



Der **Digital**
Geothermie
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Enhanced Geothermal Systems: Variscan Reservoir Characterisation by Outcrop Analogue Studies

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Introduction



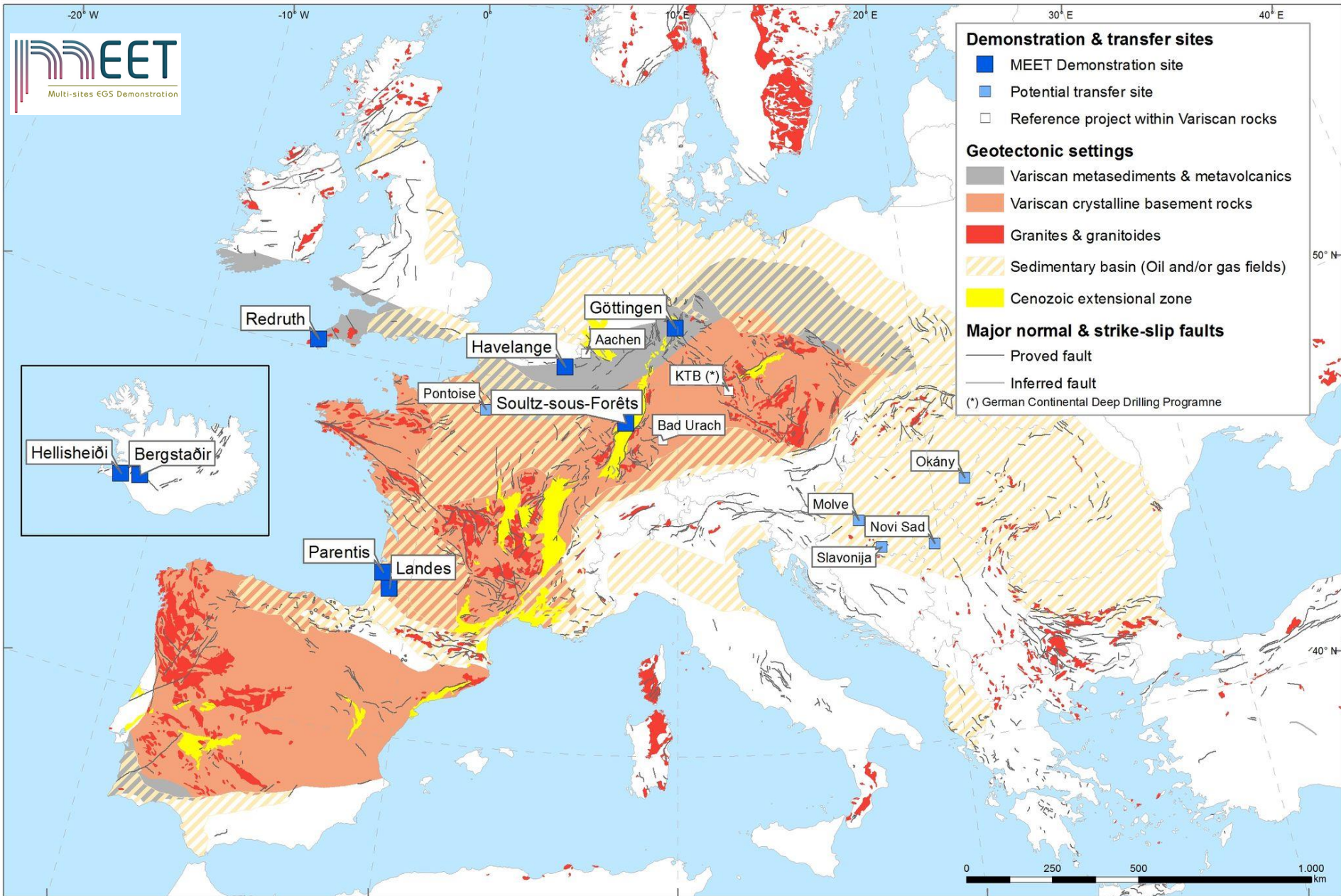
**Multidisciplinary and multi-context
demonstration of EGS exploration and
Exploitation Techniques and potentials**

- runs from May 2018 to October 2021
- 16 partners from France, Germany, Belgium, Iceland and Croatia

Main objectives

- Increasing heat production at existing plants
- Conversion of oil wells into geothermal wells
- Enhancing heat-to-power conversion at low temperature (60-90°C) by using smart mobile Organic Rankine Cycle (ORC) units
- **Exploration and exploitation of unconventional geothermal reservoirs in different geological settings**
- Technology transfer and market penetration throughout Europe

Exploration and exploitation of unconventional geothermal reservoirs in different geological settings

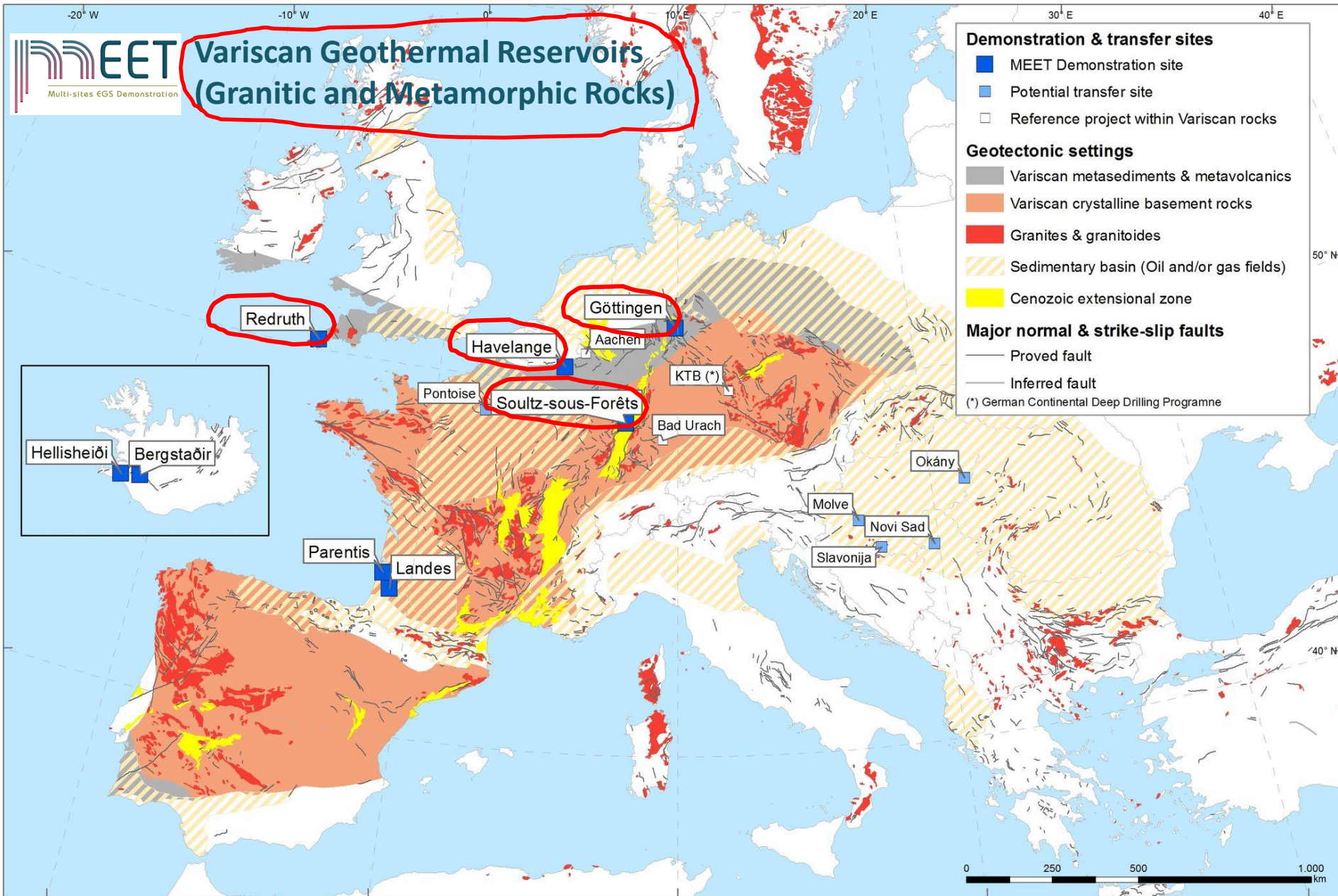


Sources of geological datasets:

Asch, K. (2005): IGME 5000: 1 : 5 Million International Geological Map of Europe and Adjacent Areas. BGR (Hannover).

U.S. Geological Survey World Petroleum Assessment 2000: U.S. Geological Survey Digital Data Series DDS60: <http://greenwood.cr.usgs.gov/energy/WorldEnergy/DDS-60>

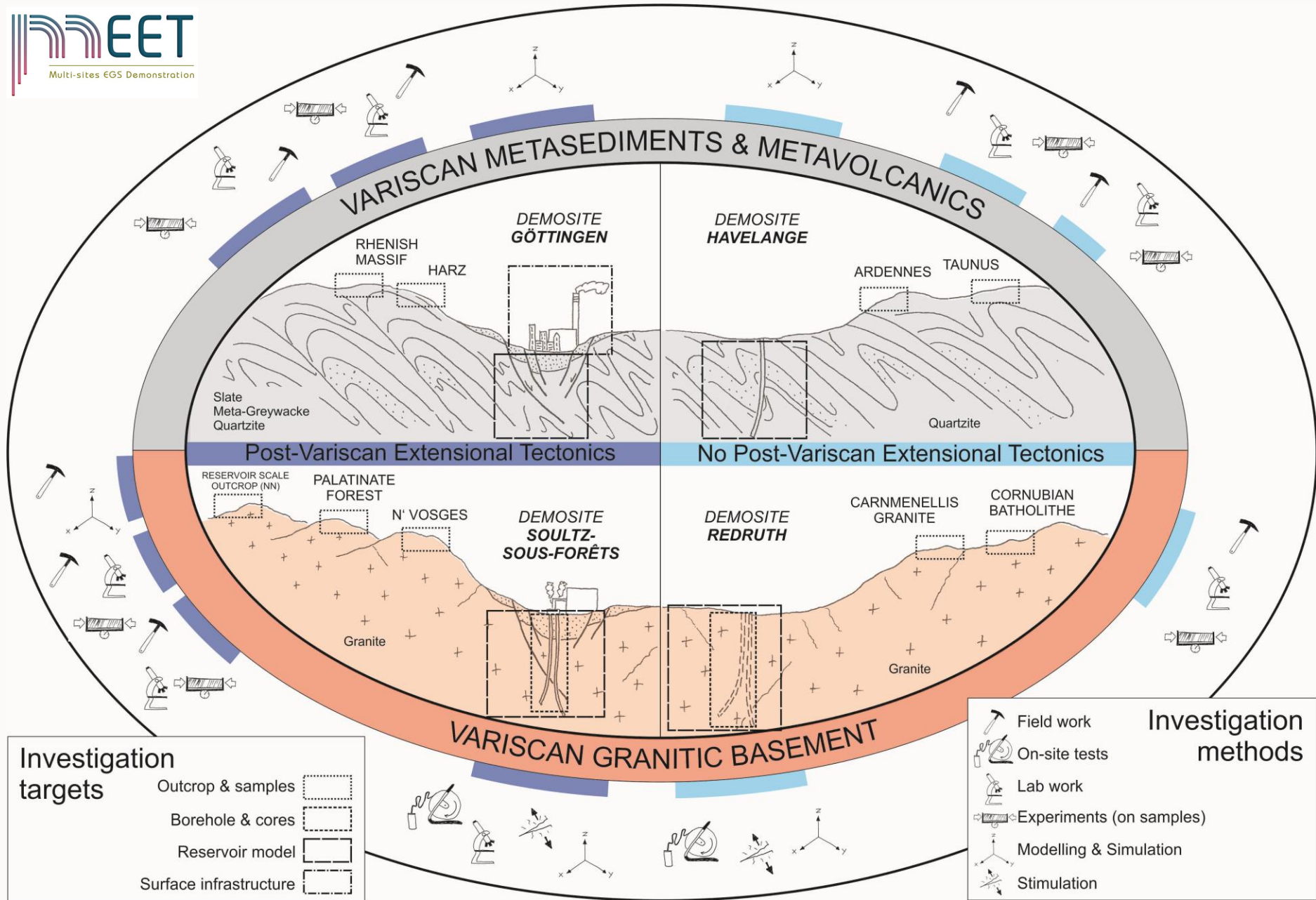
Exploration and exploitation of unconventional geothermal reservoirs in different geological settings



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**Unconventional geothermal reservoirs in different geological settings:
Variscan Granitic and Metasedimentary and -volcanic Rocks**



Requirements, selection and conclusions of the specific analogue sites

in regard to the four demo sites/reservoir types:

Variscan metasedimentary/metavolcanic successions (1) and Variscan crystalline basement (2) overprinted (3) or not by younger extensional tectonics (4);

Metamorphic well core samples complement the analogue sites (5).



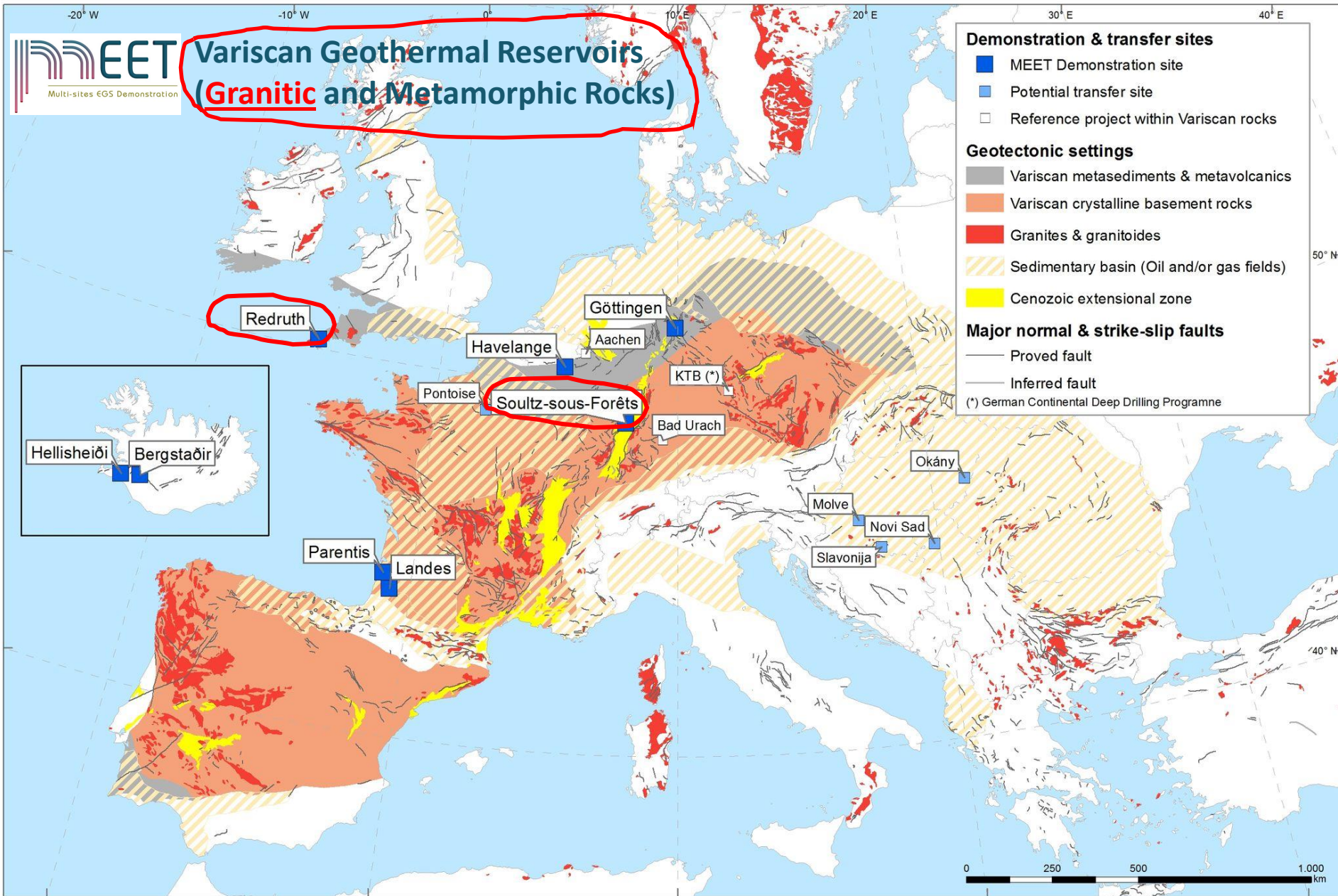
Analogue studies in what respect?

The **key features** of analogue studies need to be site-specificly defined considering e.g. the

- **Technical Readiness Level (TRL)** at power plant site (e.g. first exploration, improving an exploitation strategy or optimising an operating power plant)
- **level of previously existing data**
- scale-depending reservoir property **heterogenities** (scale-invariance) vertically and horizontally as well as in 2D or 3D
- **spatial resolution** of data needed (depends on reservoir type and exploitation strategy)
- **dimension of the target:** full reservoir size or specific elements as e.g. a characteristic fault zone
- **limitations in the comparibility** of the data gained from analogue studies and the reservoir rock itself (e.g. different tectonic setting and history or degrees of weathering, stress, temperature settings)
- **data needed** for a subsequent **reservoir modelling**



Exploration and exploitation of unconventional geothermal reservoirs in different geological settings



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Characterization of the four Variscan Reservoir types:

(1) Soultz-sous-Forêts demo site in Alsace, France and Noble Hills in California, US/ Upper Rhine Graben Valley, Germany as analogue site

Soultz-sous-Forêts is an EGS geothermal power plant utilising a **granitic reservoir** located in the Upper Rhine Graben structure, France. It is based on a former R&D site that was industrialised in 2016.

The current plant design is to produce 33 kg/s of hot brine at **160°C** and to deliver it to a binary cycle called an ORC (Organic Rankine Cycle) through 3 heat exchangers, in order to produce about **1.7 MWe** gross, i.e. 1.4 MWe net.

Objectives of MEET: To enhance productivity production from **fractured crystalline rocks** by e. g. (1) **lowering the brine reinjection temperature** down to 40°C and (2) **enhance the knowledge of the structural reservoir geometry and petrophysical properties**. This should not only help to optimise the production at the demo site, but to further exploit granitic reservoirs in this geological setting.



Source : EEIG Heat mining

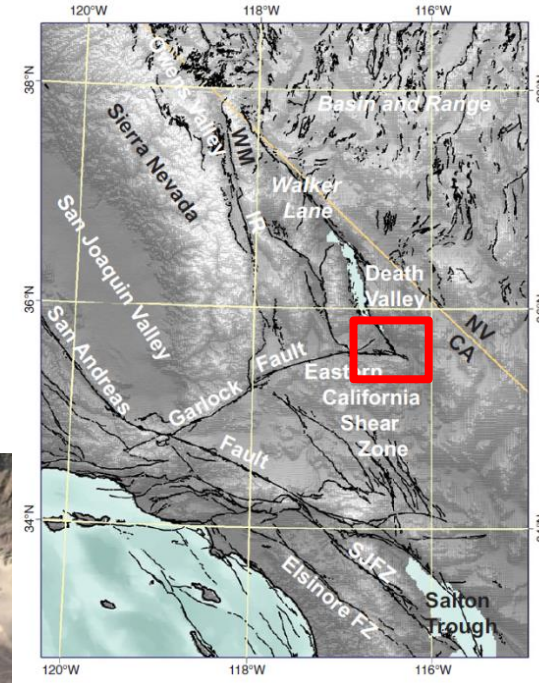


Characterization of the four Variscan Reservoir types:

(1) Soultz-sous-Forêts demo site in Alsace, France and Noble Hills in California, US/ Upper Rhine Graben Valley, Germany and France , as analogue sites

Norton, 2011

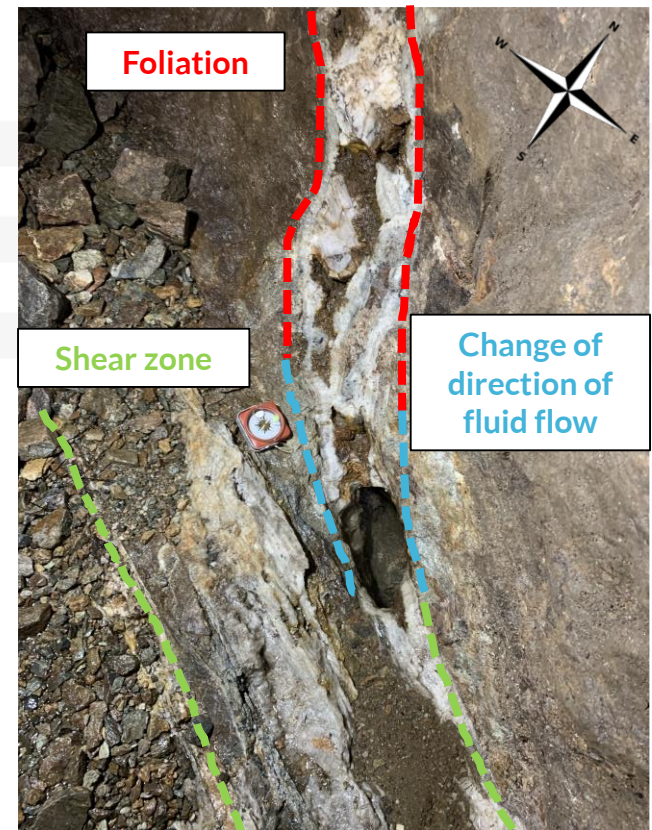
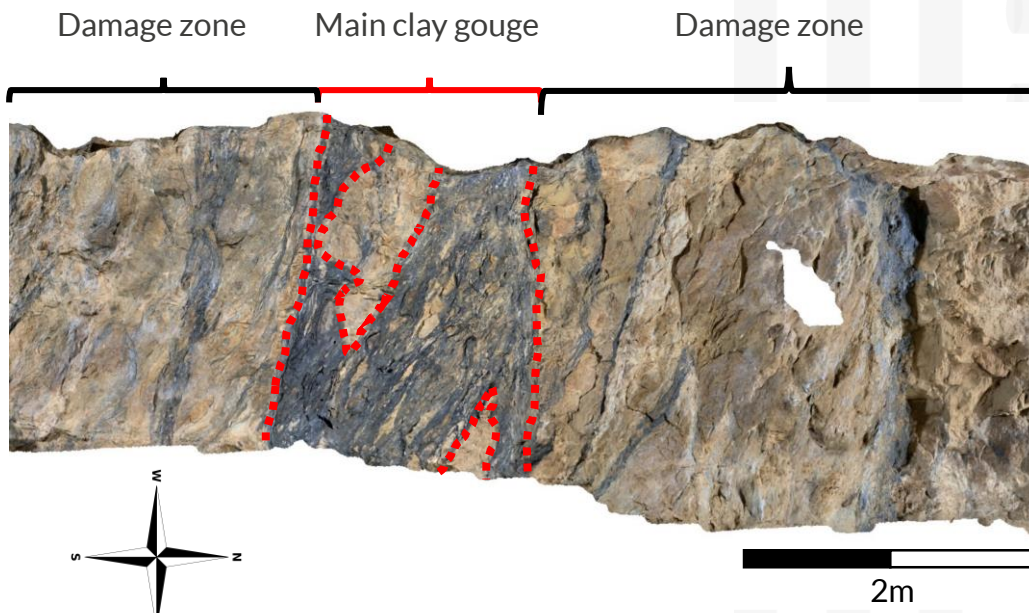
- *Main objective:* Characterization of the evolution of strike-slip zones affecting crystalline basement under progressive and fluid assisted deformation
- *Analogue site:* **Large-scale shear zone** in granites of the Noble Hills in the Death Valley, California, US (far field)
- *Investigations:* Drone survey based 3D-structural analyses, fluid rock interaction in terms of alterations and mineralizations, quantification of the deformation gradient and fracture systems
- *Conclusions:* Field surveys show a very high strain of the transcurrent Noble Hill shear zone. However, the deformation gradient allows to establish a detailed quantitative correlation between the fabric development, the fracture systems and the associated fluid circulation.



Characterization of the four Variscan Reservoir types:

(1) Soultz-sous-Forêts demo site in Alsace, France and Noble Hills in California, US/ Upper Rhine Graben Valley, Germany and France , as analogue sites

- *Main objective:* Characterization of the evolution of strike-slip zones affecting crystalline basement under progressive and fluid assisted deformation
- *Analogue sites:* Crystalline basement of the Sainte-Marie-aux-Mines mine in the Vosges Massif, France, and of the Schauinsland mine in the Black Forest, Germany (near field)
- *Investigations:* Characterization of local shear zones and mineralized veins relations
- *Conclusions:* Clay gouge zones as in the Noble Hills, obvious influence of the structural inheritance on the hydraulic behavior, lower fracture density than in the Noble Hills due to less strong deformation



Characterization of the four Variscan Reservoir types:

(2) United Downs Deep Geothermal Project as demo site and Cornubian granites as analogue sites, Cornwall, GB

General aim: Enable production of **power and heat** from the **Carmenellis granite**:

Two deep, directional **wells** have been drilled (2019):

- the **production well** UD-1 to 5275 m MD
- the **injection well** UD-2 to 2393 m MD.

Both wells have intersected the target Porthtowan Fault Zone through which a hydrothermal circulation is to be established.

Multiple hydraulic tests of both wells have been performed and are still ongoing:

- productivity and injectivity tests of UD-1
- injectivity tests of UD-2

Currently UD-1 is hydraulically (soft) stimulated.

Objective of MEET is to enhance fracture permeability by **chemical stimulation** and thus reservoir productivity.



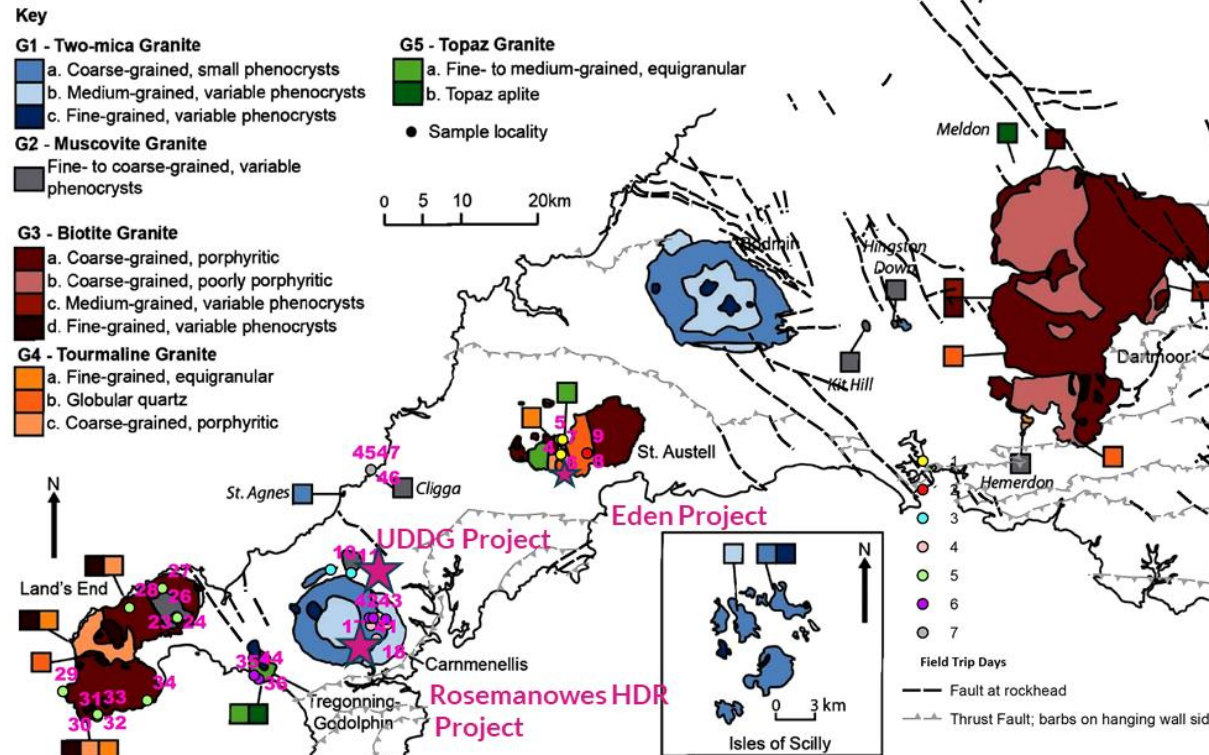
Bär 2019



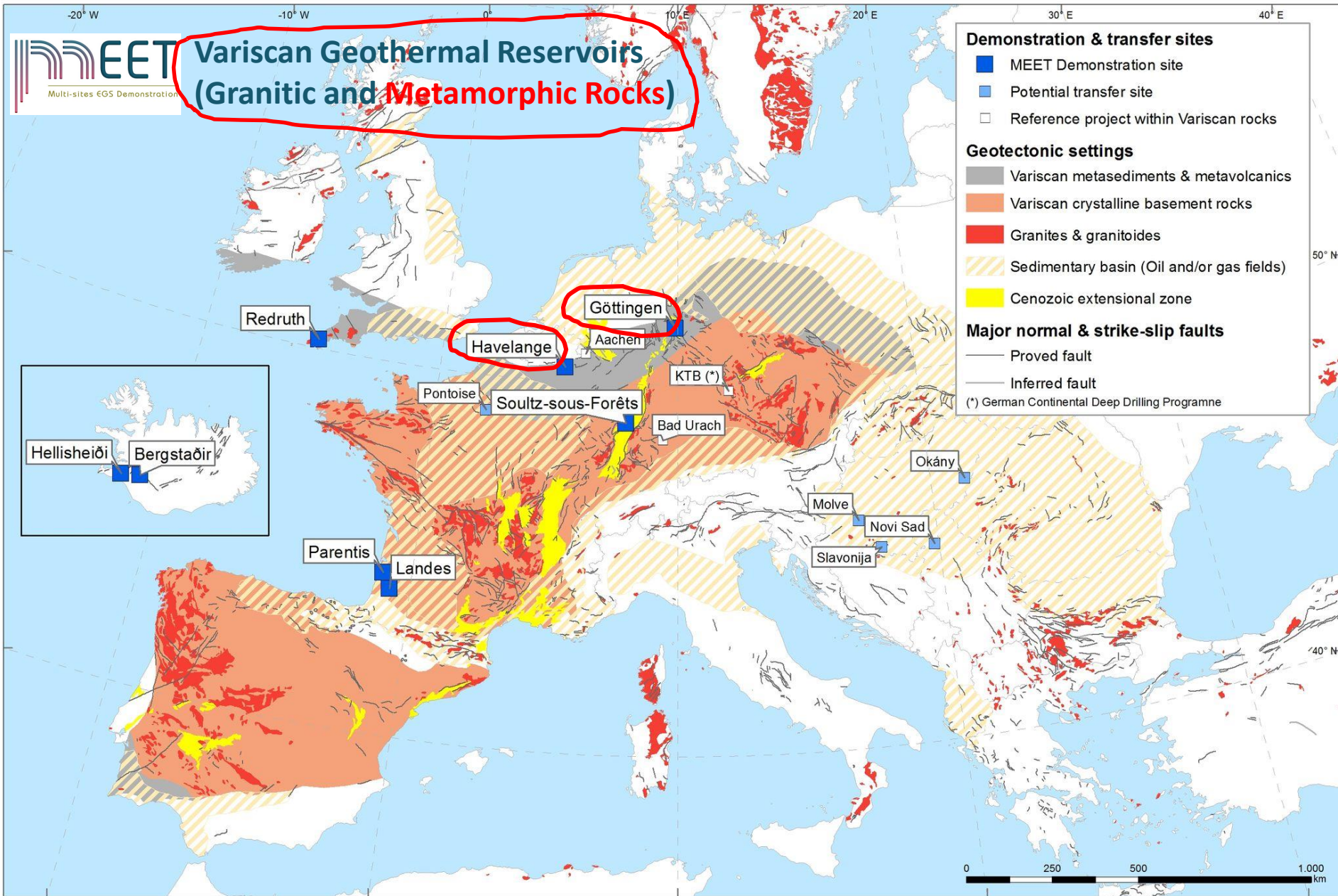
Characterization of the four Variscan Reservoir types:

(2) United Downs Deep Geothermal Project as demo site and Cornubian granites as analogue sites, Cornwall, GB

- *Main objective:* Regional geology for fault zone related reservoir characterization (e.g. size, fracture network, homogeneity); mineralogical, structural and geochemical impact on petrophysical and rock mechanical properties of the granites
- *Analogue sites:* Carnmenellis, Carn Brea, Carn Marth plutons as **near-field analogue sites** and Cligga, Land's End, St. Austell and Tregonning Godolphin plutons as **far-field analogue sites**
- *Investigations:* Collection of 47 samples from 35 outcrops, fracture network characterisation done in other projects
- *Conclusions:* Strong impact of **alterations** (hydrothermal vs. weathering); **ideal combination** of well exposed outcrops from active/ abandoned quarries or sea cliffs with information from 5 wells (UDDPG, Rosemanows): restricted transferability mainly due to weathering.



Exploration and exploitation of unconventional geothermal reservoirs in different geological settings



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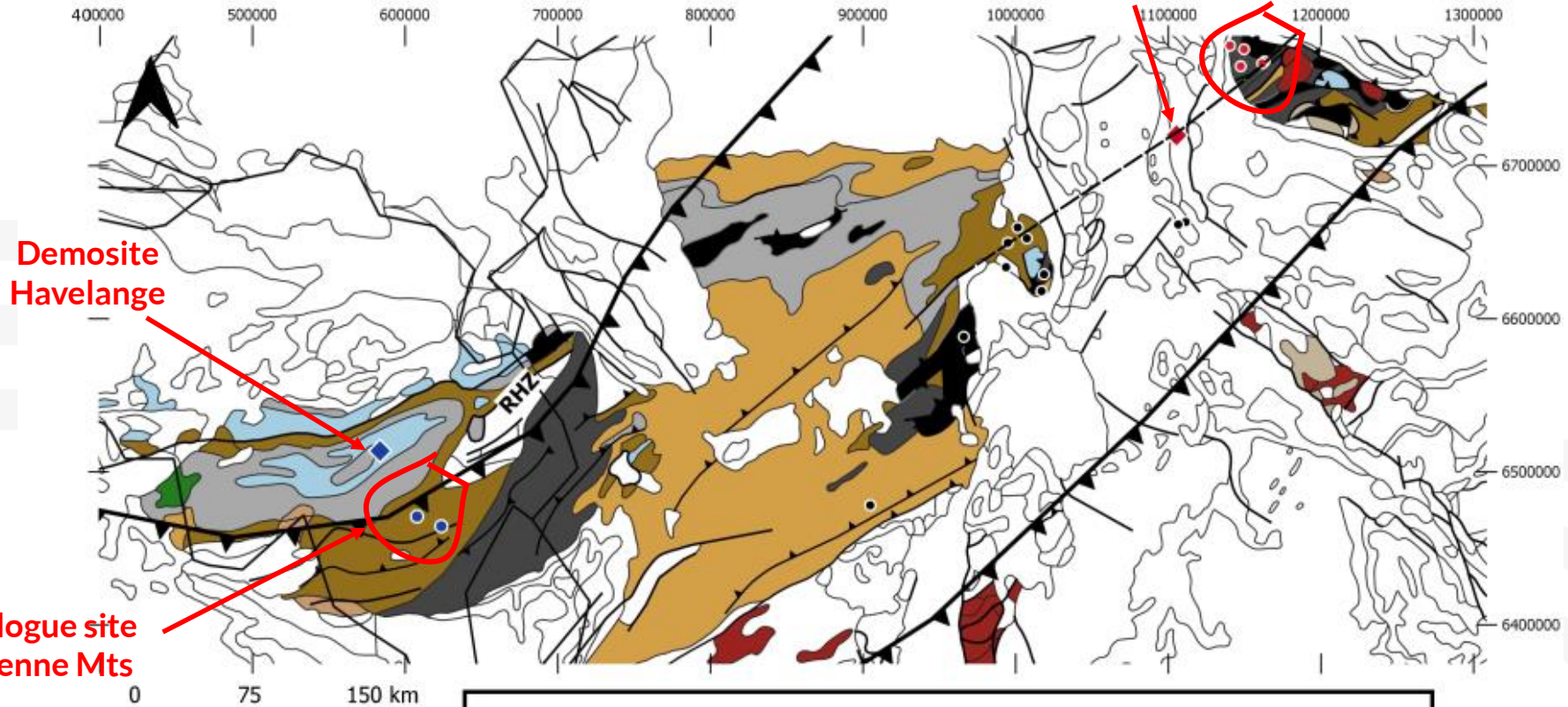
Characterization of the four Variscan Reservoir types:

(3 +4) Variscan metasedimentary and - volcanic rocks

Unvonventional Reservoirs

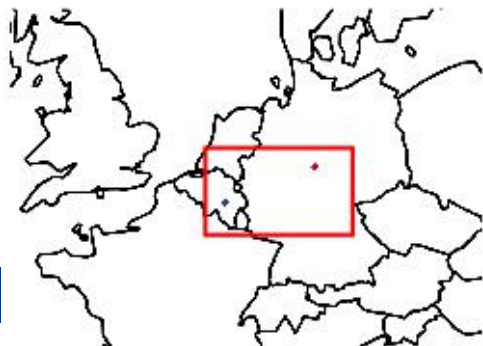
Demosite
Göttingen

Analogue site
Western Harz



Demosite
Havelange

Analogue site
Ardenne Mts



Sample Locations

- ◆ Goettingen Demosite
- Harz Mountains Samples
- ◆ Havelange Demosite
- Havelange Samples
- Rhenish Massif Samples

Boards

- country boards

Structures

- ▲ Rhenohercynian thrust zones
- fault
- strike/slip fault
- strike/slip fault dextral
- strike/slip fault sinistral
- ▲ thrust
- - Harz-Giessen nappe boundary

Variscan Geology

- carbonates, limestone, marl, chalk
- clay, silt and mudstones
- intrusive and plutonic igneous
- metamorphic, gneiss, phyllite
- meta-sediments and volcanics
- quartzite
- sandstone and conglomerates
- shale/slate
- volcanics



Characterization of the four Variscan Reservoir types:

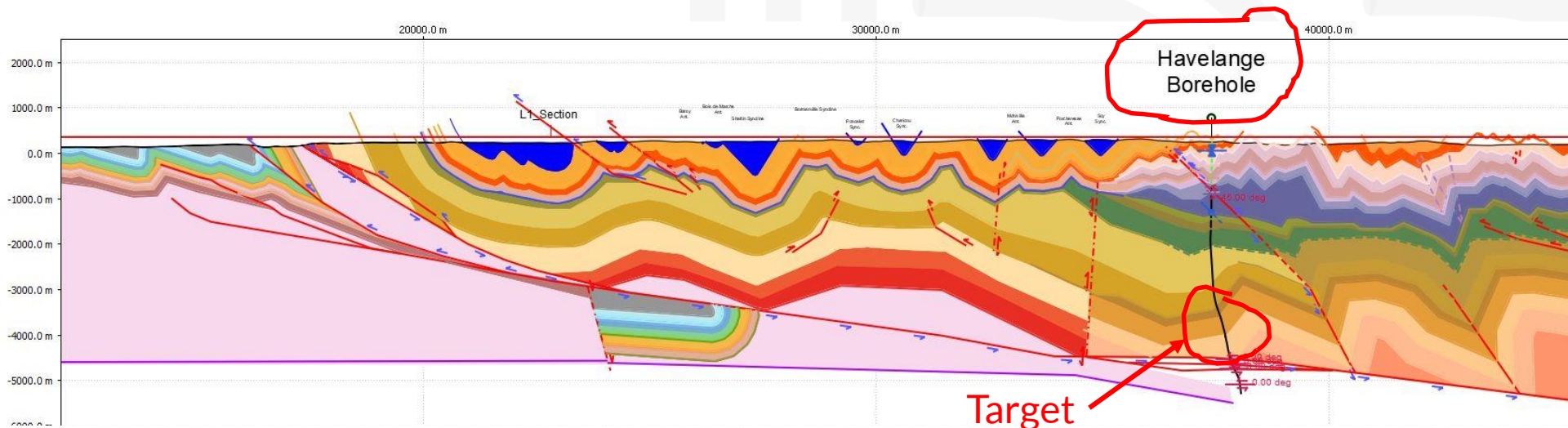
(3) Havelange demo site and Ardennes Mountains as analogue site, Belgium

The Havelange demo site is an **exploration well for natural gas** from the 1980's with a depth of **5648 m** (deepest well in Belgium)

This bore hole crosses **(meta-)sedimentary formations** from the Upper to Lower Devonian of the Rhenohercynian fold-and-thrust belt in the central part of the Dinant Synclinorium. The main décollement level (Midi Fault) was probably encountered

Main targets are the fractured Lower Devonian (Pragian) **quartzite units** between 4500 and 5400 m depth

Main objective is the **reopening of the well** for geothermal use (for research as well as for attracting consumers)



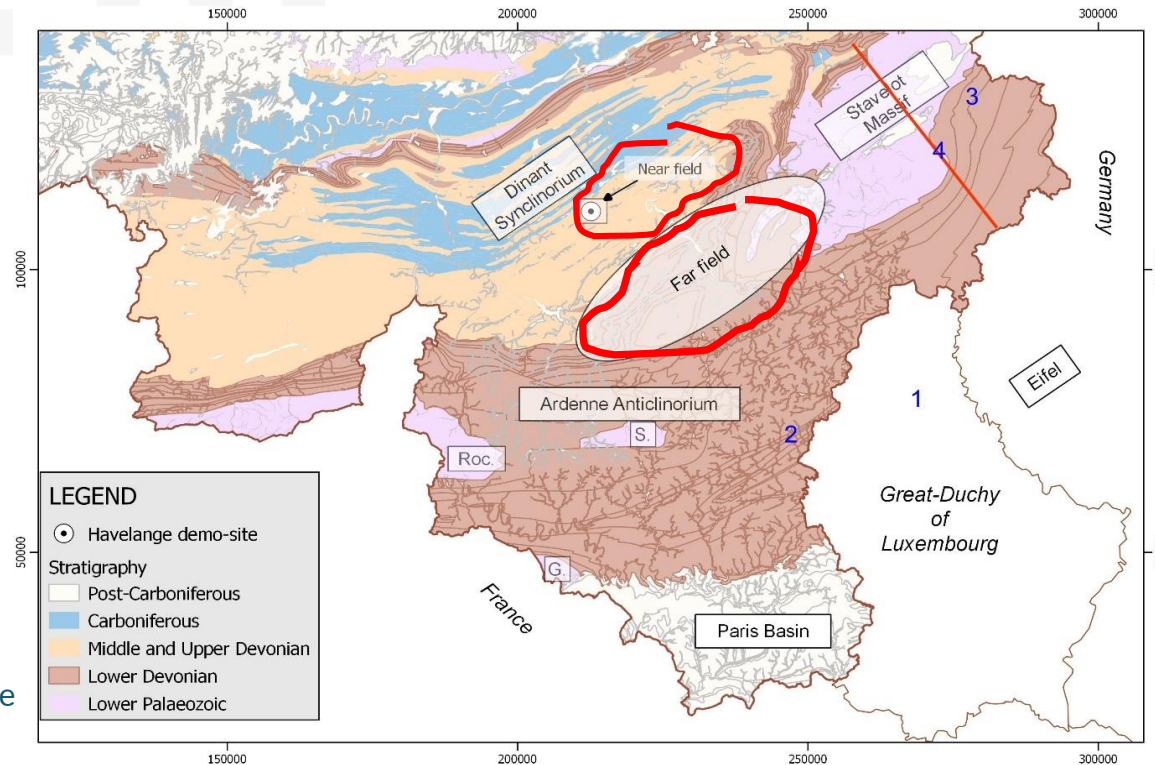
Characterization of the four Variscan Reservoir types:

(3) Havelange demo site and Ardennes Mountains as analogue site, Belgium

- *Main objective:* **Extension** of the **1D** well information to **2D+** or even 3D-structural reservoir model
- *Analogue site:* **Ardenne Allochthon** with the area directly around the well as 'near field' and the South and South-East of the Dinant Synclinorium as 'far field'
- *Investigations:* Drone survey for 3D-structural analyses (near field), lithology-related fracture network characterisation, water sampling campaign (physicochemical parameters, geochemistry), peak temperature analyses, petrophysical analysis

- *Conclusions:* **Improved 3D-model**, but with defined limits; heterogeneities and deformation sequence better defined; **differences in fracture density and directions** in well and analogue site are due to weathering and different stresses as well as different burial histories

Simplified geological map of the Ardenne Allochthon in southern Belgium



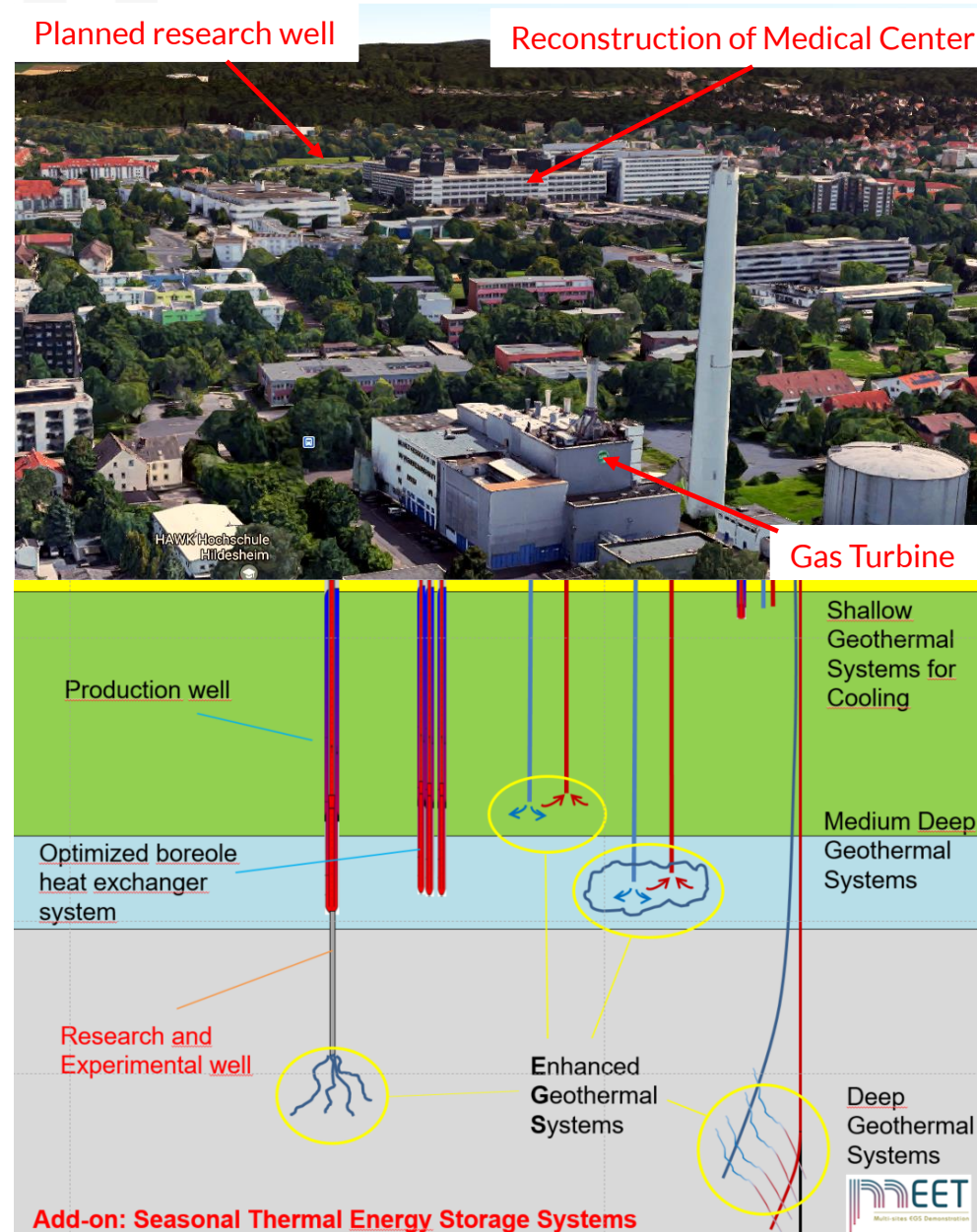
Characterization of the four Variscan Reservoir types:

(4) Göttingen demo site and Western Harz Mountains as analogue site, Germany

Heat supply for the campus infrastructure of the University of Göttingen (including the University Medical Centre) is **actually provided** by a natural gas based, combined heat and power plant (220 GWh/year heat).

In the course of the complete, stepwise reconstruction of the Medical Centre within the next 20 years, we aim to incorporate an integrated “**Enhanced Geothermal System**” for the heat supply including a seasonal thermal energy storage system at shallow and/or medium deep levels.

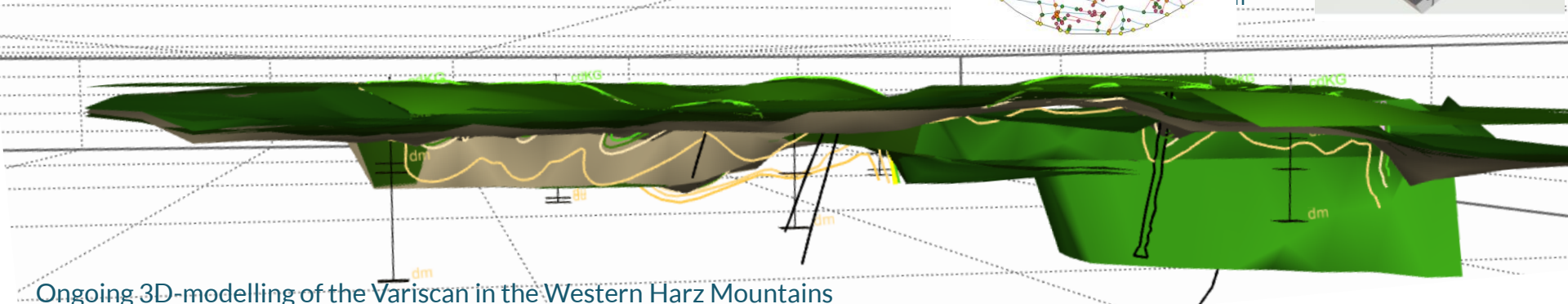
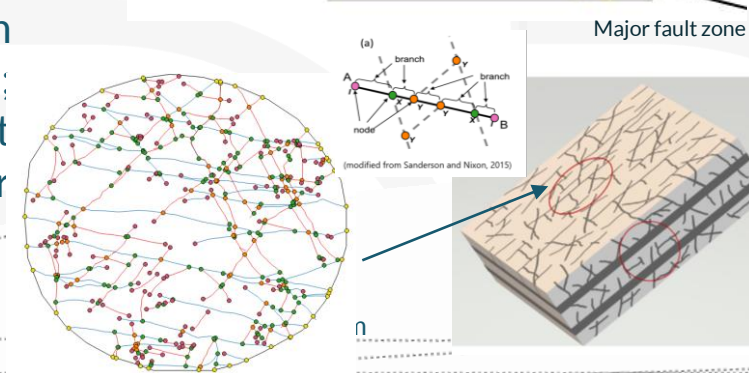
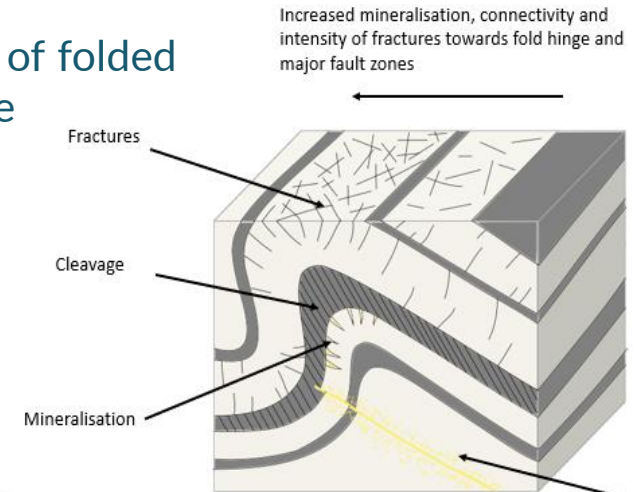
Main objective: Challenge and chance at this location is the exploration and exploitation of geothermally **unconventional reservoirs** at deep and medium deep levels.



Characterization of the four Variscan Reservoir types:

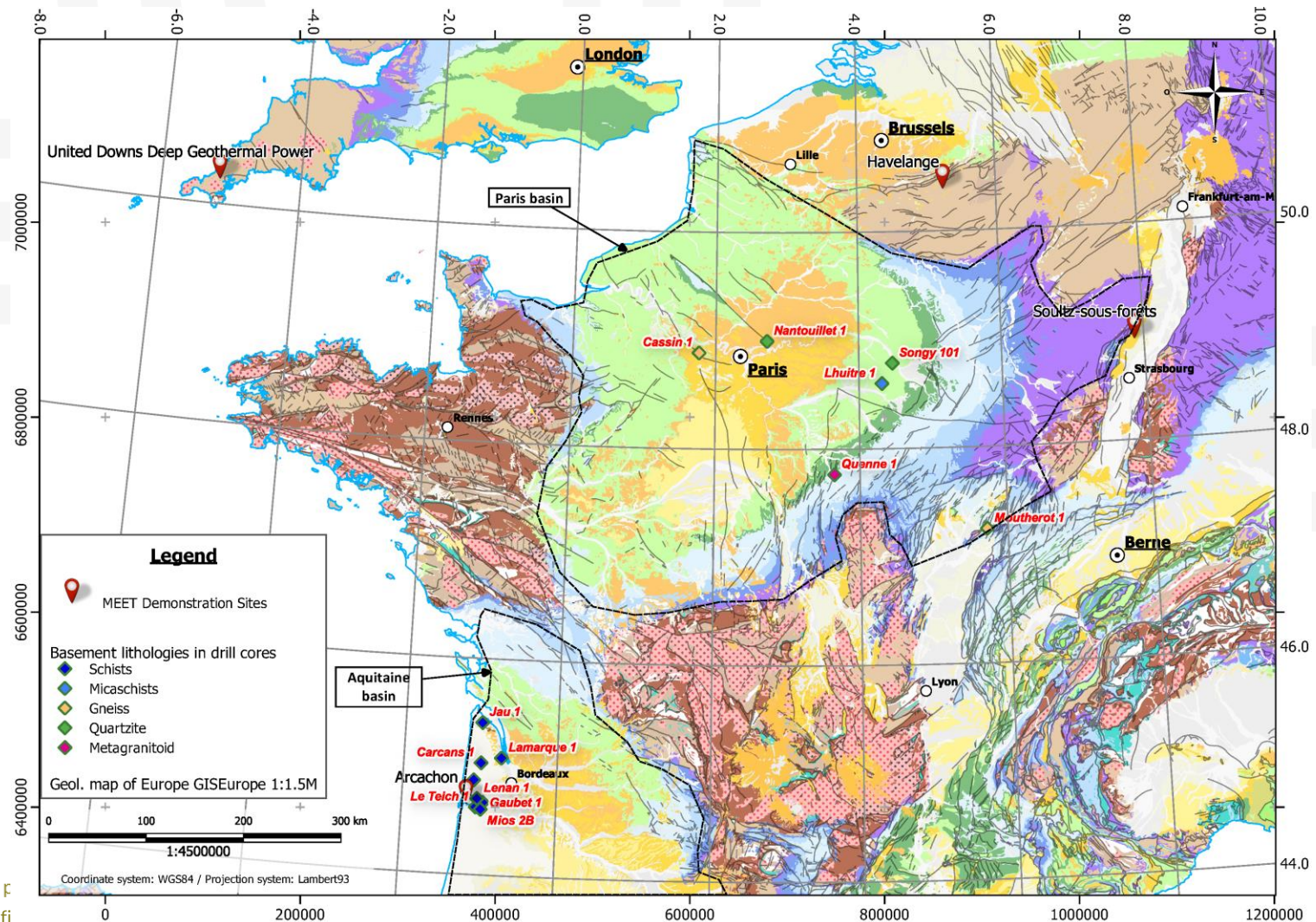
(4) Göttingen demo site and Western Harz Mountains as analogue site, Germany

- *Main objective:* Lithological and structural conceptual model of folded and thrustured greywacke-slate intercalations at reservoir scale
- *Investigations:* 2D and 3D field surveys (drones, LIDAR etc.) at outcrop scale at surface to be combined with , underground and well core data analyses, structure and lithology related fracture pattern and vein analyses, subsidence and exhumation history in view of paleo-hydrothermal systems
- *Conclusion:* early stage of an unconventional exploration approach to a new type of reservoir (play type); analogue studies help to define reservoir-relevant lithological/structural settings on a conceptual basis for stimulations



Characterization of the four Variscan Reservoir types:

(5) Complementary well core samples from the basement of the Aquitaine and Paris Basin, France, to bridge the gap between the outcropping Variscan rocks in Belgium and Southwest-England.



Characterization of the four Variscan Reservoir types:

(5) **Complementary well core samples from the basement of the Aquitaine and Paris Basin, France, to bridge the gap between the outcropping Variscan rocks in Belgium and Southwest-England.**

The well core data were acquired on **13 deep boreholes** reaching the basement of Paris and Aquitaine basins during exploration campaigns in the 1980's with depth **between 950 and 4150 m**. Boreholes cross **meta-sedimentary formations on both sides of the French Variscan belt**.

General objective is the **investigation of fluid-rock interactions and structural patterns** as underground geothermal laboratories for potential transfer from demo-sites to other target areas (for research purpose mostly)

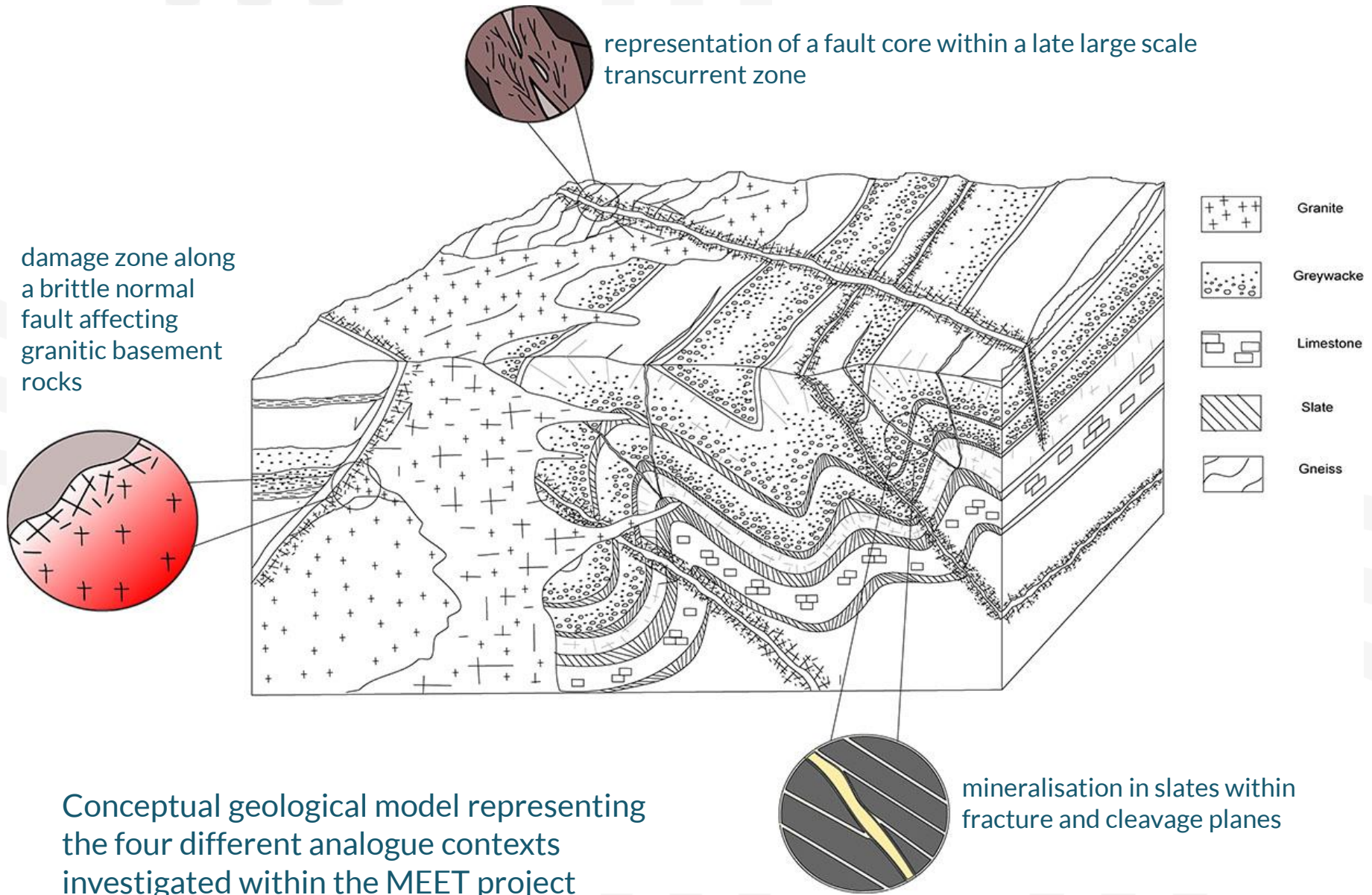
- **Main objective in MEET: Rock characterization of basement rocks under deep sedimentary basins as a 1st such database**
- **Investigations:** Raman spectroscopy (peak temperatures and mineral identification), petrophysical parameters, magnetic susceptibility, calcite content, petrographical analysis
- **Conclusions:** All 52 samples indicate greenschist facies ($T_{\max} \sim 470-500^{\circ}\text{C}$ in Raman), hydrothermal overprint and intense shearing; microstructures of an initial protolith are overprinted by brittle deformation features; tight rocks with discontinuities (e.g. Ca-rich fractures)





Conclusions of the outcrop analogue evaluation





Conceptual geological model representing the four different analogue contexts investigated within the MEET project (from Deliverable 5.4)



Conclusions

- Studies of reservoirs and on according **well-selected reservoir analogues** create a sound database for predicting **reservoir characteristics** in the deeper subsurface
- Such studies are particularly useful in **areas with little information** from wells in order to **reduce the risk of exploration**
- The following points need to be considered when using outcrop analogues for reservoir characterization:
 - lithostatic loading or stress relief due to erosion/exhumation
 - in-situ stress conditions, regime,
 - orientation and offset of the fault zone
 - pore pressure
 - history of subsidence/uplift and deformation
 - interactions with (paleo-)fluids (solution/precipitation/alteration) and
 - thermal evolution through time
- Especially where **no sufficient exploration data is available**, analogue studies are a **useful, low-cost tool to reduce** the risk of exploration and exploitation



References

Bär, K., Reinsch, T., Bott, S. (2020): THE PETROPHYSICAL PROPERTY DATABASE (P³) – A GLOBAL COMPILATION OF LAB-MEASURED ROCK PROPERTIES. Earth Syst. Sci Data, 12, 2485-2515, <https://doi.org/10.5194/essd-12-2485-2020>.

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Trullenque G., Bär K., Turan A., Schulz K., Leiss B., Ford F., Reinecker J. and Vanbrabant Y., (2020): EVALUATION OF OUTCROP ANALOGUES OF THE FOUR VARISCAN RESERVOIR TYPES. Public Deliverable 5.4 of the EU-H2020 project MEET, 48 pp.

Trullenque G., Genter, A., Dalmais, E. (2020): EVALUATION OF CRYSTALLINE OUTCROP ANALOGUE. Public Deliverable 3.4 of the EU-H2020 project MEET, 26 pp.

Deliverables are publicly accessible soon,
e.g. via ZENODO

https://zenodo.org/communities/eu_project_meet
or send us an e-mail:

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YOUR ATTENTION**

