GEOTHERMIE
SCHWEIZ SUISSE SVIZZERA
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www.connect4geothermal.ch

Geothermal subsurface characterization: State of the art technologies & Innovation

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Geothermal subsurface characterization: State of the art technologies & Innovation

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Agenda

- Challenges in the Geothermal industry in Europe
- Digital solutions/Innovations vs geothermal lifecycle
- Case study
- Conclusions

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World Leaders are United for Net Zero

80%

World’s economy aiming for net zero

And increasing…

University of Oxford, Nov 2021

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Geothermal | Landscape in Europe

Overview of the Geothermal Energy landscape in Europe

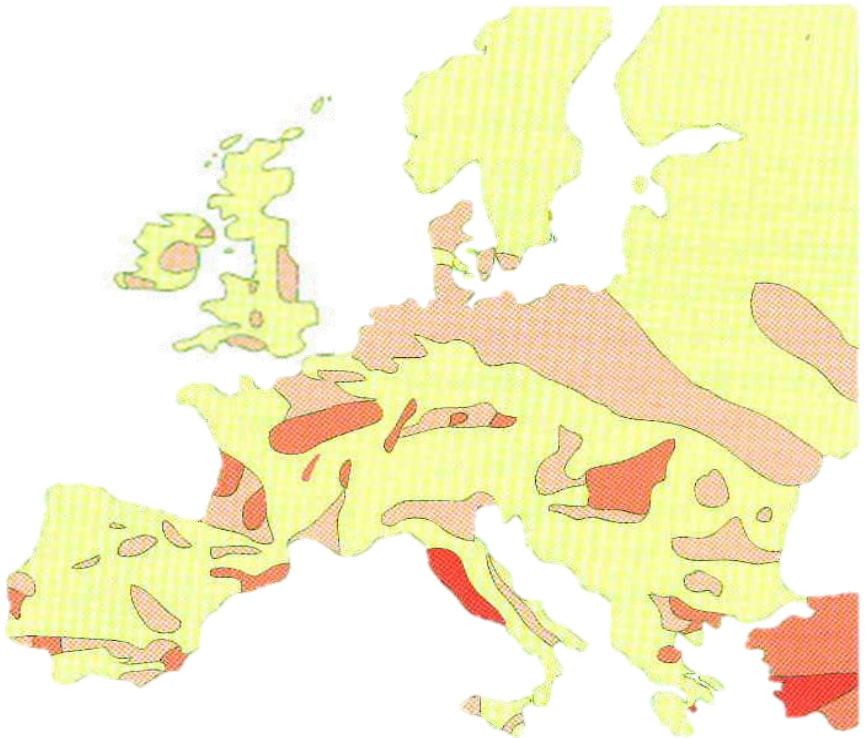
Challenges

One of the significant challenge today is the transformation of "potential new developments" to near mature and mature landscape. We can achieve this through integration of innovation, AI & ML workflows with high contributing on reducing uncertainties

Value Proposition for Transformation

- Improving predictability and reducing uncertainty
- Leveraging the cloud compute for gaining efficiency on modeling predictions
- Deploying better drilling strategies for maximum recovery and efficiency on geothermal operations

New development areas:
lithium + heat extraction
France, Germany, UK



New Development Areas:
Heating & Power , Poland, Hungary and Croatia

Mid enthalpy
used for district heating
France, Germany

High enthalpy:
used for power generation
Italy, Turkey, Iceland

Note: shallow geothermal not mentioned

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Geothermal | Geothermal Project Risks

"Knowing the risk and creating the plan for mitigation"

Project Risks

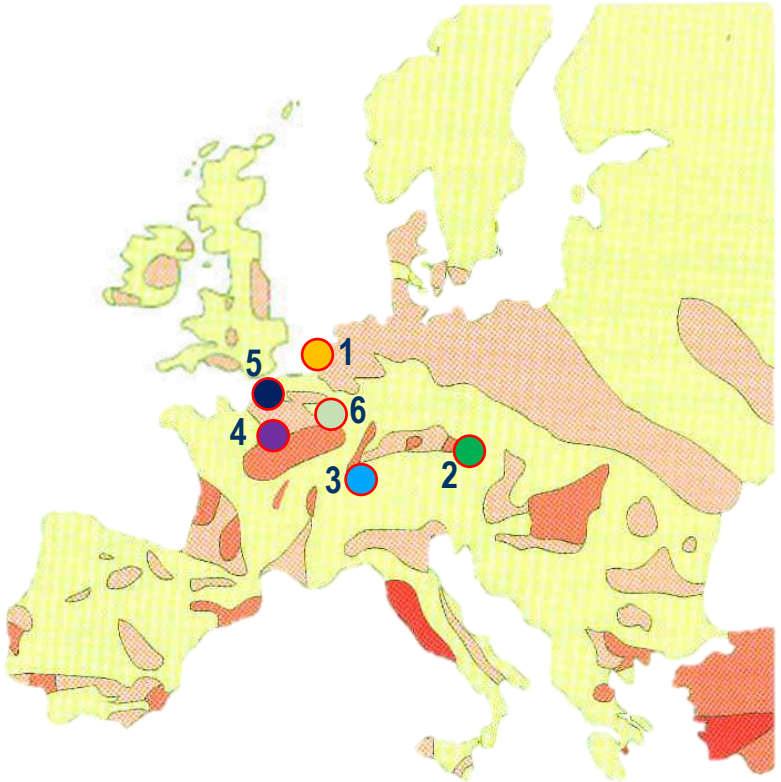
The success of "Geothermal" projects lies in the inception of risks and hazards earlier on in the exploration phase. Mitigating the risks earlier with understanding on implications will help us to operate projects more efficiently and with agility to achieve **"Landscape Transformation"**

Mitigation Plan

- Understanding project risks and implications due to business challenges
- Addressing the business challenges with technology and workflow solutions
- Deploying AI and ML workflows for reducing uncertainty
- Fit for Purpose business strategies and workflow deployment

Project risks:

- **Resource risk**
- **Plant oversizing**
- Financing risk
- Completion/delay
- **Operational risks (drilling, seismicity…)**
- Regulatory risks and public perception



1 Project halted to review economics and risks

2 Targeted known reservoir but found insufficient permeability

3 Project cancelled due to induced seismicity

4 Well targeted unexpected facies due to reservoir uncertainties

5 Encountered equipment issues during drilling and testing

6 Launched a seismic campaign to mutualize exploration risks

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Geothermal | Technical key pillars for Geothermal

Overview of the technology landscape for Geothermal Energy

Integrating Classic Domain Technology

Application of Integration into Interpretation and Modeling

Artificial Intelligence & Machine Learning

Deploying AI and ML for Improving Predictions & Reducing Uncertainty

Cloud Based Technologies & Transformation

Leveraging cloud technologies for adopting digital transformation

Exploration → Feasibility → Appraisal → Drilling & Construction → Operations

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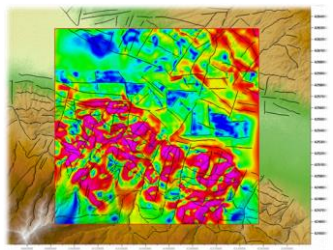
Geothermal | Multiphysics Methods

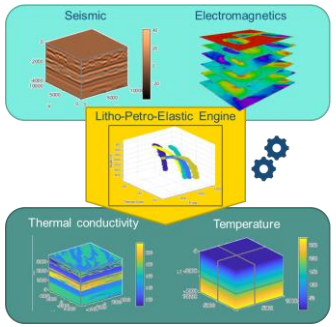
Using non-seismic methods for exploration phase with integration of AI/ML and Cloud Technology

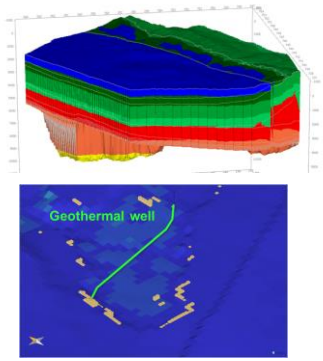
Exploration | Feasibility | Appraisal | Drilling & Construction | Operations

Integrating Classic Domain Technology

- Structural geological framework delineation
- Lithology change mapping
- 3D thermal and temperature models from multi-geophysical data
- Thermal profiles and geohazards from basin models

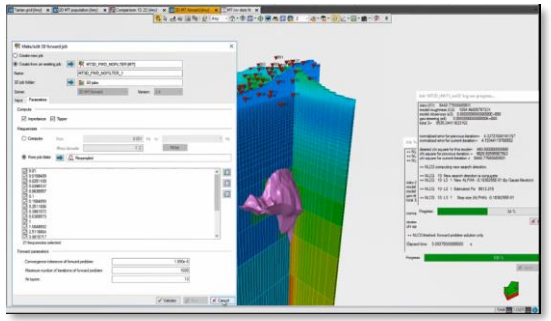


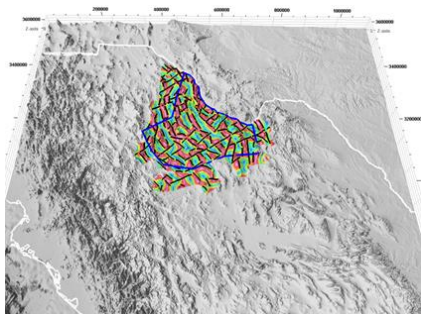




Artificial Intelligence & Machine Learning Leveraging Cloud Transformation

- Cloud-based 3D electromagnetic modeling
- ML assisted lineament delineation on potential field data





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Geothermal | Seismic Workflows & Methods

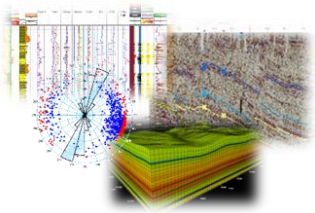
Using seismic for aiding exploration phase with integration of AI/ML and Cloud Technology

Exploration → Feasibility → Appraisal → Drilling & Construction → Operations

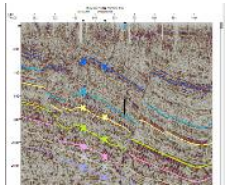
Integrating Classic Domain Technology

- Seismic Processing and Imaging
- Seismic Data Conditioning
- Seismic Interpretation Workflows
- Seismic Inversion and Uncertainty Analysis
- Simple and Advanced Velocity Modeling
- Seismic Monitoring for appraisal & project feasibility

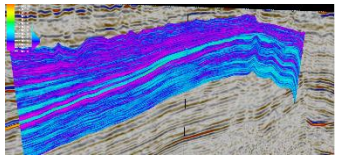
Seismic Data Conditioning



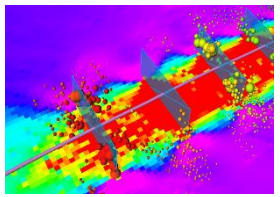
Seismic Interpretation



Seismic Inversion



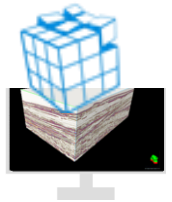
Seismic Monitoring



Artificial Intelligence & Machine Learning Leveraging Cloud Transformation

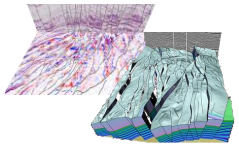
- SEGY to “Cloud specific” Format Compatibility
- Automated Well-tie and Seismic Inversion
- Seismic Data Ingestion into Open Subsurface Data Universe
- ML Assisted Horizon Tracking and Interpretation
- ML Assisted Structural Model construction & validation

Open ZGY SEGY to ZGY Support



ML Automated Horizon Tracking

ML Automated Seismic Interp.



Prospect Analog Advice & Insights

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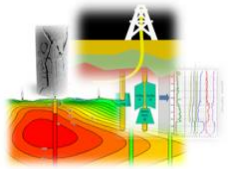
Geothermal | Geological Interpretation and Petrophysical Workflows

Deploying integrated geological workflows with petrophysical solutions

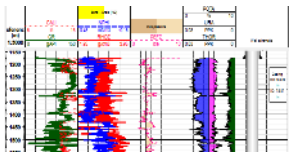
Exploration | Feasibility | Appraisal | Drilling & Construction | Operations

Integrating Classic Domain Technology

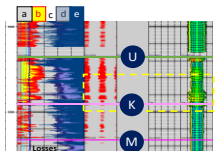
- Geological Interpretation / Mapping
- Fracture modeling conditioned with dynamic data (PLT, Well tests))
- Near wellbore data integration for structural model update
- Image and Petrophysical well data interpretation
- Well Bore Stability Workflows



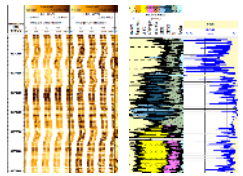
Log Data Interpretation



Data Input QA/QC



Wellbore Stability

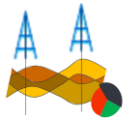


Petrophysical Analysis

Artificial Intelligence & Machine Learning Leveraging Cloud Transformation

- Automated Log Data QA / QC
- ML Assisted Log QC and Reconstruction
- Batch Processing & Automation
- Dynamic Prospect and Analog Insights for project feasibility

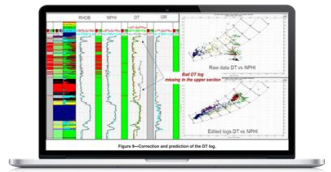
ML Model Management



Wellbore 50-200X speed up of petrophysical processing

Automated Log Data Quality and Delivery Workflows

ML Assisted Log QC & Reconstruction



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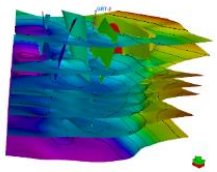
Geothermal | Geological & Geomechanical Modeling

Integrating datasets for geological and geomechanical predictive modeling

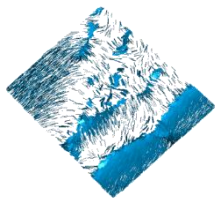
Exploration | Feasibility | Appraisal | Drilling & Construction | Operations

Integrating Classic Domain Technology

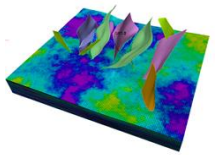
- 3D Geological Models
- 1D and 3D Mechanical Earth Models
- Well Bore Stability Workflows
- Geomechanical Earth Models
- Basin Source Modeling for Screening Workflows



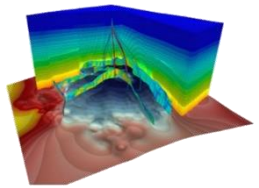
3D Structural Framework



Fracture Models



3D Geological Models

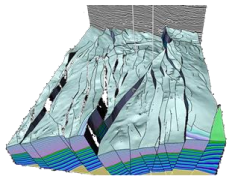


Mechanical Earth Models

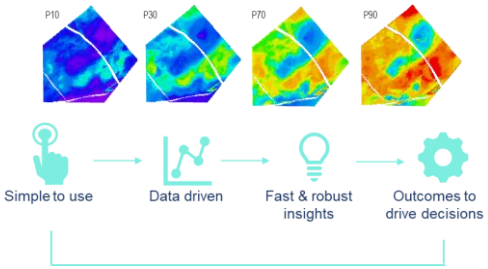
Artificial Intelligence & Machine Learning Leveraging Cloud Transformation

- ML Assisted Structural Model construction & validation
- ML Property Modeling Workflow
- Analog Insights and Screening Advice
- Cloud compute

ML Automated Structural Models



Prospect Analog Advice & Insights



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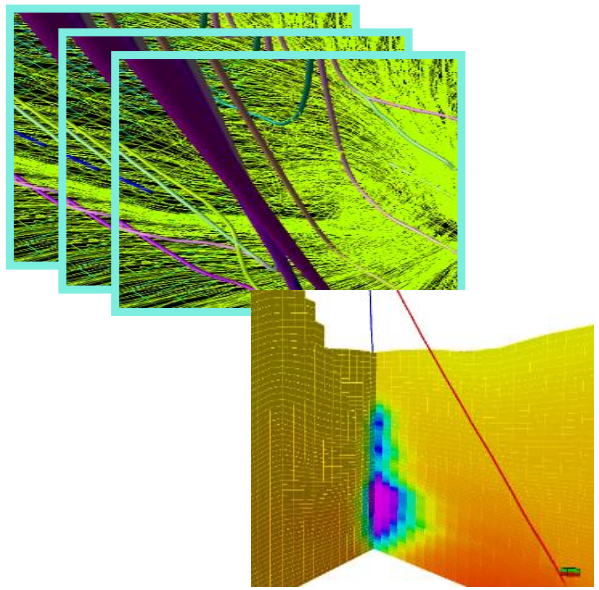
Geothermal | Simulation

Quantifying the reservoir

Exploration | Feasibility | **Appraisal** | Drilling & Construction | Operations

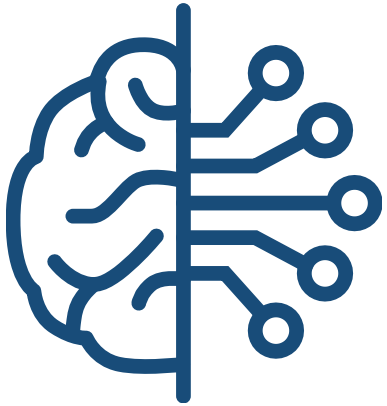
Integrating Classic Domain Technology

- Thermal simulations
- Steam flow to well
- 3D reservoir with immobile steam
- Single/Multi component brine
- Component solubility in water
- Reservoir Networks
- Hydraulic fracturing
- Streamlines for connectivity

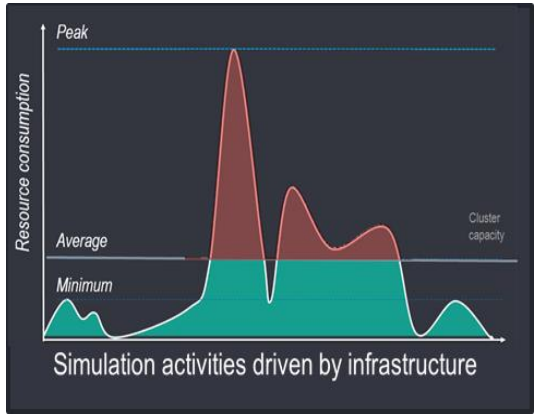


Artificial Intelligence & Machine Learning Leveraging Cloud Transformation

- Dynamic tunning
- Intelligent Time stepping



- Cloud computing for simulators
- Flexibility and efficiency
- No restrictions
- Cost for hardware reduced



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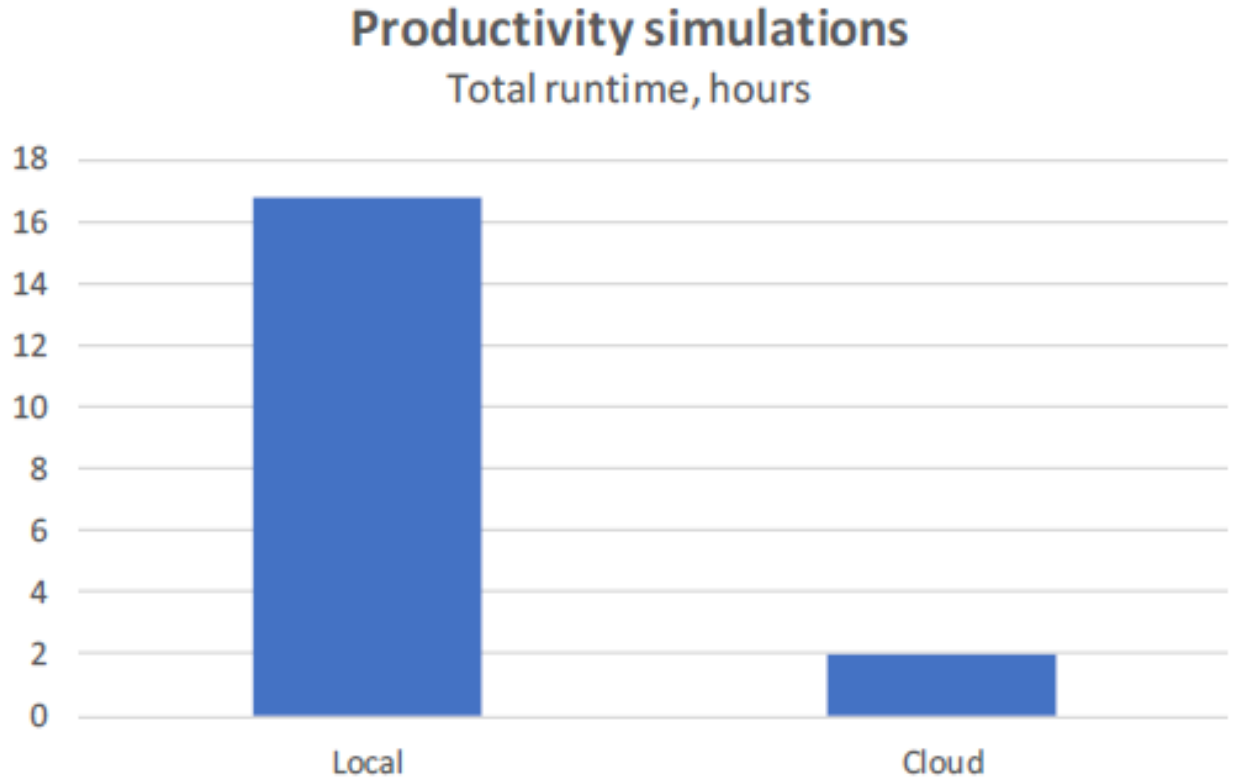
Cloud-Based Simulations for Sensitivity Analysis of a Geothermal Project, Bavaria, Germany

- Evaluate sustainable utilization and impact on neighboring projects
- "Hybrid" solution: on-demand reservoir simulation (local model, cloud-based simulator)
- Multiple-realization sensitivity study with up to 216 simulations for up to 50-year forecasts
- Results obtained in ~10-25% of traditional (local) simulations
- Reduction in infrastructure and license cost



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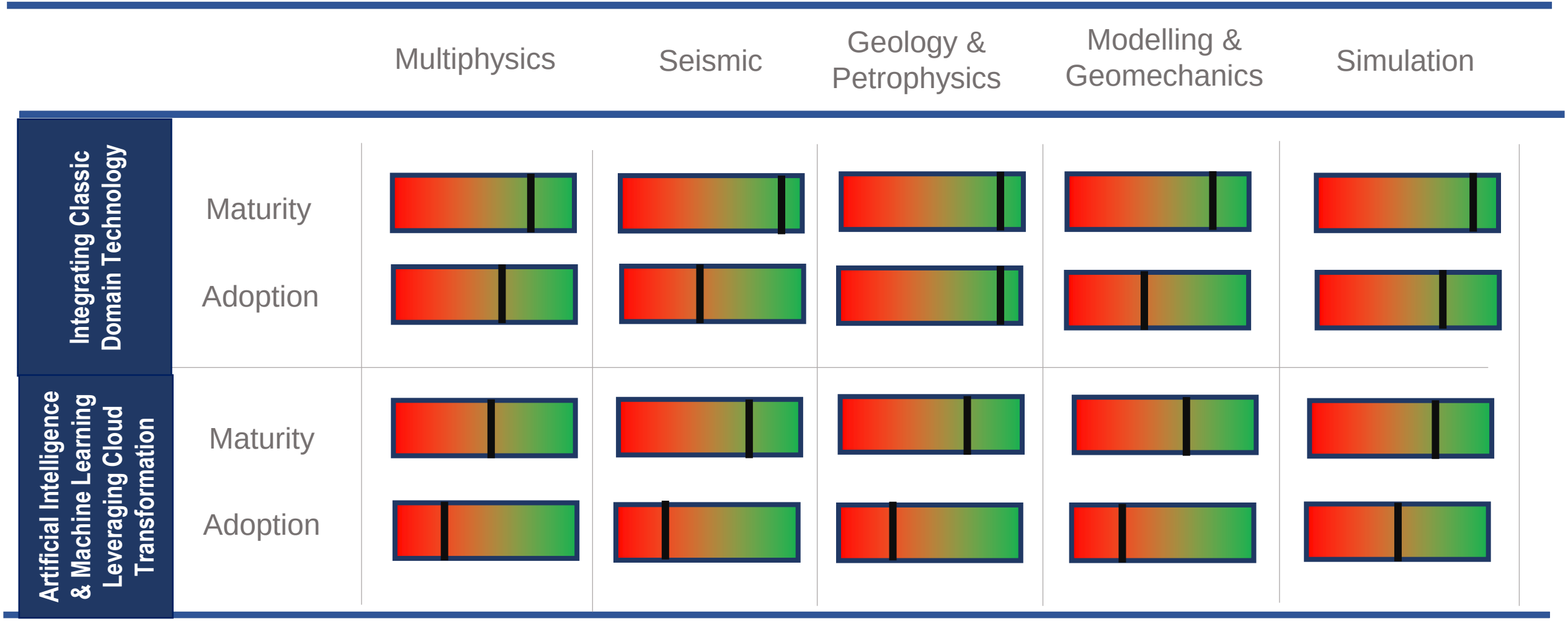
Geothermal | Technology Landscape for Geothermal Workflows - Summary



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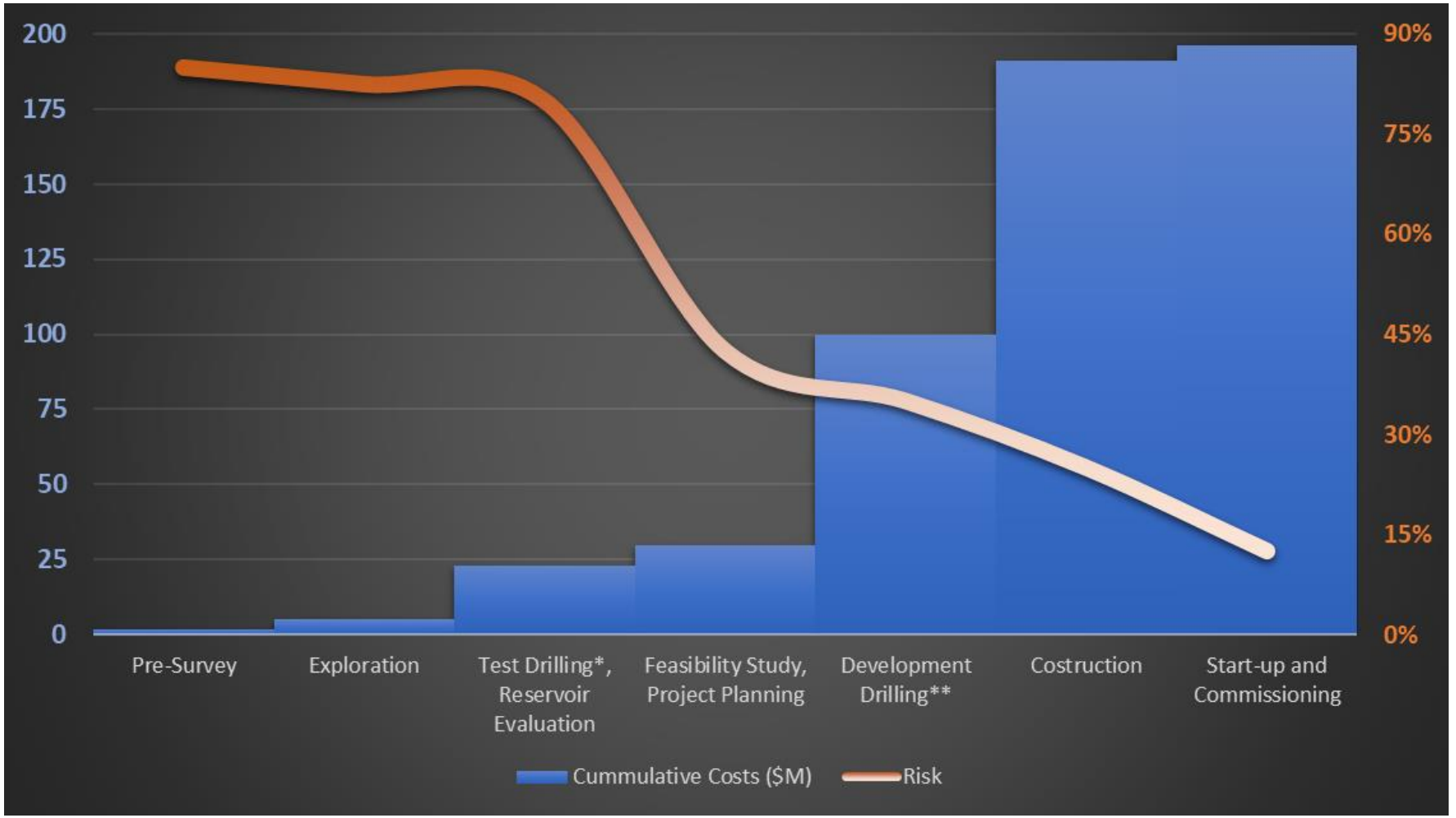
Geothermal project cost and risk profiles at various stages



Project risks:

- **Resource risk**
- **Plant oversizing**
- Financing risk
- Completion/delay
- **Operational risks (drilling, seismicity…)**
- Regulatory risks and public perception

Prepared by Paul Hultzsch with data from ESMAP 2012

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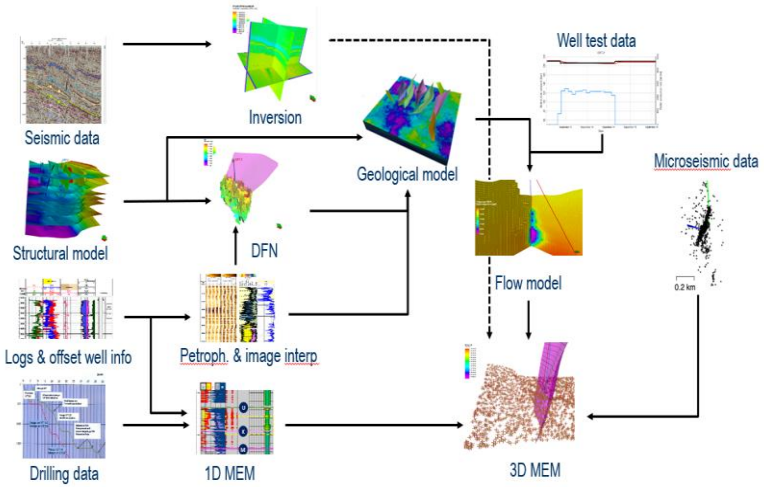
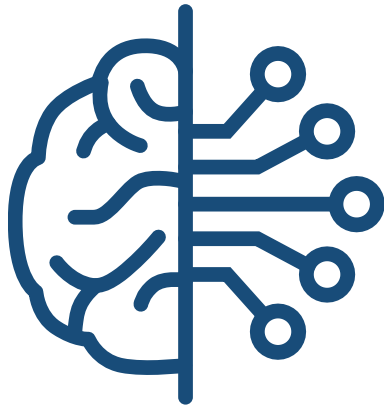
Conclusion

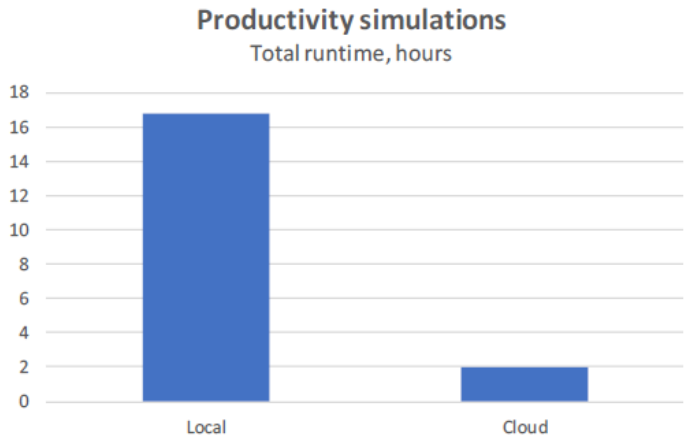
Integrating Classic Domain Technology



Artificial Intelligence & Machine Learning



Cloud Based Technologies & Transformation



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Thank You

Klaus Eder
Giovanni Sosio
Annalisa Campana
Ammar Ahmad
Luca Masnaghetti
Dan Knight
Rabah Ould braham
Myriam Ait Youcef