Geothermal potential assessment via Multiphysics modelling: a case study from Gran Canaria

Introduction

The Canary Islands have for quite some time relied on imported fossil fuels, which historically accounted for the majority of their energy consumption. This reliance has been a significant concern, given the environmental and economic implications. In response, the Canary Islands government has adopted the Agenda Canaria de Desarrollo Sostenible 2030 (ACDS 2030), aligning with the United Nations' 17 sustainable development goals established in 2015. (United Nations General Assembly's resolution, 25 September 2015). Among the 17 goals, there is one dedicated to affordable and clean energy production. The goal, set by the government of the Canary Islands is to significantly increase the proportion of renewables in all energy sources by 2030. Due to the historic dependency of the archipelago on the import of fossil fuels, the proportion of renewable energy in total final energy consumption before 2017 was relatively low (~8%). After 2017, thanks to the exploitation of various renewable sources, including wind and solar energy, the percentage has grown, reaching ~17% in 2020 (Anuario Energético de Canarias 2020). To reach the 2030 goal set by ACDS, geothermal energy production is also under examination. In this context, various geophysical surveys were conducted in the years, including primarily electromagnetic measurements, namely magnetotelluric (MT) and potential field measurements such as gravity (see, among others, Montesinos et al. 2022). The MT method, which images the electrical resistivity of the subsurface, provides valuable insights into the geological and hydraulic conditions of geothermal systems (e.g., Ceci et al. 2021) while gravity measurements can assist in determining the geometries of geothermal reservoirs by identifying areas of low density and high permeability. In 2023, a new comprehensive data acquisition campaign was conducted across Gran Canaria, collecting both MT and gravity data. This campaign resulted in the most extensive data set to date, facilitating the integrated modelling of the multidisciplinary data set presented in this paper.

Geologic context

The Canary Archipelago was built over a 175- to 150-million-year-old Jurassic oceanic crust and every island is composed by an independent volcanic edifice, with their ages progressively younger from East to West. Gran Canaria is the third largest and most densely populated island within the archipelago, boasting a rich geological history marked by volcanic activity. The island's geology is characterized by a diverse range of volcanic rocks, shaped by eruptions spanning over 14 million years. Notably, Gran Canaria is a geologically mature island, where erosion has played a significant role in sculpting its current landscape, featuring rugged terrain and steep cliffs (Rodriguez-Gonzales et al. 2018). Despite its volcanic origins, Gran Canaria currently exhibits no active volcanism, a testament to its long and complex geological evolution. The settings of the island are potentially favourable for the generation of a geothermal system.

Multiphysics acquisition

Multiphysics data was collected, including 165 magnetotelluric (MT) and 179 gravity sites, supplemented by 577 sites from the public domain (IGN - Instituto Geografico Nacional, BGI - Bureau Gravimetric International, and from Montesinos 2022). These data sets were then subjected to multiphysics analysis and modelling, which included 3D inversion of MT data, followed by 3D inversion of gravity data. Before the inversion process, the data sets were scrutinized, preconditioned and in the case of gravity, combined with satellite and legacy data. The satellite gravity data, consisting of a regular grid of 4,376 points covering an area of approximately 20000 km^2, was incorporated into the analysis to alleviate boundary effects and to provide broader coverage and regional context to the local acquisition. The dataset composed of onshore 2023 and legacy gravity data was were edited, removing noisy datapoints, levelled, and merged with offshore data. Combined data was gridded, obtaining a free-air anomaly map, adopted for the subsequent modelling steps (Figure 1). Complete Bouguer anomaly with different reduction values was also computed, for qualitative analysis.

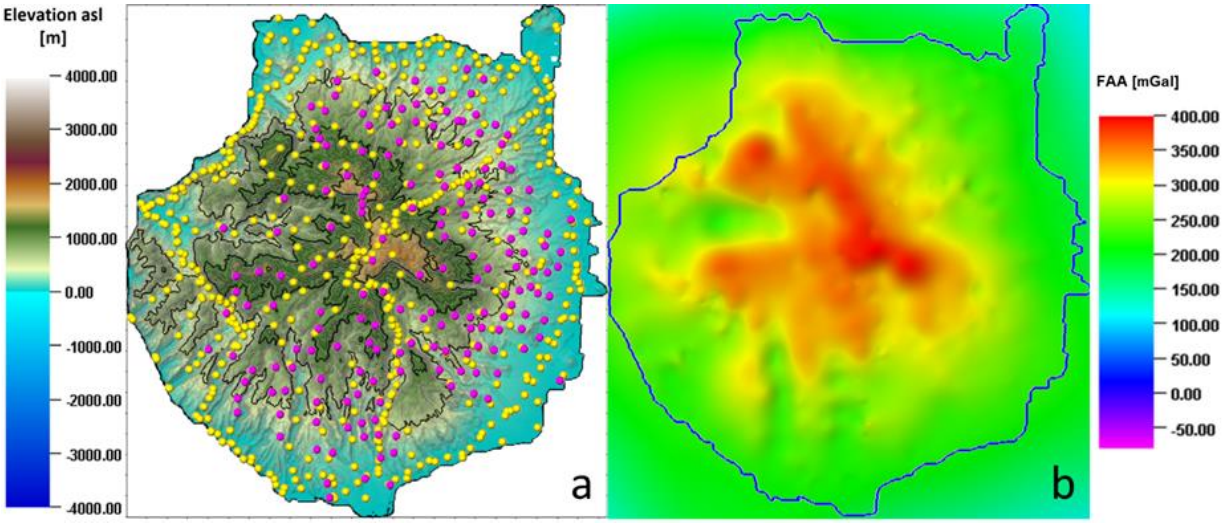

Figure 1 *(a) Acquired and legacy gravity data (magenta and yellow dots, respectively) over shuttle radar topography mission (SRTM) elevation grid. (b) obtained free-Air anomaly map, including also offshore data from satellite measurements.*

Following quality control and preconditioning, both the MT and the combined gravity data sets exhibited high quality and mutual consistency. The wealth of geological information in the data sets was underscored during the data analysis phase prior to inversion. Indeed, the complete Bouguer anomaly from the acquired gravity data aligned with shallow geology and previous works from the literature (i.e., Rodriguez-Gonzales et al. 2018), while constant frequency maps from the edited MT data allowed to qualitatively identify coherent patterns with known structural elements with structural elements, both at shallow and deep levels (Figure 2). The agreement of the data with known geological features and other works from literature bolstered confidence in the newly acquired datasets and underscored the significance of multiphysics data sets for geothermal exploration.

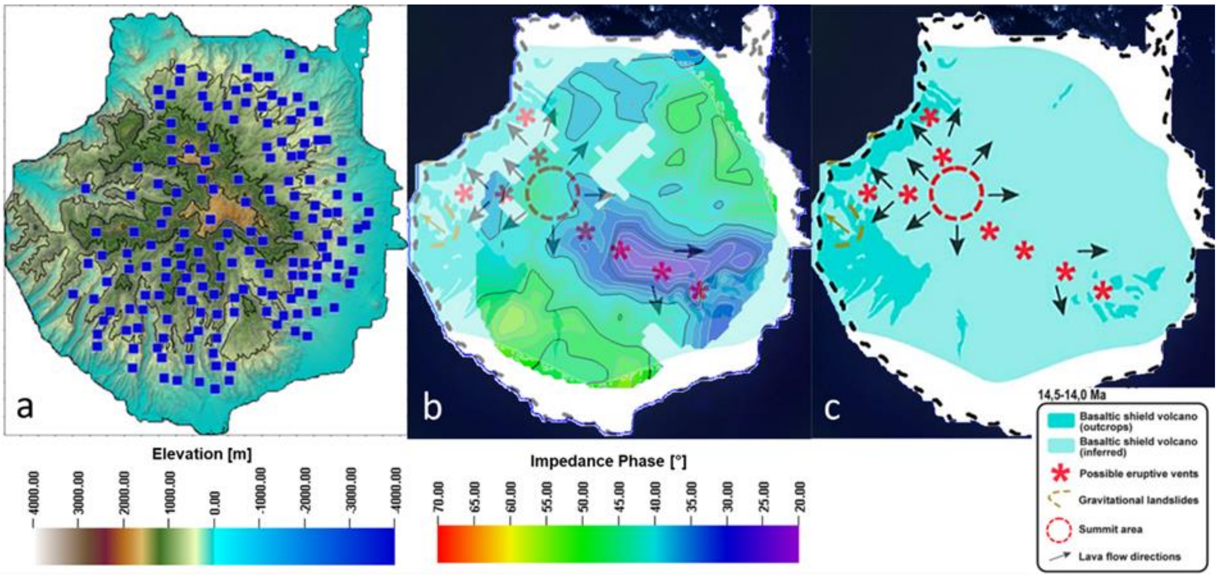

Figure *2 (a) Acquired MT stations (blue squares) over SRTM elevation grid. (b) co-render of MT XY phase map at 0.3Hz with the distribution of volcanic products corresponding to the initial stage of the shield building;(c) after Rodriguez-Gonzales et al., 2018). Data rotated N0°E.*

Modelling workflow

A 3D MT resistivity model was obtained using data from 160 stations, selected after the preconditioning phase. The inversion method used was unconstrained, meaning there were no abrupt changes in the regularization scheme and no penalties for changes in resistivity. The initial model was a uniform half-space including the sea water layer, with a smooth vertical transition offshore between resistivity of seawater and sediments below the mudline. The full impedance tensor and Tipper data were modelled in four stages, gradually reducing the regularization parameter to steadily decrease the MT station misfit without adding unnecessary roughness to the final resistivity model.

The density model was created in a single step of unconstrained gravity inversion, using the free-air anomaly map that was derived from the combination of the available data sets previously described. The initial model for gravity inversion was obtained by applying a rock-physics model, based on well logs, to the results of the 3D MT inversion across the entire area. Information about surface geology and geological background, obtained by reviewing existing published geological, structural, and geodynamic information, was also incorporated into the input density model (Figure 3).

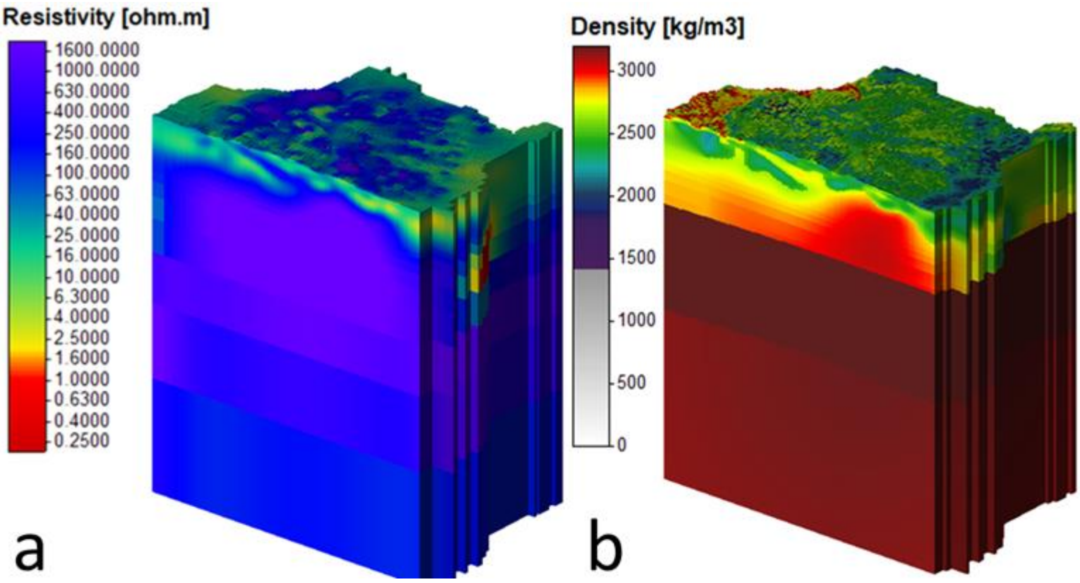

***Figure** 3 (a) Inverted MT resistivity model and (b) input density model, obtained from application of rock-physics model and incorporating surface geology and geological background information.*

The MT inversion first and gravity inversion second, independently converged the models smoothly, which are geologically plausible and characterized by low misfit values against observed quantities. Updates to both resistivity and density indicated changes from the initial property fields from shallow to deep, aligning with known geological features and previous work documented in the literature, while also providing new insights into structural elements, such as the dip of the Tejeda fault (one of the most important structural elements of the island) and the lateral distribution of shallow low-density features.

Conclusions

The MT phase of the integrated multiphysics modelling workflow provided images of both shallow and deep structural components, which are essential for comprehending the island's structural layout. Additionally, gravity inversion brought to light intriguing local characteristics, such as a low-density anomaly associated with the collapsed caldera, among other features. By jointly interpreting the two volumes of resistivity and density, it became possible to assess the geothermal potential of Gran Canaria. This evaluation aids in determining the feasibility of geothermal energy production, which could significantly contribute to achieving the goal on sustainable, affordable, and clean energy for the most densely populated island of the Canary archipelago.

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References

Agenda Canaria de Desarrollo Sostenibile 2030, https://www.gobiernodecanarias.org/agendacanaria2030/

Anuario Energético de Canarias 2020, https://www3.gobiernodecanarias.org/

Bureau Gravimetric International, https://bgi.obs-mip.fr/.

Ceci, F. and Battaglini, A. G. [2021]. Reducing geothermal exploration uncertainty via multiphysics joint inversion, Geoscience & Engineering in Energy Transition conference, Online Event, 23-25 November 2021.

Instituto Geografico Nacional, https://www.ign.es/web/gmt-area-gravimetria

Ledo, J., Garcia-Merino, M., Larier, H., Slezak, K., Pina-Varas, P., Marcuello, A., Queralt, P., Perez., N. M., Schminke, H. U., Sumita. M. [2021]. 3D electrical resistivity of Gran Canaria island using magnetotelluric data, *Geothermics* **89**.

Montesinos, F.G., Arnoso, J., Gómez-Ortiz, D., Benavent, M., Blanco-Montenegro, I., Vélez, E., Martín-Crespo, T., Gorbatikov, A.V., and Stepanova, M.Y. [2022]. Imaging the Volcanic Structures Beneath Gran Canaria Island Using New Gravity Data. *Journal of Geophysical Research: Solid Earth*, **127**

Rodriguez-Gonzalez, A., Perez-Torrado, F.J., Fernandez-Turiel, J. L., Aulinas, M., Paris, R., Moreno-Medina, C. [2018]. The Holocene volcanism of Gran Canaria (Canary Islands, Spain) *JOURNAL OF MAPS*, **14**(2), 620–629.

UN General Assembly, Transforming our world: the 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1.