Ref. Ares(2023)7430844 - 31/10/2023

CRM-GEOTHERMAL DELIVERABLE D1.1

# REPORT ON DATA OBTAINED FROM LITERATURE REVIEW AND EXISTING DATABASES INCLUDED IN THE CRM-GEOTHERMAL DATABASE

*Summary:*
This deliverable summarises the methodology and results of the data collection from literature, reports and projects for the CRM-geothermal Fluid Atlas.

*Authors:*
Anna Seres, University of Miskolc, Researcher
Éva Hartai, University of Miskolc, Honorary Professor
Tamás Tompa, University of Miskolc, assistant professor
Martin Szabó, University of Miskolc, assistant professor
Kalliopi Savva, INLECOM, AI Engineer

Funded by
the European Union

| | | | |
|---|---|---|---|
| **Title:** | Report on data obtained from literature review and existing databases included in the CRM-geothermal database | | |
| **Lead beneficiary:** | University of Miskolc | | |
| **Other beneficiaries:** | GFZ, IZTECH, UKRI-BGS, UoI, UNES, HI, GEL | | |
| **Due date:** | 30 October 2023 | | |
| **Nature:** | Public | | |
| **Diffusion:** | all Partners | | |
| **Status:** | Final | | |
| **DOI:** | Version 3.0: 10.5281/zenodo.12720903<br>All versions: 10.5281/zenodo.10057306 | | |
| **License information:** | CC-BY-4.0 | | |
| **Recommended Citation:** | Seres, A., Hartai, É., Tompa, T., Szabó, M., Savva, K.; The Horizon Europe CRM- geothermal project: Deliverable 1.1 - Report on data obtained from literature review and existing databases included in the CRM-geothermal database, Zenodo, DOI: 10.5281/zenodo.10057306. | | |
| **Related Data:** | | | |
| **ORCID:** | Anna Seres: ORCID ID 0000-0001-8003-1445<br>Éva Hartai: MTMT 10012199 | | |
| **Document code:** | D.1.1_CRM-geothermal_V3 | | |
| | | | |
| **Revision history** | Author | Delivery date | Summary of changes and comments |
| **Version 01** | Anna Seres | 24.10.2023 | Working document |
| **Version 02** | Anna Seres | 26.10.2023 | Update regarding the URL of data collection template and section 4.2 by Inlecom |
| **Version 03** | Anna Seres | 27.06.2024 | Modifications after the reviewer's comments |

| **Approval status** | | | |
|---|---|---|---|
| | Name | Function | Date |
| **Deliverable responsible** | Anna Seres | WP leader | 27.06.2024 |
| **WP leader** | Anna Seres | WP leader | 27.06.2024 |
| **Project Coordinator** | Katrin Kieling | Project manager | 27.06.2024 |

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them.

## TABLE OF CONTENTS



## FIGURES



## TABLES

# 1 EXECUTIVE SUMMARY

CRM-geothermal Deliverable 1.1 is an outcome of Task 1.1 – Data collection and database creation. This task is about compiling the formerly existing data from literature and databases. The evaluation of these data and making any conclusions related to the geothermal and CRM potential of the selected study sites are performed in the frame of other work packages.

The recent deliverable summarises the methodology and the outcomes of the collection of formerly existing data from publications, reports and databases of other geothermal projects for the CRM-geothermal Fluid Atlas. Data on wells, fluids, rocks, as well as scales and gases were collected from the study sites of five geothermal settings that were identified in Deliverable 2.1 – Report identifying pre-existing sources of data at the selected sites (Rochelle et al. 2022). Detailed information on the geology, the geochemical characteristics and the geothermal conditions of these sites is available in D2.1. The geothermal settings and the related study areas are as follows: (1) High-enthalpy volcanic geothermal areas (Reykjanes, Tuzla geothermal field); (2) Metamorphosed flysch (Seferihisar); (3) Low salinity water in fractured crystalline rock (Cornwall); (4) Saline water in sedimentary basins (North German Basin, Upper Rhine Graben, German Molasse Basin); (5) Alkaline geothermal area (Djibouti, Tanzania, Malawi, Kenya, Rwanda, Ethiopia).

Within Task 1.1, first a template for the data collection was created with detailed guidelines. The template is an excel file with five working sheets. A separate data collection template was established for each study site. Data from the REFLECT database and other projects' databases were reviewed and assessed, and responsible partners were asked to provide articles and reports and also to populate the excel templates. Together with this process, an online data collection platform has been developed. Data from the excel files will be imported to the online platform, which started to be populated in October 2023.

The RFELECT database contains data from 21 countries, from more than 3000 wells, almost 4000 fluid samples, 450 rock samples and about 1000 reservoirs. These data were re-assessed and imported into the CRM-geothermal database. The CHPM2030 database was also examined but no data were imported from this project as the fluid composition data are very sporadic and they are not linked to specific wells. The PERFORM dataset contains data on 53 wellbores with 26 plants, 153 fluid samples, 14 rock samples, 13 particles in fluids and 4 scale samples. These data have been included in the CRM-geothermal database.

Articles and reports were provided by the project partners responsible for the selected study sites. Data on the wells, fluids and rocks were extracted from these studies and filled to the template by UNIM and GFZ. The reviewed articles and reports are listed in Section 4.4 of this deliverable.

In this report, the status of data collection on 20th October 2023 is considered. However, the database will be completed by additional data from literature and new data will be added, which are generated in the frame of the CRM-geothermal project by sampling and analysis. After a thorough data assessment, all data will be comprised in the CRM-geothermal Fluid Atlas, which will be presented by the end of the project.

# 2 INTRODUCTION

In many cases, geothermal fluids contain dissolved elements that the EU considers as critical raw materials (CRM). Having these elements from the fluids, combined with the extraction of heat and power, can maximise returns on investment and minimise environmental impact. This technology requires no additional land use, has near-zero carbon footprint, and contributes to the domestic supplies of CRM.

There are already existing metal extraction technologies from fluids, but these technologies need to be adapted to the special conditions of such geothermal systems (high temperature, pressure and salinities). In the CRM-geothermal project, combination of materials and flow-schemes will be examined at lab-scale to optimise systems for different geothermal settings and CRM.

To assess overall supply potential, CRM-geothermal will enlarge an existing geothermal fluid atlas by collecting formerly existing and newly generated data by sampling wells for their CRM content in Europe and East Africa. The potential of different geological settings for combined extraction will be evaluated. In line with this aim, a modular, mobile plant will be developed and deployed at existing geothermal sites to conduct pilot studies, investigating upscaling and system integration.

The environmental and social impacts will also be assessed to ensure good governance. An UNFC/UNRMS compliant reporting template will be developed to create trust among investors, regulators and the public. The project will advance key reference points for stakeholder engagement, in order to obtain and maintain a 'social license to operate'.

Combined extraction creates new business opportunities for both SMEs and larger companies, and its economics under likely future market developments will be investigated with a view to proposing suitable business models.

The CRM-geothermal project will provide solutions to screen, develop, and test the combined extraction of heat and critical raw materials from geothermal fluids. It offers new and fundamental information, a deeper understanding, and innovative technologies that allow exploitation of such resources in an environmentally friendly way. The project also intends to create geochemical tools to better guide future exploration for CRM-rich geothermal systems worldwide. CRM-geothermal will open up a potentially huge untapped resource and deploy solutions to help Europe fulfil the strategic objectives of the EU Green Deal and the Agenda for Sustainable Development.

The CRM-geothermal project comprises 7 work packages:

- WP1 – Screening and mapping of CRM content in geothermal settings
- WP2 – Geological controls of CRM mobility, source and long-term sustainability in different geothermal settings
- WP3 – Development and optimisation of extraction technologies for CRM from geothermal brines
- WP4 – Deployment of the combined extraction of CRM and energy from geothermal fluids
- WP5 – Testing, validation, integration (of design requirements, systems and components)
- WP6 – Dissemination, communication and exploitation
- WP7 - Coordination

From the list of CRMs[1] that has been updated by the EU in 2020 some elements, such as Li, are already known to occur in economically-relevant concentration in geothermal fluids and extraction efforts are underway. Although other elements also occur in relevant concentrations in geothermal fluids (brine and gas phase) or in precipitates (solid phase forming in geothermal settings = scaling/scales), a systematic data collection on the abundance of these elements in geothermal settings is missing so far. Many CRM of interest are not routinely measured in deep groundwaters/geothermal brines, since monitoring of geothermal fluids mostly focussed on elements that could have a negative impact on the heat production by causing scaling (precipitation) or corrosion. Thus, a data/knowledge gap exists that hinders our ability to predict the concentrations of CRMs in a range of geological/geothermal settings.

In the frame of Work Package 1, the CRM content of geothermal fluids in Europe and East Africa is assessed, from both formerly existing datasets and newly measured sample analysis. Beside CRM, the presence of other strategic elements in geothermal fluids is also examined. This is carried out by collecting existing data, e.g. from the REFLECT Fluid Atlas database (Kovács et al. 2023) or literature review, and the analysis of geothermal fluids at several geothermal sites with focus on critical raw materials. Data will be visualised through the online available CRM-geothermal Fluid Atlas aided by digital integration and AI-based simulations. Beside Europe, the Atlas will be extended to East African countries and to lower temperature fluids.

The recent deliverable is an outcome from Task 1.1 - Data collection and database creation, and discusses the process and status of collecting data from formerly existing databases, scientific articles and reports. Data that are generated within the project lifetime by sampling and analysis will be assessed in the frame of D1.2, which is due in M38.

During the data collection, the focus is on the fluid composition but scales and gases are also considered, and the well data are also needed for the geographical reference. The collected data are reviewed and processed for incorporating them into the CRM-geothermal Fluid Atlas.

[1] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

# 3 METHODOLOGY OF DATA COLLECTION

In the REFLECT project, which was completed in September 2023, the European Fluid Atlas was created (https://www.reflect-h2020.eu/efa/). This online atlas contains fluid, well, rock and reservoir data from 21 European countries. Data came from two sources:

- formerly existing data from articles and technical reports,
- new data from field measurements and laboratory analysis.

The CRM-geothermal project applies a similar approach with the following main differences:

- Data collection is focused on the test sites;
- CRMs are added to the list of requested data.

## 3.1 IDENTIFICATION OF THE SITES FOR DATA COLLECTION

In CRM-geothermal Deliverable 2.1, five geothermal settings were identified and characterised. One or more test areas were allocated to each geothermal setting (Rochelle et al. 2022). Data collection has been limited to those test areas. Responsible partners provided data from the relevant test sites *(Table 1)*.

**Table 1:** Geothermal settings and the identified test areas

| Geothermal setting | Selected study sites | Country | Partner providing data |
|---|---|---|---|
| High-enthalpy volcanic geothermal areas | Reykjanes | Iceland | UoI |
| | Tuzla geothermal field | Turkey | IzTech |
| Metamorphosed flysch | Seferihisar | Turkey | IzTech |
| Low salinity water in fractured crystalline rock | Cornwall | UK | UKRI-BGS, CLL, GEL |
| Saline water in sedimentary basins | North German Basin | Germany | GFZ |
| | Upper Rhine Graben | | GFZ |
| | German Molasse Basin | | HI |
| Alkaline geothermal area | | Djibouti | JUB, GFZ |
| | | Tanzania | |
| | | Malawi | |
| | | Kenya | UNES |
| | | Rwanda | |
| | | Ethiopia | |

## 3.2 IDENTIFICATION OF THE REQUESTED DATA

Discussion on the identification of the requested data and the structure of the data collection template started at the project's kick-off meeting. After several smaller meetings and discussions in e-mails, the plan for the data collection template was finalised by the beginning of 2023.

First, the template was an excel file and project partners started to work with that because the creation of the online data collection platform took several months and was completed in October 2023. Data from the excel file will be imported into the platform, and from the middle of October, project partners can populate the online template.

The five working sheets of the excel template are as follows: (1) well data, (2) fluid sample data, (3) rock sample data, (4) PGE-REE in fluids and (5) PGE-REE in rocks. The last two sheets were added because the list of elements would have been too long if they were detailed on the fluid or rock sheets. On the fluid and rock sheets, only 'PGE' and 'REE' are indicated with reference to the last two sheets.

The requested data types (variables) are indicated in the headlines of columns *(Annex 1)*. Explanatory notes are provided in most of the cells in the headlines. Selection from drop-down menus help the harmonisation of data. Data providers were asked to list the wells vertically, and fill in the data to the relevant wells horizontally. References to the data are requested in each sheet. The data types in the working sheets are as follows:

*Well data:*
In this group, 31 attributes are listed, for example well ID, geographic location, date of well completion, wellhead elevation, surface elevation, well depth, screened interval, hydraulic head, PZ data, temperature of bottomhole and outflow, well yield, etc.

*Fluid sample data:*
Data are listed here by wells and fluid samples. This sheet contains the largest number of requested data. These data are divided into three main groups:

- Fluid sample identification: 6 items, e.g. sampling method, date, location, etc.,
- Fluid sample physical properties: 9 items, e.g. pressure, temperature density, etc.,
- Fluid sample chemical properties:
  - general properties: 9 items, e.g. pH, alkalinity, TDS, etc.,
  - dissolved major cations: 5 items,
  - dissolved major anions: 9 items,
  - dissolved trace elements: 35 items (PGE and REE are not detailed),
  - organics and petr. components: 3 items,
  - dissolved gas: 8 items,
  - isotopes: 10 items.

*Rock sample data:*
Data in this sheet are listed by wells and rock samples, and are divided into six groups:

- Reservoir data: 3 items (reservoir type, reservoir pressure, hydraulic conductivity),
- Rock sample identification: 6 items, e.g. sampling method, sample depth, etc.,
- Rock sample geological information: 6 items, e.g. mineralogical composition, age, etc.,
- Main elements in rock sample: 10 items, major elements in oxide wt%,
- Trace elements in rock sample: 35 items (PGE and REE are not detailed),
- Rock sample physical properties: 4 items, e.g. porosity, permeability, etc.

*PGE-REE in fluids:*

Data are listed by wells and fluid samples. In this sheet, each platinum group element and rare earth element is listed separately. This is needed because it is important to know which specific members of these groups are present in the given sample.

*PGE-REE in rocks*

Data are listed by wells and rock samples. In this sheet, each platinum group element and rare earth element is listed separately.

If the need arises, separate scale and gas worksheets can be added to the template.

# 4 PROCESS OF DATA COLLECTION

Collection of formerly existing data was carried out through two approaches:

- Re-assessing the REFLECT database and review of the databases of other geothermal projects,
- Collecting data from articles and technical reports.

## 4.1 PARTNERS INVOLVED IN THE DATA COLLECTION

Partners involved in the data collection and their contribution are listed below. In the recent deliverable only the data from literature, databases and reports are considered. The newly generated data from sampling and analysis will be detailed and assessed in Deliverable 1.2.

- University of Miskolc (UNIM), Hungary: coordinating the data collection, extracting data from articles and reports provided by other partners
- Cornish Lithium Plc (CLL), UK: providing literature with fluid data for the Cornwall area
- Haskoli Islands (UoI), Iceland: providing literature on geothermal wells from Iceland
- Helmholtz Zentrum Potsdam Deutsches Geoforschungszentrum (GFZ), Germany: input for Djibouti, Kenya and Cornwall, extracting data from articles and reports provided by other partners
- Hydroisotop GmbH (HI), Germany: providing data of about 100 wells from Northern Germany to the database
- Izmir Institute of Technology (IzTech), Turkey: providing data and scientific background for the AI tool for Task 1.4
- Jacobs University Bremen (JUB), Germany: providing literature for Djibouti, Tanzania and Malawi
- United Kingdom Research and Innovation (UKRI-BGS), UK: providing research reports on geothermal wells from Cornwall
- University of Nairobi (UNES), Kenya: providing literature on geothermal wells from East Africa, especially Kenya, Djibouti and Tanzania

## 4.2 RE-ASSESSMENT OF THE REFLECT DATABASE

REFLECT - Redefining geothermal fluid properties at extreme conditions was a H2020 project (https://www.reflect-h2020.eu/) similar to CRM-geothermal. The database built there contains well, fluid, rock and reservoir data, but only for wells above 50°C – CRM-geothermal has no temperature limit - and as the project focused on electricity production and not on raw material utilization, it consists of general data, not specialized on critical raw materials. It contains data from 21 countries, from more than 3000 wells, almost 4000 fluid samples, 450 rock samples and about 1000 reservoirs.

As the basic questions asked when creating the REFLECT database were the same, we also need to know in CRM-geothermal, we could import the REFLECT database into CRM. The CRM-geothermal database fully includes the geographical coverage of the REFLECT database over Europe, including Iceland and Turkey, but extends further to the East African Rift countries (Djibouti, Tanzania, Malawi, Kenya, Rwanda, Ethiopia). The main differences in the structure of the two databases can be seen in *Table 2*.

The structure of the well data is about the same, the CRM-geothermal just has a few extra columns that clarifies some of the data that could be misunderstood in REFLECT. The basis of the fluid sheets is very similar, but critical raw materials were added to the elements asked. These extra CRMs are Au, Be, Bi, Ga, Hf, In, Nb, PGE, REE, Sb, Sc, Ta, Ti. Remarks columns were added to each data group to encourage users to fill their remarks here and not in the data columns.

The rock sheet structures are also similar in the two databases, but the CRM-geothermal database contains a lot more attributes. First, some basic reservoir properties were added here, as there is no separate reservoir sheet in the CRM-geothermal template, like in REFLECT. Next, the main elements in the rock samples, like $Al_2O_3$, $Fe_2O_3$, MgO, were added in weight percent, followed by the trace elements, like Ag, As, B, Be, Bi, etc, in ppm. Platinum group elements (PGE) and rare earth elements (REE) both for fluids and rocks are added as separate worksheets to keep the size of the excel table manageable.

**Table 2:** Comparison of the structure and scope of the REFLECT and CRM-geothermal databases

| | REFLECT | CRM-geothermal |
|---|---|---|
| Number of worksheets in the template | 4 sheets (well, fluid, rock, reservoir) | 3+2 sheets (well, fluid, rock, PGE+REE in fluids, PGE+REE in rocks) |
| Temperature limit | T>50°C; with focus on fluids with T>100°C (for geothermal electricity generation) | No temperature limit |
| Geographic coverage | Europe (+Iceland + Turkey) | Europe (+ Iceland + Turkey) and East African Rift |
| Well data | General information on wells | Same structure, some added columns |
| Fluid data | Identification, physical properties, chemical properties (general, cations, trace elements, anions, organics and petr. comp., dissolved gas, isotopes) | Same structure, added columns (CRMs) |
| Rock data | Identification, geological information, physical properties | Identification, reservoir data, geological info., physical properties, main elements, trace elements |
| Reservoir data | General reservoir data | No reservoir sheet (some info included in rock sheet) |
| PGE+REE | | PGE+REE in fluids |
| | | PGE+REE in rocks |

When taking the data from the REFLECT database, they were restructured to fit into the CRM-geothermal database and were copied there. During the reassessment, the data was cleaned in the following way:

1. ID-s: Well_IDs, Fluid sample_IDs and Rock_IDs were checked and harmonized
2. Units of measurement, unit harmonization: Values that were not given in the asked measurement unit, were converted to the right unit. These include:
    i. Well: geothermal gradient (K/100m): K/km, K/m, C/m, C/50m, were converted to K/100m
    ii. Rock: Permeability ($m^2$): some data were given in $m^2$, some in Darcy (we assume)

All data were changed to $m^2$, original number in Darcy multiplied by 9.869233*10^-13

iii. Fluid: Pressure (Pa): MPa, kPa to Pa, correcting typos (1 zero missing, etc., based on other similar values in the given region)

iv. Fluid: Density (kg/dm$^3$): ~ signs were removed, units were harmonized g/cm$^3$, kg/m$^3$ to kg/dm$^3$

- Fluid: pH: invalid values, like 28 were deleted
- Fluid: Alkalinity (mEq/l): alkalinity was asked in mEq/l, but data was given in other units as well. These were all converted to mEq/, based on the following concept:
    - 1 mmol/l =2 mEq/l, as hardness in water is mainly caused by bivalent ions, like $Ca^{2+}$ and $Mg^{2+}$
    - 1 mg CaCO3/l=0.02mEq/l (if we consider CaCO3 as the main contributor to alkalinity)
    - 1dH°=0.3566mEq/l.
- Fluid: Total Dissolved Gas, TDG, (Nml/kg): Cases, where dissolved gas were given in ppm, were converted to vpm (ml/kg), see later by Dissolved gas. Vpm numbers were added to get the total dissolved gas. in ml/kg.
- Fluid: Dissolved gas (Vol%): dissolved gases were asked in vol%. However, in some cases it was given in vpm and many cases in ppm, as we found out. To convert ppm to vol%, first it was converted to vpm the following way. We used the equation p*V=n*R*T for standard laboratory pressure (101325Pa and 293 K). n was calculated as ppm (mg/l) /molar mass (in mg/mol). Calculating the upper equation for V, we recieved the volume as m3/kg. Converting this to vpm(ml/kg), we had to multiply to previous numbers by 1 000 000. These vpm numbers were added to get the Total dissolved gas. Considering this as 100%, the percentage of each dissolved gas was calculated based on their contributing vpm. In the cases, where only one type of gas was measured and the measurement unit was not known, it was impossible to convert the data into Vol%. These were left as they are, only flagged with a different colour.

3. Incorrect values, typos
    - Typos were corrected/ removed
    - Dissolved major anions, major cations and trace elements: *Table 3* shows the maximum threshold values we found in literature, the number of outliers, the number of all cases, the actual maximum values and the percentage of the outliers for each element. First the unit of measurement was checked. If it was found right, in case there were a large percentage of outliers, then probably the literature only referred to a specific location and at other locations, with different surroundings, the numbers were completely different. In these cases, the outliers were not omitted. In case there was only a few outliers, these were checked one by one to find out what can cause the deviation from the threshold value and omitted or left as they are accordingly.
    - Total anion and cation charge were calculated from the total major anions and cations, by first calculating how many mols do each entry mean from each element's molar mass, and then, this number was multiplied with the charge number of the given ion. These were then added for each major anion and cation to create the total anion/cation charge. These were then compared to each other, to check the goodness of the data. The difference between the anion and cation charge is a few percent in most of the cases, which means the data is good. In a few cases, the difference is 30-50%. In these cases, further investigation is needed about the causes, but usually it is a missing data on a major anion or cation.

**Table 3:** Maximum threshold values for checking incorrect values in the database

| | Ca | K | Mg | Na | Si | Cl | F | SO4 | PO4 |
|---|---|---|---|---|---|---|---|---|---|
| Maximum threshold value, based on literature | 30 000 | 2000 | 30 000 | 140 000 | 500 | 200 000 | 50 | 900 | 1 |
| Number of outliers | 27 | 77 | 0 | 0 | 610 | 2 | 4 | 174 | 23 |
| Number of all cases | 2783 | 2779 | 2834 | 2838 | 1791 | 3041 | 1584 | 2756 | 288 |
| Maximum value | 56500 | 56100) | 4592 | 110000 | 1172 | 259503 | 430 | 8482 | 1705 |
| Percent of outliers | 0.97 | 2.77 | 0 | 0 | 34.06 | 0.06 | 0.25 | 6.31 | 7.98 |

| | Al | As | B | Ba | Br | Cu | Fe | Hg | I | Li | Mn | Pb | Rb | Sr | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum value, based on literature | 10000 | 10 | 350 | 100 | 6000 | 3 | 1000 | 0 | 1400 | 500 | 6 | 100 | 4 | 1000 | 500 |
| Number of outliers | 0 | 19 | 0 | 4 | 4 | 3 | 13 | 4 | 0 | 1 | 156 | 12 | 41 | 32 | 1 |
| Number of all cases | 548 | 696 | 1279 | 608 | 929 | 375 | 1341 | 177 | 234 | 851 | 819 | 472 | 230 | 676 | 517 |
| Maximum value | 1900 | 306 | 284 | 170 | 10000 | 10 | 6300 | 155 | 45 | 3176 | 780 | 201 | 427 | 2500 | 2436 |
| Percent of outliers | 0.00 | 2.73 | 0.00 | 0.66 | 0.43 | 0.80 | 0.97 | 2.26 | 0.00 | 0.12 | 19.05 | 2.54 | 17.83 | 4.73 | 0.19 |

4. Missing values:
   - In case of reservoirs, a new column, Reservoir type (high entalpy/volcanic; crystalline basin; sedimentary) was added to aid Task 1.4. Data for this column was filled in based on existing data, literature and professional knowledge.
   - Some missing values could be filled in from data in other columns
   - TMC (Total Major Cations): In cases, where TMC was filled in, not left blank, a comparing calculation was made by summarizing the values of the major cations. The difference between the two values (TMC and SUM(Major Cations)) are very low, mostly less, than 1%, with a few exceptions: In case of a few entries in France, the difference is around 50%, but it only means 1-2 mg, as it's main component is gas, so it was considered correct. In case of the Czech fluids however, the difference in in the thousands. It might mean that the values are given in g/ml, but then, the values would be too high, unless the missing Ca is very high. As no values were given for Ca, it is not possible to calculate TMC by adding up the major cations, so the values were moved to the 'Remarks' column. In cases where TMC was left blank, but all major cations were filled in, TMC was calculated by summing these values.
5. Empty cells, no data:
   - NA, N/A values were deleted and a blank cell was left
   - Cells, where there was a space " ", this character was removed and a blank cell returned
6. Outlier detection: Each column was checked for outliers in two ways:
   - One is based on statistical means. As the geological setting of the wells is so different, the data varies in a huge extent. The best solution seemed to be, when the outliers were searched for the fluid data from each well separately.
   - The other way was just removing the impossible values, like wells that are deeper than the deepest well in the world, dissolved element values in fluids that are higher than the maximum solubility of the given material, etc.

As part of task 1.4, relating to INLECOM's effort in the REFLECT database, INLECOM, firstly, introduced a new column dedicated to the identification of duplicate sample entries, a measure implemented to safeguard data integrity. Subsequently, a thorough review of major cation and anion columns was conducted, enabling the identification and highlighting of non-numerical entries. To enhance data accuracy, INLECOM introduced dedicated columns adjacent to cation and anion columns, exclusively housing numerical values while eliminating non-numerical and unspecified entries. Lastly, z-score calculations were applied to identify outliers associated with each Well ID, specifically for cases with more than five samples for each Well ID. Outlier entries were subsequently removed. These comprehensive data cleaning endeavours culminated in a refined dataset, free from duplicate entries and outliers, thereby elevating data quality and reliability for subsequent analysis. Further details regarding the data pre-processing for the development of the AI models will be presented in the forthcoming deliverable (D1.4, M36).

## 4.3 REVIEW OF THE DATABASES OF FORMER H2020 PROJECTS

Above REFLECT, two other H2020 projects were analysed in order to import data from their databases: CHPM2030 and PERFORM.

*CHPM2030*

CHPM2030 - Combined Heat, Power and Metal extraction from ultra deep ore bodies (https://www.chpm2030.eu/) was implemented from January 2016 to June 2019. The aim of the project was to develop a technology which combines heat and energy production with the extraction of metals from the geothermal fluid. In order to enhance the metal content of the fluid, the concept was to establish an EGS system on a deep mineralisation and leach the metals from the ore body.


**Figure 1**: A section of the CHPM info platform with the locations of the data sources

In the frame of the project, data on the geothermal potential and deep mineralisations were collected from 24 European countries. These data have been published on an interactive platform: https://www.chpm2030.eu/chpm-info-platform-on-prospective-areas/ *(Figure 1)*. Information, including the chemical elements in rocks appear in pop-up windows. Unfortunately, data for the fluid composition are very sporadic and they are not linked to specific wells. As for the geochemical data from the mineralisations, the problem is that only their presence is indicated, there are no data on their amounts or the locations of the rock samples. Because of these reasons, the data from the CHPM2030 database cannot be used for the CRM-geothermal database.

*PERFORM*

The PERFORM project aimed to improve the performance of geothermal plants, by lowering operational expenses and extending the lifetime of infrastructure. This was carried out by combining data collection, predictive modelling, innovative technology development and in-situ validation.

The full version of the PERFORM database contains both confidential and public data. The complete set was used internally among the members of the PERFORM consortium. The publicly available data can be downloaded from the project website (www.geothermperform.eu).

The structure of the data is somewhat similar to CRM-geothermal (*Table 4*), it contains data on wells, fluids, rocks and particles in fluids and scales in addition, but generally, it has much less attributes asked in each worksheet. It has 5 Critical Raw Materials or Strategic Raw Materials in the fluid part, which is useful for the inclusion to the CRM-geothermal project. The public dataset contains data on 53 wellbores with 26 plants, 153 fluid samples, 14 rock samples, 13 particles in fluids and 4 scale samples.

**Table 4:** Structure of the PERFORM and the CRM-geothermal databases

| | PERFORM | CRM-geothermal |
|---|---|---|
| No. of worksheets: | 5 excel tables (wellbore, plant, brine, brine particle, rock mineral) | 3+2 sheets (wells, fluids, rocks, PGE+REE fluids, PGE+REE rocks) |
| Well data: | Wellbore and plant have some very basic information on wells and the plants that use them (10 attributes) | Well: general information on wells (31 attributes) |
| Fluid data: | Fluids: identification, physical properties, chemical properties (major cations, some major anions, some trace elements from which there are 5 CRMs or strategic raw materials and some alkanes) (54 attributes) | Fluids: identification, physical properties, chemical properties (general, cations, trace elements with emphasis on CRMs, anions, organics and petr. comp., dissolved gas, isotopes) (107 attributes) |
| Rock data: | Rock: identification and mineral composition (21 attributes) | Rock: identification, reservoir data, geological info., physical properties, main elements, trace elements (70 attributes) |
| Reservoir data: | No data on reservoir | No reservoir sheet (some info included in rock sheet) |
| | No PGE or REE | PGE+REE in fluids and rocks |
| Brine particles or scale | Particles and scales: identification, main element, some trace elements (35 attributes) | So far no scale datasheet, but possibly add one later |

## 4.4 REVIEW OF LITERATURE AND EXISTING DATA FROM THE STUDY AREAS

Responsible partners were asked to provide articles and reports from which data of geothermal fluids, wells and rocks can be obtained. They were especially asked to provide data that are not included in the REFLECT database to avoid duplicate entries. A specific folder on the shared NextCloud platform was established to collect the articles.

While the online data collection platform was being prepared, partners started to populate the excel templates. A separate excel file for each test site was uploaded to the shared NextCloud platform of the consortium and partners were asked to add the data to their specific template. The number of books, articles, reports, and the data extracted from these documents are indicated in *Table 5.*

**Table 5:** Already existing literature and data for the study areas

| Geothermal setting | Test area | Literature (+data from REFLECT) | Data obtained so far |
|---|---|---|---|
| High-enthalpy volcanic geothermal areas | Reykjanes | 1 database, 10 articles (1)* + data from REFLECT | 11 wells, 10 steam and liquid, 6 fluids with 8 REE, 50 scales with 33 PGE and REE |
| | Tuzla geothermal field | data from REFLECT | |
| Metamorphosed flysch | Seferihisar | data from REFLECT | |
| Low salinity water in fractured crystalline rock | Cornwall | 2 articles, 7 research reports (2) + data from REFLECT | 7 wells, 32 fluid data, 6 rock data. |
| Saline water in sedimentary basins | Northern German Basin | 3 books, 2 articles (3) + data from REFLECT | 100 analyses, also some containing heavy metals or trace elements |
| | Upper Rhine Graben | | 247 analyses, ca 10% containing heavy metals or trace elements |
| | German Molasse Basin | | 64 analyses, a few containing heavy metals or trace elements |
| Alkaline geothermal area | Djibouti | 3 articles (4) | 31 wells, 31 fluids with no PGE or REE |
| | Tanzania | | 17 wells, 17 fluids with 17 REE, 23 rock samples |
| | Malawi | | |
| | Kenya | 3 articles (5) | 35 wells, 23 fluids with no PGE-REE, 15 rock with 15 REE |
| | Rwanda | | |
| | Ethiopia | | |

*Numbers in the table refer to the numbers in the text below

1. Reykjanes:

- Kaasalainen H., Stefánsson A., Giroud N., Arnórsson S. (2015) The geochemistry of trace elements in geothermal fluids, Iceland: Appl. Geochem. 62, 207-223. http://dx.doi.org/10.1016/j.apgeochem.2015.02.003
- Database on hydrothermal fluid chemical composition of the University of Iceland.
- Fowler A.P.G., Zierneberg R.A., Reed M.H., Palandri J., Óskarsson F., Gunnarsson I. (2019) Rare earth systematics in boilied fluids from basalt-hosted geothermal systems. Geochim. Cosmochim. Acta 244, 129-154. https://doi.org/10.1016/j.gca.2018.10.001
- Hannington M., Hardardottir V., Garbe-Schönberg D., Brown K.L. (2016) Gold enrichment in active geotehrmal systems by accumulating colloid suspensions. Nature Geosci. 2016. http://dx.doi.org/10.1038/ngeo2661
- Hardardóttir V., Brown K., Fridriksson T., Hedenquist J.W., Hannington M.D., Thorhallsson S. (2009) Metals in deep liqid of the Reykjanes geothermal system, southwst Iceland: implications for the compostion of seafloor black smoker fluids. Geology 37, 1103-1106.
- Bonalumi M. (2006) Transport of metals and mineral precipitation in geothermal systems (Iceland). MSc thesis ETH Zurich, 67 p.
- Hardardóttir V., Hannington M., Hedenquist J., Kjarsgaard I., Hoal K. (2010) Cu-rich scales in the Reykjanes geothermal system Iceland. Econ. Geol. 105, 1143-1155.
- Grant H.L.J., Hannington M.D., Hardardóttir V., Fuchs S.H., Schumann D. (2020) Trace metal distributions in sulfide scales of the seawater-dominated Reykjanes geothermal system: constraints on sub-seafloor hydrothermal mineralization processes and metal fluxes. Ore Geol. Rev. 116, 103145. https://doi.org/10.1016/j.oregeorev.2019.103145
- V. Hardardóttir V., Hannington M., Hedenquist J. (2013) Metal concentrations and metal deposition in deep geothermal wells at the Reykjanes high-temperature area, Iceland. Procedia Earth and Planetary Science 7, 338 – 341.
- Libbey R.B., Williams-Jones A.E. (2016) Relating sulfide mineral zonation and trace element chemistry to subsurface processes in the Reykjanes geothermal system, Iceland. Journal of Volcanology and Geothermal Research 310, 225–241.
- Smith B.D. (2022) Gold Transport Through the Epithermal System in the Reykjanes Peninsula. MSc thesis, Reykjavík University 117 p.

2. Cornwall:

- Edmunds W.M., Kay L.F., McCartney R.A. (1985) Origin of saline groundwaters in the Carnmenellis granite (Cornwall, England): Natural Processes and reaction during hot dry rock reservoir circulation. Chemical Geology, 49, 287—301
- Richards H.G., Willis-Rochards J., Pye J. (1991) A review of geological investigations associated with the UK Hot Dry Rock programme. Read at the Annual Conference of the Ussher Society, 321-326
- British Geological Survey, Research Report SD/89/2, Hot Dry Rock Geochemistry Group, Geochemistry in relation to Hot Dry Rock development in Cornwall. Volume 1 – Volume 7

3. German basins:

- Carlé W. (1975): Die Mineral- und Thermalwässer von Mitteleuropa – Geologie, Chemismus, Genese. Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart, 643 pages
- Käß W. & Käß H. (2008): Deutsches Bäderbuch. E. Schweizerbart´sche Verlagsbuchhandlung

(Nägele u. Obermiller), Stuttgart, 2nd edition, 1232 pages

- Müller V.E.P., Papendieck G. (1975) Zur Verteilung, Genese und Dynamik von Tiefenwassern unter besonderer Berücksichtigung des Zechsteins. Z. geol. Wiss., Berlin 3 2, 167-196
- Boschetti T. (2023) An update on lithium mica thermodynamics and its geothermometrical application. Geothermics 109, 102661 https://doi.org/10.1016/j.geothermics.2023.102661
- Sanjuan B., Gourcerol B., Millot R., Rettenmaier D., Jeandel E., Rombaut A. (2022) Lithium-rich geothermal brines in Europe: An up-date about geochemical characteristics and implications for potential Li resources. Geothermics 101, 102385 https://doi.org/10.1016/j.geothermics.2022.102385

4. Djibouti:

- Awaleh M.O, Hoch F.B., Boschetti T., Soubaneh Y.D., Egueh N.M., Elmi S.A., Mohamed J., Mohamed Abdi Khaireh M.A. (2015) The geothermal resources of the Republic of Djibouti — II: Geochemical study of the Lake Abhe geothermal field. Journal of Geochemical Exploration 159, 129-147 https://zarmesh.com/wp-content/uploads/2016/01/The-geothermal-resources-of-the-Republic-of-Djibouti-II-Geochemical-study-of-the-Lake-Abhe-geothermal-field-2015.pdf
- D'Amore F., Giusti D., Abdallah A. (1998) Geochemistry of the high-salinity geothermal field of Asal, Republic of Djibouti, Africa. Geothermics Vol 27, Issue 2, 197-210 https://www.sciencedirect.com/science/article/pii/S0375650597100098
- Miguli A.M. (2017) Simple Modelling of geothermal resources in the Asal Rift Area, Djibouti. United Nations University Geothermal Training Programme, Reykjavík, Iceland, report 2017, number 19 https://orkustofnun.is/gogn/unu-gtp-report/UNU-GTP-2017-19.pdf

5. Kenya:

- Karingithi C.W. (2000) Geochemical characteristics of the Greater Olkaria Geothermal Field, Kenya. United Nations University Geothermal Training Programme, Reykjavík, Iceland, report 2000, number 9 http://www.os.is/gogn/unu-gtp-report/UNU-GTP-2000-09.pdf
- Alexander K.B., Ussher GT. (2011) Geothermal Resource Assessment for Mt Longonot, Central Rift Valley, Kenya. Conference: GRC Transactions Volume: 35 https://www.researchgate.net/publication/229138350_Geothermal_Resource_Assessment_for_Mt_Longonot_Central_Rift_Valley_Kenya
- Roex A.P., Späth A., Zartman R.E. (2001) Lithospheric thickness beneath the southern Kenya Rift: implications from basalt geochemistry. Contributions to Mineralogy and Petrology volume 142, 89–106 https://doi.org/10.1007/s004100100273

A comprehensive literature review, summarising the state of knowledge for each study site is available in Deliverable 2.1 – Report identifying pre-existing sources of data at the selected sites (Rochelle et al. 2022).

# 5 THE WEB APPLICATION FOR DATA COLLECTION

## 5.1 GOAL OF THE WEB APPLICATION

The goal of the web application is to provide an online platform for data collection and replace data stored in Excel with a database. The application provides the ability to give data through forms as well as to import and validate data from Excel files into the database.

The applied web technologies are the Node.js (Javascript), the Angular (Typescritp, HTML, CSS) and the MySQL. Both Node.js and Angular are widely used in web development, with Node.js often serving as the backend technology for web applications built with Angular on the frontend.

## 5.2 STRUCTURE OF THE WEB APPLICATION

The application is composed of the following developed components (visualised in *Figure 2*):

(1 ) models, (2) services, (3) confirmation-dialog, (4) well-data-form, (5) fluid-sample-data-form, (6) rock-sample-data-form, (7) pge-ree-in-fluids-form, (8) pge-ree-in-rocks-form, (9), well-view-form, (10) fluid-sample-view-form, (11) rock-sample-view-form, (12) excel-validate, (13) login-form, (14) open-street-map, (15) snackbar, (16) new-user-form, (17) user-edit-form, (18) user-profile, (19) users-list.

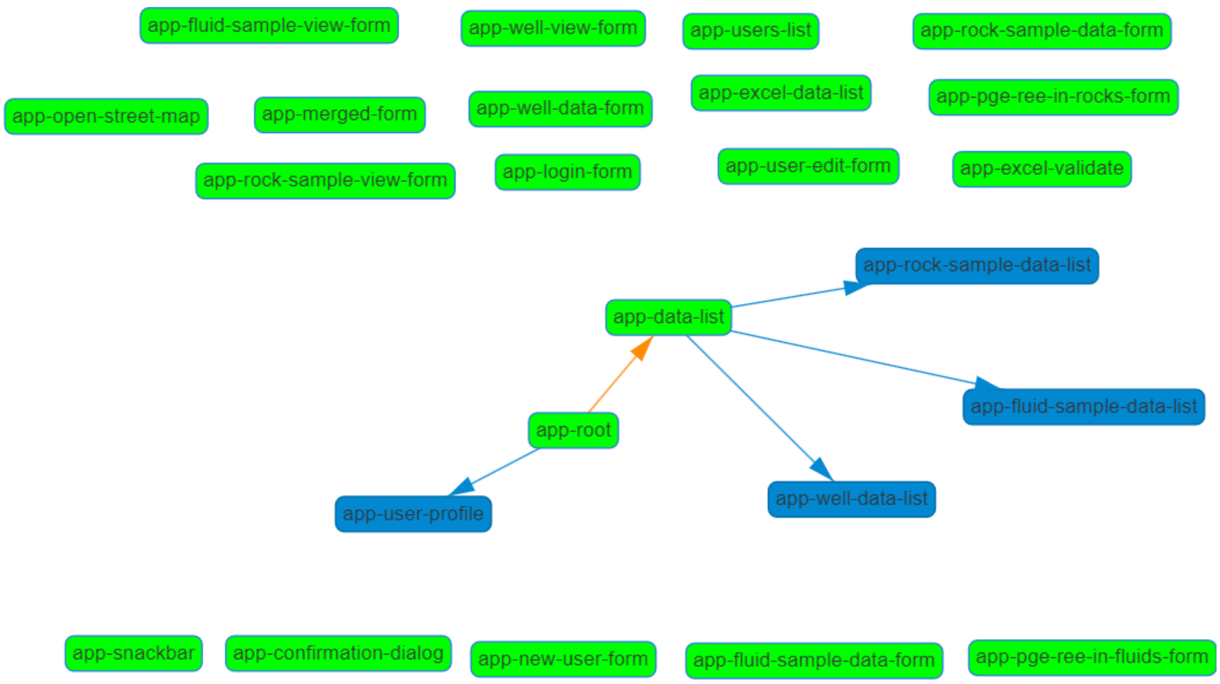



**Figure 2:** The module diagram of the system

## 5.3 THE STRUCTURE OF THE DATABASE

The applied database technology is MySQL. MySQL is a popular open-source Relational Database Management System, which means it stores data in structured tables with relationships between them. MySQL uses SQL for querying and managing the data. SQL is a powerful language for defining, manipulating, and controlling data within the database. In MySQL, data is organized into tables, which are similar to spreadsheets. Each table consists of rows (records) and columns (fields) to store and retrieve data. The tables and the relationships between them are illustrated in *Figure 3.*

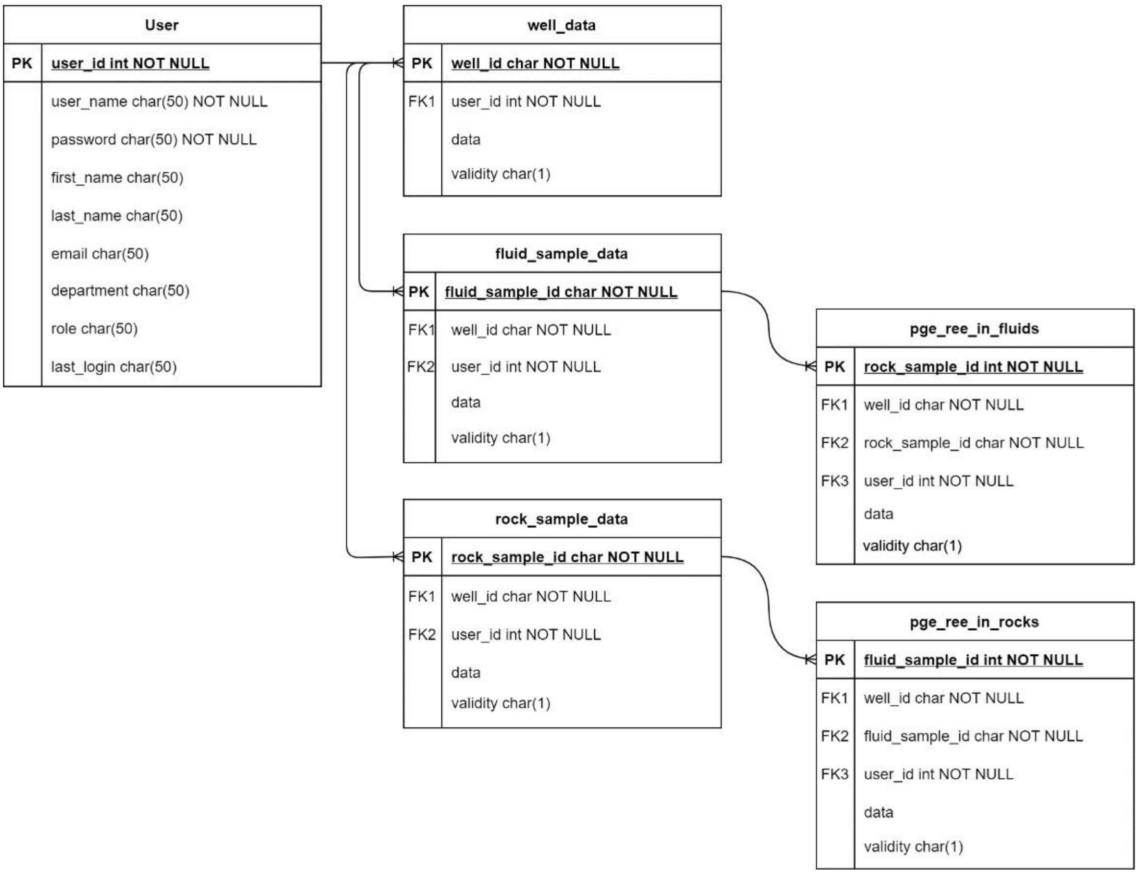



**Figure 3:** Structure of the database

## 5.4 THE USE-CASE DIAGRAM OF THE SYSTEM

The user roles and the related functions are illustrated in *Figure 4*.

*Actors*

There are two roles in the system: the administration role and the user role

- Admin: the administrator in the system, have role to manage (add, modify, delete) the users and can modify any data uploaded by any user
- User: user in the system, can add new data, modify existing own data, and excel file export and import

*Case-case*

- *login:* login in the system by the username and the related password
- *logout:* logout from the system, the user token expires in 1 day after the user automatically logged out

- *user create:* the administrator can create a new user profile by giving the user data (username, first name, last name, password, department, email, role)
- *user edit:* the administrator can modify an existing user profile
- *user delete:* the administrator can delete an existing user profile
- *data create:* create a new well data/fluid sample data/rock sample data/PGEREE in fluids data/PGEREE in rocks data
- *data edit:* modify an existing well data/fluid sample data/rock sample data/PGEREE in fluids data/PGEREE in rocks data
- *data delete:* delete an existing well data/fluid sample data/rock sample data/PGEREE in fluids data/PGEREE in rocks data
- *data view:* view an existing well data/fluid sample data/rock sample data/PGEREE in fluids data/PGEREE in rocks data
- *excel file import to DB:* export the template excel file contain into the database. The user must select the Excel file, which contains data. The system will validate data in the Excel file and if the any data in the Excel file incorrect, then the system will colouring the given data in the table by red colour
- *DB export to excel file: e*xport the template Excel file into the database. The user must select an Excel file containing data. The system will validate the data in the Excel file, and if any data in the Excel file is incorrect, the system will highlight the incorrect data in the table by the red background colour. The user (and the administrator as well) can review and edit data in the table if there are any inaccuracies using the given data form. If the incorrect data (denoted by red colour) will correct by the user, the red background colour of the given data row will be changed (white background colour).
- *user profile edit:* modify the own user profile data (username, password, first name, last name, department, email) by the user profile form

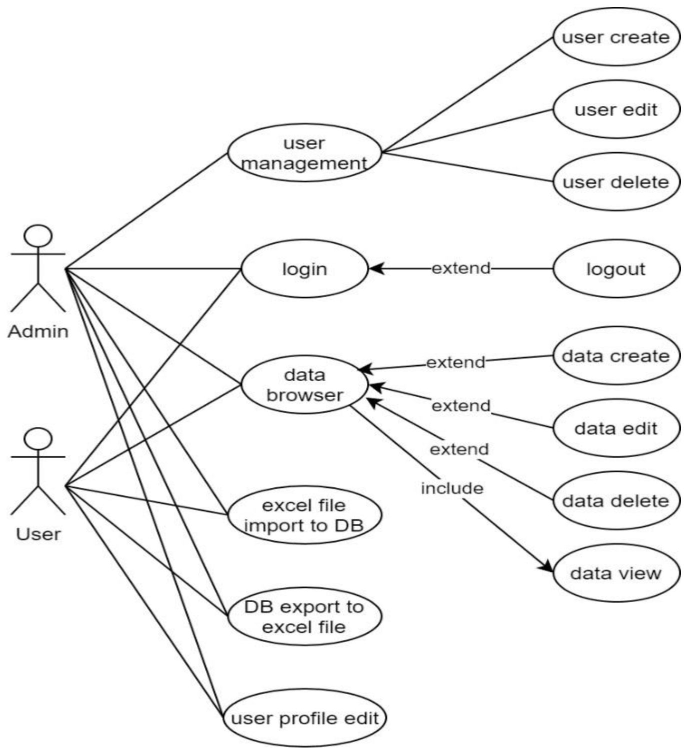



**Figure 4:** The use-cases in the system

## 5.5 THE USER INTERFACES OF THE WEB APPLICATION

The login form and the main page are shown in *Figure 5.*

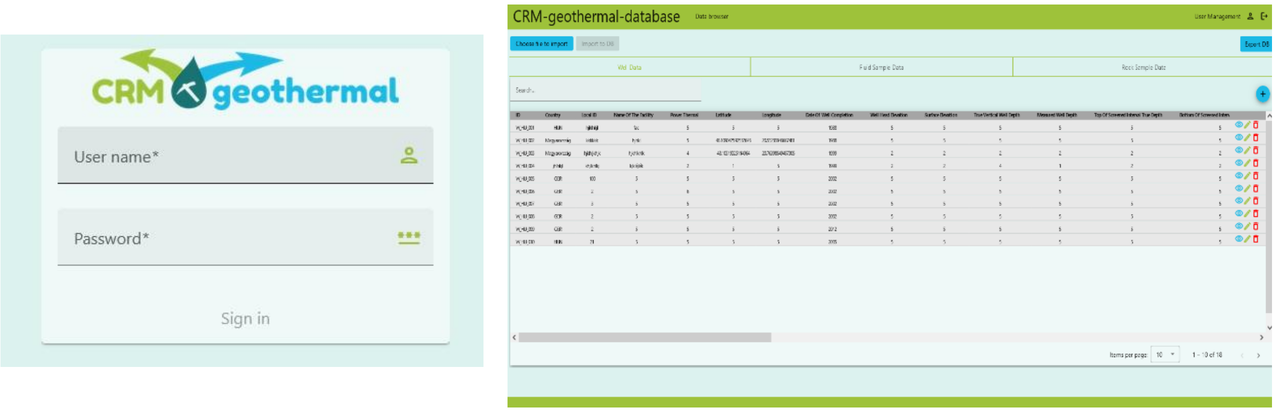



**Figure 5:** View of the login form (left) and the main page (right)

The well data view can be seen in *Figure 6.* The location selection for the well data automatically sets country, latitude, and longitude in the form based on the selected point in the map.

Well Data

| | | | |
|---|---|---|---|
| **Well ID** | W_HU_001 | **Local ID** | hjklhkjl |
| **Country** | HUN | **Name Of The Facility** | fac |
| **latitude** | 5 | **Date Of Well Completion** | 1988 |
| **longitude** | 5 | **Power Thermal** | 5 |

| | | | |
|---|---|---|---|
| **Well Head Elevation** | 5 | **Surface Elevation** | 5 |
| **True Vertical Well Depth** | 5 | **Measured Well Depth** | 5 |
| **Top Of Screened Interval True Depth** | 5 | **Bottom Of Screened Interval True Depth** | 5 |
| **Hydraulic Head** | 5 | **Geothermal Gradient In Well** | 5 |
| **PZ data** | 5 | **PZ data Depth** | 5 |
| **Bottomhole Temperature** | 5 | **Depth Of Measured Bottomhole Temperature** | 5 |
| **Outflow Temperature** | 5 | **Year Of Outflow Temp Measurement** | 2008 |
| **Well Yield** | 5 | **Year Of Well Yield Measurement** | 1988 |
| **Remarks (well yield)** | kjkljéh | | |
| **Scaling Exists** | yes | **Inhibitor Added** | yes |
| **References** kjhjh | | | |

OK

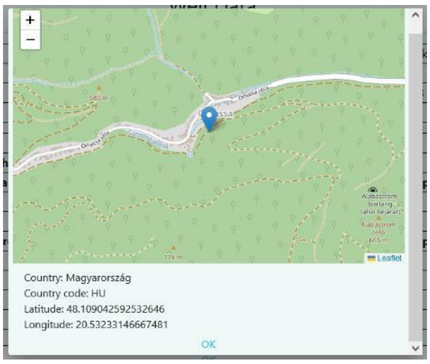



**Figure 6:** View of well data and the location selection

Separate data forms are available for the wells, fluids, rocks, PGE-REE in fluids and PGE-REE in rocks, according to the working sheets of the original excel template *(Figure 7)*.

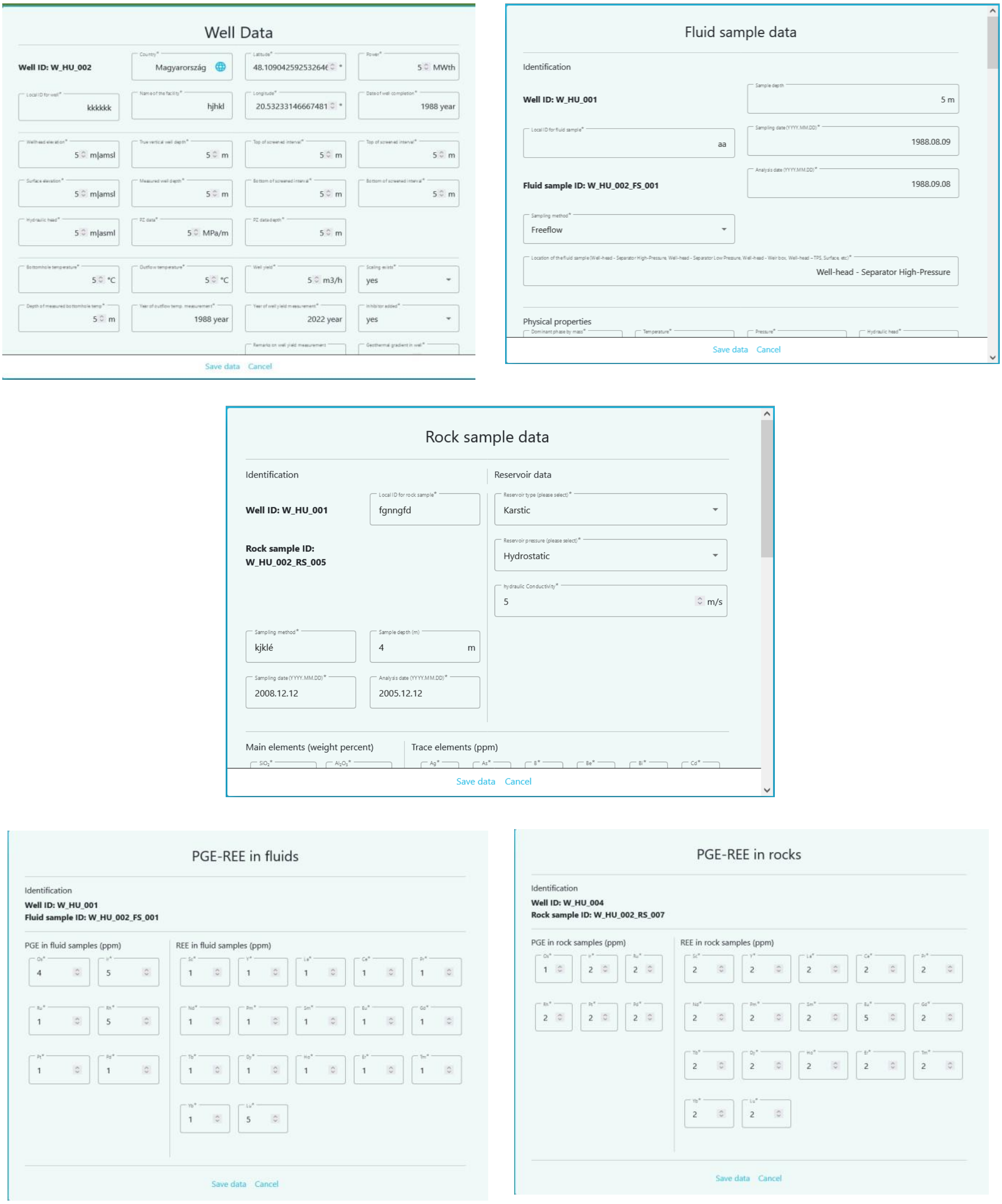



**Figure 7:** View of the separate data forms for wells, fluids, rocks and PGE-REE in fluids and rocks

For each form field, a corresponding pop-up window contains a description of that field *(Figure 8).*

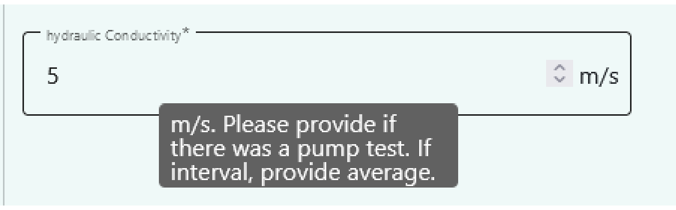
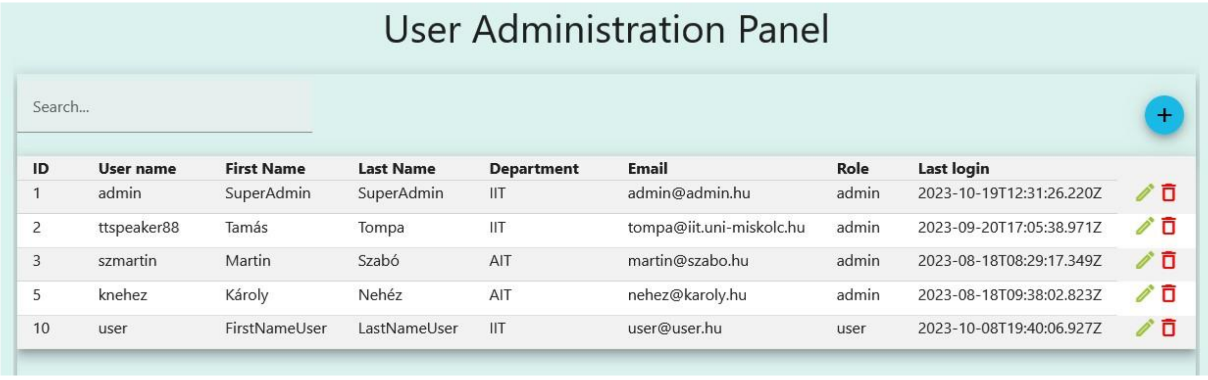



**Figure 8:** Pop-up window with explanation for the given field

For the admin roles users an administration table is available *(Figure 9).* New users have to fill a form and existing users can edit their data *(Figure 10).*


User Administration Panel

Search...

| ID | User name | First Name | Last Name | Department | Email | Role | Last login |
|---|---|---|---|---|---|---|---|
| 1 | admin | SuperAdmin | SuperAdmin | IIT | admin@admin.hu | admin | 2023-10-19T12:31:26.220Z |
| 2 | ttspeaker88 | Tamás | Tompa | IIT | tompa@iit.uni-miskolc.hu | admin | 2023-09-20T17:05:38.971Z |
| 3 | szmartin | Martin | Szabó | AIT | martin@szabo.hu | admin | 2023-08-18T08:29:17.349Z |
| 5 | knehez | Károly | Nehéz | AIT | nehez@karoly.hu | admin | 2023-08-18T09:38:02.823Z |
| 10 | user | FirstNameUser | LastNameUser | IIT | user@user.hu | user | 2023-10-08T19:40:06.927Z |

**Figure 9:** The user administration table (only for the admin roles users)

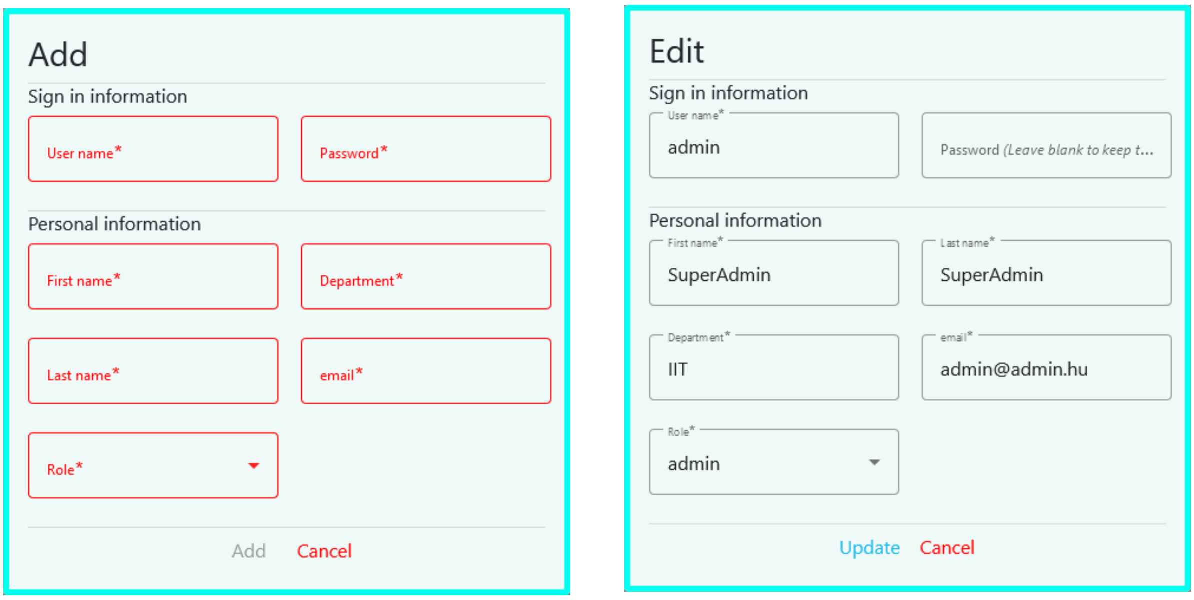



**Figure 10:** Forms of the new user creation (left) and edit existing user data (right)

All form data is validated, and the user cannot save the data in the form until all data is correctly defined. If any data has an incorrect format (or value), it is indicated with a red outline around the respective form field *(Figure 11).*

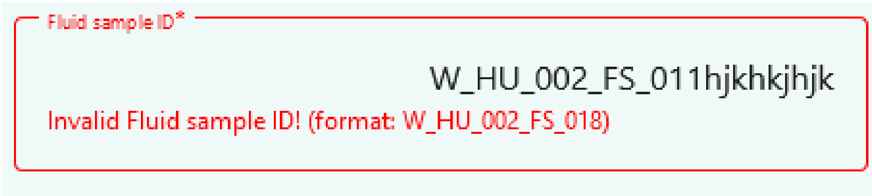



**Figure 11:** Example for an incorrect fluid sample ID

All the IDs in the data forms will be generated automatically once the user fills in the required data for ID generation. For example, in the case of the well ID, the location needs to be selected on the map to create the well ID. The number part of the new IDs will be incremented based on the number part of the last existing ID in the database. In case of PGE-REE in fluids/rocks data, the ID will be generated based on the parent fluid/rock data ID. The user has possibility to modify the generated ID. The web application will be available via [https://crmgeothermal.iit.uni-miskolc.hu/](https://crmgeothermal.iit.uni-miskolc.hu/) .

# 6 CONCLUSIONS

Geothermal fluids often contain dissolved metals, including the critical raw materials (CRMs). In the frame of the CRM-geothermal project, in Work Package 1, a database is being built that collects data on the CRM content of geothermal fluids and the related rocks, together with the identification of other strategic elements. The collected data will be visualised through the CRM-geothermal Fluid Atlas. Data from all over Europe as well as from East Africa are considered. The focus is on five geothermal settings, which are represented by one or more study areas:

- High-enthalpy volcanic geothermal areas (Reykjanes, Tuzla geothermal field),
- Metamorphosed flysch (Seferihisar),
- Low salinity water in fractured crystalline rock (Cornwall),
- Saline water in sedimentary basins (North German Basin, Upper Rhine Graben, German Molasse Basin),
- Alkaline geothermal area (Djibouti, Tanzania, Malawi, Kenya, Rwanda, Ethiopia).

In line with Task1.1, this report provides an overview on the methodology and results of collecting formerly existing data from articles, reports and databases of geothermal projects. Data which are generated during the recent project implementation by sampling and analysis are not discussed here but later they will also be included in the Fluid Atlas.

For the data collection, first an excel template was used with separate working sheets for the well, fluid and rock data. Two additional sheets were added for the fluids and the rocks, in which the PGE and REE elements are listed in details. This was needed to keep the size of the fluid and rock sheets manageable. While the excel templates were being populated, an online data collection platform was developed as a web application. This will be used for gathering further data and the formerly collected data will also be imported from the excel templates. The web application will be available via https://crmgeothermal.iit.uni-miskolc.hu/.

In the first phase of the data collection, the REFLECT and the PERFORM databases were screened and data have been imported to the CRM-geothermal database. The REFLECT database contains data from 21 countries, more than 3000 wells, almost 4000 fluid samples, 450 rock samples and about 1000 reservoirs. The PERFORM public dataset includes data of 53 wellbores with 26 plants, 153 fluid samples, 14 rock samples, 13 particles in fluids and 4 scale samples.

Respective partners also contributed with articles, reports and data in excel tables. As of the end of October 2023, for the study areas of the five geothermal settings, 3 books, 22 articles, 7 research reports and a dataset were provided and reviewed. From these sources, data of 102 wells, 530 fluid samples, 44 rock samples and 50 scale samples have been extracted.

Collection of formerly existing data has not been finished with the submission of the recent report. In the process of the development of the CRM-geothermal Fluid Atlas, partners can add further literature data through the online template, together with the new data from sampling and lab analysis.

The Fluid Atlas, presenting all collected data will be provided by the end of the project. Work on the Atlas started in M15, in the frame of Task 1.3 – Establishing the CRM-geothermal Fluid Atlas. The aims, the methodology and outcomes of creating it, as well as the improvements compared to the REFLECT

Fluid Atlas will be discussed in Deliverable 1.3 – Online GIS based CRM-geothermal Fluid Atlas for Europe and Eastern Africa.

As an important impact of the CRM-geothermal database, a better geological understanding will be established that explains the occurrence and mobility of CRM-rich geothermal fluids. This will help to identify geothermal provinces where co-production of CRMs and energy will be possible. With this approach, the knowledge on CRMs and other strategic elements in the examined geothermal setting will help companies and investors to set up geothermal projects with metal extraction in Europe and also worldwide.

# 7 REFERENCES

Kovács, K., Seres, A., Hartai,É. (2023): The H2020 REFLECT project: Deliverable 3.2 - European Fluid Atlas online available, GFZ German Research Centre for Geosciences. 16p

Rochelle, C., Bau, M., Baba, A., Regenspurg, S., Stefánsson, A., Ayzit, T., Farndale, H., Peach-Gibson, A., Shaw, R., Salisbury, A., Tonkul, S. and Yeomans, C. (2022): The Horizon Europe CRM-geothermal project: Deliverable 2.1 - Report identifying pre-existing sources of data at the selected sites. 138p

# 8 ANNEXES

## 8.1 ANNEX 1: CRM-GEOTHERMAL DATA COLLECTION TEMPLATE

Well data template

**Well data**

| Well ID | Country | Local ID for the well | Name of the facility | Power (thermal) (MWth) | Latitude (WGS84, decimal degree) | Longitude (WGS84, decimal degree) | Date of well completion (year) | Wellhead elevation (m, amsl) | Surface elevation (m, amsl) | True vertical well depth (m) | Measured well depth (m) | Top of screened interval (m, below wellhead, true vertical depth) | Bottom of screened interval (m, below wellhead, true vertical depth) | Top of screened interval (m, below wellhead, measured depth) | Bottom of screened interval (m, below wellhead, measured depth) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | |

| Hydraulic head (m amsl) | PZ data (MPa/m) | PZ data depth (m) | Bottomhole temperature (°C) | Depth of measured bottomhole temperature (m) | Outflow temperature (°C) | Year of outflow temp. measurement | Well yield (m3/hour) | Year of well yield measurement | Remarks on well yield measurement | Scaling exists (Y/N) | Inhibitor added (Y/N) | Geothermal gradient in well (°C/100m) | References for the data (link/DOI/ISBN/ISSN/national archive identifier) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |

Fluid data template

**Fluid sample data**

| | | Fluid sample identification | | | | | | Fluid sample physical properties | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Well ID | Fluid sample ID | Local ID for fluid sample | Sampling method (please select) | Sample depth (m) | Sample location | Sampling date (YYYY.MM.DD) | Analysis date (YYYY.MM.DD) | Dominant phase by mass (please select) | Tempera-ture (°C) | Pressure (MPa) | Hydraulic head (m amsl) | Density (kg/dm3) | Kinematic viscosity (m2/s) | Dynamic viscosity (kg/m/s) | Specific heat capacity (J/K/kg) | Electrical conductivity (µS/cm, EC25) | pH | Dissolved oxigen (mg/L) | Eh (mV) | Total alkalinity (meq/L) | Carbonate alkalinity (meq/L) | TDS (mg/L) | TDG (Nml/kg) | GLR | Remarks |
| | | | | | | | | | | | | | | | | | | | | | | | | | |

| Fluid sample chemical properties | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dissolved major cations (mg/L) | | | | | | | Dissolved trace elements (mg/L) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ca | K | Mg | Na | Si | TMC | Remarks major cations | Ag | Al | As | Au | B | Ba | Be | Bi | Br | Co | Cr | Cu | Cs | Fe | Ga | Ge | Hf | Hg | I | In | Li | Mn | Nb | Ni | Pb | PGE | Rb | REE | Sb | Sc | Sr | Ta | Ti | W | Zn | Remarks trace elemen[ts] |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Dissolved major anions (mg/L) | | | | | | | | | | [Org]anics and petr. comp. (m[g/L]) | | | | Dissolved gas (Vol%) | | | | | | | | | Isotopes (‰) | | | | | | | | | | | References for the data (link/DOI/ISBN/ISSN/national archive identifier; list if multiple) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cl | S | F | CO3 | HCO3 | SO4 | PO4 | HBO2 | TMA | Remarks major anions | TOC | TPH | BTEX | Remarks org. petr. comp. | CO2 | O2 | H2S | N2 | CH4 | Ar | H2 | He | Remarks dissolved gas | Oxigen-18 | Deuterium (2H) | Tritium (3H) | Oxigen-18 (SO4) | Sulfur-34 (SO4) | Sulfur-34 (H2S) | Carbon-13 (CO2) | Lithium-7 | Boron-11 | 87Sr/86Sr | Remarks isotopes | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Rock data template

**Rock sample data**

| | Reservoir data | | | | Rock sample identification | | | | | Rock sample geological information | | | | | | Main elements in rock samples (weight percent) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Well ID | Reservoir type (please select) | Reservoir pressure (please select) | Hydraulic conductivity (m/s) | Rock sample ID | Local ID for rock sample | Sampling method | Sample depth (m) | Sampling date (year) | Analysis date (year) | Rock type (please select) | Age of rock (please select) | Mineralogical composition | Formation name | Formation code on geological map | Link to geological map | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TO_2$ | $P_2O_5$ | MnO | Remarks: main elements |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Trace elements in rock samples (ppm) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ag | As | B | Be | Bi | Cd | Ce | Co | Cr | Cu | Ga | Ge | Hf | Hg | In | Li | Mo | Nb | Ni | Pb | PGE | Rb | REE | S | Sb | Se | Sn | Sr | Ta | Th | Tl | U | V | W | Zn | Zr | Remarks: Trace elements |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Rock sample physical properties | | | | | |
|---|---|---|---|---|---|
| Permeability (D) | Porosity (%) | Heat capacity (J/K/kg) | Thermal conductivity (W/m/K) | **References for the data (link/DOI/ISBN/ISSN/national archive identifier; list if multiple)** | **Remarks** |
| | | | | | |

## PGE and REE in fluid samples

| Well ID | Fluid sample ID | PGE in fluid samples (ppm) | | | | | | REE in fluid samples (ppm) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Os | Ir | Ru | Rh | Pt | Pd | Sc | Y | La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| | | | | | | | | | | | | | | | | | | | | | | | | |

## PGE and REE in rock samples

| Well ID | Rock sample ID | PGE in rock samples (ppm) | | | | | | REE in rock samples (ppm) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Os | Ir | Ru | Rh | Pt | Pd | Sc | Y | La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| | | | | | | | | | | | | | | | | | | | | | | | | |

## 8.2 ANNEX 2: GUIDELINES FOR THE CRM-GEOTHERMAL DATA COLLECTION TEMPLATE

**BACKGROUND**

In Work Package 1 'Screening and mapping of CRM content in geothermal settings' a database will be built with a view to assess the CRM content in geothermal brines and the related rocks across Europe and the East African Rift countries by collecting and reviewing relevant publications and reports. New data will be added from sampling various geothermal fluids. The data will be visualised in a comprehensive, digital CRM-geothermal fluid atlas including geographical, geological, physical and chemical characteristics.

The creation of an online platform for data collection is in progress. However, the collection of data can start using the provided Excel template because it will later be imported into the online platform.

When filling the data to the template, please consider the following instructions:

**GENERAL REMARKS**

Please provide zero only if data is indeed zero. If no data or not applicable, please leave the cell blank! If any measurement is below detection limit (e.g. < 0.05), then please provide the detection limit(without the „<" sign) and in the corresponding remarks column add an explanation that it is the detection limit! For example: if the detection limit for Lithium in your measurements is 0.05 and you have a measurement under this value, please provide 0.05 in the Li column and add DL_Li_0.05 in the corresponding Remarks column (Remarks trace element in this example)!

**REMARKS FOR WELL DATA**

**Well ID**: IDs should be specific, unique and uniform in the Fluid Atlas' database. Well ID: first the initial of well (W), then the two-digit country code, then the numbering of the wells in increasing order from 001. Example: W_HU_002
**Country**: name of country
**Local ID for the well**: local ID of well as found in original paper
**Name of the facility:** name of the facility where the well is found
**Power (thermal) (MWth):** If thermal, power produced in MWth
**Latitude (WGS84, decimal degree)**: latitude coordinate in WGS 84, decimal degrees (between -90 and 90)**.** Please use only numeric characters!
**Longitude (WGS84, decimal degree):** longitude coordinate in WGS 84, decimal degrees (between -180 and 180)**.** Please use only numeric characters!
**Date of well completion (year)**: please provide only the year
**Wellhead elevation (m, amsl):** elevation above mean sea level in meters
**Surface elevation (m, amsl)**: elevation above mean sea level in meters
**True vertical well depth (m)**: distance between wellhead and bottom of well (postive number), measured along a vertical line
**Measured well depth (m):** distance between wellhead and bottom of well (postive number), measured along the well
**Top of screened interval (m, below wellhead, true vertical depth)**: If there are more screened sections, please provide the tops of the screened sections as a list by Alt+Enter. The corresponding bottom measurements will be given in the next column. (positive number) Depth given as true vertical depth

**Bottom of screened interval (m, below wellhead, true vertical depth)**: If there are more screened sections, please provide the bottoms of the screened sections in the respective order as a list by Alt+Enter. Depth given as true vertical depth (positive number)
**Top of screened interval (m, below wellhead, measured depth):** the same as above, but with measured depth
**Bottom of screened interval (m, below wellhead, measured depth):** the same as above, but with measured depth
**Hydraulic head (m, amsl):** Height of a vertical column of water at rest referenced to a datum plane. Derived as p/(ρg)
**PZ data (MPa/m)**: Pressure (P) change along a vertical axis (Z), given as the gradient of the pore pressure: how the pressure is changing over a unit depth: (P2-P1)/(Z2-Z1) [MPa/m]. If you have multiply PZ data, please list it with Alt+Enter. Provide the corresponding depth also as a list in the next (PZ data depth) column.
**PZ data depth (m):** Depth of the measured pressure change (PZ). Please provide as a list by Alt+Enter in the respective order.
**Bottomhole temperature (°C):** temperature at the bottom of the well in °C. Please provide the measurement depth in the next column.
**Depth of measured bottomhole temperature (m):** Depth of the measured bottomhole temperature
**Outflow temperature (°C):** Outflow temperature in °C. If there are multiple measurements, please provide them as list by Alt+Enter. If applicable, provide the year of the measurement in the next column in respective order.
**Year of outflow temp. measurement:** Year of the outflow temperature measurement. If there are more measurements, please provide them as list by Alt+Enter in the respective order.
**Well yield (m3/hour)**: Well yield in $m^3/h$. Please provide the year and remarks of measurement in the next columns if applicable, list with Alt+Enter if needed.
**Year of well yield measurement:**
**Remarks of well yield measurement:** e.g. artesian, pumping
**Scaling exists (Y/N)**
**Inhibitor added (Y/N)**
**Geothermal gradient in well (°C/100m):** If data is an interval, please provide average. Please pay attention to the measurement unit.
**References for the data (link/DOI/ISBN/ISSN/national archive identifier):** List by Alt+Enter if multiple
**Remarks:** Please provide remarks here if needed for any column

**REMARKS FOR FLUID SAMPLE DATA**

***FLUID SAMPLE IDENTIFICATION***
**Well ID:** Respective Well ID of the fluid sample, as explained on Well data sheet
**Fluid sample ID :** IDs should be specific, unique and uniform in the Fluid Atlas' database. Fluid sample ID: first the reference to the well ID, then the initials of 'fluid sample' (FS), then the numbering of the fluid samples in increasing order from 001. Example: W_HU_002_FS_018.
**Local ID for fluid sample**: local ID of fluid sample as referenced in literature
**Sampling method (please select):** Choose from Freeflow, Pumping, Pointwise (with bailer), Pumping with packers, Gas-lift test and fluid inclusion method**.**
**Sample depth (m)**: m below wellhead. Interval if packers used. If unknown, leave blank.
**Sample location:** Location of the fluid sample, like Well-head - Separator High-Pressure, Well-head - Separator Low Pressure, Well-head - Weir box, Well-head – TPS, Surface, etc
**Sampling date:** Date of sampling
**Analysis date:** Date of the analysis of the fluid sample

***FLUID SAMPLE PHYSICAL PROPERTIES***

**Dominant phase by mass (please select):** Please choose from: Liquid, Gas, Condensate, Two-phase.

**Temperature (°C):** temperature of the fluid sample in °C.
**Pressure (MPa):** Pressure at the sampling depth (MPa).
**Hydraulic head (m):** At the sampling depth, given in m amsl as h0+p/(ρg). Please note that it is not calculated from the wellhead, but the mean sea level.
**Density (kg/dm3):** please pay attention to the unit (kg/dm$^3$) (numeric, between 0 and 2)
**Kinematic viscosity (m2/s)**
**Dynamic viscosity (kg/m/s)**
**Specific heat capacity (J/K/kg)**
**Electrical conductivity (µS/cm, EC25)**

***FLUID SAMPLE CHEMICAL PROPERTIES***

**pH**: On site measurement. Analyses may be for a different phase to that recorded for the well. Range 0-14
**Dissolved oxigen (mg/L)**: In situ measurement
**Eh (mV)**: Redox potential, in situ measurement
**Total alkalinity (meq/L)**: In situ measurement (0-2500)
**Carbonate alkalinity (meq/L)**: In situ measurement
**TDS (mg/L):** Total Dissolved Solid
**TDG (Nml/kg):** Total dissolved gas in Normal ml/kg H2O
**GLR:** Gas/Liquid Ratio
**Remarks**: Analytical method or any other comments regarding the previous variables in fluid samples

***DISSOLVED MAJOR CATIONS (MG/L)***

**Ca, K, Mg, Na, Si (mg/L)**
**TMC:** Total Major Cations (mg/L). Value must be approximately the sum of the major cations listed above.
**Remarks major cations**: Analytical method for dissolved major cations analysis or any other comments regarding dissolved major cations

***DISSOLVED TRACE ELEMENTS (MG/L):***

**Ag, Al, As, Au, B, Ba, Be, Bi, Br, Co, Cr, Cu, Cs, Fe, Ga, Ge, Hf, Hg, I, In, Li, Mn, Nb, Ni, Pb**
**PGE:** Platinum Group Elements, if you have PGE data, please fill in the „PGE and REE in fluid samples” sheet
**REE:** Rare Earth Elements, if you have REE data, please fill in the „PGE and REE in fluid samples” sheet
**Rb, Sb, Sc, Sr, Ta, Ti, W, Zn**
**Remarks trance elements:** Analytical method for trace element analysis or any other comments regarding trace elements in fluid samples

***DISSOLVED MAJOR ANIONS (MG/L)***

**Cl, S, F, $CO_3$, $HCO_3$, $SO_4$, $PO_4$, $HBO_2$ (mg/L)**
**TMA:** Total Major Anions (mg/L). Value must be approximately the sum of the major anions listed above.
**Remarks major anions:** Analytical method for dissolved major anions analysis or any other comments regarding dissolved major anions

***ORGANICS AND PETR. COMP. (MG/L)***

**TOC:** Total Organic Carbon (mg/L)
**TPH:** Total Petroleum Hydrocarbon (mg/L)
**BTEX:** Benzene, Toluene, Ethylbenzene and Xylene (mg/L)
**Remarks organics and petr. components**: Analytical method or any other comments regarding organics and petroleum components

***DISSOLVED GAS (VOL%):*** Volume % of the total dissolved (gas TDS) as 100%
**$CO_2$, $O_2$, H2S, $N_2$, $CH_4$, Ar, $H_2$, He**
**Remarks dissolved gas:** Analytical method or any other comments regarding dissolved gas

***ISOTOPES (‰)***
**Oxigen-18**
**Deuterium (2H)**
**Tritium (3H):** For Tritium, please give the value in Bq/L (Becquerel/liter), not in ‰
**Oxigen-18 ($SO_4$)**
**Sulfur-34 ($SO_4$)**
**Sulfur-34 (H2S)**
**Carbon-13 ($CO_2$)**
**Lithium-7**
**Boron-11**
**87Sr/86Sr**
**Remarks isotopes:** Analytical method or any other comments regarding isotopes in fluid sample

***REFERENCES FOR THE DATA (LINK/DOI/ISBN/ISSN/NATIONAL ARCHIVE IDENTIFIER; LIST IF MULTIPLE):*** List by Alt+Enter if multiple

***REMARKS:*** Please provide remarks here if needed for any column

**REMARKS FOR ROCK SAMPLE DATA**

*RESERVOIR DATA*
**Well ID:** Respective Well ID, as explained on Well data sheet
**Reservoir type (please select):** Please select from Porous, Karstic, Fractured, Double porosity
**Reservoir pressure (please select):** Please select from Hydrostatic, Subhydrostatic or Overpressured. Subhydrostatic: at least 5 bar less than the hydrostatic; Overpressured: 10 bar higher than the hydrostatic
**Hydraulic conductivity (m/s):** Please provide if there was a pump test. If interval, provide average.

*ROCK SAMPLE IDENTIFICATION*
**Rock sample ID:** first the reference to the well ID, then the initials of 'rock sample' (RS), then the numbering of the rock samples in increasing order from 001. Example: W_HU_002_RS_001
**Local ID for rock sample:** local ID for the rock sample
**Sampling method:** method of taking the rock sample
**Sample depth (m):** m below wellhead. Interval if packers used .
**Sampling date (year):** Year when the rock sample was taken
**Analysis date (year):** Date of the analysis of the rock sample

*ROCK SAMPLE GEOLOGICAL INFORMATION*
**Rock type (please select)**: Please select from the list: Granite; Granodiorite; Tonalite; Syenite; Monzonite; Diorite; Gabbro; Peridotite; Pyroxenite; Hornblendite; Carbonatite; Rhyolite; Trachyte; Dacite; Andesite; Basalt; Alkali basalt; Ultramafic volcanic rock; Rhyolitic volcaniclast; Dacitic volcaniclast; Andesitic volcaniclast; Basaltic volcaniclast; Marble; Quartzite; Slate; Phyllite; Schist; Gneiss; Granulite; Hornfels; Greenschist; Serpentinite; Amphibolite; Eclogite; Migmatite; Pelite; Psammite; Arcose; Psephite; Conglomerate; Breccia; Carbonatic siliciclastic rock; Marl; Dolomite; Micritic limestone; Sparitic limestone; Biolithite; Bioclastic rock; Fresh-water carbonate rock; Sulphate

salt rock; Chloride salt rock; Nitrate salt rock; Borate salt rock; Mixed salt rock; Chert; Phosphorite; Coal; Oil shale; Iron ore; Manganese ore; Aluminia ore; Non-ferrous metal ore
**Age of rock:** Please select from the list: Quaternary; Neogene; Paleogene; Cretaceous; Jurassic; Triassic; Permian; Carboniferous; Devonian; Silurian; Ordovician; Cambrian; Precambrian
**Mineralogical composition**: Please list the main minerals, separated by Alt+Enter.
**Formation name:** Name of the formation where the rock sample was taken from
**Formation code on geological map**: Code of the formation
**Link to geological map**

***MAIN ELEMENTS IN ROCK SAMPLES (WEIGHT PERCENT)***

Weight % of main elements in oxide form in the rock sample. The total dissolved solid (TDS) as 100%. Please indicate the analytical method in the 'Remarks: main elements' column.
**$SiO_2$**
**$Al_2O_3$**
**Fe2O3**
**MgO**
**CaO**
**$Na_2O$**
**$K_2O$**
**$TiO_2$**
**$P_2O_5$**
**MnO**
**Remarks: main elements:** Analytical method for main element analysis or any other comments regarding main elements in rock samples

***TRACE ELEMENTS IN ROCK SAMPLES (PPM)***

Amount of trace elements in the rock sample in PPM. Please indicate the analytical method in the 'Remarks: trace elements' column.
**Ag, As, B, Be, Bi, Cd, Ce, Co, Cr, Cu, Ga, Ge, Hf, Hg, In, Li, Mo, Nb, Ni, Pb, PGE, Rb, REE, S, Sb, Se, Sn, Sr, Ta, Th, Tl, U, V, W, Zn, Zr**
**Remarks: trace elements:** Analytical method for trace element analysis or any other comments regarding trace elements in rock samples

***ROCK SAMPLE PHYSICAL PROPERTIES***

**Permeability (Darcy):** Permeability of rock in Darcy
**Porosity:** Ratio of the volume of voids to the total soil volume in percent.
**Heat capacity (J/K/kg)**
**Thermal conductivity (W/m/K)**
**References for the data (link/DOI/ISBN/ISSN/national archive identifier; list if multiple)**
**Remarks**