PLAN OVERVIEW

A Data Management Plan created using DMPTuuli

Title: Deep-HEAT-Flows: Discovering deep geothermal resources in low-enthalpy crystalline settings

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Project abstract:
The rapid displacement of fossil fuels by sustainable and affordable energy sources will require novel technologies that can meet large-scale commercial demands. Deep geothermal resources offer near-unlimited clean and reliable energy across multiple spheres of our economy and society, including direct heating, industrial use, and electricity generation. While substantial energy figures are promptly achieved in hot volcanic and rifting zones, unlocking the full potential of geothermal resources will require a new understanding of how heat flows and accumulates at lower-temperature conditions. Our Deep-HEAT-Flows project identifies the fundamental thermogeological processes that create large (>1 km^3) and deep (>1 km) geothermal reservoirs in low-enthalpy (<150 °C) crystalline settings. We will develop conceptual models and new tools to resolve geological uncertainties of deep drilling in areas with enormous geothermal potential rarely pursued by the energy industry, with a particular interest in the EU Nordic region. Our multidisciplinary approach combines insights from geophysics, structural geology, petrophysics, geochemistry, thermodynamics, and rock mechanics into a unified model that explains low-enthalpy crystalline reservoir formation. We will conduct a suite of laboratory-based experiments on rock samples from deep boreholes and analogue outcropping rock formations, quantifying critical microscale (<10 cm) variables of crystalline reservoirs such as pore-space morphology, fracturing, and mineral alteration. Additionally, we will collect and assess high-resolution drone photogrammetric data and interpret geophysical surveys to investigate the large-scale (cm to >100's m) impact of ancient faults and igneous intrusions on crystalline reservoirs. Finally, micro-and large-scale results will be combined to develop computational models that calculate the volume and simulate the energy yield from deep, low-enthalpy crystalline reservoirs. Deep-HEAT-Flows will leap forward to understand the petrophysical and thermal properties of the deep crystalline crust and comprehend heat generation, transfer, and storage at low-enthalpy conditions - essential information that permits accurate forecasting of geothermal resources. Ultimately, our project will ensure that large geothermal resources can become predictable at industrial scale and economically available globally - key to achieve energy security while building a sustainable, resilient, and low-carbon society.

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DEEP-HEAT-FLOWS: DISCOVERING DEEP GEOTHERMAL RESOURCES IN LOW-ENTHALPY CRYSTALLINE SETTINGS

1. GENERAL DESCRIPTION OF DATA

1.1 What kinds of data is your research based on? What data will be collected, produced or reused? What file formats will the data be in? Additionally, give a rough estimate of the size of the data produced/collected.

Our project collects geological information and samples from outcrop locations and deep boreholes perforated across Finland. Drillcore samples are currently stored at GTK's National Drill Core Archive. Geological information collected from these samples includes petrophysical, thermal, and geomechanical data on crystalline reservoirs. Data will be summarized in Excel spreadsheets and exported as csv files for publication (Task 1.1, 1.2 and 1.3). Photographs of the key rock types will be stored as png files and will be organized as a PDF rock catalogue. Raw computer tomography data will be stored as raw files, and Micro-XRF analysis as xrf files or alike type (Task 1.4). Drone photogrammetric digital models will be stored as GeoTIFF data or alike file types (Task 2.1). Most rock tests are non-destructive and the samples will be preserved for further studies. After data collection, drillcore samples will be returned to GTK's National Drill Core Archive and key outcrop samples will be stored in the University of Turku and the University of Strasbourg petrophysical rock archives. An exception applies for samples that will be submitted to rock mechanical tests that will introduce fractures in the rocks and thus only rock fragments with size >5 cm will be stored. We will reuse diverse rock samples from previous GTK projects. Samples are currently in the National Drill Core Archive. In addition, published and freely available petrophysical information will be compiled to produce global databanks describing critical parameters or crystalline reservoirs.

We estimate that our digital data will require a total storage capacity of nearly 8 TB as follow:

- Excel spreadsheets with petrophysical, thermal, geomechanical data, and rock photograph catalogue (<100 GB);
- Raw computer tomography data (1 TB)
- Micro-XRF analysis as XXX files (500 MB)
- Drone photogrammetric digital models (1 TB)
- Computational models (5 TB)

The final digital data size relies on a series of variables that include the (i) number of samples necessary for rock characterisation, (ii) the chosen resolution of the images, (iii) the file compression power of the software and hardware, and (iv) the number and dimension of outcrops necessary for drone photogrammetry.

1.2 How will the consistency and quality of data be controlled?

Each method described in the Research Plan requires strict protocols to ensure the quality and consistency of the data. Our data quality will build on the extensive research experience of our group, following strict laboratory protocols of GTK and the University of Strasbourg. Collectively, the projects PI and the research team have nearly 250 years of industry and academic experience, including conducting large scientific programmes and publishing 500+ peer-review papers which, will ensure the quality and trust of our data within the scientific community.

Below we highlight some key steps to help achieve consistency and maintain high-quality data standards:

- Our team accounts with clear and detailed protocols outlining the procedures for geological sampling, description and storage

- We provide comprehensive training to the individuals involved in data collection. Where the method is new to us, we seek guidance from partners or search for standard protocols

- We have implemented robust quality control measures in our laboratories. This may involve periodic checks of blind samples to assess the accuracy of the data

- We maintain meticulous documentation of the data collection process and distribute this data documentation among researchers. Each researcher is requested to check the data quality at each step of the project

- Our data management plan is an evolving document that will be updated in the course of the project

2. ETHICAL AND LEGAL COMPLIANCE

2.1 What legal issues are related to your data management? (For example, GDPR and other legislation affecting data processing.)

The project does not require information or any other sensitive cultural, religious, ethnic or gender data that may constitute an ethical issue. Most information regarding obtaining rock samples from the Drill Core Archive is downloadable free of charge at the Hakku service (https://hakku.gtk.fi/). Drill cores can be studied in these facilities with the help of GTK's experts if required. Visits are free of charge for GTK researchers' use. The use of equipment, labour and accommodation may be subject to charges, which will be covered with funds from the research as per the Research Plan budget. Sampling is possible according to the terms and conditions (https://www.gtk.fi/en/terms-and-conditions-for-delivering-and-subsampling-of-drill-cores/).

Legal issues that may be related to our data management can encompass:

- Data Privacy: GTK and its partners on this project adhere to FAIR principles of freely distributing data generated by the project

- Data Protection: GTK and its partners have strict safeguarding data against unauthorized access, loss, or destruction policy

- Intellectual Property: We will only use data that have appropriate permissions or licenses to use copyrighted

- Consent and Permissions: We will seek proper consent and permissions if collecting and using data from private sources

2.2 How will you manage the rights of the data you use, produce and share?

All data and materials produced with funding from this research grant will be made freely available during the course of the project and after publication in scientific journals. Reused and previously published data will be appropriately cited and acknowledged. Initially, data will be stored on GTK's server and made available only for researchers involved in this project via a Teams platform and secured personal access to the GTK's server. There is no need for sharing large amounts of data between research institutions since most work that requires large files (e.g. CT-scan, drone photogrammetry) will be performed and interpreted at GTK labs. Research data will be made freely available via geoscientific data repositories as soon as possible after the research results have been published (details in the following sections). At the end of the project, all results (Terabytes of data) will be made available as open-access information at the geoscientific data repositories and at https://hakku.gtk.fi/en, through a Creative Commons licence (e.g. https://creativecommons.org/licenses/by/4.0/) such that future users do not need to contact the PI to use the data. Users may however need to create personal profiles to access the data.

3. DOCUMENTATION AND METADATA

3. How will you document your data in order to make the data findable, accessible, interoperable and re-usable for you and others? What kind of metadata standards, README files or other documentation will you use to help others to understand and use your data?

Data documentation will be the responsibility of each researcher that collect the data, under the supervision of the PI of the project and in close collaboration with the core team listed in section 3 of the Research Plan. All new data, tools and knowledge developed within this project will be distributed to the public domain free of charge. A crystalline reservoir rock catalogue including basic information about each study area will be implemented and regularly updated on the Deep-HEAT-Flows webpage as such the general public will have knowledge about the data that has been generated and where it is stored. The data will be findable as it is accessible through the established hakku.gtk.fi geoscientific data repository and through other well-established (geo)scientific data repositories. Accessibility is guaranteed by providing direct download access to the published data which use open, interoperable, file formats such as csv, GeoTIFF and PDF. Furthermore, metadata is included in all platforms where the data is released through the use of the repository description capabilities and through README files included with the data when necessary. Included metadata will be in plain text which guarantees interoperability. All data will be licensed with the Creative Commons license guaranteeing reusability.

4. STORAGE AND BACKUP DURING THE RESEARCH PROJECT

4.1 Where will your data be stored, and how will the data be backed up?

During the implementation of the Deep-HEAT-Flows research project, data will be stored and backed up on secured GTK and University of Strasbourg servers that provide daily automatic backing up and recovery of data.

4.2 Who will be responsible for controlling access to your data, and how will secured access be controlled?

Data access will be the responsibility of the PI. The core team (listed in the Research Plan) will have free access to the project data via GTK-hosted Teams space and secured GTK server access. As required, the project PI can add collaborators to the Teams space and grant access to new members and partners.

5. OPENING, PUBLISHING AND ARCHIVING THE DATA AFTER THE RESEARCH PROJECT

5.1 What part of the data can be made openly available or published? Where and when will the data, or its metadata, be made available?

GTK and other partners of this project align with the principles of FAIR (www.go-fair.org/) data policy. It's not expected that any sensitive data will be produced on this project, thus, all information generated will be made publicly available and free of charge immediately after publication of the research results, using (geo)science repositories such as GTK Hakku (https://hakku.gtk.fi/), Zenodo (https://zenodo.org/) and Pangea (https://www.pangaea.de/). In the case any data or knowledge generated by this programme is proprietary to our partners, we will seek agreement to publish key findings as part of an open-access strategy. A Deep-HEAT-Flows research project webpage will be created under the GTK website and linked with voog or a similar webpage platform where a list of data generated by the project will be available and linked to the Finnish National Repository of Geological Information (https://hakku.gtk.fi/).

5.2 Where will data with long-term value be archived, and for how long?

Scientific results will be disseminated via open-access publications in high-impact, international peer-reviewed scientific journals, conference presentations, and workshops and are typically stored on the journal webpage for decades long. As results are obtained and publications are submitted to peer-review journals, new metadata will be published in each paper and will be made available in the well-established Earth Science data repositories Pangaea or alike repositories, which freely store data up to 50 Gb for decades long. All files stored in online repositories will be

allocated a DOI. Metadata such as CT-Scan images will also be stored in GTK Hakku (https://hakku.gtk.fi/). Core samples will be returned to GTK National Archive. Outcrop samples will be discarded in a local landfill or dump station upon the end of the project.

6. DATA MANAGEMENT RESPONSIBILITIES AND RESOURCES

6.1 Who (for example role, position, and institution) will be responsible for data management?

Data management is the PI's and the Postdoctoral researcher's responsibility. In addition, all project members are responsible for storing, backing up and sharing data as outlined in the previous sections (details about the project's team can be found in the Research Plan document).

6.2 What resources will be required for your data management procedures to ensure that the data can be opened and preserved according to FAIR principles (Findable, Accessible, Interoperable, Re-usable)?

The GTK Hakku service is financially supported by GTK. Hakku hosts a geothermal exploration data repository that will be complemented with information obtained on this research project. The costs of generating the database will be covered by GTK. No additional data storage costs are expected to impact the research budget since we will opt for using free-of-charge scientific data repositories or our own GTK repository.