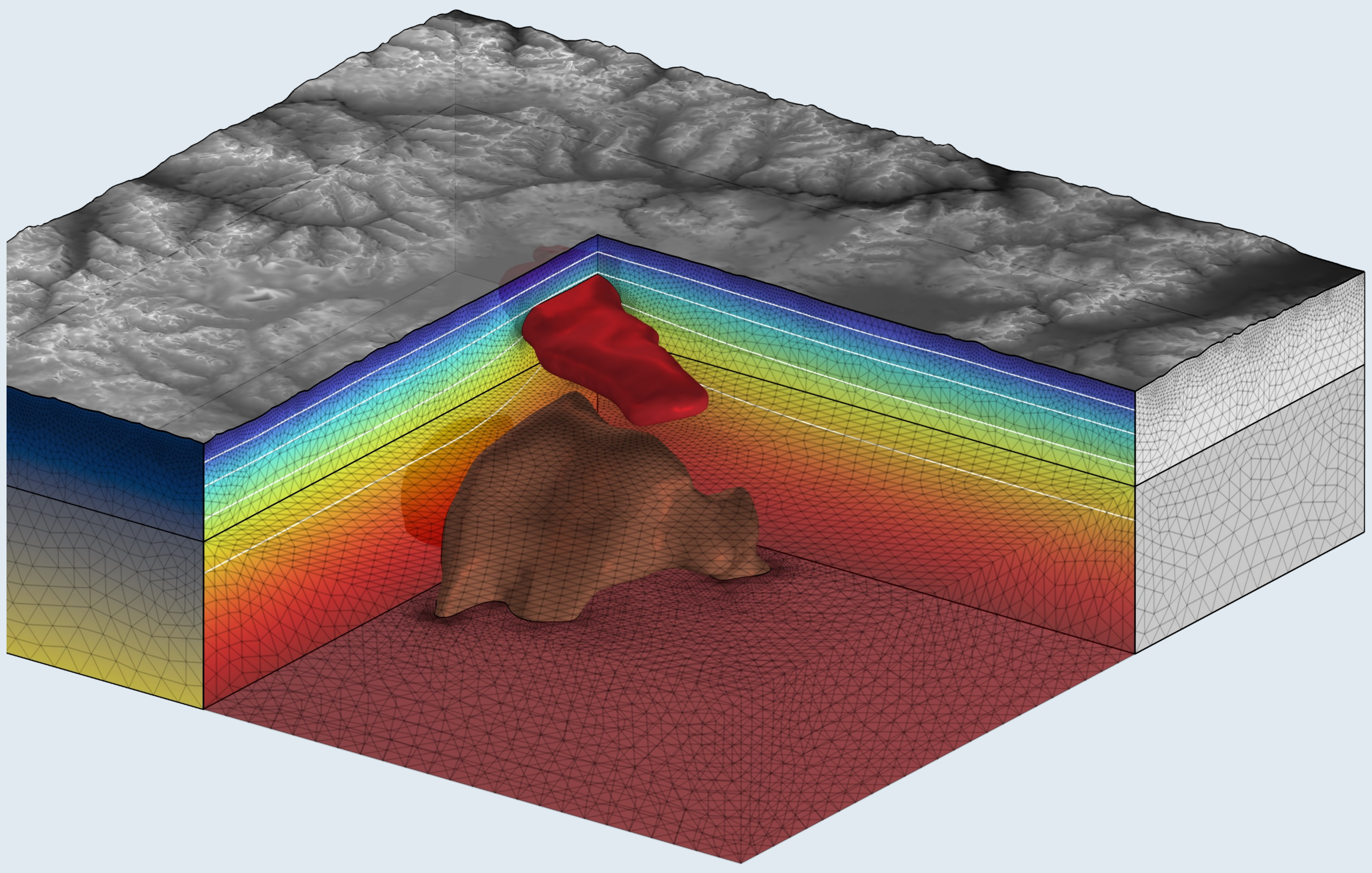

# Thermo-Rheological Modelling of the Yellowstone Caldera: Insights into Volcanic Processes

There is growing interest among geoscientists in modelling the thermal state of volcanic and geothermal regions. The Yellowstone Caldera, the world's most famous supervolcano, represents a perfect laboratory for testing effective modelling approaches in such tectono-magmatic environments.

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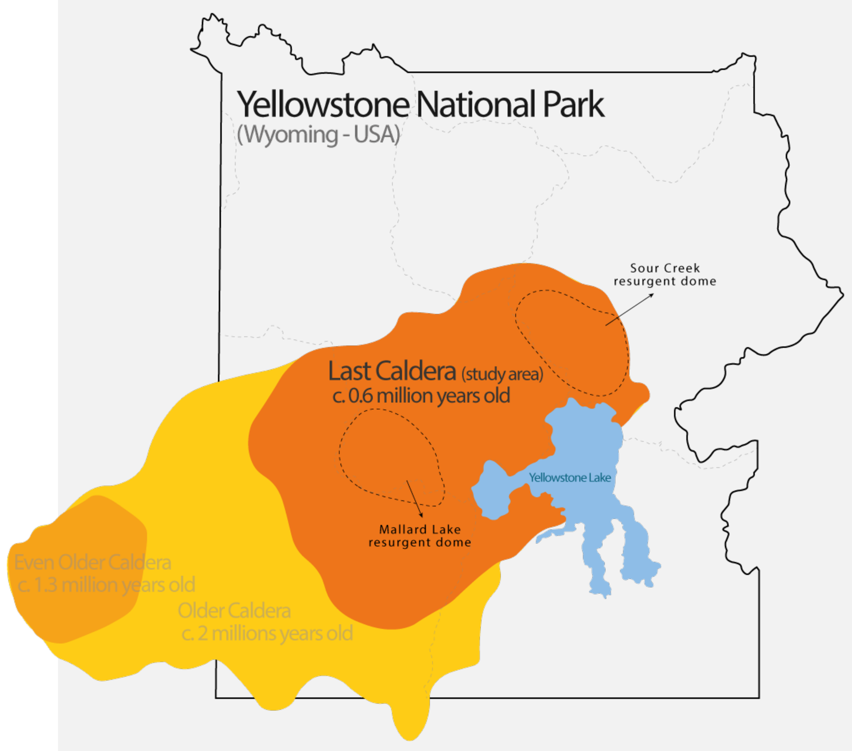
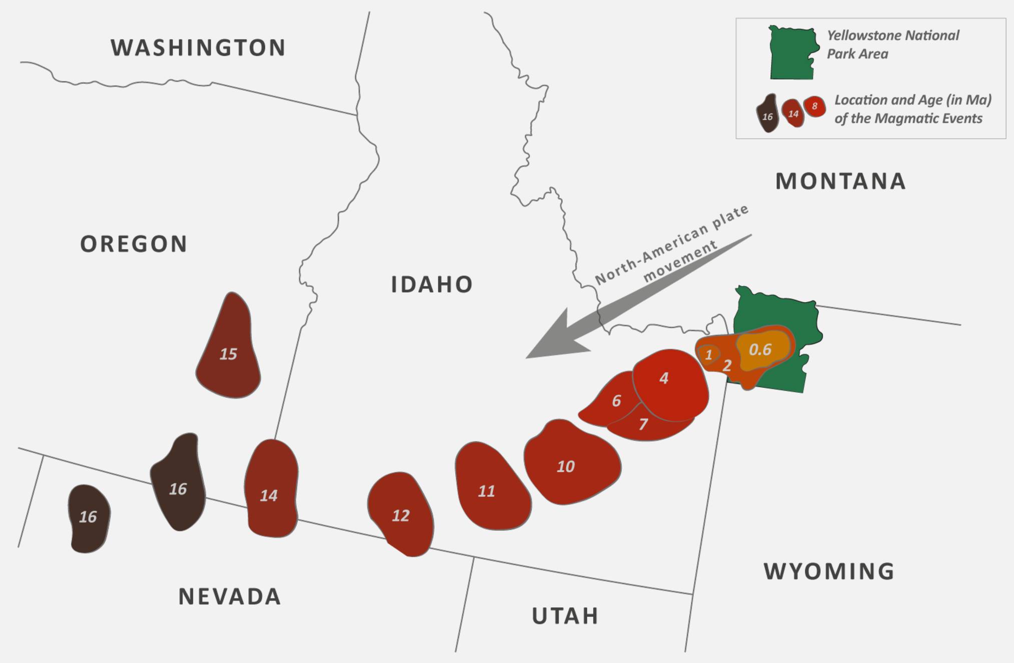
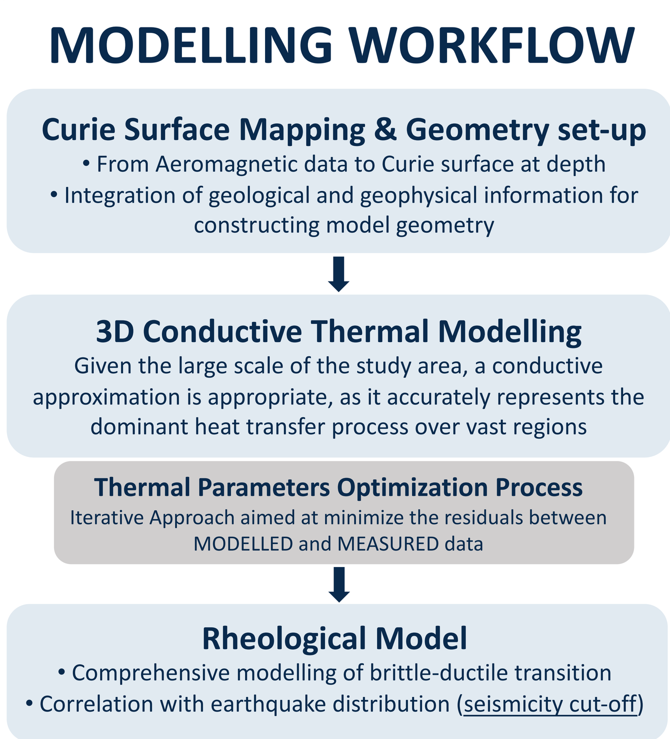


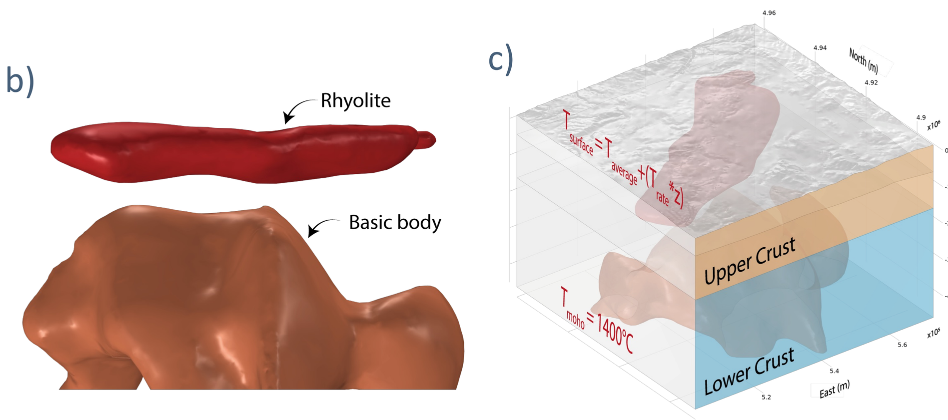

## Introduction & Goals

The **Yellowstone hotspot** is responsible for a series of volcanic eruptions over millions of years, creating the Yellowstone Caldera and other volcanic features [1]. Our **goal** is to investigate the **thermo-rheological** state of Yellowstone crust, focusing on the interactions between thermal dynamics and crustal mechanics, which are essential for evaluating volcanic activity, **geothermal potential**, and the region's long-term stability.




a)




d)

| Parameter | Symbol | Law | Upper Crust scenario 1 $k_{ii} = k_{jj}$ | Upper Crust scenario 2 $k_{zz}$ | Lower Crust | Rhyolite | Basic Body |
|---|---|---|---|---|---|---|---|
| Thermal conductivity (scenario 1) | $k_{ii} = k_{jj} = k_{zz}$ [W/(m$^3$ K)] | $k(T) = \left[k_M + \left(\frac{T_{ref} \cdot T_M}{T_M - T_{ref}}\right) \cdot (k_{ii,jj,zz} - k_M) \cdot \left(\frac{1}{T} - \frac{1}{T_M}\right)\right]$ | 2.1* | 2.1* | 4 | 2.4 | 1.6 |
| Thermal conductivity (scenario 2) | $k_{ii} = k_{jj} \neq k_{zz}$ [W/(m$^3$ K)] | $k_M$ = 1.8[W/(m$^3$ K)]; $T_{ref}$ = 293[K]; $T_M$ = 1473[K] [Sekiguchi, 1984] | 2.2* | 1.2* | 4 | 2.4 | 1.6 |
| Heat capacity | $c_p$ [J/(kg·K)] | / | 900 | | 1000 | 840 | 950 |
| Density | $\rho$ [kg m$^{-3}$] | / | 2500 | | 2800 | 2500 | 2900 |
| Radiogenic Heat production | $HP_{rad}$ [µW m$^{-3}$] | $A(z) = A_0 \cdot e^{-z/D_a}$ [Lachenruch, 1970] | 4.0* | 4.5* | | | |
| | | $D_a$ [m] | 17.4* | 19.4* | | | |
| Additional Heat production (scenario 1) | HP [µW m$^{-3}$] | / | 8.0* | / | | | |
| Magmatic Heat production | HP [µW m−3] | / | | | | 1.45* | 19.0* |
| Power law creep | A [MPa$^{-n}$ s$^{-1}$] | / | 1.5·10$^{-3}$ | | 3.2·10$^{-3}$ | 1.3·10$^{-3}$ | 1.4·10$^{4}$ |
| | n [-] | / | 2.4 | | 3.2 | 2.4 | 4.2 |
| | Q [kJ/mol] | / | 220 | | 270 | 220 | 445 |

* optimized parameters

FIGURE 1. a) Modelling workflow; b) 3D View of the magmatic system [3] and c) FE geometry domains; d) Table of physical parameters and constitutive laws.

## Methodology

The study began with Curie surface mapping and the set-up of magmatic reservoir geometry. Aeromagnetic data was used to determine the Curie surface at depth, corresponding to a temperature of 573°C. This information was combined with geological [2] and geophysical (seismic tomography, [3]) data to construct the model geometry. Subsequently, two 3D conductive **thermal models** were developed, investigating different scenarios characterized by: (1) homogeneous upper crustal thermal conductivity and an additional 'additional' heat source; (2) heterogeneous thermal conductivity.

## Results

For both physical scenarios, the thermal parameters were optimized to determine the best finite element (FE) model configuration. Our thermal analysis demonstrated that, in order to align with both the **regional surface heat flow (SHF)** estimate [4] and the minimum Root Mean Square Error (RMSE), the optimal setup includes additional heat production diffused within the upper crust. This could be due to the presence of **smaller-scale magmatic bodies** in the upper crust that are unresolved by tomography [3]. Finally, a comprehensive rheological model of the studied crustal section was developed, correlating the model with the seismicity cut-off. A minimum **strain rate of 1E−8 s$^{-1}$** was applied to match the observed seismicity distribution (1974–2024).

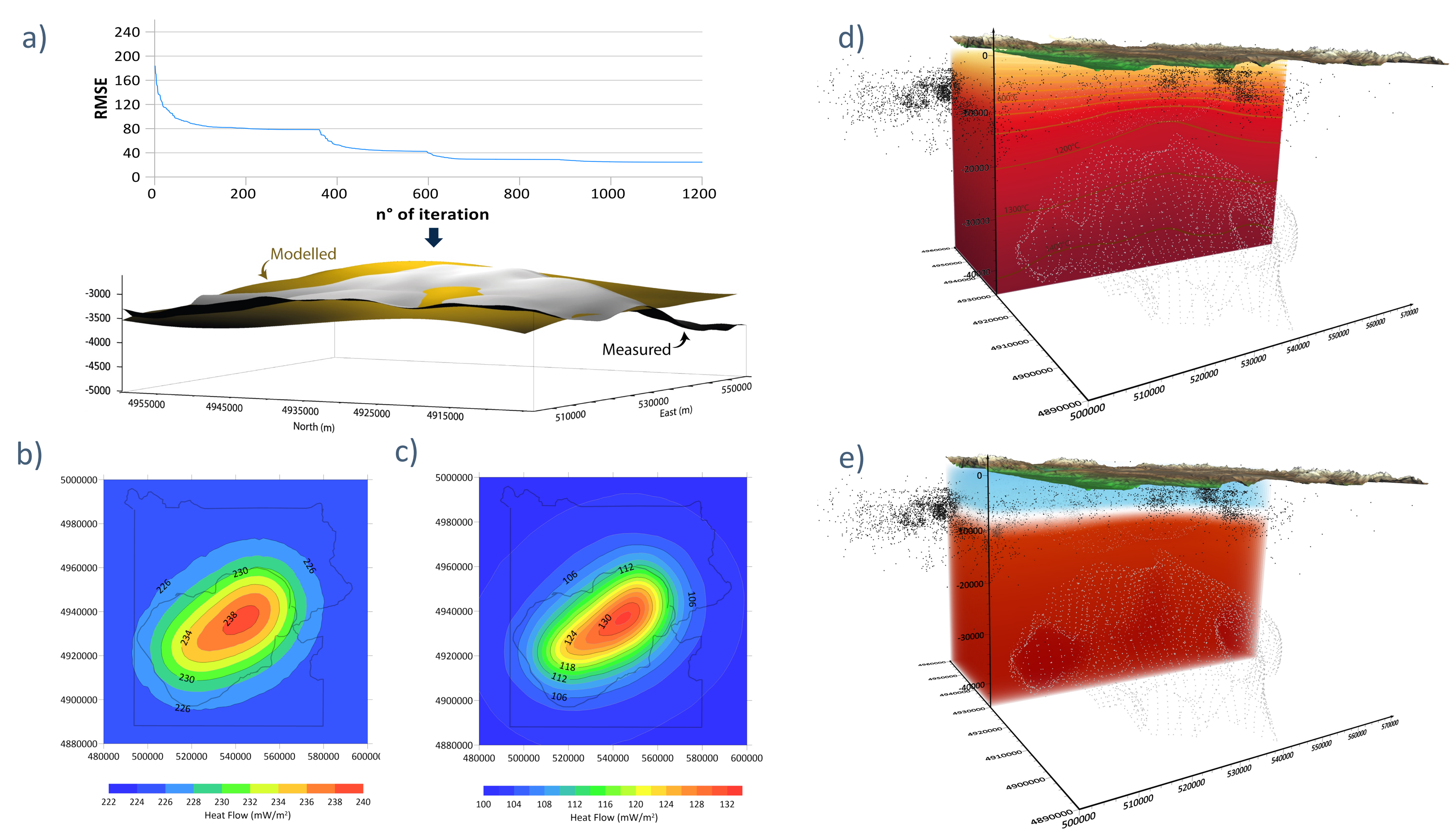



FIGURE 2. - a) Composite picture illustrating the Optimization Process – Scenario 1; b) Modelled SHF for Scenario 1 and c) Scenario 2; d) 3D Temperature distribution and the associated e) 3D rheological model.

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