Where are we now?

As our project coordinators Simona Regenspurg and Katrin Kieling from the German Research Centre for Geosciences (GFZ) write:

"We have just reached the project's halfway point and thus successfully completed our first review meeting with the European Commission. At this stage of a project, a significant amount of data is typically generated, and the first highlights appear:

*For the **CRM-geothermal Fluid Atlas**, the database has been established based on the European Geothermal Fluid Atlas, formerly established by the REFLECT project, and extended to include critical raw materials (CRMs). As a living document, we continue to increase the dataset throughout the project's lifespan and beyond. A special highlight is the application of machine learning algorithms (e.g., "decision tree model") to uncover patterns by discerning relationships between CRMs and chemical elements coexisting in fluid samples.*

***Sampling campaigns** for different CRMs in brine, rock, scales, and gasses in various geothermal-geological focus areas were conducted in Turkey (Tuzla and Seferhisar), Cornwall (UK), and Africa (Tanzania, Malawi). We anticipate more field trips to Rwanda, Kenya, and Iceland this year. Initial results indicate that the CRM content in fluids does not necessarily reflect the CRM content in the corresponding host rock. So far, our project focuses on lithium, strontium, copper, rare earth elements, and helium. However, tungsten and platinum group elements also occasionally appear enriched.*

*Various **extraction technologies** have been tested for different methods and elements. Some methods already have a high Technology Readiness Level (TRL), such as gas-diffusion electro-crystallization (GDEx), which allows already for the selective extraction of lithium from geothermal brines with over 95% efficiency (by VITO). Other technologies are facing stronger obstacles as especially the high salinity makes it very difficult to selectively extract CRMs. For helium extraction via membrane technologies, a milestone was reached with the selection of tubing with the highest potential for robust and cost-efficient extraction.*

*The development of the miniplant for the **demonstration site** in Cornwall is set to start soon. Hydraulic testing at the Cornwall site, a prerequisite for using this site for co-production, has already taken place, demonstrating the granitic formation to be a good choice due to its high productivity and lithium content.*

Furthermore, we have completed a total of 1 Bachelor's thesis and 4 Master's theses within the framework of CRM-geothermal, with 2 more Master's theses ongoing, as well as 5 ongoing PhD works.

Thanks for your interest in our project!"

Milestone reached for helium extraction from geothermal fluids

by crm | Feb 12, 2024 | News | 0 comments

Researchers from the German GeoForschungsZentrum (GFZ) in Potsdam have reached a project milestone concerning the efficient extraction of helium from geothermal fluids through membrane-based gas-water separation technology.

Generally, natural gas with a helium concentration of more than 0.3 Vol% presents an economically viable resource, if helium extraction can be integrated into existing processes, instead of disrupting them (Halford et al., 2022; Hamedi et al., 2019). The implementation of robust and durable tubular membrane material in existing geothermal production streams is therefore envisaged as an economically viable solution for the gas extraction and Helium production from geothermal brines during production cycles.

A laboratory test rig was developed to evaluate membrane performance across various media. In first tests, two types of tubular polymers, polydimethylsiloxane (PDMS) and polytetrafluoroethylene (PTFE), were identified as the most reliable and cost-effective solutions.

In lab settings, batch-type experiments demonstrated the efficiency of PDMS and PTFE membranes in separating helium from artificial nitrogen-dominated gaseous feed compositions. A gas mass spectrometer was used for continuous gas analysis and forms the basis for further experiments.

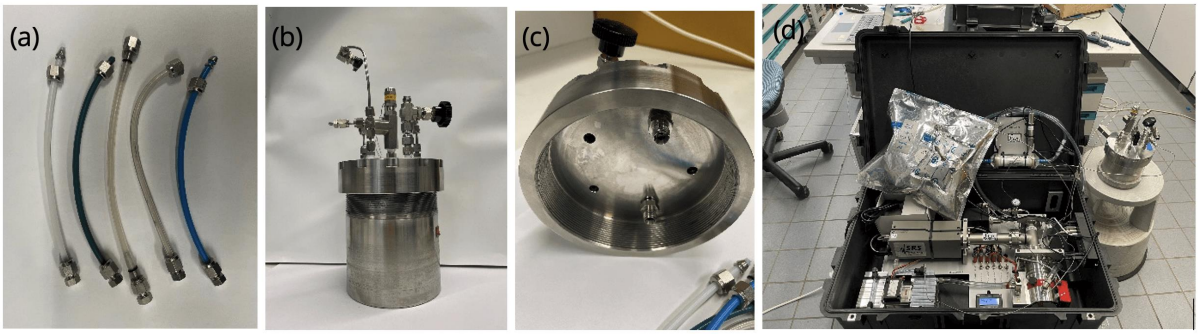


Fig. 1: (a) Various tubular membrane materials were prepared with supportive filler material and standardized end fittings for batch-type tests in (b) the autoclave. (c) Two membrane tubes were connected to the lid for parallel assessments. (d) The autoclave was flushed with helium-enriched feed gas, the composition of the feed gas, and the permeate was continuously monitored with the gas mass spectrometer to evaluate the membrane performance.

During a pump test of geothermal water, conducted at the Cornish Lithium Site in Cornwall, UK, the suitability of PDMS and PTFE for gas separation from production brine under ambient field conditions could be confirmed. Notably, PTFE exhibits rapid responsiveness to changes in gas composition and concentration.

Next, the long-time performance in saline and high temperature liquid environments will be evaluated. The focus will be on the two above-mentioned polymer types.

The results of the first field test are currently being prepared for publication. Stay tuned for more information!

Field trip to Malawi – the “warm heart of Africa”

by crm | Feb 5, 2024 | News

End of September 2023, the four scientists Franziska Wilke, Bettina Strauch, Martin Zimmer, and Simona Regenspurg from the German GeoForschungsZentrum (GFZ), embarked on a sampling field trip in Malawi to collect gas, water, and rock samples within the project’s Work Package 2, which investigates critical raw materials (CRM) in the alkaline geothermal systems of the East African Rift valley.

Dr. Kondwani Gondwe, a geologist from Mzuzu University and local expert on the geothermal situation in Malawi, guided the expedition. Interestingly, despite the relatively high geothermal potential, no geothermal wells have been drilled so far. Hot springs are only utilised as local washing places.

The sampling campaign progressed with approximately 20 sampling sites from the Karonga area in the north of Malawi, along Lake Malawi, down to the southern part of Malawi, near Blantyre. The group collected water for rare earth element analyses and gases to determine the

helium content. Additionally, rock samples were taken to gain insight into the source of potential critical raw materials carried by the upwelling geothermal fluids.

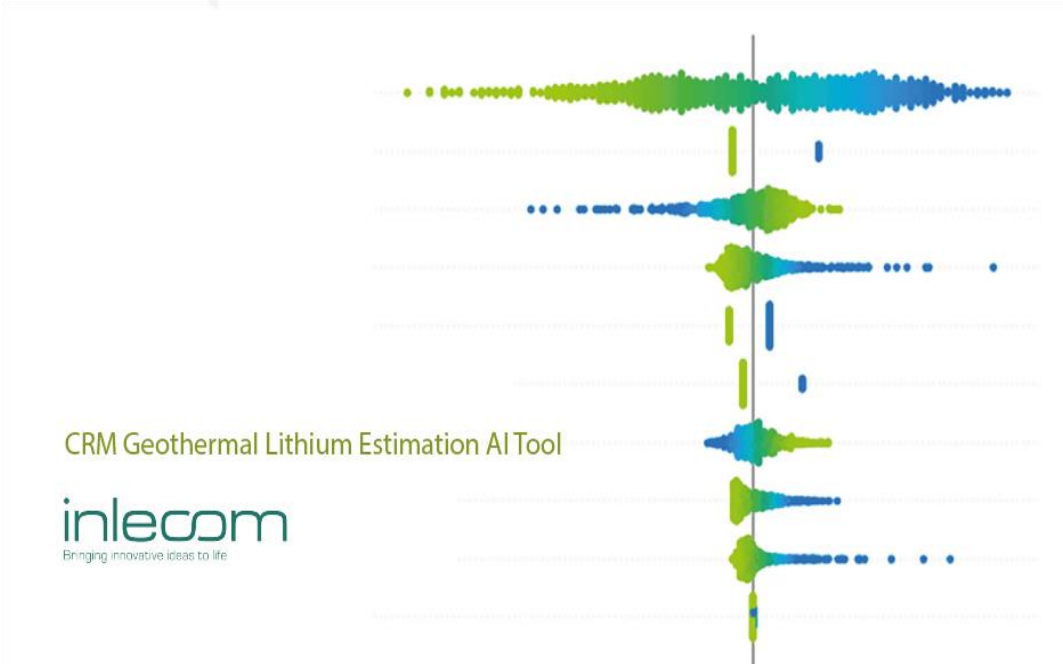
In addition to the adventurous and successful sampling mission, the CRM-geothermal scientists were invited by the vice chancellor of Mzuzu University to present their project work. In Lilongwe, the CRM-geothermal project was introduced to local mining and energy authorities, and options for further collaborations were discussed.

Thanks to the help and support from locals who eagerly showed us the stony or non-existing pathways to the often hidden sampling spots, the mission was very successful.

More information and pictures in the following link: https://crm-geothermal.eu/2024/02/05/field-trip-to-malawi-the-warm-heart-of-africa/

Exploring the CRM potential of geothermal fluids with our AI Tool

by crm | Mar 21, 2024 | News | 0 comments



Understanding the intricate processes governing Lithium occurence within geothermal fluids is akin to decoding the Earth's geological narrative. Lithium, a highly sought-after element, exhibits diverse behaviours influenced by geological and hydrochemical conditions within reservoirs. By discerning correlations and interdependencies among major cations, anions, and fluid characteristics, project partner INLECOM INNOVATION aims to unravel the complex web of factors controlling Lithium concentrations. These insights not only optimise geothermal resource exploration but also contribute to a deeper understanding of Lithium's broader geological context, crucial given its pivotal role in energy storage technologies.

INLECOM INNOVATION's task represents a pioneering effort to uncover the intricate relationships between elemental features and Lithium concentrations through the application of advanced Machine Learning methodologies. At the heart of this endeavour lies the development of the CRM AI Tool—a sophisticated platform designed to provide accurate estimations of Lithium concentrations while ensuring interpretability in geothermal data analysis.

INLECOM INNOVATION's journey commenced with the refinement of the **REFLECT** Dataset into the upgraded CRM-AI Database, laying a robust foundation for subsequent analyses enabling the identification of relationships between key elements such as Magnesium, Potassium, Calcium, Sodium, Chlorine, temperature, electrical conductivity and Lithium extracted from well samples. Through meticulous data pre-processing and the application of cutting-edge Machine Learning models such as Tree-Based regression, INLECOM INNOVATION enhanced data reliability and accuracy in Lithium concentration estimations.

How does the CRM AI Tool work?

The CRM AI Tool represents a fusion of geological insights and Machine Learning expertise, offering a multifaceted approach to Lithium concentration estimation in geothermal waters. Here's a glimpse into its workings:

1. **Data Input:**Users can input elemental concentrations from geothermal fluid samples into the CRM AI Tool's interface.
2. **Machine Learning Algorithms:**Leveraging sophisticated Machine Learning algorithms, such as Decision Trees, the tool analyses the input data to estimate Lithium concentrations accurately.
3. **Real-time Exploration:**With backward navigation through Decision Tree nodes, users can explore the AI model decision process
4. **Explainable AI (XAI):**The tool incorporates Explainable AI techniques, including Shapley values, to provide transparency into the decision-making process of Lithium concentration estimation. Users can understand the impact of individual features on Lithium estimations, enhancing interpretability.
5. **Visualisations:**The tool generates visualisations such as scatterplot maps, showcasing geographical variations in Lithium concentrations. These visual aids offer users a deeper understanding of spatial patterns and correlations.
6. **Sensitivity Analysis:**Additionally, the CRM AI Tool offers Sensitivity Analysis, empowering users with sliders to adjust the ranges of every input element, electrical conductivity, and outflow temperature. This feature allows users to explore how variations in these parameters affect Lithium concentration estimations, providing valuable insights into the sensitivity of the model.

In conclusion, INLECOM INNOVATION's CRM AI Tool stands as a testament to the power of collaboration between geoscientists and data scientists, paving the way for enhanced exploration and utilisation of geothermal resources.

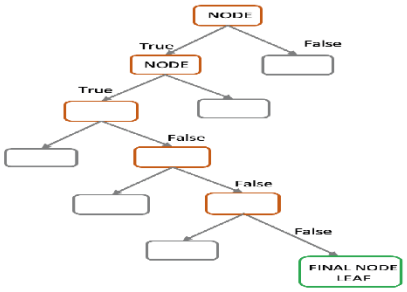
For more information, check out the infographic

inlecom

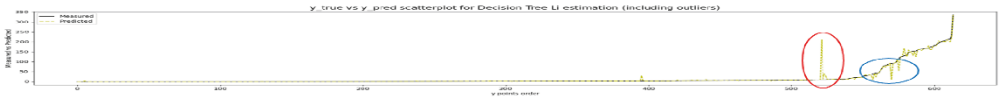
CRM AI Machine Learning Model

Decision Tree

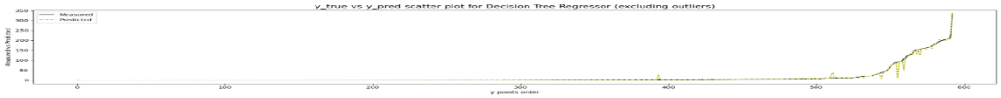
- Each tree is trained on the training subset of the data and features
- Tree represents a set of rules that help make predictions based on the input variables
- Nodes are the decision points within a tree. They split the data based on specific criteria
- Leaves, also known as terminal nodes, are the endpoints of a tree. They contain the final predictions or outcomes.
- The final prediction is the mean value of samples in the leaf



The Measured Lithium vs Predicted Lithium plot below illustrates the final model's performance. This representation provides a clear visualisation of the model's predictive accuracy



Bespoke methodology tailored for outlier detection, to discern between genuine outliers and instances of inherent variance in Lithium concentrations within specific wells.



Decision Tree estimation model evaluation metrics:

- Mean Arctangent Absolute Percentage Error (MAAPE): 0.1504
- Root Mean Squared Error (RMSE): 9.7353

CRM AI Tool

Lithium Estimation Mechanism & Visualisations of a single sample: Demonstration example based on an existing fluid sample

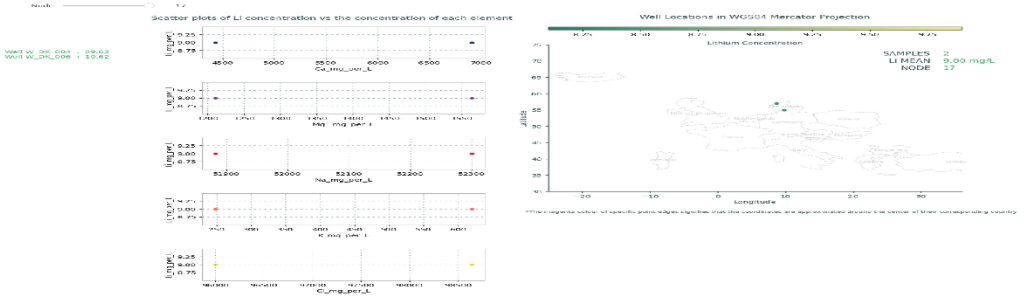
An example is presented from a sample taken in Denmark with Well ID W_DK_004, which is part of the test dataset. In this test sample, the model's estimated Lithium concentration is 9 mg/L, while the ground truth value is recorded as 12 mg/L

Sample to check:

	fw_ID	Ca_mg_per_L	Mg_mg_per_L	Na_mg_per_L	K_mg_per_L	Cl_mg_per_L	Li_mg_per_L
137	W_DK_004	4410.0	1220.0	52200.0	670.0	96000.0	12.0

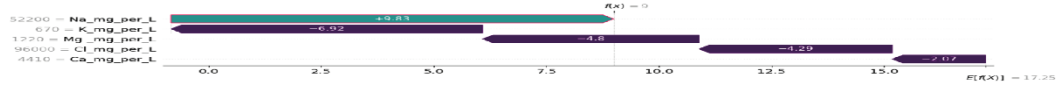
Estimated Li concentration (in mg/l): 9.0

The algorithm reached a decision after traversing 17 nodes, concluding at the final leaf that encompasses two fluid samples (both with Lithium 9mg/L) taken from distinct wells in Denmark that exhibit a mean Lithium concentration including training, test subsets- of 9.62 and 10.62 mg/L respectively.



Explainable AI

Upon examining the Waterfall Shapley plot below, E[f(X)] = 17.25mg/L is the average predicted Lithium across 615 samples in the test dataset and f(x)=9mg/L is the predicted Lithium for this specific sample. The Shapley values are all the values in between. They tell us how each feature has contributed to the prediction when compared to the average prediction. On the y-axis we have the feature values. The Sodium value of 52,200 mg/L appears to have the highest impact on the specific sample, and it has increased the predicted Lithium value by 9.83mg/L compared to the average predicted Lithium. Conversely, Potassium, Magnesium, Chlorine, and Calcium have decreased the prediction by 6.92, 4.8, 4.29 and 2.07 mg/L respectively. This resulted in a final predicted Lithium of 9 mg/L.



Meet our researchers!

We asked the CRM-geothermal researchers to talk about their work on the project.

Learn more via our YouTube playlist and discover the faces behind CRM-geothermal!

See videos on https://www.youtube.com/watch?v=2lQR-7ey7UY&list=PL6Yl2PYNfyXrLrZ2HJqNCUa-nFf1bJGJm

Open call for stakeholders

Our Stakeholder Board comprises experts in geothermal energy and critical raw materials and we currently have an open call to further enlarge the group as we start to implement the first engagement activities. Stakeholders are involved on a voluntary basis and your commitment entirely depends on your availability, but will not exceed 2 hours per month.

As a member, you will:

- Obtain first-hand insights into the research we are performing
- Contribute to the development of the CRM-geothermal technology by providing insights and expectations to bridge it to the market. This contribution will be given through participation in foresight exercises (i.e., Focus Groups and Scenarios)
- Obtain official acknowledgement of your support to the project implementation

Are you interested in this exciting opportunity?

Then reach out via info@crm-geothermal.eu with your CV or a link to your LinkedIn profile and a short statement expressing your interest in our project.

Contact us!

Where to meet us?

European Geothermal PhD Days

The 15th edition of the European Geothermal PhD Days (EGPD) will take place at TU Delft frm 3 to 5 April 2024. Our colleagues from the Izmir Institute of Technology will present CRM-geothermal at this occasion.

Learn more

Where to meet us: https://www.egpd2024.com/

EGU 2024

From 14 to 19 April, the EGU General Assembly 2024 brings together geoscientists from all over the world to one meeting covering all disciplines of the Earth, planetary, and space sciences. Project coordinator Simona Regenspurg will represent CRM-geothermal.

Learn more

Where to meet us: https://www.egu24.eu/

245th ECS Meeting

The 245th Meeting of the Electrochemical Society (ECS) will take place in San Francisco, USA, from 26 to 30 May 2024. Our colleagues from the University of Padua will present their work on Lithium Recovery from Geologic Brines by Advanced Cation-Exchange Ionomers.

Learn more

Where to meet us: https://www.electrochem.org/245

Latest project deliverables

- Seres, A., Éva, H., Tompa, T., & Szabó, M. (2023). 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. https://doi.org/10.5281/zenodo.10057307

- Christopher Rochelle, Michael Bau, Alper Baba, Simona Regenspurg, Andri Stefánsson, Tolga Ayzit, Serhat Tonkul, Hazel Farndale, Amy Peach-Gibson, Alistair Salisbury, Richard Shaw, & Chris Yeomans. (2022). The Horizon Europe CRM-geothermal project: Deliverable 2.1 - Report identifying pre-existing sources of data at the selected sites (Version 1). Zenodo. https://doi.org/10.5281/zenodo.7495744