriasian (150 to 140 ma), the rift had shallow depositional platforms composed of carbonates, and sand in the depths. From Valanginian–Hauterivian (140 to 130 ma) carbonate-rich sediments were formed. From Valanginian–Hauterivian (130 to 94 ma) oxygen was poor, and there were six periods with no oxygen (anoxic events). From Turonian–Paleocene (94 to 66 ma) oxygen was again available, and sediments were reddish or multicolored. Some areas show evidence of strong currents. In the Paleocene (66 to 59 ma) the deposition of fine-grained sediments and later formation of dark black shales suggests a lack of oxygen in stagnant water. From Thanetian to Oligocene (59 to 34 ma) and through the Tertiary to present day, calcareous and siliceous sediments have been deposited. Strong deep-water circulation started at approximately 34 ma and continues presently.

The oceanic anoxic events have been independently sorted by their ages: the Bonarelli event (OAE2 at 93.5 ma; caused by volcanic eruptions in the Caribbean); the Mid-Cenomanian Event (96 ma); OAE 1b, OAE 1c, and OAE 1d in the Albian (around 100 to 112 ma). The carbon in the black shales appears to have evolved from both oceanic and continental deposition. Nitrogen fixation was also elevated during these periods.

The Lusitanian Basin is rich in fossils, mostly consisting of (but not limited to) marine invertebrates and vertebrates. Dinosaur bones and tracks have also been identified in this region.

Brian E. Tucholke; Jean-Claude Sibuet (2007). "Leg 210 synthesis: Tectonic, Magmatic, And Sedimentary Evolution Of The Newfoundland-Iberia Rift". *Proceedings of the Ocean Drilling Program, Scientific Results. Proceedings of the Ocean Drilling Program. Vol. 210.*

M. Julivert; F. J. Martinez; A. Ribeiro (1980). "The Iberian segment of the European Hercynian foldbelt". *Geology of Europe from Precambrian to the post-Hercynian sedimentary basins. Bureau de Recherches Géologiques et Minières Société Géologique du Nord. pp. 132–158.*



GEOTHERMAL CONTEXT

PORTUGAL

In Portugal, the presence of high enthalpy geothermal resources is restricted to the volcanic islands of Azores Archipelago, located in the North Atlantic Ocean. These islands are associated with the triple junction of the North American, Eurasian and African (or Nubian) plates. Power production from geothermal resources in Azores meets about 23% of the total demand of the archipelago, but the geothermal projects are confined to the S. Miguel and Terceira islands.

Geothermal energy is expected to assume an even more impressive role for electric power self-sufficiency of this Autonomous Region of Portugal, particularly in S. Miguel and Terceira Islands. However, its development is now moving towards integration of other energy sources (particularly wind energy and waste production), energy storage systems and daily need/consumption solutions.

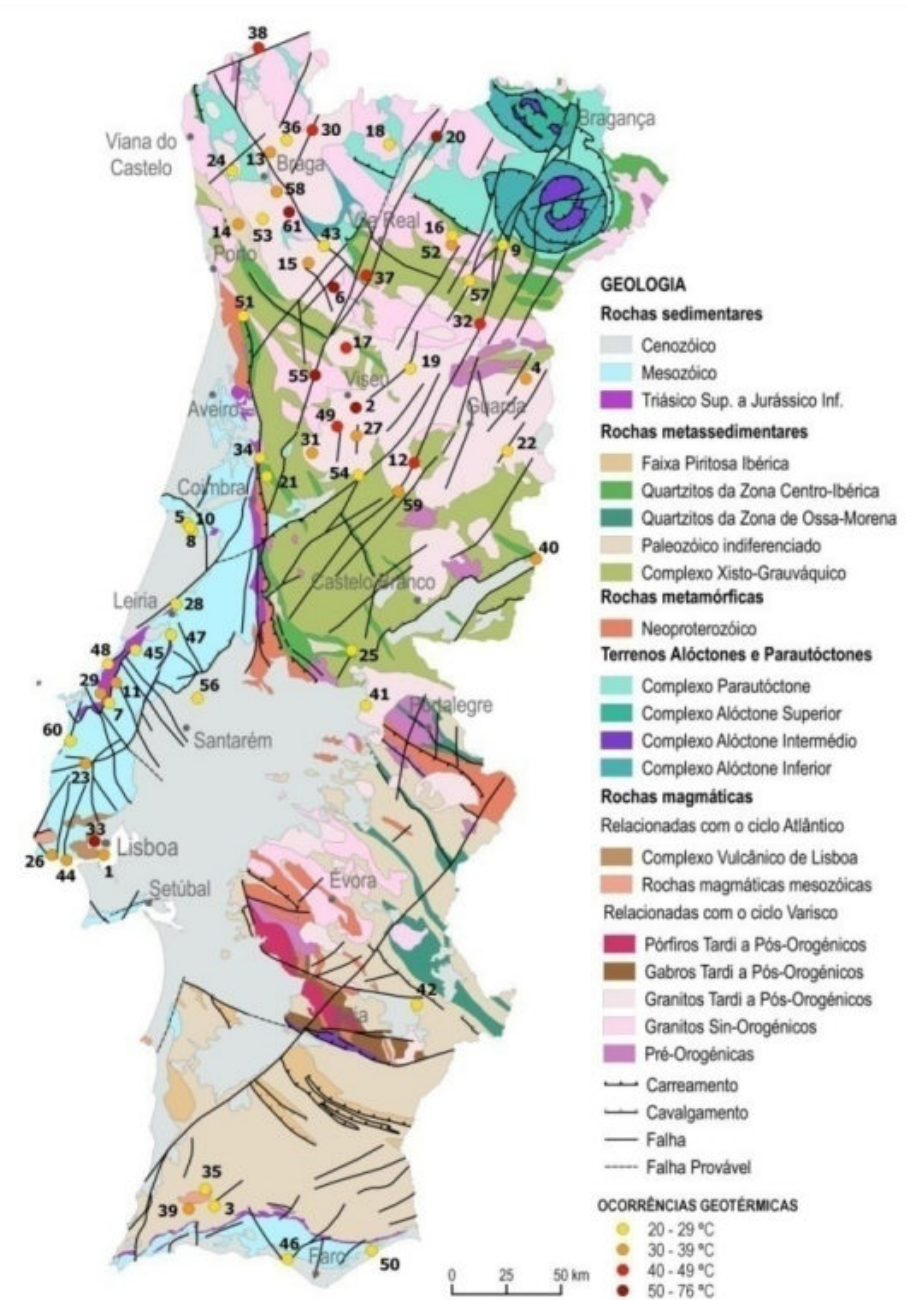
Low-temperature geothermal resources in Mainland Portugal are exploited for direct uses in balneotherapy and small heating systems. In the Azores Archipelago, low enthalpy resources are also traditionally used in balneotherapy, and pilot (demonstration) projects are being developed to take advantage of this resource for domestic water heating and building-based air conditioning.

In Portugal, ground source heat pump technology is a growing market and is needed for the heating and cooling of buildings. New regulations for shallow geothermal purposes are being prepared to manage all new GSHP installations (including registration), to avoid bad practices and to obtain realistic statistical data on the new installations. These new regulations, financing programs, and data (for incorporation in a Portuguese heat flow density map), will indefinitely enhance geothermal in Portugal Mainland.

At Madeira Archipelago, the LNEG - Portuguese National Laboratory for Energy and Geology carried out in 2013 a geothermal survey for the EEM - Empresa Eléctrica da Madeira, including geological, geochemical and geophysical investigations (e.g. magnetotellurics). The available results indicate the existence of geothermal potential within the island that support conditions for the development of an enhanced geothermal system (EGS).

In Mainland Portugal, classical geothermal resources are generally associated with the following origins: i) thermo-mineral waters related to active faulting and diapirism; and ii) deep circulation in some peculiar structures in the basement and particularly in the sedimentary borders via permeable formations.

The prolific geothermal resources occur in the Hesperian (or Iberian) Massif, which happens to be the most extensive segment of the Hercynian basement in Europe. The Hesperian Massif consists of mainly pre-Mesozoic formations, metasediments and plutonic rocks (primarily granites). The majority of the sources are located in the Central Iberian Zone, close to the active faults of NNE-SSW trend. Occurrence of hot waters is related to zones of uplift during the Quaternary (the vertical movement consisted of about 500 m in the northern and 100 to 300 m in the southern parts of Portugal) and a mechanism of seismic “pumping” has been proposed to explain the migration of hot fluids to the surface. Although in the field the distance between the sources and the mega-fractures can occasionally reach many kilometers, detailed hydrogeological studies have revealed intersections of transverse secondary faults and ENE-WSW sub-vertical fracture systems, which make excellent pathways for fluid travel.



<https://www.geothermal-energy.org/pdf/IGStandard/WGC/2020/01080.pdf>

Naturally available discharged fluid from former exploitation systems reached a maximum flowrate of 10 L/s. New wells up to 1,000 m depth drilled after the 1970's allowed moderate improvements in sustainable production and extraction temperatures.

Regarding chemistry, the following groups could be observed at the Central Iberian Zone:

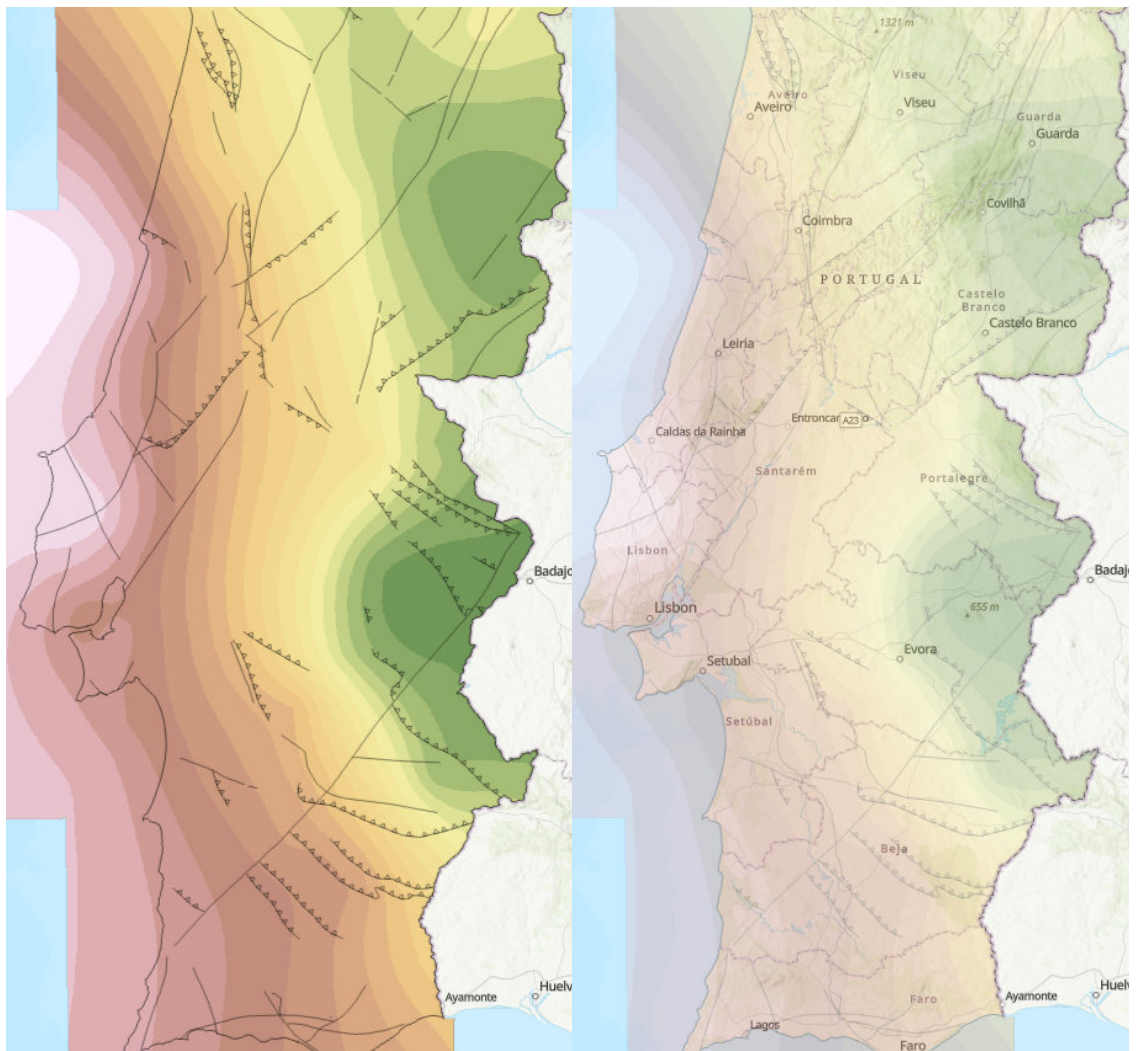
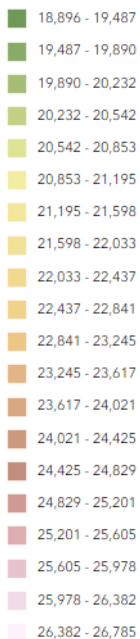
- (i) hypo-saline waters with total dissolved solids (TDS) less than 150 ppm, and frequently under 50 ppm, associated to quartzite reservoirs;
- (ii) sulphurous waters with up to 1,000 ppm and temperatures up to 62 °C; and
- (iii) carbonated sparkling waters with TDS up to 2500 ppm and temperatures up to 76 °C.

Low enthalpy geothermal resources have been identified in the sedimentary borders of Mainland Portugal:

- Western border sediments with thicknesses up to 4,000 m contain thermal fluid related to deep faulting and diapiric tectonics; in this location, water at 35 °C of sodium-chloride composition (partially sulfurous) is used for balneotherapy purposes.
- In the Tejo and Sado basins, temperatures of 75°C were estimated for a Jurassic limestone reservoir source at 2,500 m, with 5,000 ppm TDS water.
- In the Lisbon region, cretaceous formations are reservoirs of thermal water that have been historically exploited (since Roman occupation) for balneological purposes, as spring water temperatures reached up to 40 °C. A 1,500 m deep well with 53°C - bottom hole temperature (BHT) has been emplaced; the water shows Cl-Na facies and 500 mg/l.

The existing temperatures restrain utilization to direct-only. Twenty-four springs are officially used in balneotherapy, having discharge temperatures of 25 to 76 °C. The common range of values obtained by the appropriate geothermometers yields temperatures of 70 °C to 130 °C. The elevated geothermal gradient is ~3.5°C or ~2.68 °C per 100 m according to public information in the LNEG portal. Normal gradients are in the range of 2.1°C per 100 m, indicating an average temperature of approximately 50 °C at 1,500 m depth. The regional heat flow density (HFD) is ~60 to 90 mW/m² in the Central Iberian Zone and 40 to 90 mW/m² in the sedimentary basin.

Gradiente Geotérmico (°C/km)



<https://geoportal.lneg.pt/mapa/?lang=en#>



GEO THERMAL PROJECTS

PORTUGAL

Direct use application in Mainland Portugal and Azores is restricted to small district heating operations and balneological applications.

District Heating:

Two main operations are running, mainly for the purpose of heating thermal baths:

- **Chaves**, Northern Portugal: there is one dedicated well (150 m deep, 76 °C, TDS of 2500 mg/L, 5 L/s capacity) cutting through metamorphic slates with quartz veins, which is used in a small district heating network (swimming-pool and hotel). A second well (at 208 m deep, 74 °C, TDS of 2500 mg/L, 10 L/s capacity) tapped hot water in metamorphic slates with quartz veins and feeds the Thermal Bath as well the district heating network. A third well (100 m deep, 68°C) is maintained as a backup well.
- **S. Pedro do Sul**, central Portugal, the main Portuguese Spa: there is one inclined well (500 m deep, 69 °C, 350 mg/L TDS, 10 L/s with artesian flow) in fractured granite that is used to supply heating to a Thermal Bath. This well also feeds a small heating operation financed by the THERMIE Program designed for the heating of two hotels and the inside of the Spa. The total available production rate (former classical spring and well AC1) is 17 l/s.

Several minor district heating operations are running in Caldas de Monção, Termas da Longroiva, Alcafache in Mainland Portugal and at Furnas hotels in S. Miguel (Azores archipelago).

Bathing and Swimming

Balneological activities using thermo-mineral waters are quite popular in Portugal for wellbeing and touristic purposes. About 30 Thermal Baths are operating within a legal framework. Most are open only in summer, but some are operated regularly across the year. All balneological activity inside the baths occurs within strict medical constraints.

Since 2004, the INOVA Institute and the Azores Government undertook several initiatives to begin studies focused on exploitation and valuing of the Azorean low temperature geothermal resources for direct use, including touristic activities and balneology. As a result, new shallow wells were established in Ferraria (S. Miguel), Varadouro (Faial) and Carapacho (Graciosa).

<https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01080.pdf>

Ground Source Heat Pumps

According to the latest data recorded by the European Heat Pump Association (EHPA), there were no new sales of GSHP in Portugal in 2014. The aggregated sales until 2014 were on the order of 54 units, with an installed capacity of 0.65 MW. Considering typical values, the average installed capacity was 12 kW, with 1,340 operating hours and a typical Seasonal Performance Factor (SPF) of 3.425. Obtaining data after 2014 was not possible. It is difficult to follow the evolution of new GSHP projects because Portugal doesn't have legislation to encourage the registration of this kind of project, especially in the residential sector. It is possible that a greater number of small installations are performed each year, but go unreported. Having a goal to increase data availability in this area and inherently to promote the dissemination and proper use of GSHP, four national entities (DGEG, LNEG, APG and ADENE) established a collaboration protocol to create a baseline study, analysis and dissemination of geothermal use through GSHP. The Portuguese Platform of Shallow Geothermal Energy (PPGS) was created in 2013 with the mission to disseminate the best practices involving GSHP, promote a dialogue in the geothermal community, collaborate on new legislation, and spread knowledge of technical standards and procedures. In doing this, they contributed to the training of agents involved in these projects and promoted the development of new projects. However, weak interest in the application of shallow geothermal energy in Portugal caused this platform to end its activity in 2017. One of the discouraging factors for the development of shallow geothermal energy is the lack of a legal framework. A new legislative framework concerning shallow geothermal use should impose the obligation to register installed GSHPs. With a legislative framework, new statistical data of installations would become available. In spite of the lack of registration, some information about GSHP projects developed in Portugal were still recorded and are listed below.

- **Brigantia Ecopark in Bragança:**

This system is equipped with three GSHPs, one for domestic hot water (DHW) heating and two for air conditioning. To dissipate heat generated by the GSHP, 45 boreholes, with a depth of 120 m, were installed. Regarding GSHP for DHW, only heat is produced and the system is interconnected with a DHW reservoir. Concerning the other two GSHP, for acclimatization, heating and cooling is produced and the system is connected to a buffer tank of 9,000 L. When the tanks are full, the excess heated or cooled water is dissipated into the borehole heat exchangers. Under this building a set of tubes serves as air inflow pre-heating to reduce energy consumption, thereby improving the system efficiency.



- **Superior School of Technology of Setúbal (EST Setúbal):**

The Polytechnic Institute of Setubal, a partner in GROUNDHIT European Project (6th Framework Program), has a demonstration site for high energy efficiency GSHPs. Two GSHPs of 15 kWt for heating and 12 kWt for cooling each, were installed in the thermodynamics laboratory to condition 7 office rooms with areas between 13 and 17 m² and 2 classrooms with 63 and 65 m². The project mission was to monitor the improved energy efficiency heat pumps (COP higher than 5.5) prototype in real conditions of a Mediterranean climate,



and to test two different Borehole Heat Exchangers (BHE) types: double-U pipes and coaxial pipes. The demo site results showed that the GSHPs COP is comparable to the expected values calculated in the design phase (COP of 5.19 for cooling and 6.05 for heating in real conditions), with a reasonable performance of terminal units (fan-coils, secondary circuit), boreholes (primary circuit) and GSHP.

- **Regional authority administration building in Coimbra:**

This is another European project (7th Framework Program) called GROUNDMED, that aims at verifying sustainability of heat pump technology for heating and cooling of buildings in a Mediterranean climate. The Portuguese GROUNDMED installation was developed for a regional authority administration building with offices and laboratories located in Coimbra city. One GSHP with a heating capacity of 56 kWt and cooling capacity of 61 kWt (Eurovent conditions) serves the building 3rd floor offices. The GSHP is coupled to seven double U, 125 m vertical borehole heat exchangers. The heating/cooling distribution system consists of 33 ceiling Coanda effect fan coil units with high efficiency permanent magnet EC motors, installed in 22 offices, with a total area of 600 m². Since all systems were designed to function with moderated temperatures, the real cooling capacity is 63.5 kWt and the real heating capacity is 70.4 kWt, allowing for increased performance. The results showed reasonable results with a GSHP COP of 5.65 and an EER of 6.19.



- **Aveiro University:**

Aveiro university has 5 buildings acclimatized with GSHP.

- **Sines Tecnopolo:** This system, which includes heating, cooling and domestic hot water production, is attached to an existing renewed building with 251 m², a laboratory building with 534 m² and an office building with 1,286 m². These buildings are all served by GSHPs. The existing renewed building is served by one GSHP with a heating capacity of 24.5 kWt and cooling capacity of 18.4 kWt, coupled to 2 simple U-tube 150 m vertical borehole heat exchangers.
- **Ombria Resort, Algarve:** This resort includes one golf course, the club house, one hotel, one Spa and villas, constituting the largest system installation of shallow geothermal energy in Portugal. At the moment, this field is in the final phase of the installation, being completed this year. The total required capacity based in GSHP is about 2370 kW of heating and 1100 kW of cooling. The club house has an area of 1,260 m² and the hotel, spa and villas have an area of 15,940 m². Forty BHEs of 100 m depth each were installed for the clubhouse, sixty BHEs of 125 m depth each were installed for the hotel and 144 BHEs of 115 m depth each were installed for the spa and villas. Solar collectors (vacuum type) were utilized for DHW, hot water for the swimming pools and heat injection via BHEs to equilibrate the balance of energy injected and extracted by the GSHP system throughout the year. A total of 108 solar collectors were installed for the club house, and 48 solar collectors were emplaced for the hotel.

ORGANIZERS

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Volcanoes – Municipality & Institutional support



Geysers – \$250 to \$500



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