Joint IAATO/COMNAP Antarctic Fellowship 2022

Fellowship Project title: "Constraining the eruptive mechanisms of Three Sisters, Orca and Deception Island volcanoes (Bransfield Strait, Antarctica) through Noble Gases isotopic ratios. Implications for Geochemical Monitoring (BRANSVOLC)"

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The fellowship project, which is also a part of my PhD work, aims, firstly, to characterize the magmatic sources feeding the submarine volcanoes Three Sisters and Orca (Bransfield Strait, West Antarctica). This will be achieved through Noble Gas geochemistry analysis of the fluid inclusions hosted by glass or olivine phenocrysts present within the volcanic rocks. Additionally, the project involves the investigation of gas emanations (bubbling, heated ground, fumaroles) at Deception Island volcano, located 60 km east of Three Sisters. Therefore, a goal of the project is also to complement an in-progress research on Deception Island (e.g., Álvarez-Valero et al., 2022), towards a more detailed characterization of the magmatic system beneath this volcano, and potentially identify the most suitable tools for the future geochemical monitoring.

Consequently, the fellowship was divided in two phases. The first phase involved a research stay at INGV sezione di Palermo to conduct the Noble Gas geochemical study of the Three Sisters and Orca volcanoes. The second phase encompassed field sampling at Deception Island volcano within the framework of the 2022 – 2023 Spanish Antarctic Campaign. All the details related to both phases are explained below, along with comprehensive budget allocations. Additionally, a compilation of deliverables, as well as all dissemination and outreach initiatives undertaken during the project, has been provided.

1st Phase, Research Stay at INGV sezione di Palermo

A three-month research stay (September 2022-November 2022) was conducted at INGV sezione di Palermo (Italy). There, the research primarily focused on the Three Sisters and Orca submarine volcanoes. The study considered volcanic rock samples from the Polar Rock Repository (https://prr.osu.edu), consisting of five samples, dredged in both volcanoes. Additionally, one sample obtained from the Edifice C submarine volcano, situated 10 km east of Three Sisters, as well as one sample from an unnamed seamount (hereafter referred to as "Seamount"), positioned 20 km NE of Orca were also analysed (Fig. 1a, b).

All seven rock samples were crushed and sieved. Olivine is the best mineral phase to perform noble gas analysis due to the excellent retentivity of He within this mineral (e.g., Graham, 2002). Nevertheless, a minimum of 1g of glass shards (Fig. 1c,d) was hand-picked up since they were the most abundant phase, there was low quantity of olivines and in a context of submarine volcanism, glass is also suitable for noble gas analyses. An exception was made for Seamount, where 1g of olivine phenocrysts was collected due to the higher concentration (Fig. 1e).

Both glass shards and olivine phenocrysts were cleaned in ultrasonic bath. Then, they were loaded into a stainless-steel sample holder that was placed within a hydraulic crusher. Each sample was crushed in a single step and the released gas was conducted through a purification line composed of cold fingers and cold heads to purify and separate the different noble gases for measuring their isotopic ratios ($^{3}He/^{4}He$, $^{20}Ne/^{22}Ne$, $^{21}Ne/^{22}Ne$, $^{40}Ar/^{36}Ar$ and $^{38}Ar/^{36}Ar$).

Results showed $^{3}He/^{4}He$ ratios from 4.6 to 6.5 R_a (R_a means $^{3}He/^{4}He$ ratio normalized to the $^{3}He/^{4}He$ ratio of the atmosphere: 1.38×10^{-6}). The average value is 5.8 R_a in agreement with water measurements of Schlosser et al., (1988) (Fig. 1b). It was concluded that this uniformity likely arises from a common source richer in radiogenic He than the MORB (Mid-Ocean Ridge Basalt) mantle reservoir. Hence the mantle below the volcanoes of the Bransfield strait is distinguished from that sourcing Deception Island volcanism, which from the noble gas perspective shows affinity with MORB as discussed in Álvarez-Valero et al. (2022).

The Ne ($^{20}Ne/^{22}Ne$ = 9.9-10.25 ,$^{21}Ne/^{22}Ne$ = 0.029-0.031) and Ar ($^{40}Ar/^{36}Ar$ = 295-310) isotopic ratios ranged close to atmospheric values ($^{20}Ne/^{22}Ne$ = 9.8, $^{21}Ne/^{22}Ne$ = 0.029, $^{40}Ar/^{36}Ar$ = 298.56), pointing to strong atmospheric contamination. In the context of submarine volcanism like this, atmospheric contamination should be negligible since magma cooling is fast enough to prevent any atmospheric interactions (e.g., Ozima and Podosek, 2002). Potential explanations include: (i) atmospheric Ar introduction at the magma source through fluids from the Phoenix subducting plate, responsible of Bransfield Strait opening (Livermore et al., 2000), (ii) interactions between the shallow magmatic plumbing system beneath the volcano and the surface via fractures, or (iii) interaction with seawater during magma eruption during which cooling was not fast enough to prevent atmospheric interaction. To ascertain these mechanisms, additional criteria, such as petrography (observation of microfractures in the materials), major and trace element geochemistry; and O and H isotope geochemistry, are necessary. O and H isotope analyses are currently underway at the Stable Isotope Laboratory of the University of Salamanca (Spain). The research related mainly to the noble gas analyses has been presented in the EGU General Assembly 2023 (Polo Sánchez et al., 2023; See Deliverables).

Major elements (Si, Al, Mg, Fe, Ti, Ca, Na, K) analyses were made on the glass shards, olivine phenocrysts and in other mineral phases (clinopyroxene, plagioclase) present in the rock samples. They were carried out employing an electron microprobe at INGV Roma (Italy) in October 2022.

Major elements also served as internal standard to get the trace element compositions (e.g., Sr, Ba, REE). The trace element analyses were performed employing a LA-ICP-MS (laser ablation mass spectrometer) at the University of Perugia (Italy) at the end of the research stay in November 2022. It is worth noting that the analyses were free of economical costs due to an award granted by the University of Perugia given in 2021 (http://pvrg.unipg.it/laicpms2021/). Nowadays, major and trace element data are undergoing interpretation.

The concluding task of the research stay was focused on the preparations for the phase of the project involving Deception Island (second phase). It involved first the attendance to the Spanish Antarctic Campaign meeting held in Madrid in October 2022 followed by gas sampling training in November 2022 in Mt. Etna volcano, as well as in the gas emissions present in Umbria and Tuscany regions (Italy).

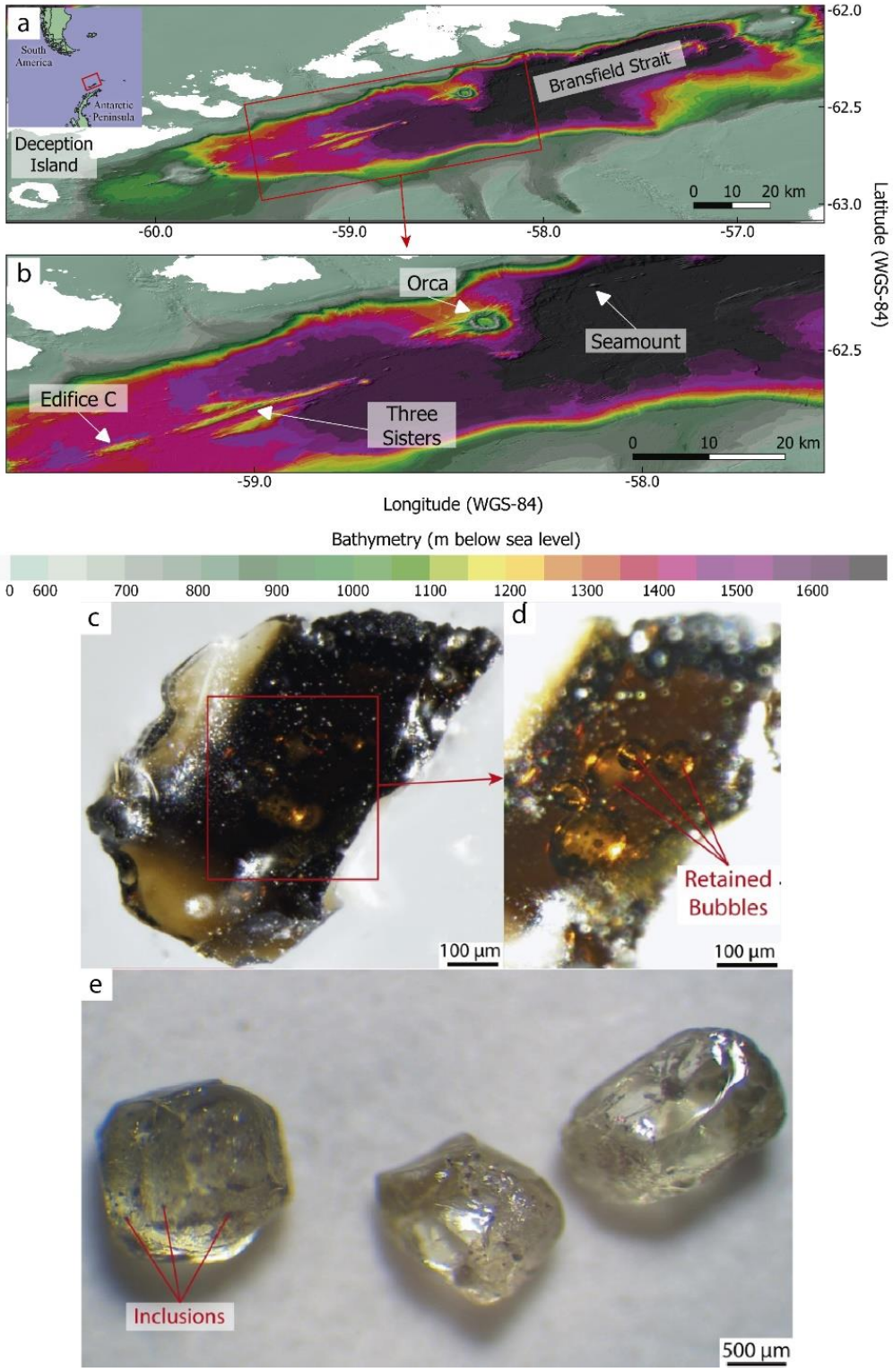

Figure 1. Location of Bransfield Strait and Deception Island (a). Location of Three Sisters, Orca, Edifice C and Seamount (b). Example of glass shard considered in the 1st phase of the present project(c). Zoom image of the glass shard showing retained bubbles with gas inside. This gas was extracted through crushing (d). Example of olivine phenocrysts also considered in the 1st phase €. Coordinates expressed in decimal degrees under system WGS-84. Bathymetry from the GMRT database (https://www.gmrt.org)

2nd Phase, Deception Island fieldwork

This phase was carried out in February-March 2023 at Deception Island. An exploration was first made along several volcanic gas emissions (fumaroles, Fig. 2a, b; bubbling in water, Fig. 2c, d; heated soil) mainly along the shore of Port Foster Bay. The most appropriate ones were sampled employing either a stainless-steel probe (fumaroles and heated ground) (Fig. 2b) or a stainless-steel funnel (bubbling in water) (Fig. 2d). Either the probe or the funnel was connected to a three-valve system. From the three valves, one was connected to a 100 cm^3 syringe to control the gas flux, while the other was connected to a valve tank that retained the targeted gas sample. Over the course of the fieldwork, a total of 13 locations, covering most of the bay, were sampled. For each site, 2-3 tanks were employed.

The tank contents were analysed mainly for noble gas at INGV sezione di Palermo (Italy) following a similar procedure as the one described in the first phase (the hydraulic crusher will not be employed since they are free gas samples). In addition, the isotopic compositions of carbon (C) from CO_2 together with the chemical composition of the volcanic gases, will be also analysed at the same institution. Currently, results obtained are being interpreted.

In addition to the gas sampling, temperature measurements were taken across the Fumarole Bay area, a location well-known for its continuous gas emissions (Fig. 2b). These measurements aimed to provide insights into the temperature distribution surrounding the fumarolic emissions. Notably, the temperature exhibited a significant decrease to the environmental soil temperature (103ºC down to 18ºC) within only a few centimetres from the fumarole.

As complementary task, several rock outcrops (Fig. 2f) at Cross Hill cone (one of the small volcanic edifices located within the island) were sampled. These specific outcrops were not sampled in previous campaigns conducted by other members of our research team. The objective was to investigate the extent of variability in terms of major element compositions, spanning from basalt to rhyolite (Geyer et al., (2019)) and not observed in the rest of the island. The collected samples have not yet undergone study, as this task is a complementary facet of our research.

All metadata (Álvarez-Valero et al., 2023a, b, c; See Deliverables) related to the fieldwork has been registered at Centro Nacional de Datos Polares and transmitted to the Antarctic Metadata Directory according to the guidelines given by “the storage and distribution of polar data in Spain (2022)” (Protocolo de remisión, almacenamiento y difusión de datos polares en España (2022)).

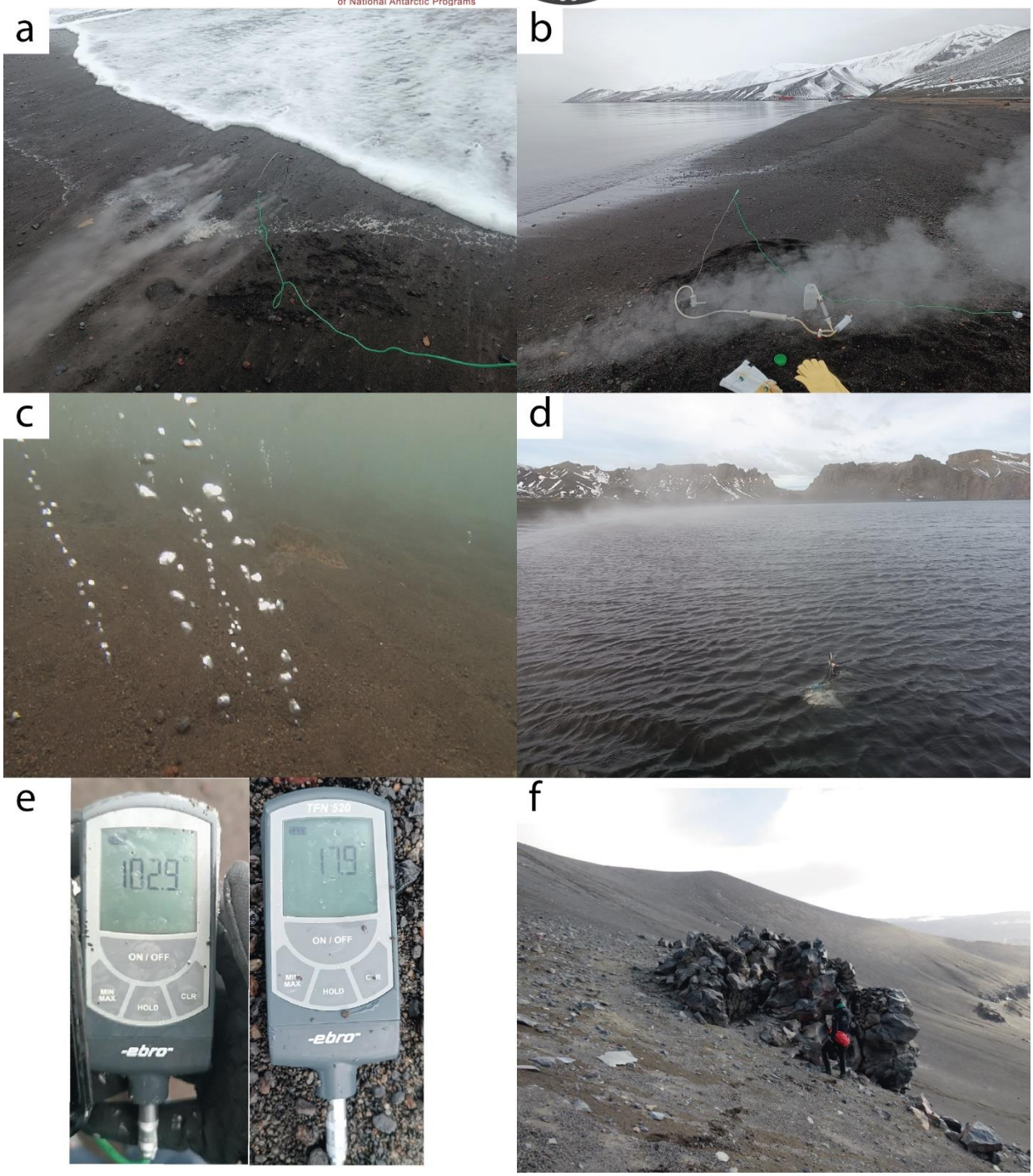

Figure 2. Volcanic gas emissions along Port Foster bay in Deception Island and sampling: Fumaroles and stainless-steel probe (a,b). Bubbling in water and stainless-steel funnel (c,d). Temperature measurements along Fumarole Bay area: Temperature within the fumarole (left) and several centimetres away from it (right) (e). Sampled outcrop at Cross Hill cone, person as scale (f).

Budget Expenses

The budget expenses encompass room, food and travel expenses, all directly related to the activities detailed above. In the second phase, only the expenses related to the transit between Spain and Chile are considered, as the transit from Chile to Deception Island is covered by the Spanish Antarctic Programme.

1st Phase

	Price (€)	Price (US $)	Notes
Travel (Salamanca-Palermo)	242.94	244.53	Train to Madrid (MD-18900) and flight from Madrid to Palermo (VY-1005 VY-6600)
Food Expenses	1000	1006.56	Food expenses for three months
Room Rent	1793.74	1805.51	Room rent through AirBnB
Travel (Palermo-Roma)	82.48	83.02	Round trip travel to perform electron microprobe measurements at INGV Roma. (Flights FR3947 and FR4908)
Hotel Expenses (Roma)	37.40	37.64	One night room rent
Travel (Palermo-Perugia)	68.80	69.25	Train (InterCityNotte 1954 Regionale Veloce 4726)
Hotel Expenses (Perugia)	107.60	108.30	Three night room rent
Travel (Perugia-Salamanca)	335.79	337.99	Train to Roma (Regionale Veloce 4725), flight to Barcelona (VY6103) and train to Salamanca (ALVIA 00638)
TOTAL		3692.80	Currency (1€ = 1.006561 US$; Global Exchage July 2023)

2nd Phase

	Price (€)	Price (US $)	Notes
Travel (Salamanca-Punta Arenas)	1723.34	1734.64	Round trip flight (Madrid-Punta Arenas; Flight numbers: LA81 LA705) and bus tickets (Salamanca-Madrid)
Hotel Expenses (Punta Arenas)	300	301.96	Hotel expenses for 5 nights before boarding Hespérides cruise to travel to Deception Island
Food Expenses	250	251.64	Food expenses for 4 days
Hotel Expenses (Punta Arenas)	240	241.57	Hotel expenses for 2 nights on the way-back travel
Food Expenses	100	100.65	Food expenses for 2 days
TOTAL		2630.46	Currency (1€ = 1.006561 US$; Global Exchage July 2023)

Deliverables

- **Polo Sánchez, A**., Caracausi, A., Álvarez-Valero, A. M., Geyer, A., and Insinga, L. (2023): Noble gas geochemistry to explore the sources of magma feeding the Antarctic submarine volcanism in Bransfield Strait (NW Antarctica), EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-3895, https://doi.org/10.5194/egusphere-egu23-3895.
- Álvarez Valero, A. M., **Polo Sánchez, A**., Caracausi, A. (2023a): ERUPTING Volcanic Gas [Data set]. CNDP. https://doi.org/10.57724/BGC_20230221_ERUPTING_VOL. http://cndp.utm.csic.es/catalogue/srv/eng/catalog.search#/metadata/CNDP_BGC_20230221_ERUPTING_VOL
- Álvarez Valero, A. M., **Polo Sánchez, A**., Caracausi, A. (2023b): ERUPTING Temperature Measurements [Data set]. CNDP. https://doi.org/10.57724/BGC_20230221_ERUPTING_TEMP. http://cndp.utm.csic.es/catalogue/srv/eng/catalog.search#/metadata/CNDP_BGC_20230221_ERUPTING_TEMP
- Álvarez Valero, A. M., **Polo Sánchez, A**., Caracausi, A. (2023c): ERUPTING Rock Sampling [Data set]. CNDP. https://doi.org/10.57724/BGC_20230221_ERUPTING_ROCK. http://cndp.utm.csic.es/catalogue/srv/eng/catalog.search#/metadata/CNDP_BGC_20230221_ERUPTING_ROCK

Outreach of the fellowship

After the official announcement of the fellowship recipients in December 2022, the university and the local press issued several press notes related to the fellowship and the Deception Island field work. Find the links below:

- https://saladeprensa.usal.es/node/135819
- https://salamancartvaldia.es/noticia/2023-01-16-el-doctorando-de-la-usal-antonio-polo-unico-espanol-del-programa-internacional-de-becas-de-investigacion-en-la-antartida-para-jovenes-cientificos-313494
- https://www.tribunasalamanca.com/noticias/319332/de-la-usal-a-la-antartida-para-estudiar-los-volcanes-dicen-que-es-muy-adictivo-y-el-que-va-repite

- https://www.salamanca24horas.com/local/regreso-isla-decepcion-donde-fuego-hielo-conviven-investigadores-usal-estudian-emanaciones-volcan_15065567_102.html
- https://www.elconfidencial.com/tecnologia/ciencia/2023-01-27/canarias-antartida-pistas-erupciones-volcanicas_3565520/
- https://www.salamanca24horas.com/universidad/investigadores-usal-capturan-gases-en-punto-mas-alto-volcan-activo-isla-decepcion-monte-pond_15071525_102.html

References

- Álvarez-Valero. A. M, Sumino. H, Caracausi. A, Polo Sánchez. A, Burgess. R, Geyer. A, Lozano-Rodríguez. J. A, Albert. H, Aulinas. M, Núñez-Guerrero. E (2022). Noble gas isotopes reveal massive degassing-derived eruptions at Deception Island (Antarctica) and current high levels of activity at Deception Island (Antarctica). Scientific Reports, 12(1), 19557.
- Graham, D. W. (2002). Noble gases in MORB and OIB: observational constraints for the characterization of mantle source reservoirs. Reviews in Mineralogy and Geochemistry, 47, 247–318.
- Geyer, A., Álvarez-Valero, A. M., Gisbert, G., Aulinas, M., Hernández-Barreña, D., Lobo, A., Marti, J. (2019). Deciphering the evolution of Deception Island's magmatic system. Scientific Reports, 9(1), 373.
- Livermore, R., Balanyá, J, C., Maldonado, A., Martínez, J, M., Rodríguez-Fernández, J., Sanz de Galdeano, C., Galindo Zaldívar, J., Jabaloy, A., Barnolas, A., Somoza, L., Hernández-Molina, J., Suriñach, E., Viseras, C., (2000) Autopsy on a dead spreading center: the Phoenix Ridge, Drake Passage. Antarctica Geology, 28, 607–610.
- Ozima, M., Podosek, F. A. (2002). Noble gas geochemistry. Cambridge University Press.
- Schlosser, P., Suess, E., Bayer, R., Rhein, M. (1988). ^{3}He in the Bransfield Strait waters: indication for local injection from back-arc rifting. Deep Sea Research Part A. Oceanographic Research Papers, 35(12), 1919-1935.