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Evaluation of the Geothermal Potential on the South-East of Gran Canaria

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Summary

This study evaluates the geothermal potential in an Area of Interest (AOI) in the southeast of Gran Canaria, focusing on location selection near the rift zone and NW-SE vertical fracture zones.

Via a 3D resistivity model nine conductive bodies were identified in the AOI. Then interpretations of the location of these bodies were constructed based on magnetetelluric (MT), density, and S-wave velocity data with geochemical analyses of gas emissions, groundwater chemistry, temperature gradients and the geological history of the AOI. Eventually the geothermal potential of these locations within the AOI was assessed via six criteria: degree of hydrothermal alteration, depth, hydrothermal activity, marine intrusion, top-down area size and fracture density.

Finally a conceptual geological model of the most promising location was made with a sub-vertical fracture system. Several scenarios were tested as part of a sensitivity analysis, all of which are plausible and therefore not irrelevant. In these scenarios key parameters such as porosity, permeability, geothermal gradients, and the permeability ratio (kz/kx/ky) within the fracture zone were varied. One of the main findings was that the 10/10/1 permeability ratio, considered the most realistic for sub-vertical fractures, showed minimal impact on production performance.

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Introduction

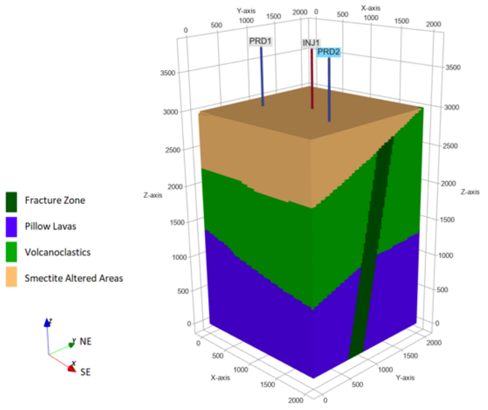
Gran Canaria, part of the Canary Islands, currently generates only 17.5% of its electricity from renewable sources but has set an ambitious goal to achieve carbon neutrality by 2040 (Red Eléctrica de España, 2021). The island's mountainous terrain, limited available land, and stringent environmental policies present significant challenges to expanding solar and wind energy capacity, making geothermal energy an interesting alternative. Although hydrothermally altered minerals have been identified on Gran Canaria, no conclusive evidence of active geothermal systems has been found, and shallow exploration wells at Agüimes and Barranco did not identify active systems. However, the presence of similar systems on other Canary Islands suggests the potential for hydrothermal active systems on Gran Canaria.

This project aimed to evaluate the geothermal potential within a specific Area of Interest (AOI), in the southeast of Gran Canaria. This part of the island is characterized by three geological elements: an ancient seamount, the Tejeda Caldera, and the rift zone. These geological features are prominently reflected in the magnetotelluric (MT) data, providing valuable insights into the geophysical processes within the AOI. By linking the interpretation of the data to the signatures of these key geological elements in the MT data, the analysis was significantly improved, allowing for a more accurate understanding of the subsurface dynamics.

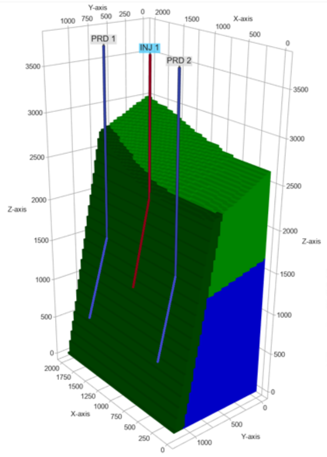
The primary objective of this study was to identify the areas with high geothermal potential, taking into consideration two possible conceptual models: first, high enthalpy volcanic system with altered clay cap, and second, fault controlled Geothermal system, with water flows at temperatures above 160°C, sufficient for geothermal electricity generation. This involved a comprehensive analysis of various previously conducted geothermal potential studies, integrating interpretations of recently acquired 3D magnetotelluric (MT) data, density and S-wave velocity data, alongside geochemical analyses of gas emissions, groundwater chemistry, outcrop examinations, and well temperature measurements. The 3D MT model played a pivotal role in the interpretations, enabling the identification of low-resistivity zones indicative of hydrothermal alteration which in turn serves as key indicator of geothermal activity. It was found that Gran Canaria does not show clear signs of the presence of high enthalpy volcanic systems, as on Lanzarote. Additionally, this study aimed to evaluate the production potential of the most promising location by performing flow simulations, utilising a conceptual geological model for the region as well as considering geological uncertainties.

Methods

First, low resistive bodies from the MT data were identified. In total nine different conductive bodies were identified using the 3D MT model, which were then ranked in a weighted matrix to select the most promising location. The six criteria used in this ranking were: 1. degree of hydrothermal alteration, 2. depth, 3. hydrothermal activity, 4. marine intrusion, 5. top-down area size and 6. fracture density. Fracture density was an important criterion as sufficient fluid flow would be unachievable with the primary permeabilities expected from the prognosed volcanic reservoir of the geothermal system. The potential presence of fractures was assessed based on lineament maps, recent eruptions, dike density maps, and proximity to the volcanic rift, which is expected to host a higher density of fractures. Hydrothermal activity was assessed based on degassing of CO_2, He and Rn, Quartz and Albite-Anorthite geothermometry, and temperature measurements from water extraction wells.



	Total Energy [PJ], 50 yrs			Percentage from Base Case			[mD]	[mD]	[-]
Scen.	grd: 15	grd: 30	grd: 45	grd: 15	grd: 30	grd: 45	k_z	k_{volc}	$k_z/k_x/k_y$
1	50.65	51.67	52.71	-5.30%	-6.27%	-7.66%	20	0.01	10/1/1
2	50.69	51.74	52.81	-5.22%	-6.14%	-7.48%	20	0.1	10/1/1
3	50.66	51.69	52.73	-5.28%	-6.23%	-7.62%	20	1	10/1/1
4	51.99	52.66	53.30	-2.79%	-4.48%	-6.62%	20	0.01	10/10/1
5	52.03	52.74	53.40	-2.71%	-4.33%	-6.45%	20	0.1	10/10/1
6	52.10	52.86	53.60	-2.58%	-4.12%	-6.10%	20	1	10/10/1
7	52.51	53.08	53.67	-1.82%	-3.71%	-5.97%	20	0.01	1/1/1
8	52.56	53.17	53.80	-1.73%	-3.55%	-5.75%	20	0.1	1/1/1
9	52.60	53.26	53.94	-1.65%	-3.38%	-5.50%	20	1	1/1/1
10	53.64	55.02	56.59	0.29%	-0.19%	-0.86%	200	0.01	10/1/1
11	53.66	55.06	56.65	0.33%	-0.12%	-0.75%	200	0.1	10/1/1
12	53.66	55.08	56.68	0.33%	-0.08%	-0.70%	200	1	10/1/1
13	53.48	55.13	57.08	0.00%	0.00%	0.00%	200	0.01	10/10/1
14	53.51	55.18	57.18	0.05%	0.10%	0.18%	200	0.1	10/10/1
15	53.54	55.24	57.27	0.10%	0.20%	0.33%	200	1	10/10/1
16	54.69	57.19	60.07	2.26%	3.74%	5.24%	200	0.01	1/1/1
17	–	57.24	60.13	–	3.83%	5.34%	200	0.1	1/1/1
18	–	57.29	60.20	–	3.93%	5.47%	200	1	1/1/1
19	54.65	55.04	53.86	2.18%	-0.16%	-5.64%	2000	0.01	10/1/1
20	54.66	55.05	53.88	2.20%	-0.14%	-5.61%	2000	0.1	10/1/1
21	54.68	55.07	53.93	2.24%	-0.10%	-5.54%	2000	1	10/1/1
22	[illegible]	55.35	54.93	1.98%	0.41%	-3.77%	2000	0.01	10/10/1
23	–	–	–	–	–	–	2000	0.1	10/10/1
24	–	–	–	–	–	–	2000	1	10/10/1
25	–	–	–	–	–	–	2000	0.01	1/1/1
26	–	–	–	–	–	–	2000	0.1	1/1/1
27	–	–	–	–	–	–	2000	1	1/1/1



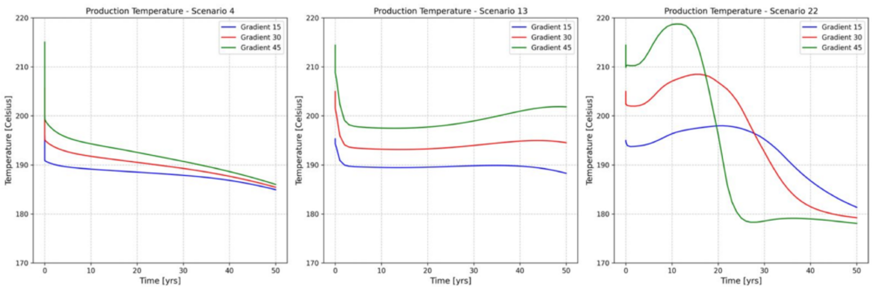


Figure 1 *Conceptual model constructed with Rapid Reservoir Model software with well spacing within the fracture zone (Note: Z-axis inverted in figure; 0 at depth of 4000 meters [left]). Production capacity, percentual deviations were normalized to scenario 13 for each thermal gradient [top right]. Production temperatures over time for scenarios 4, 13 and 22 and thermal gradients of 15, 30, 45°C/km [bottom right].*

A production potential study was performed on the top location which followed from the location selection. From the MT cross-sections, a conceptual model of the chosen location was made. The model was developed using Rapid Reservoir Modeling Software (RRM), which allows users to manually draw layers representing stratigraphical units based on cross-sections. This model can be seen in *Figure 1*. Porosities and permeabilities assigned to the different vulcanoestratigraphic units. Porosity and permeability data was obtained from La Palma petrographic data (unpubl. results), since formations similar to the subsurface of Gran Canaria outcrop at La Palma. Both the permeabilities and the porosities of the sections were very low. Therefore, fracture zones are assumed to be the primary pathways for hydrothermal circulation in this study. A sub-vertical fracture zone was included in the model, since a "rift zone" crosses through the island. This strategy was adapted from the work of Gan et al. (2021).

Flow simulations and a sensitivity analysis were performed on different porosities, permeabilities, and geothermal gradients. The thermal gradients used were [15, 30, 45] °C/km for the fracture zone and 60°C/km for the host rock. Other analysed variables include: $k_{z,frac}$, the vertical permeability associated of the fracture zone, k_{volc}, the vertical and horizontal permeability of the host rock volcanoclastics, $k_z/k_x/k_y$, the ratio between the vertical (k_z) and horizontal (k_x & k_y) permeabilities of the fracture zone. The input values for these variables can be seen in *Figure 1*.

The simulations were conducted using a flow rate control approach, with one injection and two production wells with all simulations employing a production rate of 144 m^3/hr per well and an injection rate of 288 m^3/hr. The injection well was strategically placed in the middle of the fracture zone, injecting fluids at the upper section (1500-2500 meters depth), while the two production wells were located at the outer edges of the fracture zone in the lower section (2500-3500 meters depth), as illustrated in Figure 1. The decision to inject from the top while producing from the bottom is based on two primary considerations. First, this configuration enhances convection, as the cold fluids injected at the top will tend to downwell into the warmer regions below. Second, it reduces the minimum borehole pressure required for water injection, which could improve the coefficient of performance of the system in practical applications.

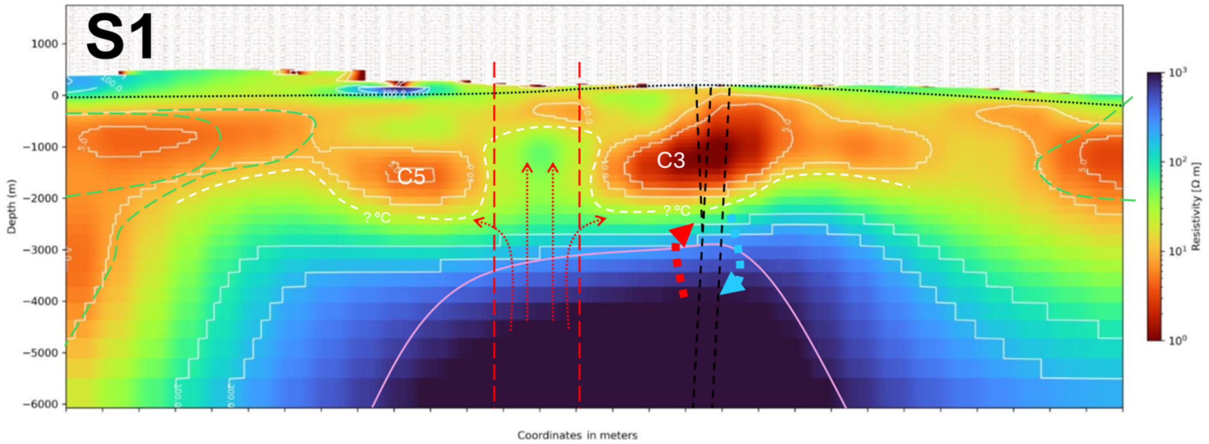


Figure 2 *MT cross-section of selected location C3. The green dashed line indicates the likely marine intrusion. The red dashed lines indicate the rift zone, the red dotted arrows indicate hydrothermal fluids. Black dashed lines indicate possible fractured zones. The red and blue dashed arrows indicate a possible hydrothermal system. A purple line indicates the seamount. Coordinates were not included due to confidentiality. Y and X axis are equally scaled, with each X tick representing 700 m with a total horizontal extent of 20.5 km.*

Results

The conductive body C3 has the highest overall geothermal potential according to the scoring matrix. The cross-section shows that the conductive body lies between 200 and 2000 meters deep, with a relatively large top-down area of 5.57 km². The conductive body shows a potential clay cap structure with the lowest resitivity values in the entire AOI (<5-10 Ωm). According to Archie's law, it is unlikely that this level of conductivity is caused by seawater intrusion in permeable rock (G. Archie, 1942). Instead, a high percentage of smectite would be expected in this formation to achieve such a level of conductivity, further indicating that hydrothermal alteration occurred at C3, as can be seen in *Figure 2*. Additionally, the density of magnetotelluric stations around C3 is relatively high, meaning that the conductive response can be interpreted as more reliable and is less likely to be a processing artifact. The fracture density at location C3 is expected to be high. This stems from the closeness of the location to the rift zone which can be seen on *Figure 2* and from the high amount of recent eruption in close proximity to C3. An elevated level of CO_2 degassing of volcanic-hydrothermal origin has been observed, as well as geothermometry results of 140°C, indicating hydrothermal activity. A high resistive body is present underneath the low-resistive body, interpreted as the intrusive core of a seamount. Taken together, the evidence strongly supports the presence of hydrothermal alteration at C3.

From the sensitivity analysis of the flow simulations conducted over a 50-year period, several conclusions were drawn. Firstly, decreasing k_z from 200 to 20 mD leads to a decline in production performance across all $k_z/k_x/k_y$ ratios. Additionally, a higher thermal gradient combined with this decrease in k_z in the fracture zone results in a greater decrease in performance. Optimally, it was observed that with a fixed ratio $k_z/k_x/k_y$ of 10/10/1 - which is considered the most realistic ratio - the negative impact on performance due to decreasing permeability was minimal. Increasing k_z from 200 mD to 2000 mD slightly improves performance for fracture thermal gradients of 15 and 30°C/km, while slightly decreases performances for a thermal gradient of 45°C/km. This pattern is attributed to enhanced convection within the fracture zone. While some induced convection can be beneficial, high values of k_z combined with elevated fracture thermal gradients can negatively impact production over a 50-year period. The effect of varying k_{volc}, associated with the host rock, was found to have a minimal impact on overall performance.

During the sensitivity analysis, several simulations encountered the (near) critical region under the intended flow rate of 144 m^3/hr per production well, leading to simulation failures. Specifically, scenarios 17 and 18 at a geothermal gradient of 15°C/km, as well as scenarios 23–27 across all gradients, were affected. Consequently, scenarios 23–27 were not considered in the analysis as they didn't run for any gradient. Scenario 13 was selected as the base case instead of scenario 14, as this choice provided a more consistent basis for comparing vertical fracture permeability variations across all geothermal gradients.

Conclusions

Nine conductive bodies were identified using MT data, with C3 ranking highest on four of the criteria in the weighted matrix: fracture likelihood, clay cap presence, top-down area size, and evidence of hydrothermal activity. However, marine intrusion poses a significant risk to its viability. Other promising locations identified were C5 and C7, these locations have a lower chance of marine intrusion.

Finally, a conceptual geological model for C3 was developed, representing a sub-vertical fracture system in a volcanoclastic environment. Sensitivity analysis was conducted by varying key parameters such as porosity, permeability, geothermal gradients, and the permeability ratio (kz/kx/ky) within the fracture zone. One of the main findings was that the 10/10/1 permeability ratio, considered the most realistic for sub-vertical fractures, showed minimal impact on production performance when the vertical permeability was reduced, in contrast to the greater effects observed with less realistic ratios.

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