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Multiphysics Analysis in the Identification of Areas with Potential for EGS in Brazil

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ABSTRACT

Geothermal energy is an abundant and renewable energy source on our planet. Currently, only a small fraction of it is currently converted into electrical energy, although the installed geothermal capacity has increased significantly worldwide in recent years. One factor preventing the exploiting of this resource is the geotectonic conditions that trap the Earth's internal heat, combined with the physical and chemical properties of the lithosphere. One solution is Enhanced Geothermal Systems (EGS), which provide an efficient way to convert vast geothermal energy resources into electricity large-scale human consumption. This study evaluated geophysical parameters in two Brazilian regions with geothermal energy exploration potential: the western edge of Borborema geostructural province in the northeast of the country, and the central-southern part of Tocantins region, spanning the central-west and south-east. Multiphysical analyses of the lithosphere included an in-depth thermal evaluation, identification of thermal sources, and analysis of radiometric variations, gravimetry, magnetometry, seismicity, and geotectonics. Thanks to the technological advances in EGS in recent years, such facilities have a promising future in the coming decades.

1. Introduction

The geothermal characteristics of the Earth's crust can reveal how the planet's interior formed and identify valuable resources, such as hydrocarbons and mineralized sources. This is because temperature and internal pressure are directly related to the generation and maturation process of these resources.

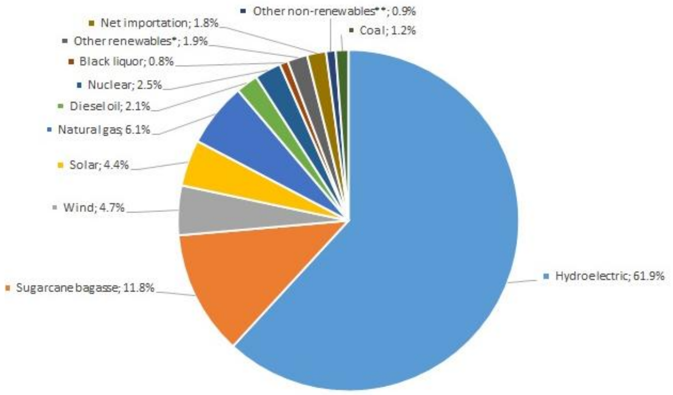
Data on the thermal regime of the lithosphere are typically derived from theoretical modelling of temperature and heat flow density variations at different depths, using analytical or numerical models. The results of these models depend on the values of thermal conductivity and radiogenic heat production used for different lithospheric domains, as well as to the boundary conditions applied.

The crustal geothermal model is based on temperature distributions at depth and heat transfer processes within the Earth's interior, demonstrating their influence on external geodynamic processes. Variations in heat flow depend on the region under analysis, and it is also necessary to consider the energy balance parameters. When studying the current thermal state of the upper crust, data on the geothermal gradient, heat flow and radiogenic heat production are used as boundary conditions to estimate temperature at greater depths.

Prospective crustal geothermal studies based on mapping and quantifying heat storage zones have been developed with a greater focus on granites in the upper crust (e.g. Hu and Ghassemi, 2020). The thermal conductivity and radiogenic heat production of these granites allow zones with heat flow values to be identified at the surface. However, as the middle to lower continental crust is mostly formed by metamorphic rocks, it is necessary for the models to take this into account in order to characterize the entire lithosphere or its boundary.

In Brazil, few studies have been conducted on the use of geothermal energy resources. This is partly due to the country's energy matrix being based on water sources (Figure 1), as well as the availability of other energy sources, such as natural gas (Castro et al. 2009).

Figure 1. Brazilian energy matrix.



This reality relegates the need to develop and promote other energy sources in Brazil to a secondary position. Another possible reason for this is the absence of tectono-magmatic activity in relatively recent geological times, implying that the thermal regime of much of the Brazilian lithosphere is stationary. This means that conditions are not favourable for the occurrence of geothermal energy resources (Gomes 2009).

However, according to Lund et al., 2011, many countries have been conducting studies on the practicality of using geothermal energy anywhere, as in countries without volcanic activity, low or moderate temperature geothermal resources can used directly with good efficiency.

According to Hamza et al. 2010, high-temperature geothermal systems have the potential to be exploited in Brazil, although this appears to be limited to the Atlantic islands of Fernando de Noronha and Trindade. Conversely, the authors report that significant numbers of low-temperature resources (90^{0}C) have been identified, primarily in the central-west and south regions. They also report that large-scale exploitation of low-temperature geothermal water for industrial use and space heating is considered significant in the central part of the Paraná basin, which is situated in the south and southeast regions of Brazil.

2. Prospective Map of Brazilian Geothermal Resources – *EGS*

The application of prospect mapping techniques to geothermal exploration has been reported in a few case studies, primarily over the last decade. Taking a similar approach, the U.S. Department of Energy's Office of Geothermal Technologies has conducted a substantial play fairway analysis (PFA) programme. *(https://www.energy.gov/eere/geothermal/play-fairway-analysis)*.

Many of the PFA-supported studies have used geographic information system (*GIS*) tools that incorporate the basin-wide distribution of known geological factors other than heat flow in order to quantify and reduce uncertainty in geothermal energy exploration.

The study, which was carried out in partnership with SGB/CPRM, published in Lacasse et al. 2022, used fuzzy logic modelling to map the suitability of geothermal resources on a regional scale, with a particular focus on *EGS* exploration in Brazil. The results represent a significant advancement in accessing GIS databases, primarily containing geological, geophysical and geothermal data, for regional mapping and identifying the feasibility of exploring accumulated thermal energy. We began by applying the methodology to two geotectonic provinces promising for geothermal energy, as determined by analyses of Brazil's heat flow map. We anticipate that this methodology developed for mapping EGS favorability in granites at a regional scale, can be applied and validated in other regions.

The geostructural provinces selected for the initial application of this prospective model were East Tocantins and Borborema (see Figure 2). Unlike other methodologies for mapping high-enthalpy geothermal resources, the fuzzy logic method is not currently designed to determine their electrical or thermal energy potential per unit area (MW/m^2). However, given its extensive use and validation in mineral exploration, the fuzzy logic method can complement these methodologies, improving the regional location of these geothermal resources regionally and suggesting target areas for exploration.

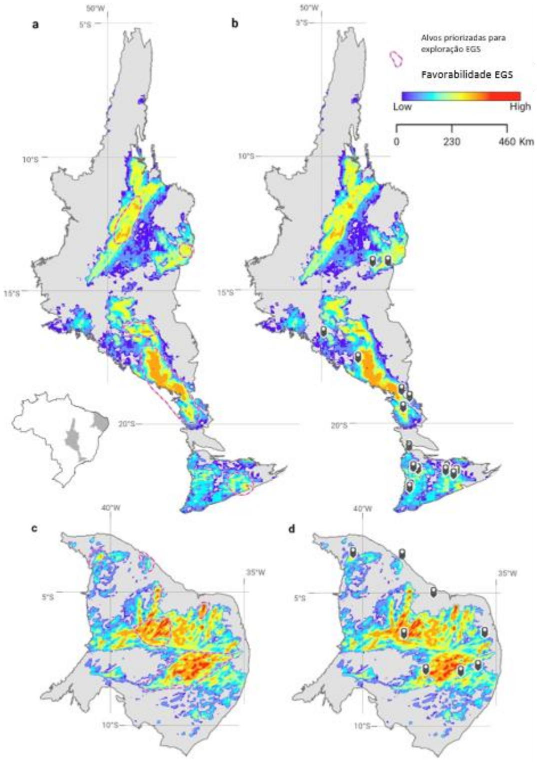
The prospective conceptual model of EGS met all the criteria proposed by Van Wees et al. 2013. This is directly linked to the identification of relatively high temperatures in poorly permeable rocks, possibly originating from vertical conduits of fluid flow through fractures and faults, or even from hot spring sites linked to granitic bodies. Thus, as a promising preliminary result, the target regions in the northern most part of the Borborema province appear to overlap with areas of heat trapped in the hot dry rock system. This result was observed in the analysis of resistivity profiles obtained using the magnetotelluric inversion method.

In Brazil, where the exploration of high-temperature geothermal energy has been neglected, adopting the fuzzy logic method used in this study can reduce uncertainty and financial risk, helping with development decision-making.

3. Final Discussions

If managed properly, geothermal heat has the potential to be an abundant, versatile, environmentally acceptable, economical and sustainable energy source. Its sustainability mainly stems from the large amount of heat stored in the subsurface.

Figure 2. Prospective map showing the EGS favourability arranged according to the presence of granites with high radiogenic heat production in the regions of the Brazilian structural provinces of: (a-b) Tocantins (c-d) Borborema. Source: adapted from Lacasse et al. 2022.



However, extracting this heat is challenging and requires advances in exploration and drilling technology, new approaches to reservoir stimulating and potentially new working fluids. Furthermore, the exploitation of thermal energy must be optimized and carefully managed, which requires effective methods of characterizing the geological formation and fluid movements within the reservoir.

As well as high temperature hydrothermal systems or engineered geothermal systems (*EGS*) for electricity production, waste heat from deep geothermal fluids or low temperature resources at shallow depths can be used for a wide variety of applications and combined uses at different temperature levels, achieving a high overall degree of efficiency. Finally, reinjection of geothermal fluids closes provides pressure and working fluid support, closing the loop and enabling sustainable energy production. Computer modelling has become standard practice for planning and managing geothermal field development over the last 20-35 years.

The feasibility of using geothermal energy in Brazil is still under discussion, and further studies are needed to reveal its true potential. While there are currently no experimental studies in Brazil aiming to exploit geothermal energy for electricity generation, the direct use of geothermal energy promising, particularly the use of water from aquifers and the strategic disposal of geothermal resources in regions such as the northwestern of the Paraná basin, the Tocantins province involving the Brasília Belt, as well as the Borborema basin in the northeast of the country. Regions of magmatic and volcanic arcs also affect the use of this heat on the Earth's surface, however, in this case, the resources are limited to direct use as heat sources, or heat pumps for air conditioning.

References:

[1] BRASIL, I. Atlas nacional do brasil. Rio de Janeiro, 2022.
[2] Carranza, E.J.M., Wibowo, H., Barritt, S.D., Sumintadireja, P., 2008. Spatial data analysis and integration for regional-scale geothermal potential mapping, West Java, Indonesia. Geothermics 37, 267–299.
[3] Castro, N. J. D., Martini, S., Brandão, R., Dantas, G. D. A., Timponi, R. R.: ‘A importância das fontes alternativas e renováveis na evolução da matriz elétrica brasileira’. V Seminário de Geração e Desenvolvimento Sustentável. Rio de Janeiro, Brasil, 2009. 19-29.
[4] Gomes, A.: ‘Avaliação de recursos geotermais da bacia do Paraná’ [geothermal resource assessment of the parana basin]. Unpublished Ph. D. Thesis, Observatório Nacional, Rio de Janeiro, Brazil, 2009.
[5] Hamza, V.M., Cardoso, R.R., Gomes, A.J.L., Alexandrino, C.H.: ‘Brazil: country update’. System, 2009, 106.
[6] Hu L., Ghassemi A.: ‘Heat production from lab-scale enhanced geothermal systems in granite and gabbro’, International Journal of Rock Mechanics and Mining Sciences, Volume 126, 2020, 104205, ISSN 1365-1609, https://doi.org/10.1016/j.ijrmms.2019.104205.
[7] Kiavarz Moghaddam, M., Noorollahi, Y., Samadzadegan, F., Sharifi, M.A., Itoi, R., 2013. Spatial data analysis for exploration of regional scale geothermal resources. J. Volcanol. Geotherm. Res. 266, 69–83.
[8] Lacasse, C. M., Prado, E. M. G., Guimarães, S. N. P., de Souza Filho, O. A., & Vieira, F. P. (2022). Integrated assessment and prospectivity mapping of geothermal resources for EGS in Brazil. Geothermics, 100, 102321.
[9] Lund, J.W.; Freeston, D.H.; Boyd, T.L.: ‘Direct utilization of geothermal energy 2010 worldwide review’. Geothermics, Elsevier, v. 40, n. 3, p. 159–180, 2011.
[10] Olasolo, P., Juarez, M.C., Morales, M.P., Sebastiano D´Amico, Liarte I.A.: ‘Enhanced geothermal systems (EGS): A review’, Renewable and Sustainable Energy Reviews, Volume 56, 2016, Pages 133-144, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2015.11.031.
[11] Pirajno, F. A.:’Classification of mineral systems, overviews of plate tectonic margins and examples of ore deposits associated with convergente margins’. Gondwana Research, Elsevier, v. 33, p. 44–62, 2016.
[12] Sadeghi, B., Khalajmasoumi, M., 2015. A futuristic review for evaluation of geothermal potentials using fuzzy logic and binary index overlay in GIS environment. Renew. Sust. Energ. Rev. 43, 818–831.
[13] Sang, X., Xue, L., Liu, J., Zhan, L., 2017. A novel workflow for geothermal prospectively mapping weights-of-evidence in Liaoning Province, northeast China. Energies 10, 1069.
[14] Singhal BBS, Gupta RP (2010) Hydrogeology of crystalline rocks. Applied Hydrogeology of Fractured Rocks, pp. 241–260. https://doi.org/10.1007/978-94-015-9208-6_11
[15] Van Wees, J. D., Boxem, T., Calcagno, P., Dezayes, C., Lacasse, C., & Manzella, A. (2013). A Methodology for Resource assessment and application to core countries. Geothermal Electricity (GEOELEC): Brussels, Belgium, 1995-2013.
[16] Trumpy, E., Donato, A., Gianelli, G., Gola, G., Minissale, A., Montanari, D., Santilano, A., Manzella, A., 2015. Data integration and favourability maps for exploring geothermal systems in Sicily, southern Italy. Geothermics 56, 1–16.