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Sensitivity and resolution of geophysical methods in response to a deep fractured geothermal reservoir model in the Upper Rhine Graben: a methodological framework

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INTRODUCTION

- Deep geothermal exploration in the Upper Rhine Graben (URG) relies on geophysical imaging of deep fracture systems, fault zones and associated fluid pathways.
- Two end-member geothermal targets are commonly considered: Soultz-type (fractured crystalline basement) and Rittershoffen-type (major fault at the sediment-to-basement interface).
- **Motivation:** In practice, geophysical methods involve trade-offs between imaging resolution, sensitivity to structural vs fluid-related contrasts, depth of investigation and operational cost. However, no target-oriented framework currently links geothermal target definition, acquisition design and expected geophysical response prior to survey implementation.
- **Objective:** Develop a structured methodological framework to evaluate which methods and acquisition configurations best constrain structural and fluid-related contrasts for deep fractured geothermal targets in the URG.

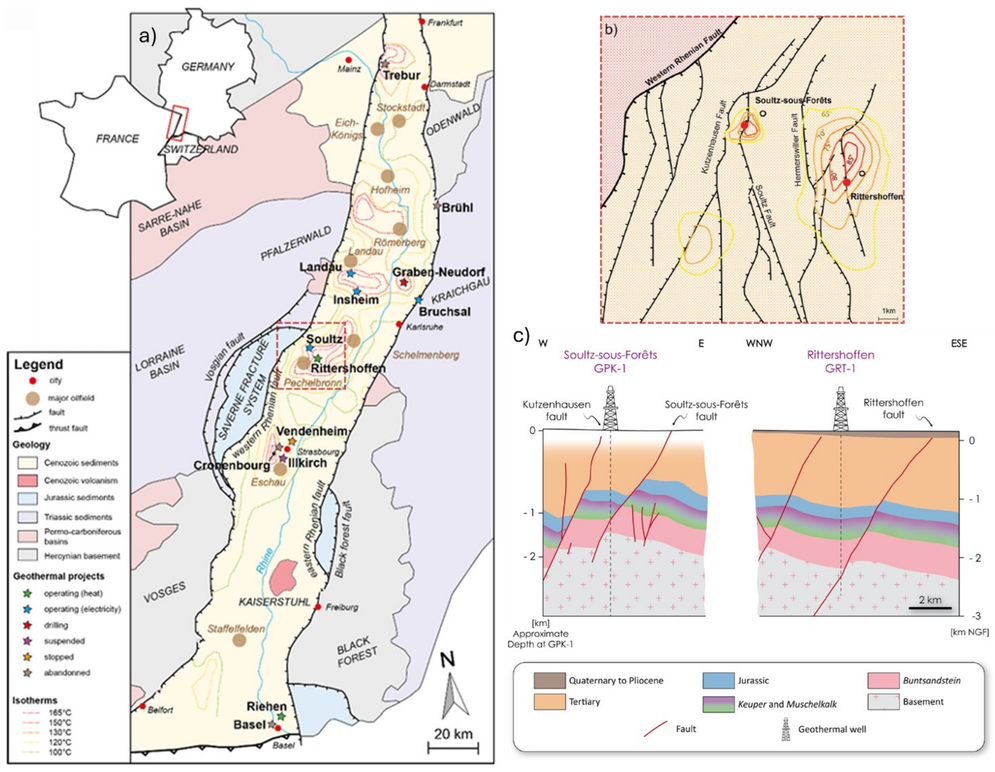


Figure 1. Geological context of the URG. (a) Regional geological framework and deep geothermal sites (modified after Glaas, 2021). (b) Structural setting of the Soultz-sous-Forêts and Rittershoffen geothermal areas (after Vidal and Genter, 2018). (c) Conceptual geological cross-sections of representative URG geothermal targets (after Harlé et al., 2019).

METHODS

Methodological approach: The framework integrates geological and petrophysical priors into geophysical forward modelling simulations to assess method sensitivity and achievable resolution for representative URG targets. Synthetic tests and benchmarking are performed under alternative acquisition configurations (airborne, grounded, downhole, or combination of both) before validation against real datasets.

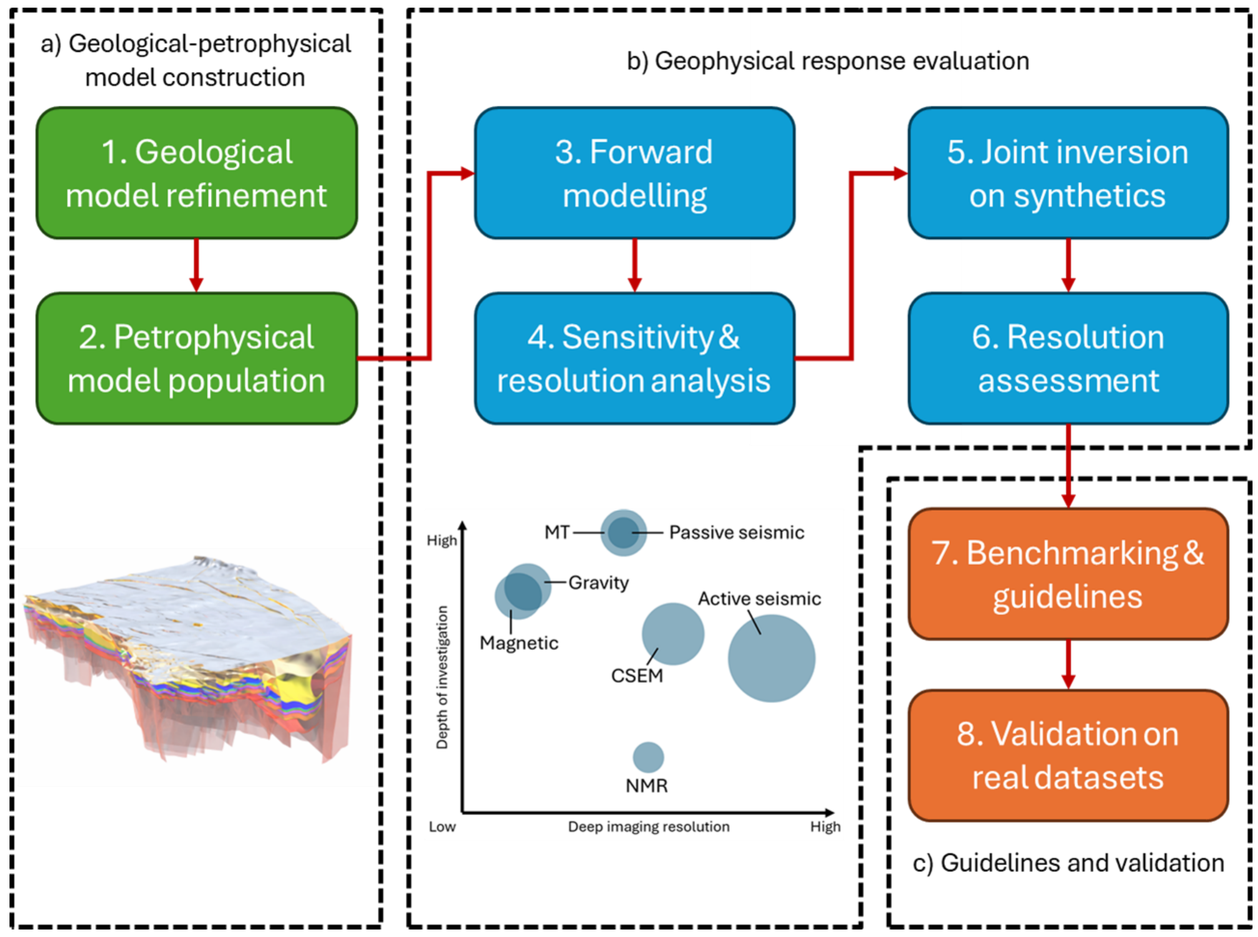


Figure 2. Methodological workflow for evaluating geophysical methods for deep geothermal targets in the Upper Rhine Graben: (a) geological–petrophysical model construction; (b) geophysical response evaluation through forward modelling, sensitivity and resolution analysis, joint inversion tests, and conceptual comparison of geophysical methods in terms of deep imaging resolution, depth of investigation and relative acquisition cost (bubble size); and (c) benchmarking, guideline development and validation on real datasets.

EXPECTED RESULTS

D1 — URG geological–petrophysical model
Refined URG geological model populated with harmonized petrophysical properties for forward simulations.

D2 — Sensitivity & resolution benchmark
Quantitative benchmarking of method-specific sensitivity and resolution for key URG targets

D3 — Target-oriented specifications
Practical recommendations of optimal methods and complementary combinations to support survey design and risk reduction

Figure 3. Expected deliverables

Target A. Soultz-type

Imaging priority: fracture-network geometry and associated fluid-related contrasts within the crystalline basement.

Framework output:
- Ranked method combinations
- Preferred acquisition options
- Expected model resolution

Target B. Rittershoffen-type

Imaging priority: fault-zone architecture and associated fluid-related contrasts at the sediment-to-basement interface.

Framework output:
- Ranked method combinations
- Preferred acquisition options
- Expected model resolution

Figure 4. Conceptual framework output for two URG end-member targets; rankings depend on stated assumptions and operational constraints (incl. cost).

DISCUSSION

- **Trade-offs:** In the URG, method choice requires balancing resolution, sensitivity (structure vs fluids), depth and cost.
- **Complementarity:** Combining methods with different sensitivities can reduce non-uniqueness and strengthen interpretation.
- **Perspectives:** The framework can benchmark emerging approaches (e.g., passive seismic, CSEM, NMR) alongside established methods to inform future multiphysics survey design.

CONCLUSIONS

1. A target-oriented framework is proposed to benchmark geophysical methods for deep fractured geothermal targets in the URG prior to acquisition.
2. The workflow links target definition, geological–petrophysical priors, and forward/inverse modelling to support cost-aware, risk-reduction survey design.
3. Expected deliverables include method ranking and recommended acquisition options for representative URG geothermal targets.

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