

IAVCEI Commission on Volcanic Lakes

Second Circular



CVL 11th Workshop São Miguel, Azores, Portugal 28th August to 5th September 2023



Invitation

On behalf of the IAVCEI Commission on Volcanic Lakes and the Research Institute for Volcanology and Risks Assessment (IVAR), we are happy to invite you to participate in the 11th Workshop on Volcanic Lakes on São Miguel Island, Azores, from August 28th to September 5th 2023 (<https://cvl11workshop.wixsite.com/2023>).

The goal of the workshop is to bring together scientists from a wide range of disciplines, such as hydrology, geochemistry, geophysics, limnology, microbiology, and physical volcanology to enable the exchange of ideas on a broad range of topics, including: state-of-the-art field measurement techniques; geochemical, geophysical, and microbiological characteristics and monitoring of volcanic lakes; modeling of volcanic lake system processes, and hazard forecasting and mitigation.

CVL 11 will offer formal scientific sessions and field visits to volcanic areas where intracaldera lakes exist. Visits are planned to the lakes of the quiescent Fogo, Furnas and Sete Cidades volcanoes at São Miguel Island. These lakes offer ample field sampling and measurement opportunities, including water column sampling and lake-surface degassing measurements. Additional geochemical and geophysical measurements on the fumarolic field around Furnas Lake are also an option.



Furnas Lake surrounded by a fumarolic field.

Conference

The conference will be a perfect opportunity to approach a wide range of scientific activities around the study of volcanic lakes.

Scientific Program

The program will include some sessions focused on the geochemical and hydrogeochemical characterization of lake waters, to better understand some processes that may be affecting these water bodies, and also, on the interaction of the lake water masses in volcanic environments. A special session on the Azores lakes will be part of the program. Characterization of the Azorean secondary manifestations of volcanism will also be included in this section. The main topics will be:

- *Geochemical and geophysical studies of volcanic lakes;*
- *Gaseous emissions from lakes;*
- *The impact of volcanic lakes on society;*
- *Volcanic lake monitoring;*
- *Hazard assessment;*
- *Phreatic events.*

Field activities

Permits to sample three volcanic lakes will be granted by the organization and field activities may comprise:

- *Collection of lake water samples;*
- *Gas flux measurements;*
- *Geophysical measurements;*
- *Other field activities according to the participants' interests.*

Gas sampling and potential geophysical measurements in the fumarolic areas on the shore of Furnas Lake will also be possible.



Vertical profiles carried out along the water column.

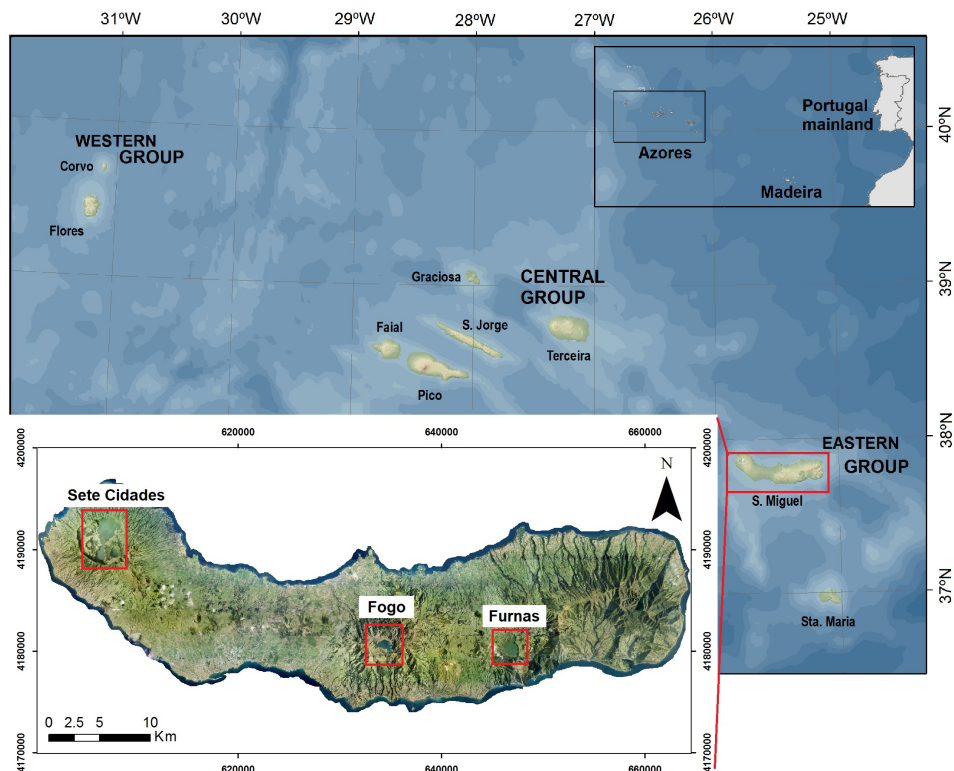


The CO₂ flux measurements using the modified accumulation chamber method.

General Information

The Azores archipelago is located in the North Atlantic Ocean between 37° to 40°N latitude and 25° to 31°W longitude, about 1500 km west of mainland Portugal. The archipelago is comprised of nine volcanic islands, spread along a ~640-km-long WNW–ESE trending zone. Geographically, the islands can be categorized into three groups: the Western Group, composed of the islands of Corvo and Flores; the Central Group, encompassing five islands (Terceira, Faial, Pico, São Jorge, and Graciosa); and the Eastern Group, including the islands of Santa Maria and São Miguel, the latter where the workshop will be held.

São Miguel is the largest island of the archipelago (area of 744 km²) and has 138,138 inhabitants. The geology of São Miguel is dominated by three quiescent central volcanoes (Sete Cidades, Fogo and Furnas), associated with highly explosive eruptions of trachytic magmas and linked by two fissure zones (Booth *et al.*, 1978; Moore, 1990; Guest *et al.*, 1999; Pacheco *et al.*, 2013). Two inactive volcanic systems (Povoação and Nordeste) are located on the eastern side of the island (Duncan *et al.*, 2015).



Location of the Azores archipelago in the North Atlantic Ocean and framework of São Miguel Island with the location of the three main lakes, Sete Cidades, Fogo and Furnas.

Areas to be visited during the CVL11

- **Sete Cidades Volcano**

Sete Cidades Volcano occupies the westernmost sector of the island and has an area of 110 km², a subaerial volume of 45 km³, and a summit caldera ~ 5 km in diameter. In addition to Sete Cidades Lake, volcanic structures such as pumice cones, *maars* and domes are present within the caldera. No subaerial volcanic eruption occurred in this volcanic system since the settlement of the islands, in the 15th Century; however, three submarine eruptions were reported (one in 1638, and two in 1811). The only visible gas emissions in this volcanic system are associated with thermal springs located offshore.

Sete Cidades Lake (261 m above sea level) has a total surface area of 4.39 km² and, due to morphological features, is subdivided into two interconnected water bodies, known as Blue Lake (Lagoa Azul; 3.58 km²) and Green Lake (Lagoa Verde; 0.81 km²). Blue Lake has a maximum length, width, and water depth of 2600, 2100, and 29.5 m, respectively, while Green Lake has a maximum length, width, and water depth of 1540, 770, and 24.5 m, respectively (Andrade *et al.*, 2020b). The total estimated water storage of Sete Cidades Lake is ~58×10⁶ m³ (Blue lake: ~47.4×10⁶ m³; Green lake: ~10.6×10⁶ m³; Pacheco *et al.*, 2018).

Green and Blue lakes are monomictic in character. Waters are cold (mean=17.6 °C), weakly mineralized (EC mean=116 µS/cm) and with neutral pH (mean=7.7). The major-ion relative composition in decreasing order is Na⁺ > Mg²⁺ > Ca²⁺ > K⁺ for cations and Cl⁻ > HCO₃⁻ > SO₄²⁻ for anions. The lake waters are mainly of the Na–Cl type, which is likely caused by sea salt input, arising from seawater spraying. Values for the CO₂ fluxes range between 0.3 and 17.2 g m⁻² d⁻¹ (Blue lake), and from 2.1 to 17.9 g m⁻² d⁻¹ for the Green lake. The most relevant degassing areas are found associated with the massive presence of macrophytes and algal blooms. The measured values, supported by isotopic data of δ¹³C, suggest one single CO₂ source, which is probably of biogenic nature. The estimated total CO₂ emission varied between 5.8 t d⁻¹ (Green lake) and 24.9 t d⁻¹ (Blue lake) (Andrade *et al.*, 2020b).

Santiago Lake is a 0.26 km² *maar* crater lake with a maximum depth of 33 m, located in the southeastern part of the summit caldera at about 400 m *a.s.l.* (Andrade *et al.*, 2019).

From the storage volume, equal to $5.3 \times 10^6 \text{ m}^3$, and the runoff inflow $2.17 \times 10^5 \text{ m}^3 \text{ yr}^{-1}$, the residence time was estimated as $\sim 24.5 \text{ yr}$.

Santiago Lake is a monomictic lake, being usually stratified during late spring and summer, with low mineralized waters of meteoric origin (EC mean = $128 \mu\text{S/cm}$), being the temperature in the range between 12.4°C (winter period) and 23.8°C (summer period), and with neutral pH (mean = 7.2). The main water type is Na-HCO_3 , and the relative major-ion composition is $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{F}^-$ for anions and $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$ for cations.

CO_2 flux values measured in the lake surface range between 0 and $34.8 \text{ g m}^{-2} \text{ d}^{-1}$, presenting a mean value of $8.3 \text{ g m}^{-2} \text{ d}^{-1}$. The higher CO_2 fluxes were measured during the winter surveys (5.6 t d^{-1}), while the lowest values (0.2 t d^{-1}) were recorded in the summer. These seasonal differences observed are associated with the monomictic character of the lake, as the CO_2 is not able to ascend to the surface when the water column is stratified during the warmer period (Andrade *et al.*, 2019).



Sete Cidades Lake inside the caldera of the Sete Cidades Volcano.

- **Furnas Volcano**

Furnas Volcano is the easternmost dormant central volcano of São Miguel Island. Growth of Furnas volcano started about 100,000 years ago, mainly due to explosive eruptions that emitted trachytic pumice deposits. Subsequent stages of caldera collapse produced a caldera complex (Guest *et al.*, 1999; 2015). Two subplinian volcanic eruptions occurred since the settlement of the island, in 1439-43 and in 1630. Secondary manifestations of volcanism include fumaroles, thermal and cold CO₂-rich springs, as well as several diffuse degassing areas both inside the caldera and on the south flank of the volcano (Cruz *et al.*, 1999; Viveiros *et al.*, 2010). One of the four fumarolic fields is located in the north part of Furnas Lake.

Furnas Lake is located inside the youngest caldera of Furnas Volcano and has a surface area of 1.87 km², a maximum length of 2025 m and a maximum width of 1600 m. The lake surface is 280 m above sea level and the estimated water storage is equal to 14x10⁶ m³ (Pacheco *et al.*, 2010). The deepest part of the lake (15 m) is located in the north-central sector (Andrade *et al.*, 2016).

Lake water temperature is cold, with temperature values between 14°C in winter period and 19°C in early autumn. Temperature values along the water column suggest a monomictic character. Water chemistry depicts a relative composition in decreasing order of Na⁺ > K⁺ > Ca²⁺ > Mg²⁺ for cations, and HCO₃⁻ > Cl⁻ > SO₄²⁻ for anions. Furnas Lake may be classified as a non-active lake, due to the neutral-diluted character of the waters, which is shown by conductivity and pH, respectively, in the range of 152 to 165 µS cm⁻¹ and 5.3 to 8.7.

Measured CO₂ flux values from Furnas Lake ranged between 0 and 20,960 g m⁻² d⁻¹, with a mean value of 424 g m⁻² d⁻¹. The total amount of diffuse CO₂ emitted to the atmosphere was estimated between ~52 and ~600 t d⁻¹, respectively, associated to early autumn and winter period. A magmatic CO₂ origin is confirmed by isotopic analysis of δ¹³C.



Furnas Lake and one of the hydrothermal fumarolic fields located inside the caldera of the Furnas Volcano.

- **Fogo Volcano**

Fogo Volcano (also known as Água de Pau), is a depressed area of about 4.8 km², with a maximum diameter of 3.2 km and walls as high as 370 m, inside which a pumice cone and several domes can be observed (Wallenstein *et al.*, 2015). Fogo Volcano dominates the central portion of the island, with an area of 132 km² and a subaerial volume of about 44 km³ and corresponds to a complex volcanic system dated from > 200 ka (Muecke *et al.*, 1974). The last magmatic events occurred already after the settlement of the island on 1563 and corresponded to a subplinian intracaldera eruption followed by a basaltic flank episode. A phreatic intracaldera episode was recorded in 1564 (Wallenstein *et al.* 2015).

Nowadays volcanic activity is characterized by the presence of fumarolic fields and thermal and cold CO₂-rich springs, all located on the north flank of the volcano (Caliro *et al.*, 2015; Cabral *et al.*, 2015). Several soil diffuse degassing areas have also been identified in this volcanic system, mainly on the north flank of the volcano (Viveiros *et al.*, 2015). No visible hydrothermal manifestations are found inside the caldera.

A geothermal power plant is located in the north flank of this volcanic system and produces about 50% of the Island's energy.

Fogo Lake is located at an altitude of 580 m and has a surface area of 1.53 km², a length of 985 m, and a width of 2280 m (Andrade *et al.*, 2020a). The maximum depth is 31.6 m and the storage volume is estimated as equal to 23.4x10⁶ m³. The watershed that drains to the lake has an area of 5.04 km², and the total inflow was estimated as 4.07x10⁶ m³/a (AHA-DRA, 2015). Water temperature of the Fogo Lake is cold (mean=16.5°C), and depict a monomictic behaviour, with water column stratification during summer resulting in higher carbon dioxide concentrations in the hypolimnion. Samples present an acid to neutral pH (mean=7.04), and in general correspond to very diluted and weakly mineralized waters (mean EC=48 µS/cm). The prevailing hydrogeochemical facies are of the Na-Cl type, which derives from atmospheric marine salts contamination, major-ion content variation with depth shows low variation, along the water column.

Measured CO₂ flux values are relatively low, ranging from 0 to 28.4 g m⁻² d⁻¹ (mean = 2.6 g m⁻² d⁻¹). The very low values measured in the central area of Fogo Lake are associated with the monomictic character of the lake. Statistical analyses suggest that the CO₂ emission is associated with a single source of CO₂, probably biogenic; in agreement with the water δ¹³C isotopic content. The estimated total CO₂ emissions from the Fogo Lake was approximately 4.2 t d⁻¹.



Fogo Lake inside the caldera of Fogo Volcano.

Conference venue and accommodations:



Campus at the University of the Azores

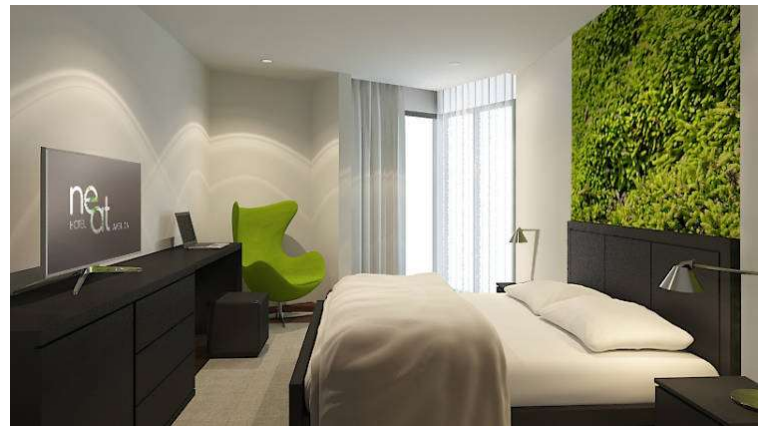


Conference site

Founded in 1976, the University of the Azores has consolidated itself over the decades as a reference institution within the archipelago, managing to build scientific and cultural ties within and between islands. The University has branches in three islands, being the IVAR located at Ponta Delgada in the Island of São Miguel.

<http://www.uac.pt>

<http://www.ivar.azores.gov.pt>



Neat Hotel Avenida and rooms.

With a premium location in the heart of Ponta Delgada, Neat Hotel Avenida is both young and hip but also professional and comfortable, and the ideal choice for those looking to discover São Miguel Island. The location is 10 minutes walking from the University of the Azores.

<https://www.bensaudehotels.com/neathotelavenida>

Program

August 28th

- Arrival of participants to São Miguel Island (Ponta Delgada airport)
 - Transport from airport to hotel (about 10 minutes travelling by car)
 - Check-in at Neat Hotel Avenida

August 29th

- Breakfast at Neat Hotel Avenida
- 8:00 – Registration in the University of the Azores
- 9:00 – Opening Ceremony in the University of the Azores
- 10:00 – Sessions - University of the Azores
- 11:00 – Coffee break
- 11:20 – Sessions - University of the Azores
- 13:00 – Lunch at the University of the Azores
- 14:00 – Sessions - University of the Azores
- 16:30 – Coffee break with poster session
- 16:50 – Sessions - University of the Azores
- 18:30 – Icebreaker

August 30th

- Breakfast at Neat Hotel Avenida
- 8:30 – Sessions - University of the Azores
- 10:30 – Coffee break
- 10:50 – Sessions - University of the Azores
- 13:00 – Lunch at the University of the Azores
- 14:00 – Sessions - University of the Azores
- 16:00 – Coffee break with poster session
- 17:00 – Visit to the IVAR (laboratories and monitoring center)

August 31st

- Breakfast at Neat Hotel Avenida
- 8:30 – Departure from the University of the Azores by bus
 - Field trip to Fogo volcano (visit to the geothermal power plant and fumarolic fields)
- 17:00 – Arrival at the University of the Azores by bus
- Preparation of field material in the laboratories of the University of the Azores

1st to 3rd of September

- Breakfast at Neat Hotel Avenida
- 8:30 – Departure from the University of the Azores by bus
 - Furnas Lake field work
 - Lunch boxes will be provided in the first two days. On September 3rd a typical Azorean lunch cooked in the fumaroles will be served followed by a visit to the botanical Terra Nostra garden (thermal swimming pool available)
- 17:00 – Arrival at the University of the Azores by bus

September 4th

- Breakfast at Neat Hotel Avenida
- 8:30 – Departure from the University of the Azores by bus
 - Sete Cidades and Santiago lakes field work
- 17:00 – Arrival at the University of the Azores by bus
- 19:30 – Farewell party at Ponta Delgada

September 5th

- Departure from Ponta Delgada

Organization and Logistics

Fees

Final costs per person in double room is 800€.

For single rooms, the individual final cost is 1160€.

* The organization assures these prices for 25 double rooms and 5 single rooms (first 55 registrations). Extra participants may need to book accommodation. Registration costs without accommodation are 400€.

Costs include:

- Registration
- Transfer Ponta Delgada airport – Hotel
- Transfer Hotel - Ponta Delgada airport
- 8 nights' accommodation in double room at Neat Hotel Avenida, breakfast included
- Bus transport to all surveyed areas (Furnas, Fogo and Sete Cidades)
- Permits and fees to the field sites
- Lunch boxes/lunches from 29th August to 4th September
- Coffee breaks
- Icebreaker
- Typical lunch at Furnas village (food cooked in hydrothermal fumaroles close to Furnas Lake)
- Visit to Terra Nostra botanical garden (thermal swimming pool available)
- Farewell party

Not included in the conference fees:

- Airline tickets
- Dinners (excluding the Farewell party)

- Lunches on the arrival and departure days
- Costs of any tourist activity outside the program

Registration and Abstract Submission

The registration must be done online before **3rd March 2023**, in the following link:

<https://forms.gle/Si5sJ8NhtKxNb1nZA>

Abstract will be submitted together with the registration using the same link. Abstracts are all written in English and include title, author(s) name(s), affiliation(s), country (ies), keywords and text (maximum 350 characters).

Scholarships

Thanks to generous contributions from the IAVCEI, the European Association of Geochemistry (EAG) and the IVAR, we offer the possibility to apply for grants covering the registration of the workshop in double room, 800 Euros each.

The grants are open to all candidates, but preference will be given to graduate students and early career scientists that work on volcanic lakes, especially in Low and Middle Income Countries. Submission of an abstract for presentation in the Workshop is a requirement, as well as a strong commitment to attend the workshop.

Interested applicants should submit an abstract no later than the **24th of February 2023**, together with a motivation letter and a CV (one page), in pdf format, through the registration form. A panel with members of the Scientific Committee will evaluate only complete applications received on time. The results will be announced by the 28th February 2023.

Payment Methods

The fees can be paid with bank transfer up to the **20th March 2023**. The IBAN and SWIFT codes are:

- IBAN: PT50 0018 000806888142020 50
- BIC/SWIFT: TOTAPTPL

Add the following information on the bank transfer: “CVL registration - NAME”. After the payment, please send the confirmation to the following e-mails:

cesar.cc.andrade@azores.gov.pt and maria.fb.viveiros@azores.gov.pt

Insurance and customs

Citizens outside the European Union may need an invitation letter to participate in the CVL workshop. Please inform the organization when you do the register. Similarly, send a list of all the material you are bringing to the workshop, so we will write a letter to each participant to be showed to the customs. Nevertheless, the organization cannot be responsible for the customs procedures when participants arrive to the Portugal border.

Important dates

- 14 October 2022 – First Circular
- 19 January 2023 – Second Circular
- 24 February 2023 – Deadline for grants application
- 28 February 2023 – Announcement of grants results
- 3 March 2023 – Deadline for registration and abstract submission
- 20 March 2023 – Deadline for the fee payment
- 28 August to 5 September – CVL Workshop

CVL Steering Committee

- Corentin Caudron
- Jennifer Lewicki
- Bruce Christenson
- Dmitri Rouwet

Local Organizing Committee

- César Andrade
- Fátima Viveiros
- José Virgílio Cruz
- Rui Coutinho

Scientific Committee

- Bruce Christenson
- Jennifer Lewicki
- Corentin Caudron
- Dmitri Rouwet
- Agnes Mazot
- Franco Tassi
- Jacopo Cabassi
- César Andrade
- José V. Cruz
- Fátima Viveiros

Sponsors

- IAVCEI
- IVAR
- CIVISA
- University of the Azores

References

- AHA-DRA, 2015. Plano de Gestão da Região Hidrográfica dos Açores – RH9. Versão para consulta pública. AHA-DRA, Ponta Delgada (in Portuguese, 5409 p.).
- Andrade, C., Cruz, J.V., Viveiros, F., Coutinho, R., 2020a. CO₂ emissions from Fogo intracaldera volcanic lakes (São Miguel Island, Azores): a tool for volcanic monitoring. *J. Volcanol. Geotherm. Res.*, 400: 106915.
- Andrade, C., Cruz, J.V., Viveiros, F., Coutinho, R., 2020b. Diffuse CO₂ emissions from Sete Cidades volcanic lake (São Miguel Island, Azores): influence of eutrophication processes. *Environ. Pollut.* 268, 115624.
- Andrade, C., Viveiros, F., Cruz, J.V., Branco, R., Moreno, L., Silva, C., Coutinho, R., Pacheco, J., 2019. Diffuse CO₂ flux emission in two maar crater lakes from São Miguel (Azores, Portugal). *J. Volcanol. Geotherm. Res.*, 369, 188–202.
- Andrade, C., Viveiros, F., Cruz, J.V., Branco, R., Moreno, L., Silva, C., Coutinho, R., Pacheco, J., 2019. Diffuse CO₂ flux emission in two maar crater lakes from São Miguel (Azores, Portugal). *J. Volcanol. Geotherm. Res.*, 369, 188–202.
- Andrade, C., Viveiros, F., Cruz, J.V., Coutinho, R., Silva, C., 2016. Estimation of the CO₂ flux from Furnas Volcanic Lake (São Miguel, Azores). *J. Volcanol. Geotherm. Res.*, 315: 51-64.
- Booth, B., Croasdale, R., Walker, G.P.L., 1978. A quantitative study of five thousand years of volcanism on S. Miguel, Azores. *Philos. Trans. R. Soc. A.*, 228, 271–319.
- Cabral, L., Andrade, C., Coutinho, R., Cruz, J.V., 2015. Groundwater composition in perched-water bodies in the north flank of Fogo volcano (São Miguel, Azores): Main causes and comparison with river water chemistry. *Environ. Earth Sci.*, 73, 2779–2792.
- Caliro, S., Viveiros, F., Chiodini, G., Ferreira, T., 2015. Gas geochemistry of hydrothermal fluids of the S. Miguel and Terceira islands, Azores. *Geochim. Cosmochim. Acta*, 168, 43-57.
- Cruz, J.V., Coutinho, R.M., Carvalho, M.R., Oskarsson, N., Gislason, S.R., 1999. Chemistry of waters from Furnas volcano, São Miguel, Azores: fluxes of volcanic carbon dioxide and leached material. *J. Volcanol. Geotherm. Res.*, 92, 151–167.
- Duncan, A.M., Guest, J.E., Wallenstein, N., Chester, D.K., 2015. The older volcanic complexes of São Miguel Island, Azores, Nordeste and Povoação, In: Gaspar, J.L., Guest, J.E., Duncan, A.M., Barriga, F.J., Chester, D.K., (eds), *Volcanic Geology of São Miguel Island (Azores Archipelago)*. Geological Society, London, Memoirs 44, 147–153.
- Guest, J.E., Gaspar, J.L., Cole, P., Queiroz, G., Duncan, A.M., Wallenstein, N., Ferreira, T., Pacheco, J., 1999. Volcanic geology of Furnas Volcano, São Miguel Azores. *J. Volcanol. Geotherm. Res.* 92, 1–29.
- Guest, J.E., Pacheco, J.M., Cole, P.D., Duncan, A.M., Wallenstein, N., Queiroz, G., Gaspar, J.L., Ferreira, T., 2015. The volcanic history of Furnas volcano, São Miguel, Azores. In: Gaspar, J.L., Guest, J.E., Duncan, A.M., Barriga, F.J., Chester, D.K., (eds), *Volcanic Geology of São Miguel Island (Azores Archipelago)*. Geological Society, London, Memoirs 44, 125–134.

- Moore, R.B., 1990. Volcanic geology and eruption frequency, São Miguel, Azores. *Bull. Volcanol.*, 52, 602–614.
- Muecke, G.K., Ade-Hall, J.M., Aumento, F., MacDonald, A., Reynolds, P.H., Hyndman, R.D., Quintino, J., Opdyke, N., Lowrie, W., 1974. Deep drilling in an active geothermal area in the Azores. *Nature*, 252, 281–285.
- Pacheco, J.M., Ferreira, T., Queiroz, G., Wallenstein, N., Coutinho, R., Cruz, J.V., Pimentel, A., Silva, R., Gaspar, J.L., Goulart, C., 2013. Notas sobre a geologia do arquipélago dos Açores. In: Dias, R., Araújo, A., Terrinha, P., Kullberg, J.C., (eds), *Geologia de Portugal*. Escolar Editora, Lisboa, pp. 595-690.
- Pacheco, D., Malcata, A., Mendes, S., Cruz, J.V., Gaspar, J.L., 2010. Monitorização da qualidade da água das lagoas de São Miguel: comparação de resultados entre 2004 e 2008. Ed. da SRAM, Gov. Reg. Açores, 217p.
- Pacheco, D., Malcata, A., Medeiros, M., Mendes, S., 2018. Monitorização da qualidade da água das lagoas de São Miguel: comparação de resultados entre 2013 e 2016. Ed. da SRAM, Gov. Reg. Açores, 217p.
- Viveiros, F., Cardellini, C., Ferreira, T., Caliro, S., Chiodini, G., Silva, C., 2010. Soil CO₂ emissions at Furnas Volcano, São Miguel Island, Azores archipelago: Volcano monitoring perspectives, geomorphologic studies, and land use planning application. *J. Geophys. Res: Solid Earth*, 115: 1-17.
- Viveiros, F., Gaspar, J.L., Ferreira, T., Silva, C., Marcos, M., Hipólito, A., 2015. Mapping of soil CO₂ degassing at São Miguel Island and its public health implications, In: Gaspar, J.L., Guest, J.E., Duncan, A.M., Barriga, F.J., Chester, D.K., (eds), *Volcanic Geology of São Miguel Island (Azores Archipelago)*. Geological Society, London, Memoirs, 44, 185–195.
- Wallenstein, N., Duncan, A. M., Guest, J.E., Almeida, M.H., 2015. Eruptive history of Fogo Volcano, São Miguel, Azores. In: Gaspar, J.L., Guest, J.E., Duncan, A.M., Barriga, F.J., Chester, D.K., (eds), *Volcanic Geology of São Miguel Island (Azores Archipelago)*. Geological Society, London, Memoirs, 44, 105–123.

