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GEOTHERMAL 2025

aiION: A Machine Learning Approach to Geothermal Exploration

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ROBERT GORDON UNIVERSITY ABERDEEN

Geothermal Overview

1

Renewable Source

Geothermal energy is derived from Earth's heat, providing stable, sustainable power.

2

Global Growth

Geothermal energy could meet 15% of global electricity demand by 2050, with a potential global capacity of 800 gigawatts - equivalent to the current electricity demand of the US and India combined (IEA 2025).

3

Key Countries

Significant in USA, Indonesia, Philippines, Türkiye, and New Zealand.

Exploration Challenges

1 Financial Risks

High costs during predevelopment stages, including surface surveys and exploratory drilling.

2 Hidden Resources

Difficulty in identifying blind geothermal resources without surface manifestations.

3 Expert Reliance

Traditional methods heavily depend on expert knowledge, leading to uncertainties.

Geochemical Analysis

Cost-Effective

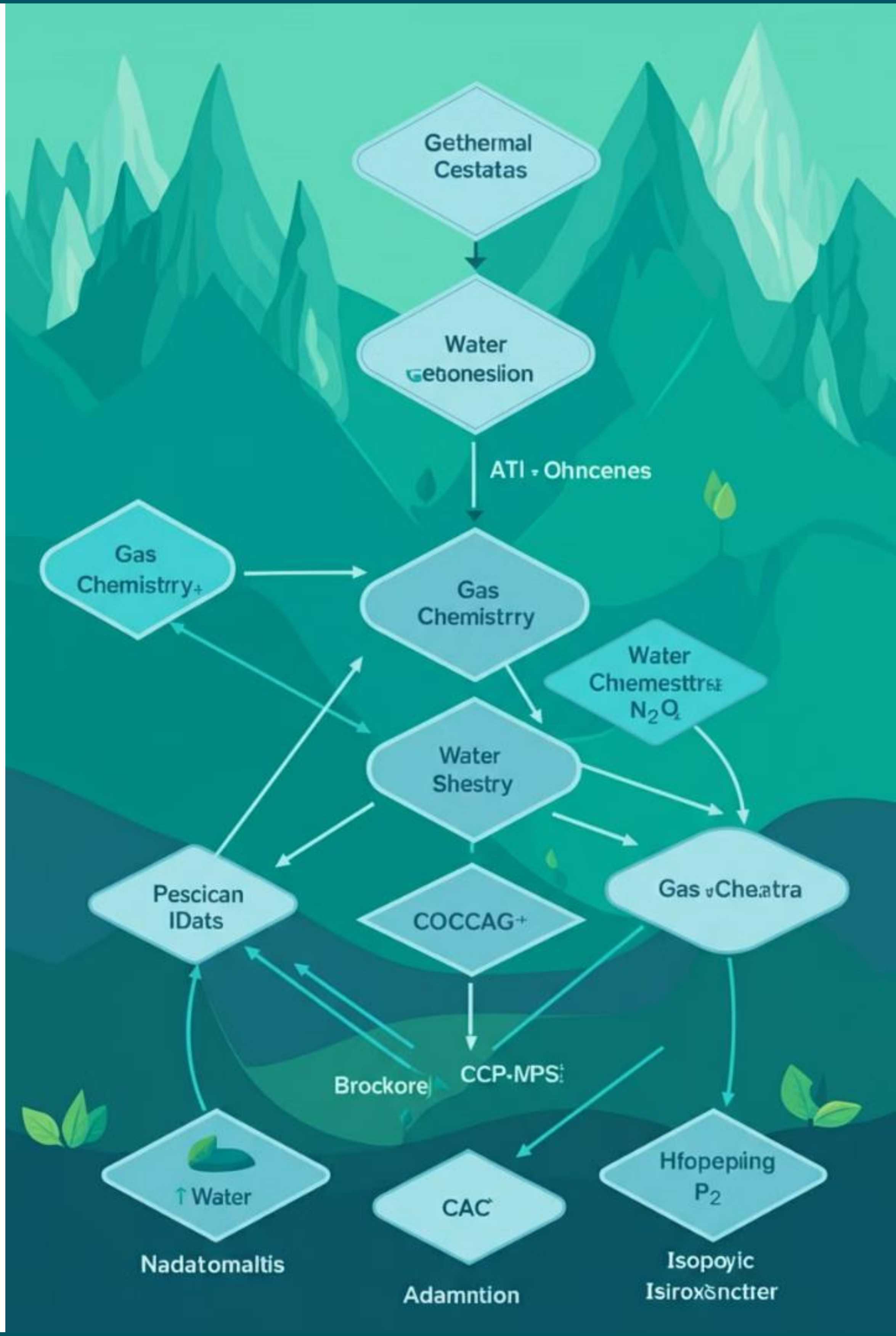
Geochemical data from groundwater samples are crucial in early exploration stages.

Insightful

Provides valuable information on subsurface characteristics and reservoir properties.

Analytical

Helps determine reservoir temperature, heat flow, and boundary conditions.



Geochemical Applications

1

Water Types

Aqueous species, major cations/anions, isotopes, and trace elements.

2

Geothermometers

Estimate subsurface reservoir temperatures based on chemical composition.

3

Reservoir Insights

Identify geothermal characteristics and potential for energy extraction.

Geothermometry

1

Classical Geothermometers

function based on temperature-dependent mineral-fluid equilibrium reactions, primarily utilizing silica concentrations and cation ratios (Na-K, Na-K-Ca, K-Mg) in geothermal waters.

2

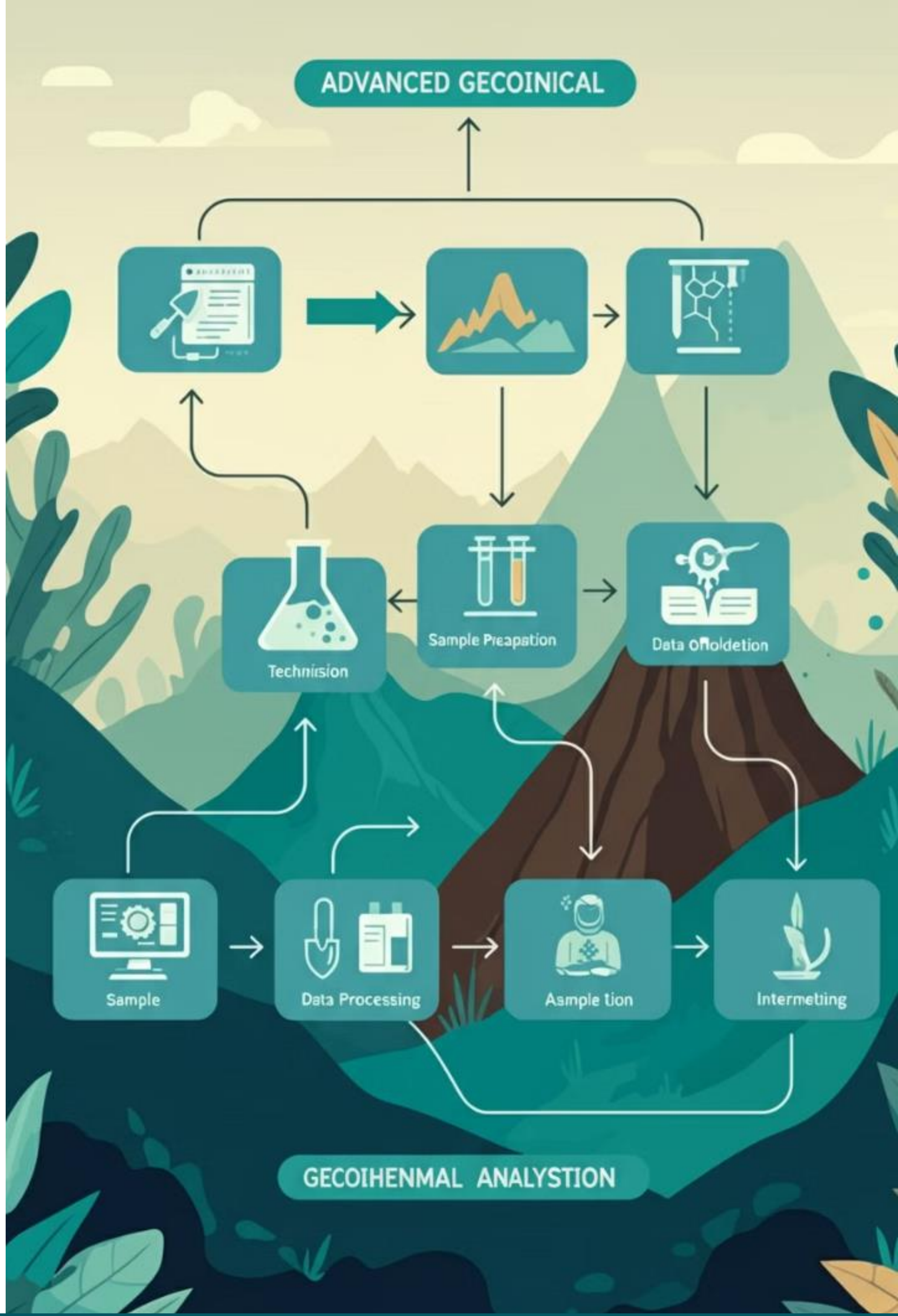
Multicomponent Geothermometry

analyzes the equilibrium between multiple minerals, focusing on the convergence of mineral saturation indices at the true reservoir temperature.

3

Data-Driven Geothermometers

a modern approach that utilizes machine learning and statistical methods to establish correlations between fluid chemistry and reservoir temperatures.



Methodology

1. ## Comprehensive Dataset

   Utilizing water samples from diverse geothermal regions in Nevada

2. ## Advanced Methodology

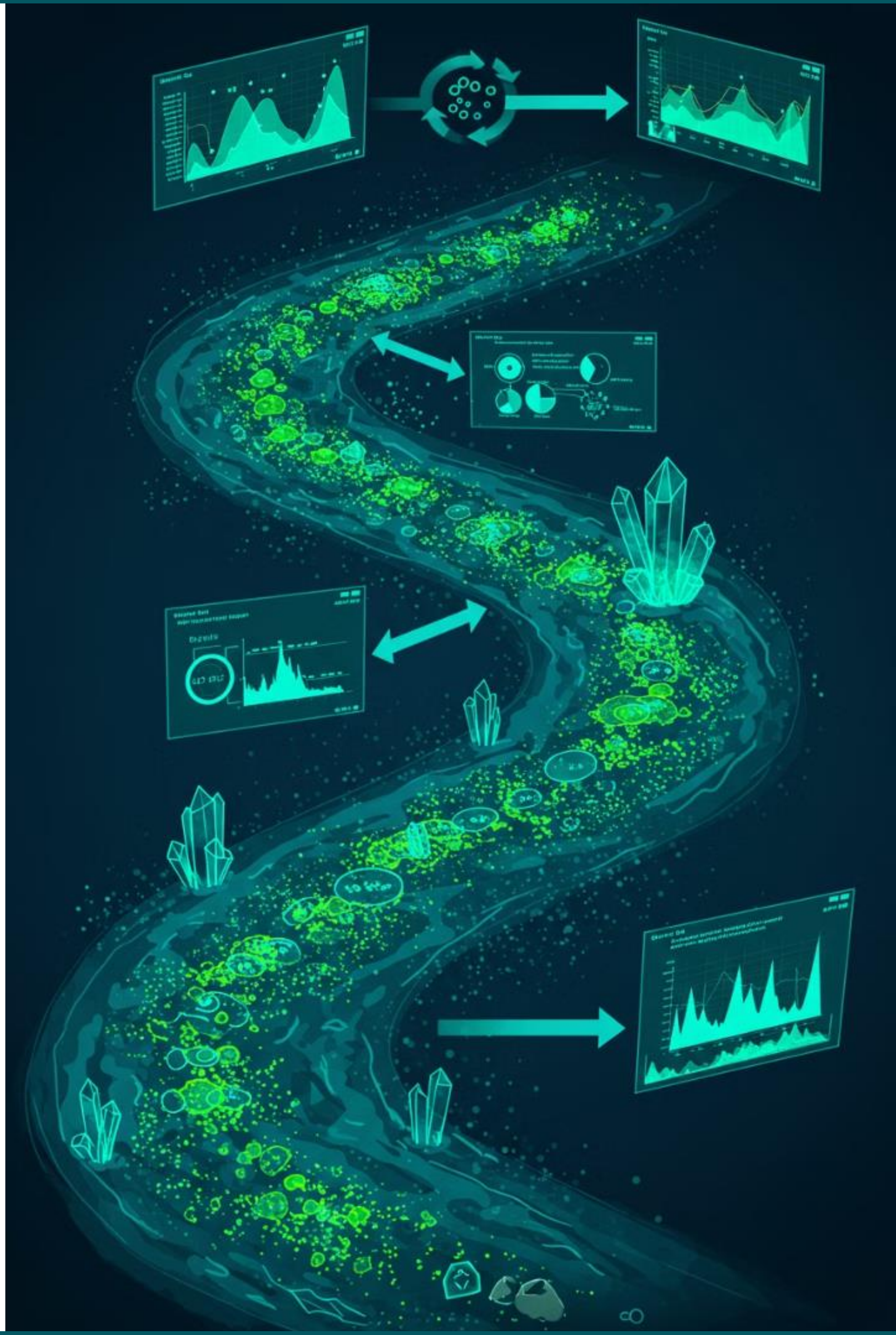
   Integrating classical geothermometers, multi-component geothermometry, and machine learning

3. ## Improved Accuracy

   Demonstrating excellent performance, explaining variance in training and test data

4. ## Global Applicability

   Evaluation on new well samples from different geothermal fields worldwide



Exploratory Data Analysis

1

Extensive Dataset

Analysis of over 14,400 geochemical samples from the Great Basin Groundwater Geochemical Database. This vast collection of information forms the backbone of the platform's predictive capabilities.

2

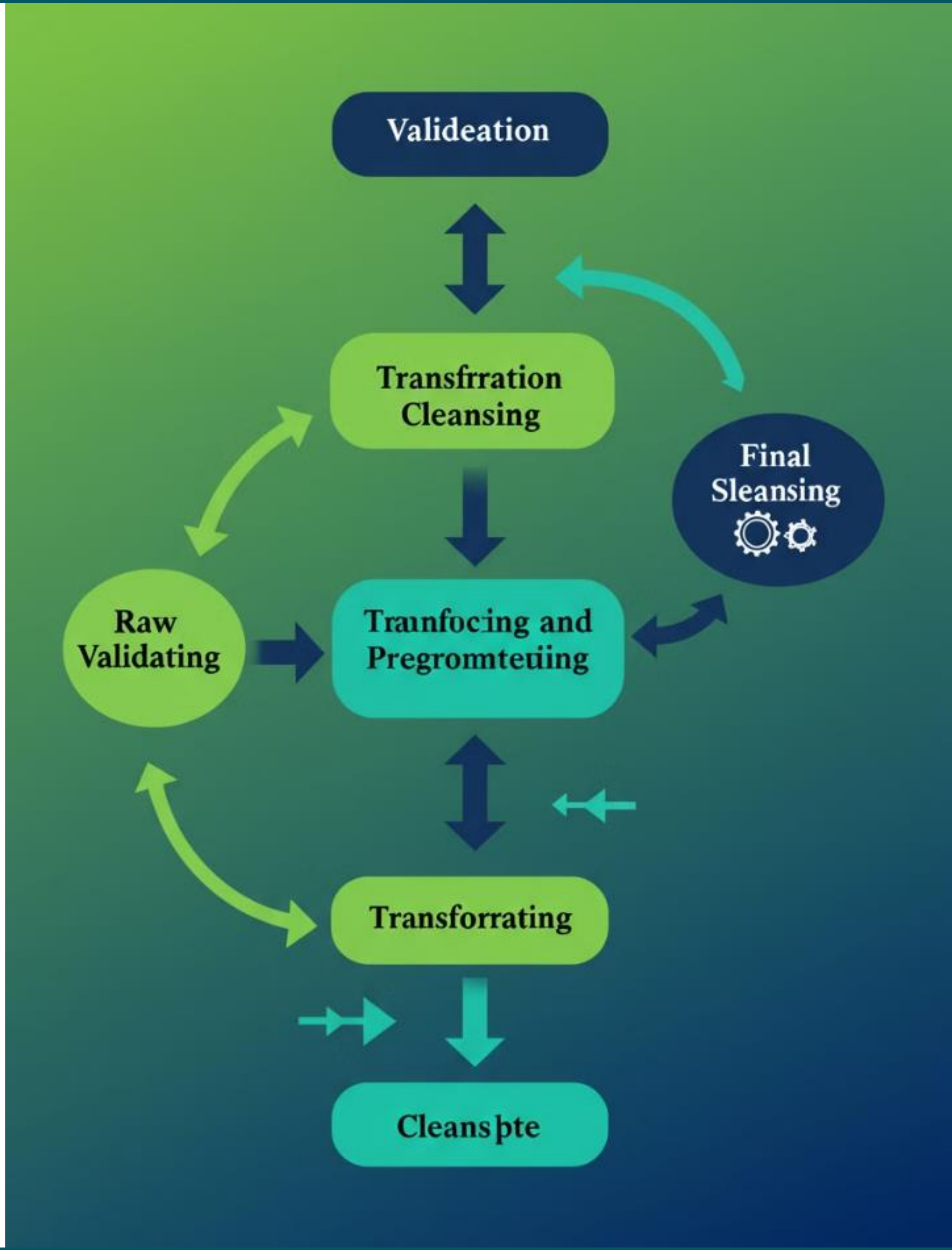
Data Integrity

To ensure data quality, the model performs a charge balance error calculation, rejecting samples outside the acceptable range of ±5%. This rigorous approach guarantees the reliability of the input data.

3

Feature Selection

Through exploratory data analysis, eight key features were identified as strong influencers of temperature: **potassium**, **sodium**, **magnesium**, **calcium**, **chloride**, **fluorine**, **silica**, and **pH**. These elements form the core of aiION's predictive model.



Data Processing

Data Transformation

Employing various data transformation methods, including z-score, logarithmic transformation, and quantile normalization. These techniques optimize model performance and ensure accurate predictions.

Clustering Analysis

The software utilized clustering techniques such as K-means and Hierarchical Clustering to identify patterns within the dataset. This approach helps in understanding the underlying structure of the geochemical data.

ML Model Development

Several machine learning algorithms were evaluated to determine each algorithm's predictive ability and to determine the best model.

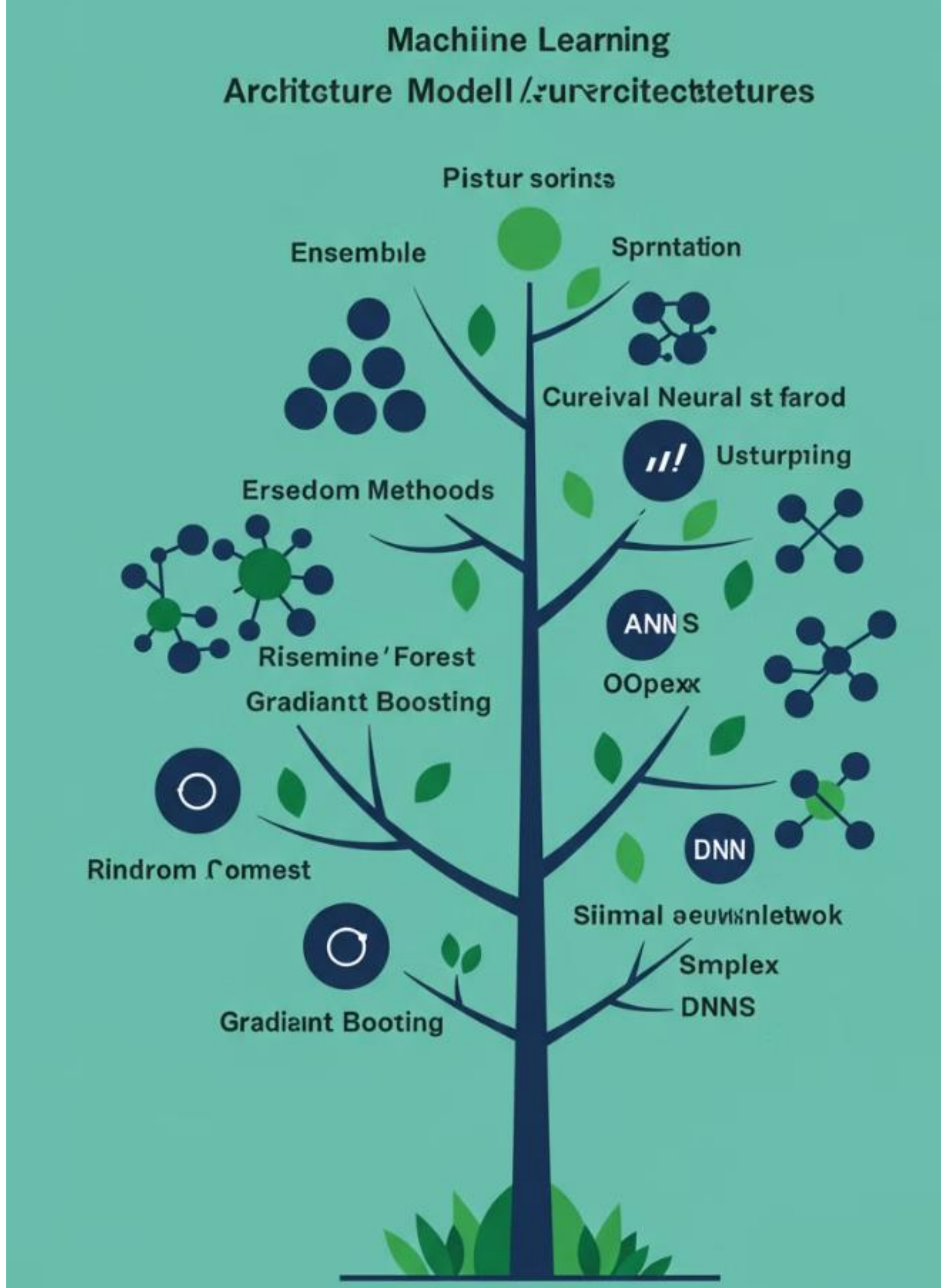
Evaluated ML Models

1 **Random Forest (RF)**
Ensemble learning method using multiple decision trees

2 **Gradient Boosting (XGB)**
Builds new trees sequentially to reduce bias from previous trees

3 **Artificial Neural Network (ANN)**
Simple backpropagation neural network with four layers

4 **Deep Neural Network (DNN)**
More complex architecture with three hidden layers and advanced techniques



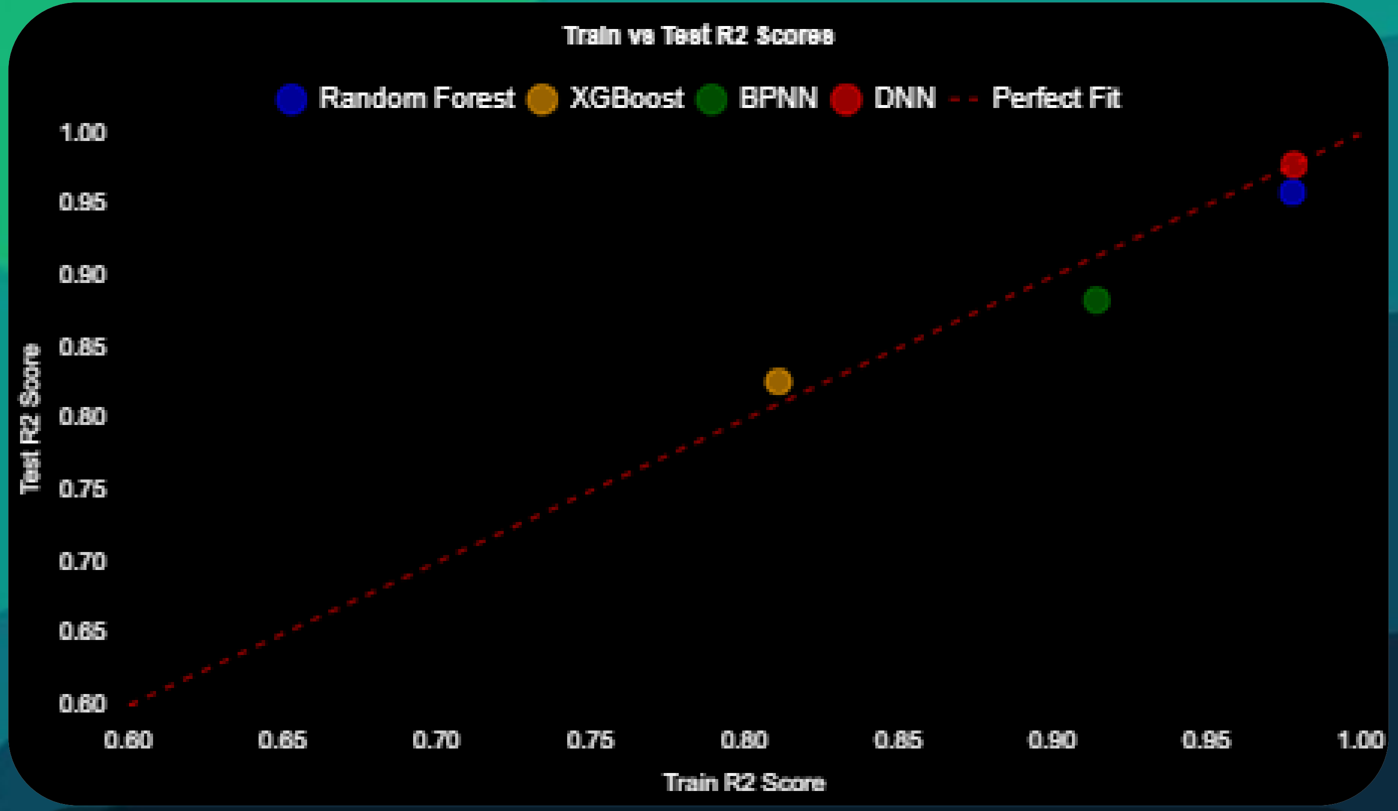
DNN Model Performance Metrics

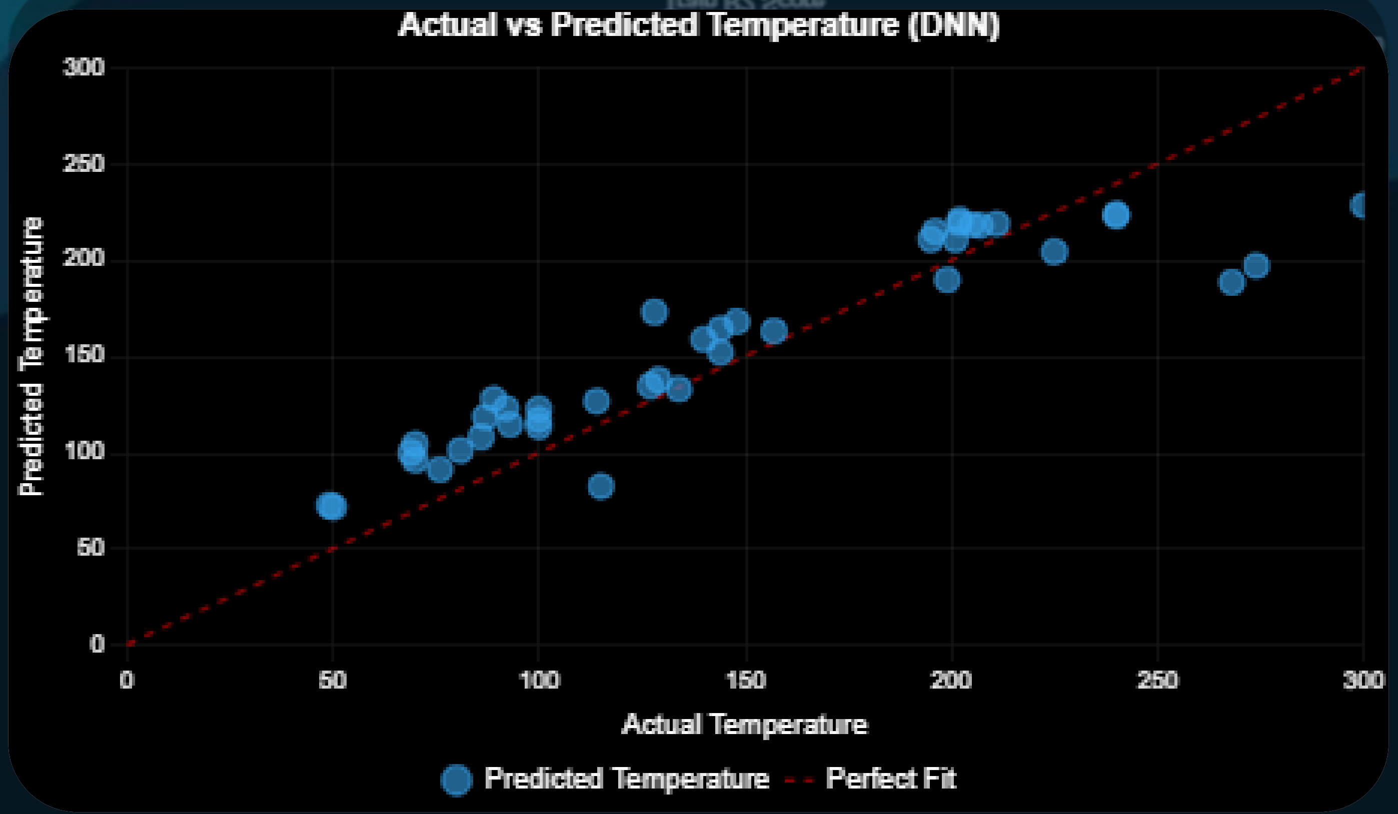
0.9784
DNN R^2 (Train)
Coefficient of determination for training data

0.9783
DNN R^2 (Test)
Coefficient of determination for test data

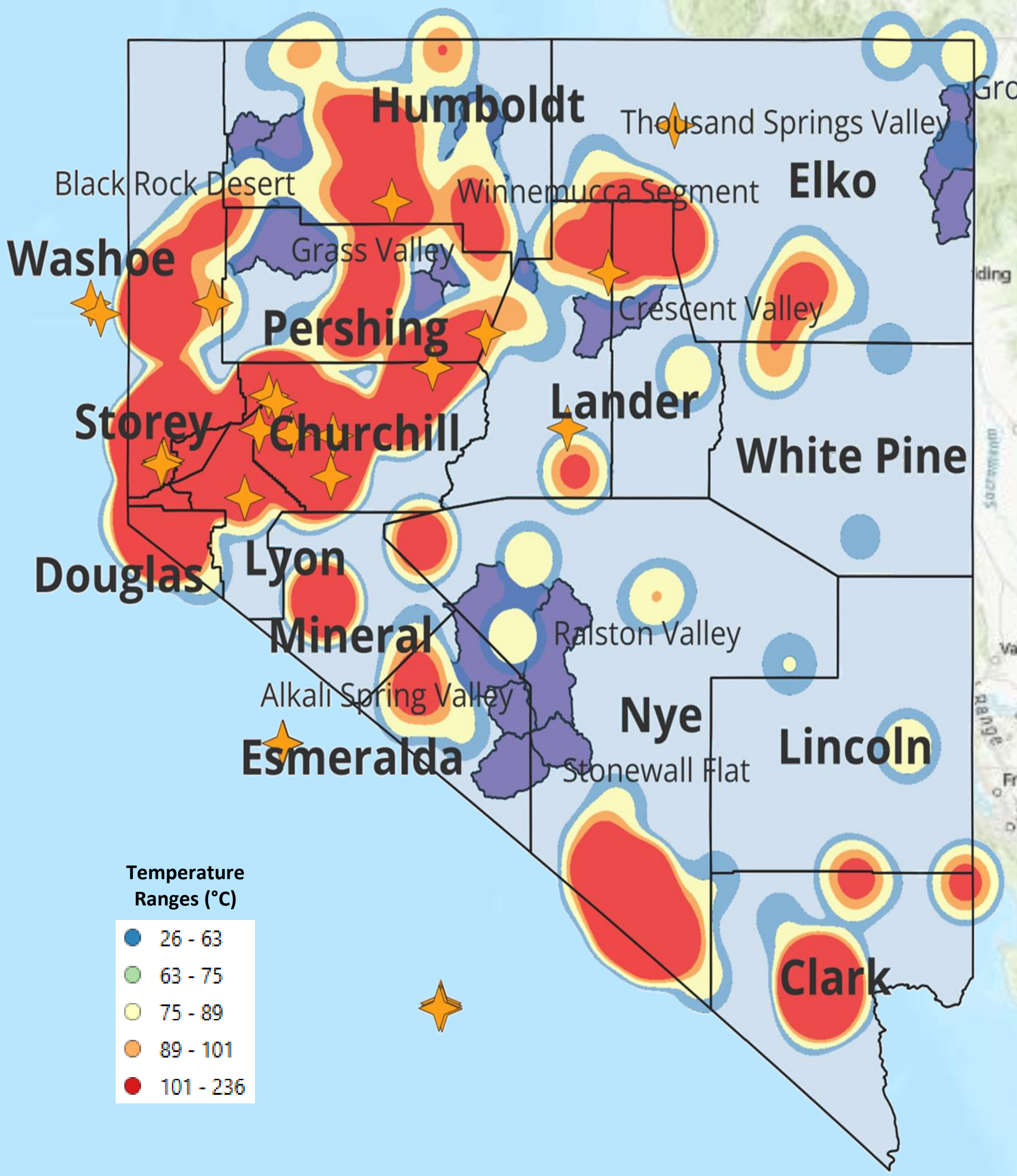
4.0097
DNN RMSE
Root Mean Square Error for test data

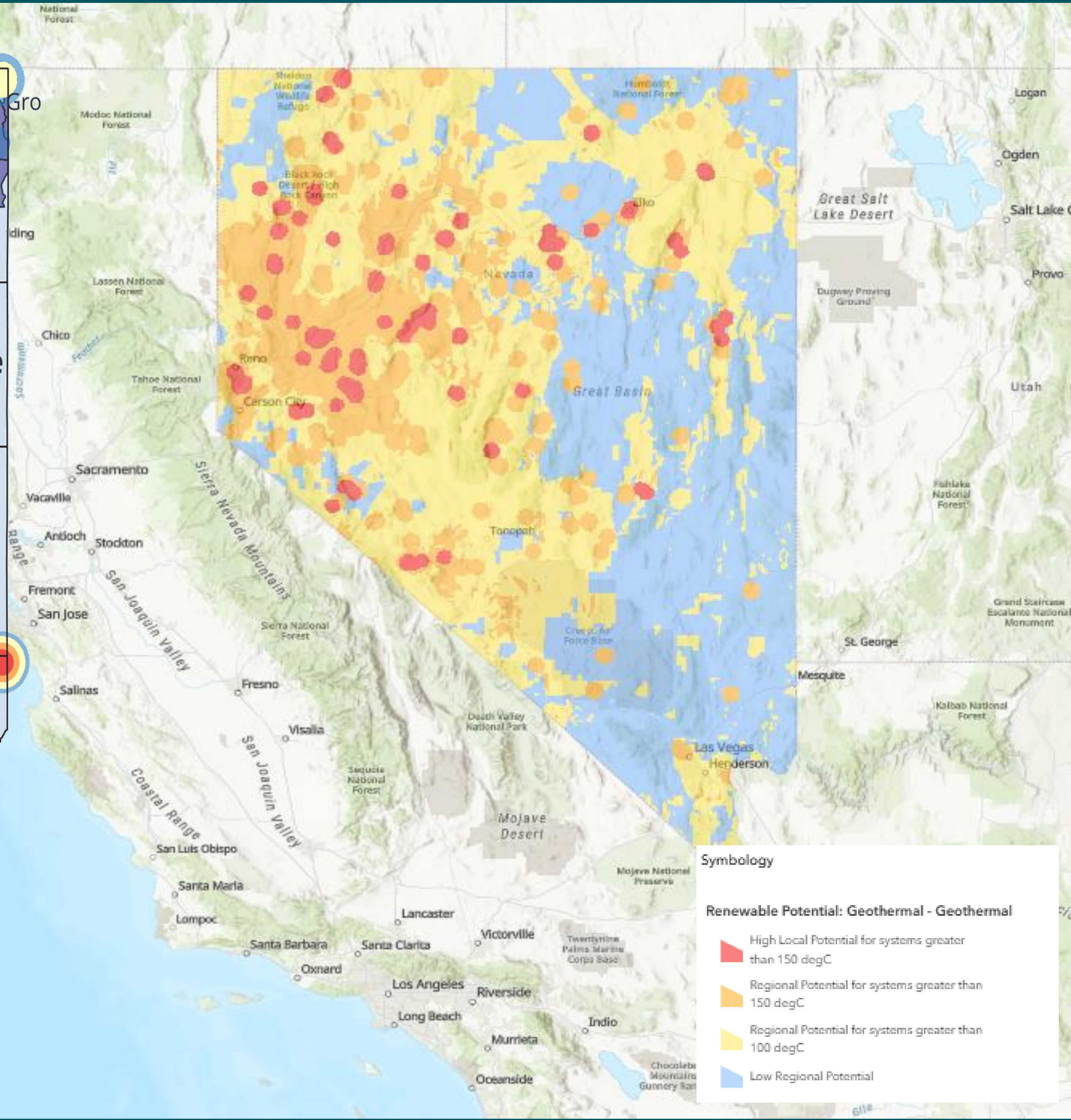
2.6363
DNN MAE
Mean Absolute Error for test data

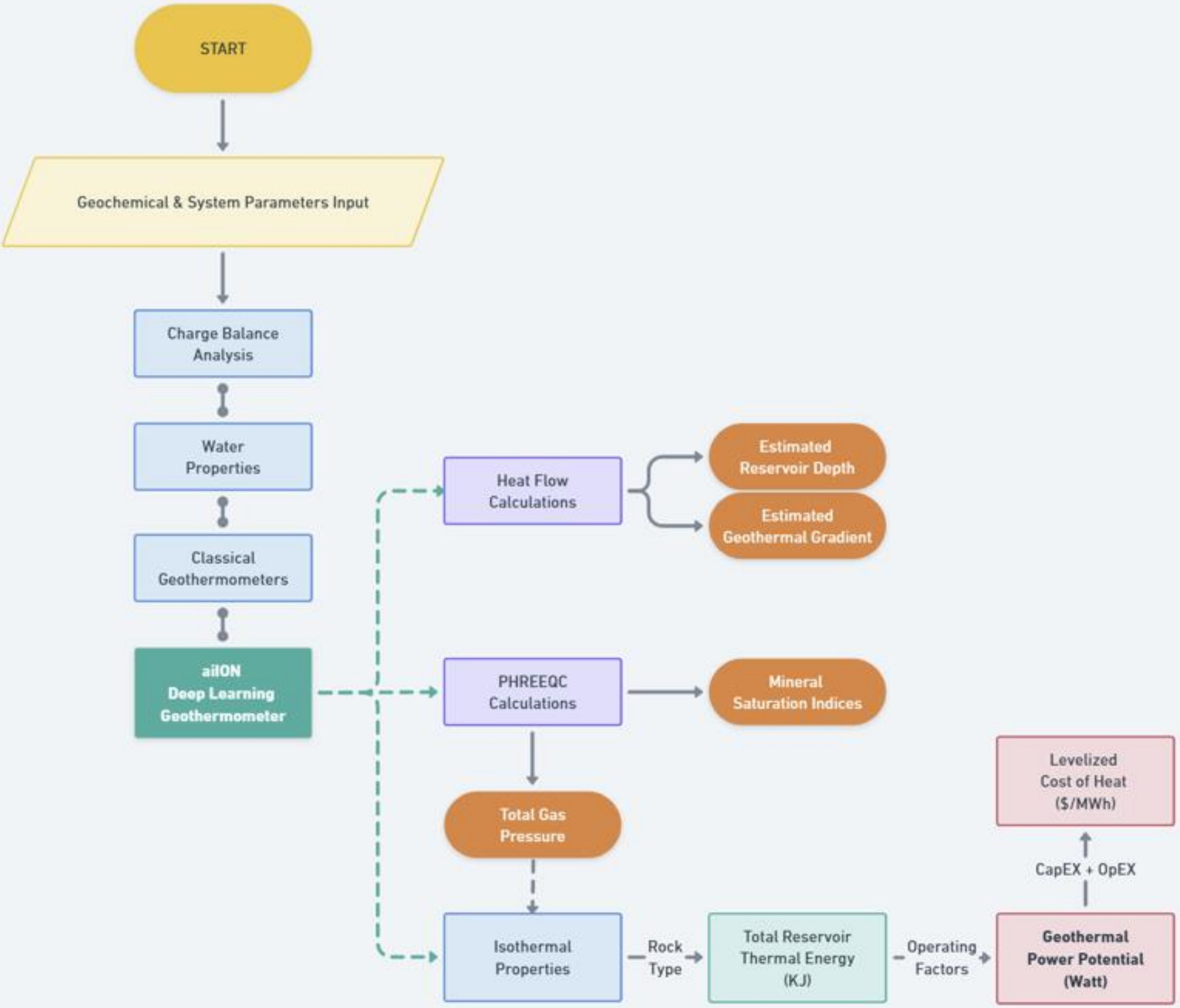




Nevada Geothermal Potential Map







START
Geochemical & System Parameters Input
Charge Balance Analysis
Water Properties
Classical Geothermometers
aiION Deep Learning Geothermometer
Heat Flow Calculations
Estimated Reservoir Depth
Estimated Geothermal Gradient
PHREEQC Calculations
Mineral Saturation Indices
Total Gas Pressure
Isothermal Properties
Rock Type
Total Reservoir Thermal Energy (KJ)
Operating Factors
Geothermal Power Potential (Watt)
CapEX + OpEX
Levelized Cost of Heat ($/MWh)

AI Solutions Addeass Geothemal Explurtion
Challengss
Heat transper
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Geothermal Modlelting
Gestoution.s
Predleneratlive
Heat Analysis
Oraganic

Water Properties Module

Classification

Categorize water based on its properties, including class, type, and description. This classification helps in understanding the nature and origin of the geothermal fluid.

Chemical Equilibrium State

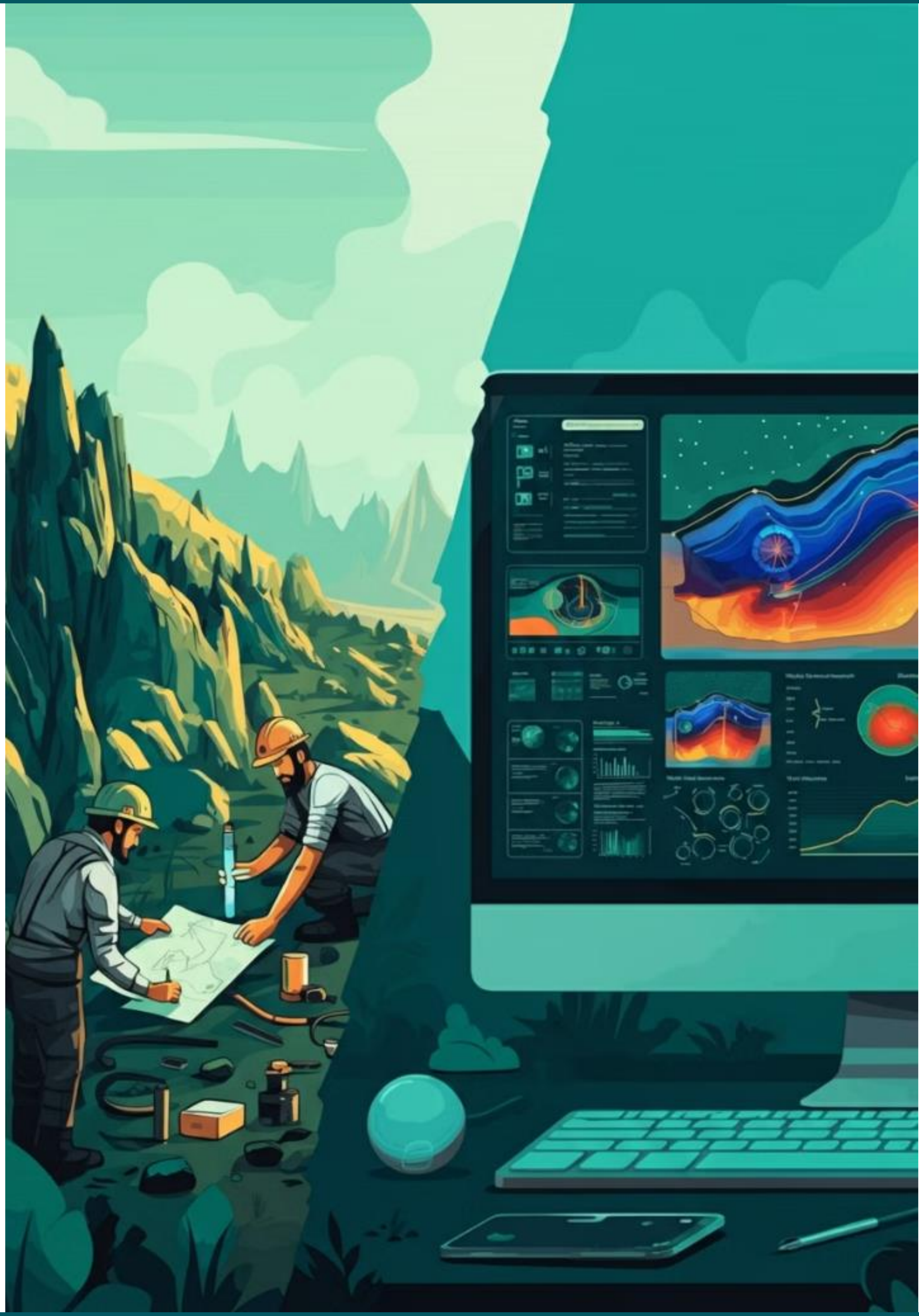
Determine the chemical equilibrium state of the water, providing insights into its maturity and potential for geothermal energy production.

Hydrogeochemical Processes

Understanding the mechanisms controlling water chemistry. It helps identify the dominant processes affecting the geothermal fluid composition and controlling water chemistry and rock weathering, categorizing samples into precipitation-dominated, rock weathering-dominated, and evaporation/ crystallization-controlled types.

Trace Elements Analysis

Ternary Diagrams to visualize the relationships between Cl^-, B, and F^- concentrations and Cl^-, B, and Li^+ concentrations in the geothermal fluid. This analysis helps in understanding the fluid's origin and evolution.



Solution Analysis Module

Molality and Moles

Lists the molality and moles of various elements, including C, Ca, Cl, F, K, Mg, Na, S, and Si.

Solution Description

Provides detailed information including Sample ID, pH, pe, Activity of water, Ionic strength, Mass of water, Total alkalinity, Total CO_2, Electrical balance and Percent error.

Species Distribution

Lists the molality, activity, and log activity of various species, such as OH^-, H^+, H_2O, HCO_3^-, Ca^{2+}, Cl^-, F^-, K^+, Mg^{2+}, Na^+, SO_4^{2-}, and SiO_2.

Mineral Saturation Analysis

This module provides a comprehensive summary of mineral saturation indices, indicating the extent of their saturation in the geothermal fluid. This information is crucial for understanding the chemical equilibrium of the system.

Gas Fugacity and Pressure

aiION calculates and reports the fugacity and partial pressure of gases in the solution, such as CO_2 and H_2O. This data is essential for understanding the behavior of gases in the geothermal reservoir.

Thermophysical Module

1

Comprehensive Solution Properties

aiION calculates crucial thermophysical properties including solution quality, density, specific volume, dynamic viscosity, thermal conductivity, internal energy, entropy, enthalpy, and heat capacity.

2

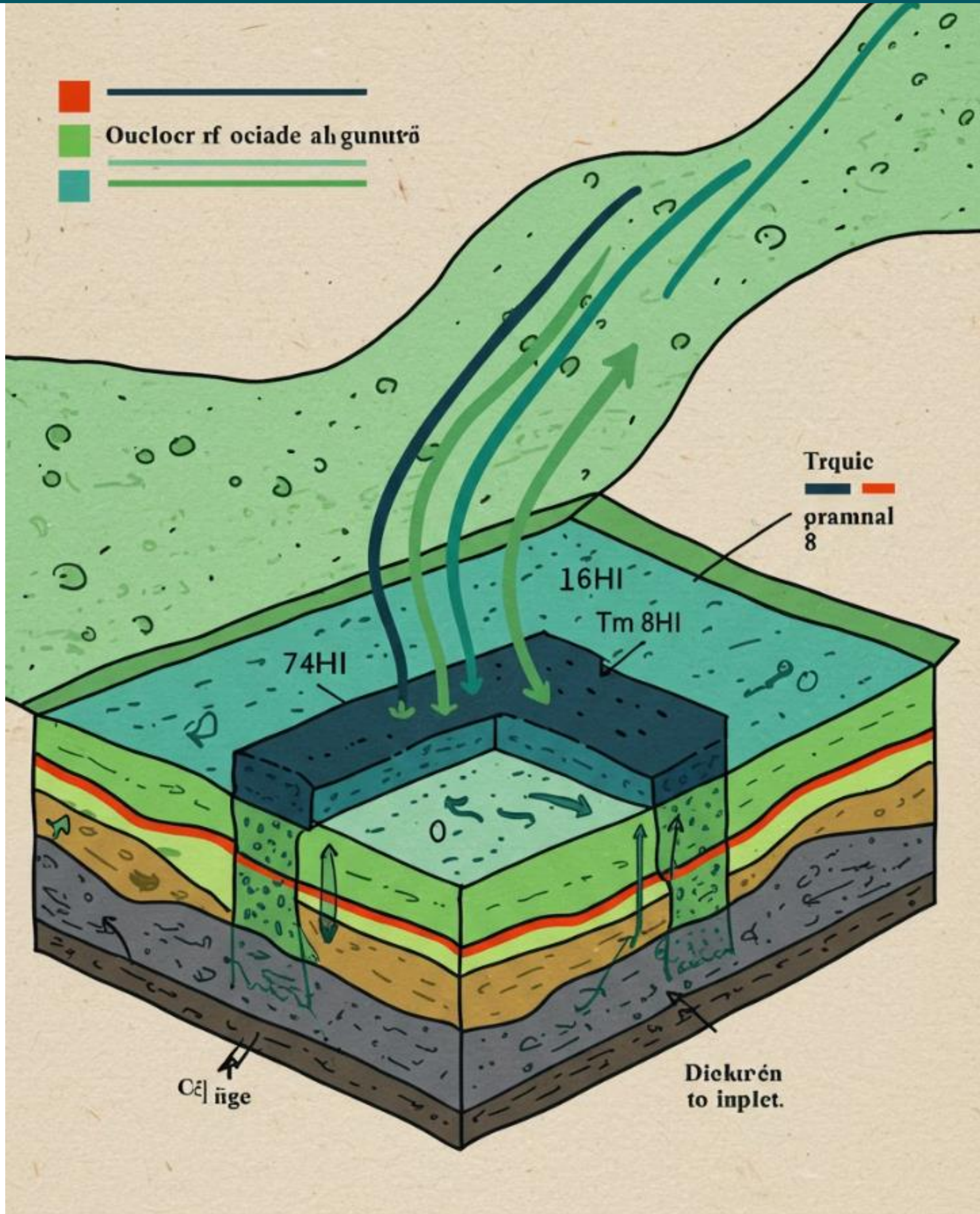
Geothermal Gradient Analysis

Computing effective thermal conductivity and geothermal gradients, providing insights into the heat distribution within the reservoir.

3

Heat Flow Assessment

aiION calculates heat flow, a critical parameter for understanding the energy potential of a geothermal system.



Geothermal Potential Module

1. **Thermal Energy Calculation**

   Computes total thermal energy of the reservoir

2. **Power Potential Estimation**

   Calculates potential power output in Watts and MWt/year

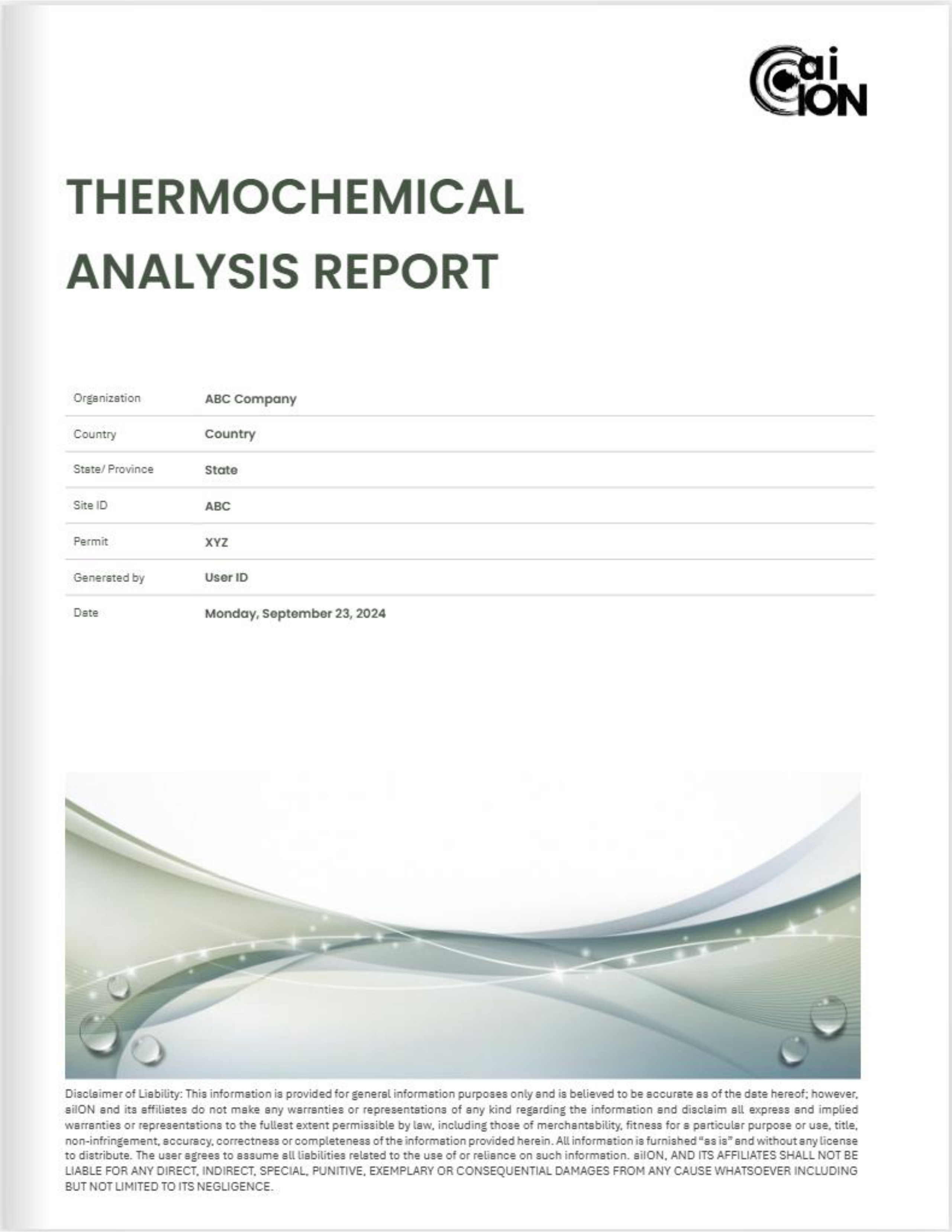
3. **Economic Viability Analysis**

   Calculation of CapEX & OpEX and determining the LCOH

4. **Sensitivity Analysis**

   Allows adjustment of key parameters for scenario planning

Comprehensive Technical Report



THERMOCHEMICAL ANALYSIS REPORT

Organization	ABC Company
Country	Country
State/ Province	State
Site ID	ABC
Permit	XYZ
Generated by	User ID
Date	Monday, September 23, 2024

Key Challenges

Data Availability

Scarcity of large, high-quality subsurface datasets limits AI model accuracy.

Data Quality

Ensuring data quality is crucial for effective AI application.

Data Accessibility

Improving access to geothermal data is necessary for wider AI adoption.

Implications for Geothermal Exploration

1

Improved Accuracy

aiION provides more reliable temperature predictions for geothermal reservoirs

2

Cost-Effective Exploration

Reduces the need for expensive drilling and testing in early exploration stages

3

Blind System Identification

Enhances ability to locate and assess "blind" geothermal systems without surface manifestations

4

Resource Assessment

Facilitates more accurate estimation of geothermal potential in unexplored areas

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