ASSESSING THE SUBSURFACE UNCERTAINTY IN THE SCREENING PHASE OF THE SITE SELECTION PROCEDURE

Screening the subsurface for a geological repository location for high-level radioactive waste

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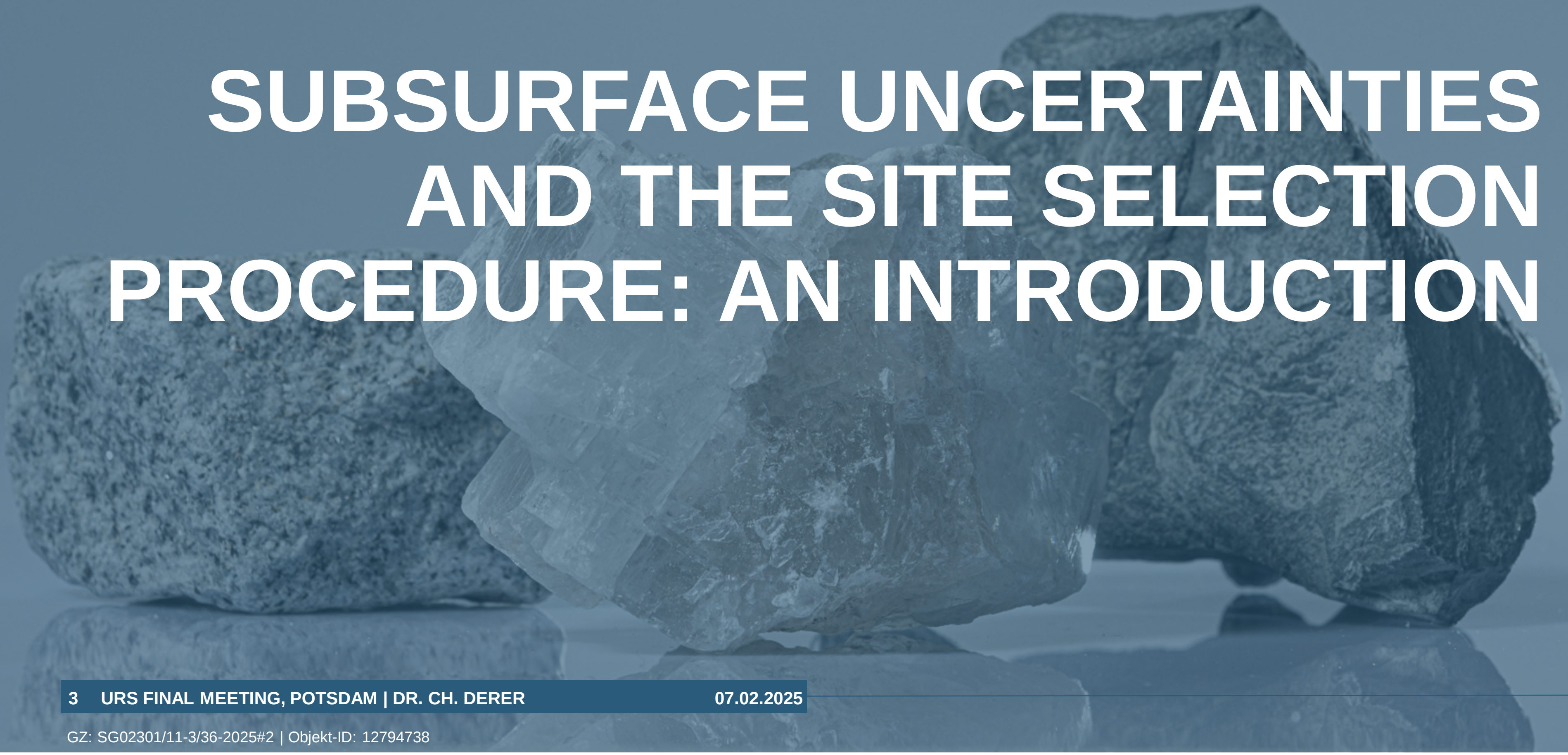
BGE BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

URS Final Meeting, Potsdam 05–07.02.2025

GZ: SG02301/11-3/36-2025#2 | Objekt-ID: 12794738

AGENDA

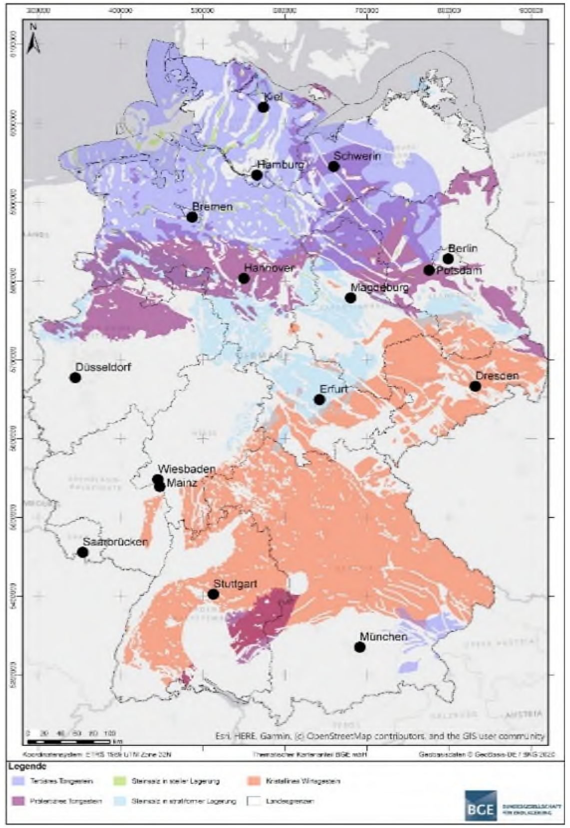


SUBSURFACE UNCERTAINTIES AND THE SITE SELECTION PROCEDURE: AN INTRODUCTION

01

SUBSURFACE UNCERTAINTIES IN THE SITE SELECTION PROCEDURE

- Approximately 54% of Germany´s subsurface needs to be screened in order to identify a reduced number of relatively small-sized site regions
- Considered host rocks: claystone, rock salt, crystalline rocks
- BGE and Terra Geoservice developed a consistent way of efficiently assessing the subsurface uncertainty of large areas and across the various host rocks
- The evaluation of subsurface uncertainties can be used for:
  - a consistent, uncertainty weighted, comparison of areas
  - assessing the safety robustness of high-potential areas
- Subsurface uncertainties will be assessed only if they are relevant to the decisions to be made in the selection process



Claystone
Diapiric rock salt
Bedded rock salt
Crystalline rock

Source: BGE

SCALE-DEPENDENT METHODS OF HANDLING THE SUBSURFACE UNCERTAINTIES DURING THE PRELIMINARY SAFETY ASSESSMENT

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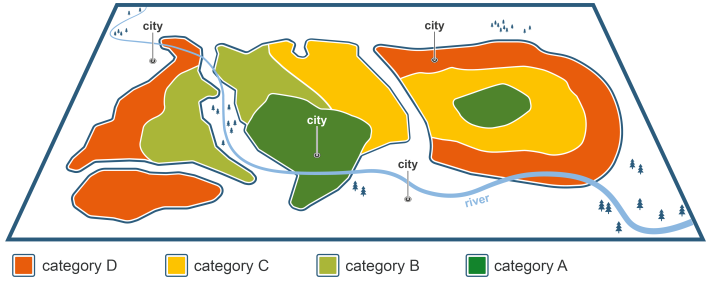


Uncertainty register “Umbrella”

Quantitative method in high-potential areas

Semi-quantitative method for large regions

Detailed geol. models

Assessment Step 1	Assessment Step 2	Assessment Step 3	Assessment Step 4a	Assessment Step 4b
Exclusion criteria and minimum requirements	Qualitative assessment of the safe containment	Quantitative assessment of the safe containment	Integrated safety assessment first part	Integrated safety assessment second part
Requirements fulfilled	Predominantly good evaluation	Threshold criteria met	Predominantly good evaluation	Best suitability

Category A

Category D
Not suited

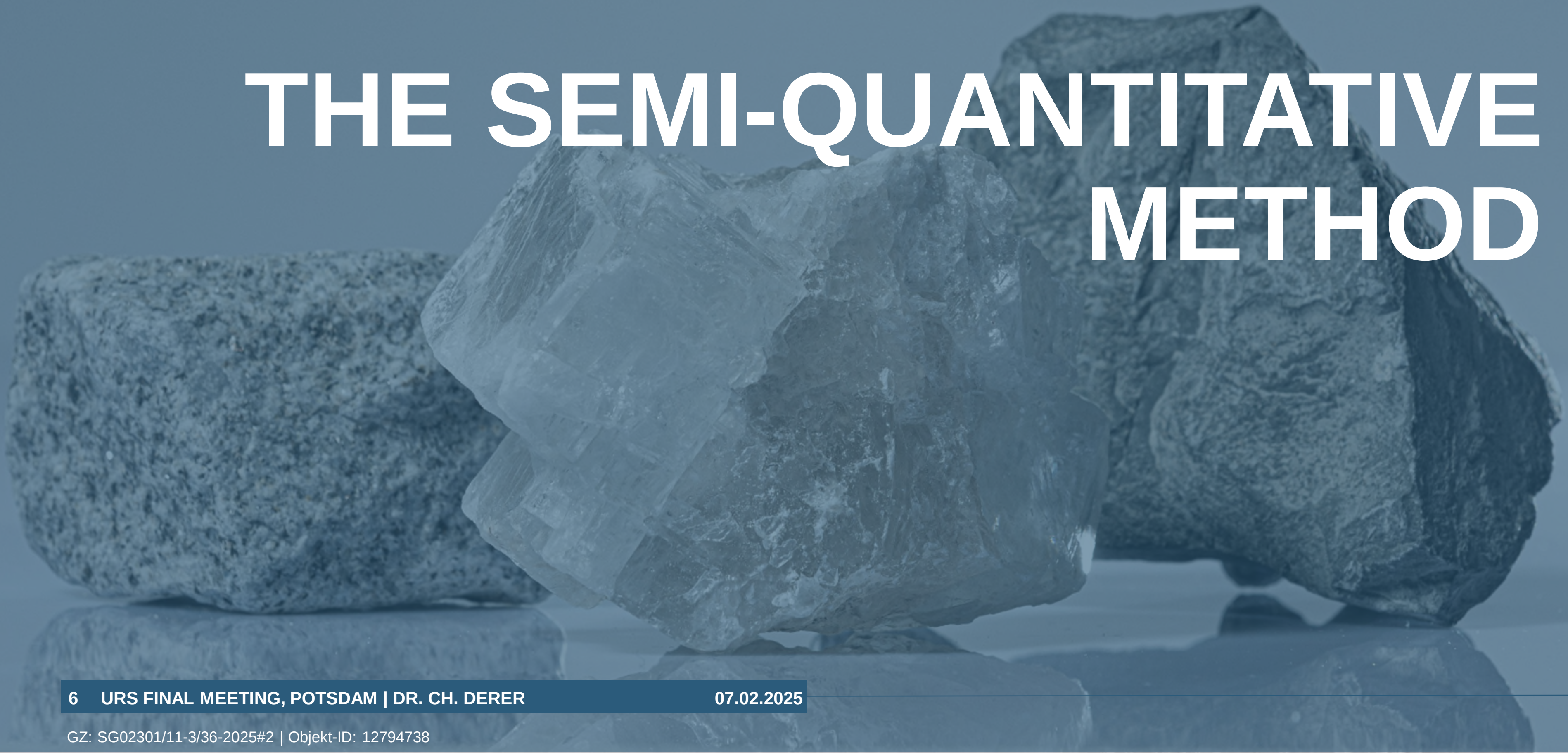
Category C
Not suited – low suitability

Category B
Good suitability

Source: BGE

THE SEMI-QUANTITATIVE METHOD

02



THE DEGREE OF CONFIDENCE: A SEMI-QUANTITATIVE METHOD

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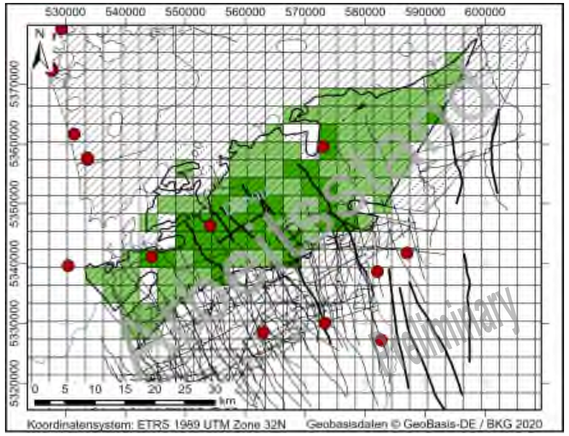
- The **degree of confidence** represents the **reliability** of a given interpretation of the subsurface in a particular area
- The **degree of confidence** is estimated via the data status and the geological complexity of any given area or structure (i.e., salt diapir)
- Subdivides large areas in 9 km^2 grid cells of varying degrees of confidence
- The degree of confidence allows a weighted comparison of different areas and host rocks
- Is a modified approach from the hydrocarbon exploration “chance adequacy matrix” (Rose 2001)



“Degree of Confidence” Matrix

Geological complexity				
Complex	Moderate	Simple		Data quantity and quality
85	90	95	Very good	
70	80	90	Good	
50	65	80	Mode-rate	
30	50	70	Poor	
5	30	60	Very poor	

Source: Modified from Terra Geoservice

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

THE DEGREE OF CONFIDENCE: THE WORKFLOW

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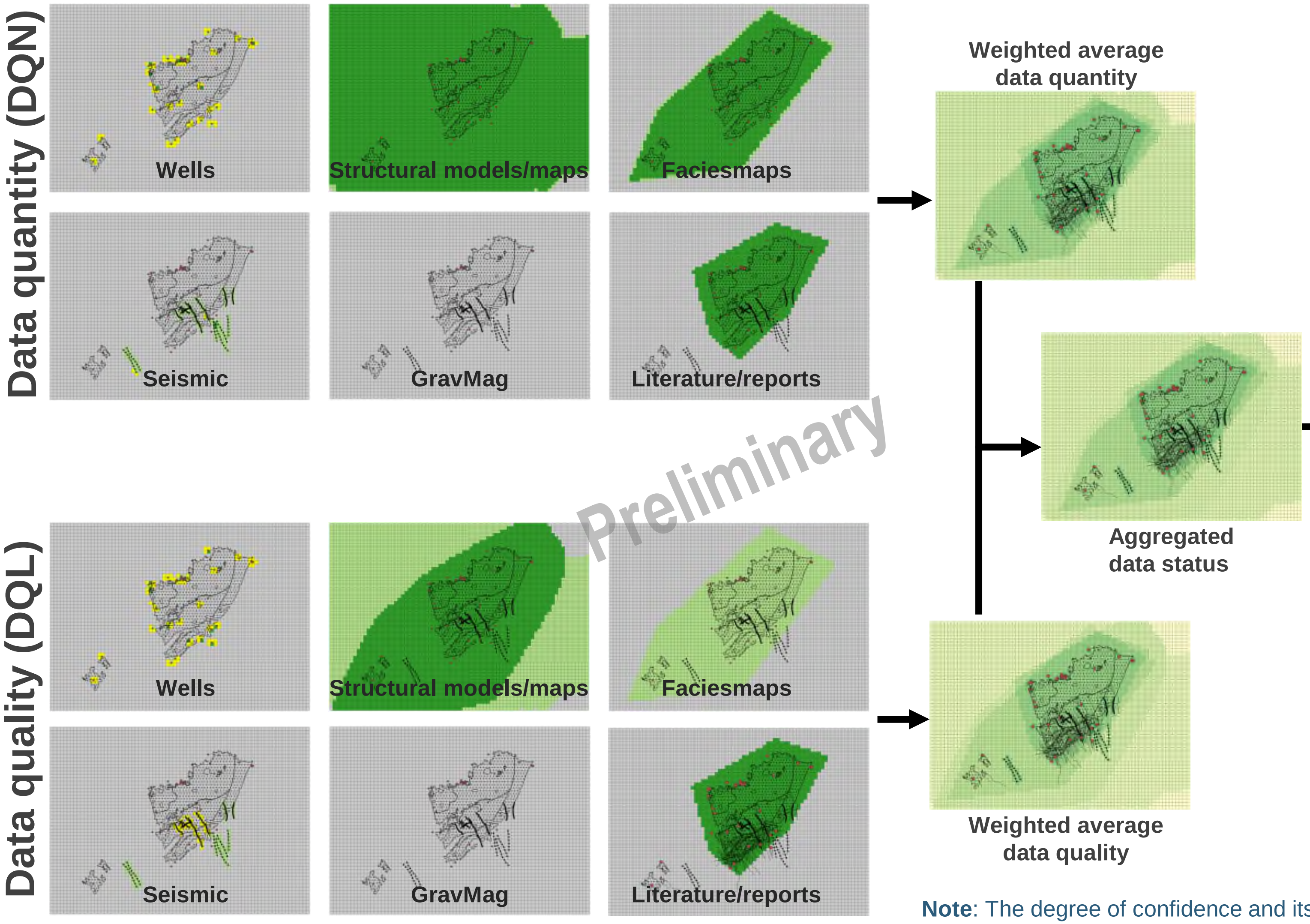

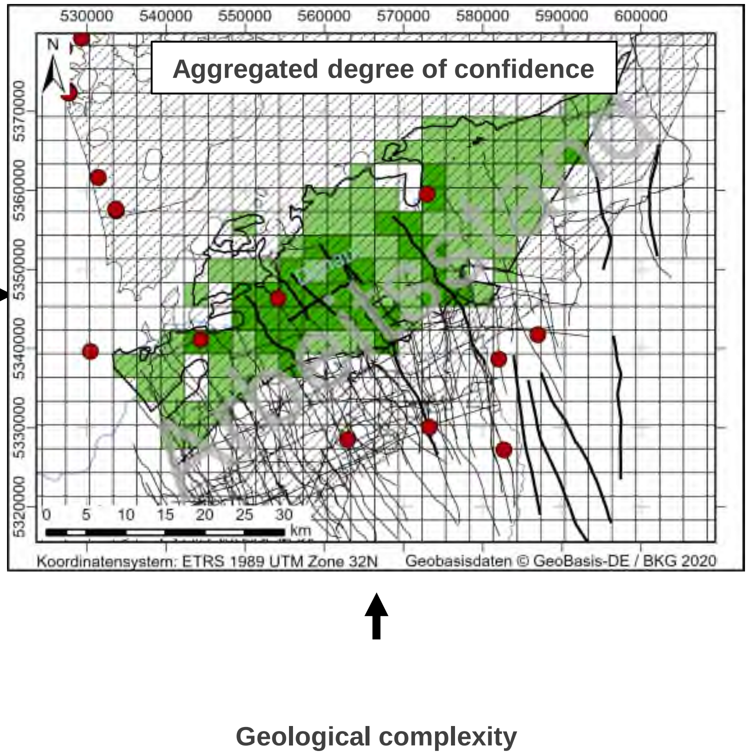

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

Source: Modified from Terra Geoservice

Data quantity	Indicator	Weighting: Geo-metry	Weighting: Facies	Weighting: Total	Categories: High (1.0)	Categories: Medium (0.8)	Categories: Low (0.6)	Categories: No data (0.5)
Wells, outcrops	Density	5	5	5	> 1 Well / 10 km2 in the host rock	1 Well / 10 km2	0 Wells / 10 km2	No data
Seismic	Areal coverage	3	1	2	Majority of area covered with 3D-seismic. Very dense 2D-line grid (>5 lines km / 10 km2)	Dense 2D-line grid (0.1 to 5 lines km / 10 km2); partly covered with 3D-seismic	Very sparse 2D-line grid	No data
Data quality Wells, Outcrops	Vintage, logs, cores	5	5	5	Younger than 1980; modern logs , cores	1950-1980	Before 1950; no modern logs, no cores	No data
	Stratigraphy				Penetrate top/base of target formations	Top/basis penetrated, but no internal stratigraphy	Only top penetrated	
	Lithology & petrography				Detailed stratigraphy and petrographic interpretation available	Detailed stratigraphy, but petrographic info. partly available	Only basic stratigraphy available	
Data quality Seismic	Acquisition, processing	5	3	4	3D or modern 2D seismic. Reprocessed (after1980) time- or depth migration	2D seismic (1950 – 1980), time-migration, metadata available	2D stacks only (before 1950), no metadata	No data
	Resolution, calibration, interpretation				(Near)Target horizons well imaged, good seismic-well tie.	(Near)Target horizons discernible. Uncertain correlation to wells.	(Near)Target horizon not well imaged, poor well tie	
	Time-depth conversion				Simple layer-cake velocity model, plenty of well control, certain depth depiction	Medium complexity in the overburden, robust time-depth conversion	High complexity, high uncertainty of depth depiction	

Source: Modified from Terra Geoservice

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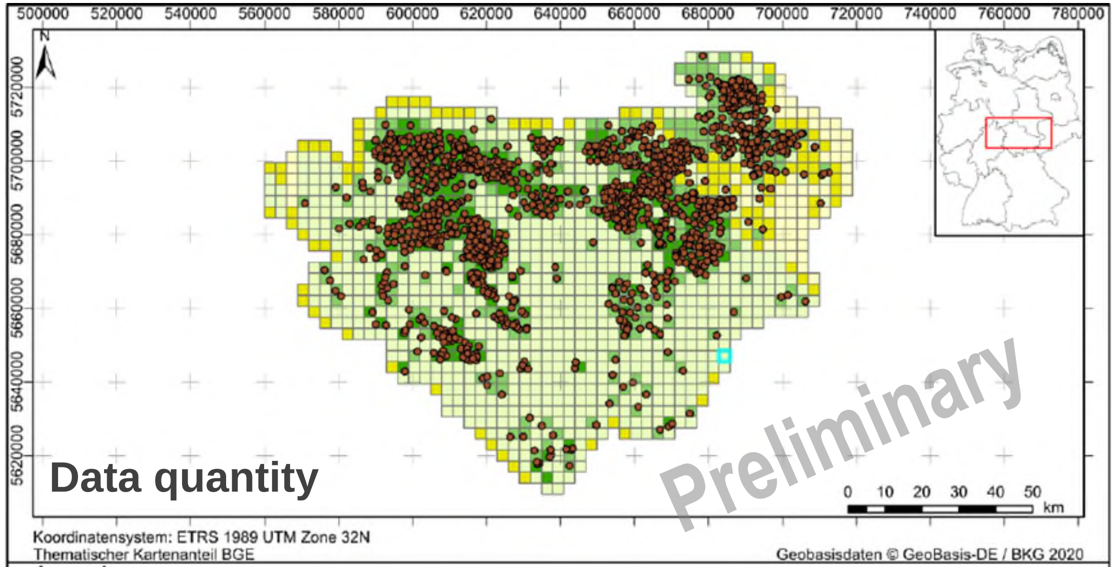
CLASSIFICATION OF DATA QUANTITY AND QUALITY

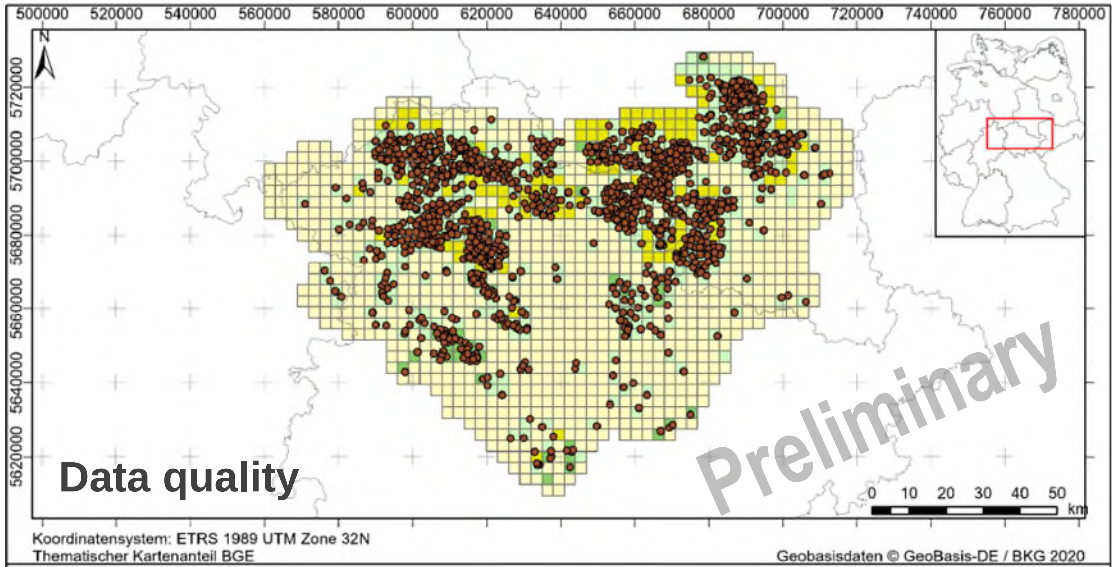
- The classification of data performed via strict and consistent criteria
- **Data types**:
  - Wells, mines, outcrops
  - Seismic survey
  - Gravimetric / magnetic survey
  - Structural models
  - Expert maps (e.g facies)
  - Studies, literature
- Weighting of data types dependent on the host rock

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

ESTIMATING DATA QUANTITY AND QUALITY

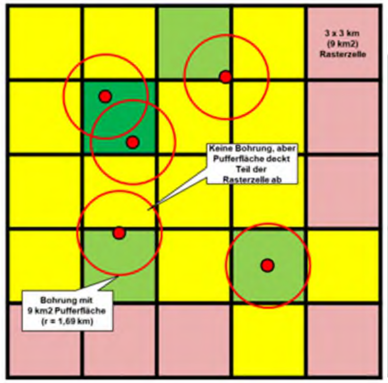


Legend
Wells
0.6
0.7
0.8
0.9
1



Legend
Wells
State boundary
0.6
0.7
0.8
0.9

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.



Data	Indicator	Weighting			Categories			
		Geometry	Facies	Final	High (1,0)	Medium (0,8)	Low (0,6)	No data (0,5)
Wells, mines, outcrops	Density	5	5	5	>1 Well / 10 km2 in the hostrock	1 Well / 10 km2	0 Wells / 10 km2	No data

Data	Indicator	Weighting			Categories			
		Geometry	Facies	Final	High (1,0)	Medium (0,8)	Low (0,6)	No data (0,5)
Wells	Vintage, logs, cores	5	5	5	Younger than 1980; modern logs, cores	1950-1980	Older then 1950; no modern logs, cores	No data
	Relevant stratigraphy				Penetrate top/base of target formations	Top/basis penetrated, but no internal stratigraphy available	Only top penetrated	
	Relevant lithology & petrography				Detailed stratigraphy and petrographic interpretation available	Detailed stratigraphy, but petrographic interpretation only partly available	Only basic stratigraphic interpretation available	

Source: BGE

CLASSIFICATION OF THE GEOLOGICAL COMPLEXITY: CLAYSTONE AND CONFORMABLE SALT STRATA

BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

	Factors	Simple	Moderate	Complex
Lithology / facies	Basin type and evolution	Regional, simple depocenter		Varying small-scaled depocenters, syn-sedimentary tectonics and erosion
	Palaeogeography	Basin center		Basin margin
	Depositional setting, facies, diagenesis	Homogenous lithofacies on scale > 100 km²; uniform diagenesis		Heterogeneous facies, with unfavorable intercalations. Frequent lateral and/or vertical lithofacies variations
Tectonic and structure	Regional structural setting (tectonics, deformation)	Regionally uniform		Locally variable
	Degree of structural deformation, fault density	Horizontal or regional low-angle dipping formations. Low fault density.		Numerous regional and sub-regional faults, sub-regional tectonics with numerous fault blocks
	Regional subsidence and/or uplift history	Simple tectonics, simple subsidence and/or uplift		Polyphase tectonics (e.g. inversion), with varying stress-regime and complex thermal history

Source: Modified from Terra Geoservice

- The geological complexity is estimated on regional (basin, sub-basin) scale
- The geological complexity is given by two elements:
  - Regional variations of facies
  - Regional variations of structural (deformation) features

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

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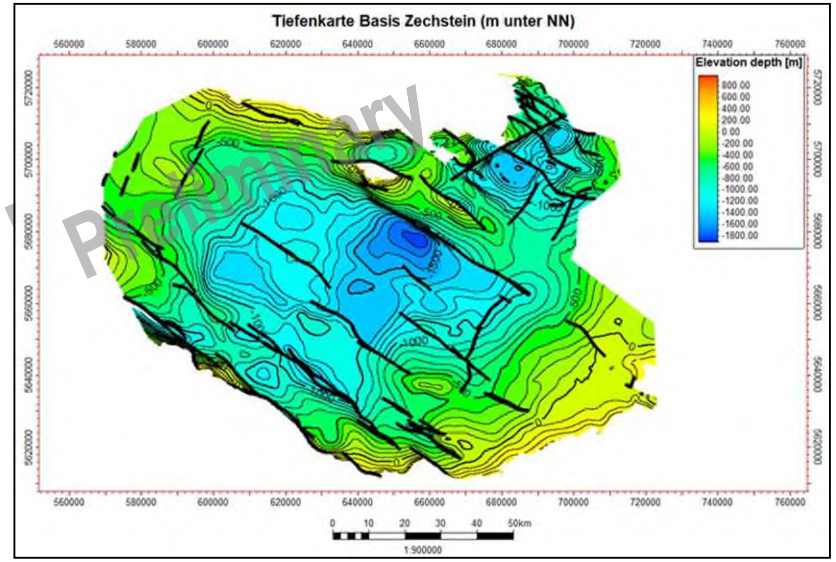
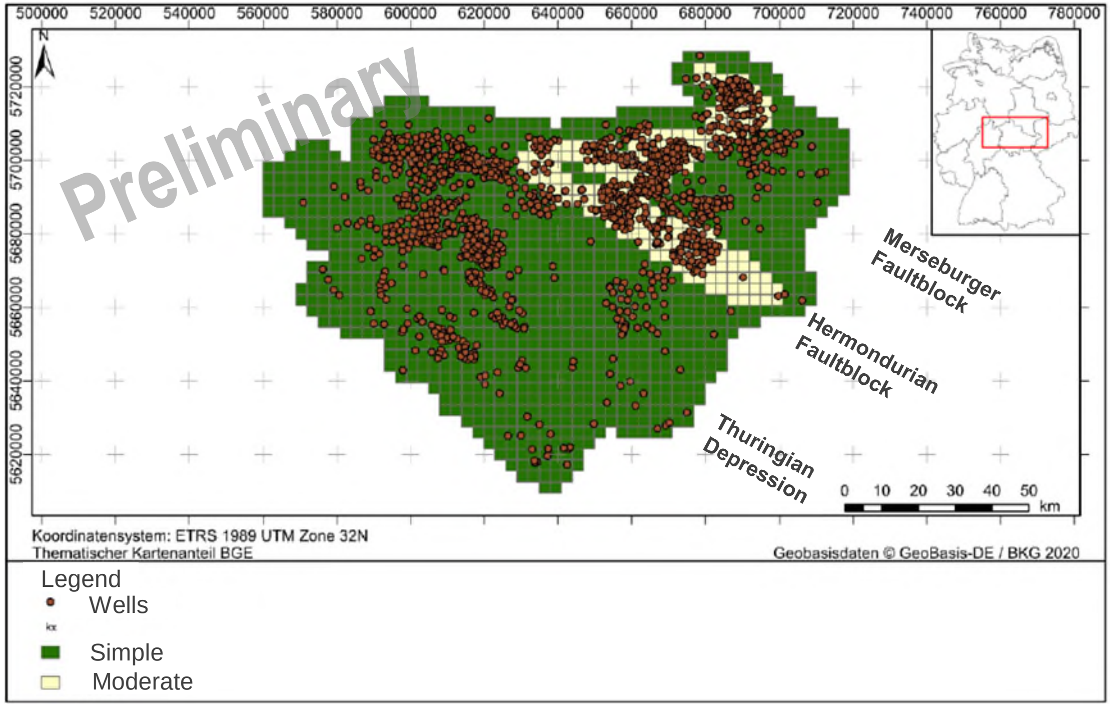
ESTIMATING THE GEOLOGICAL COMPLEXITY



- Structural map



- Estimated geological complexity

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

Source: BGE

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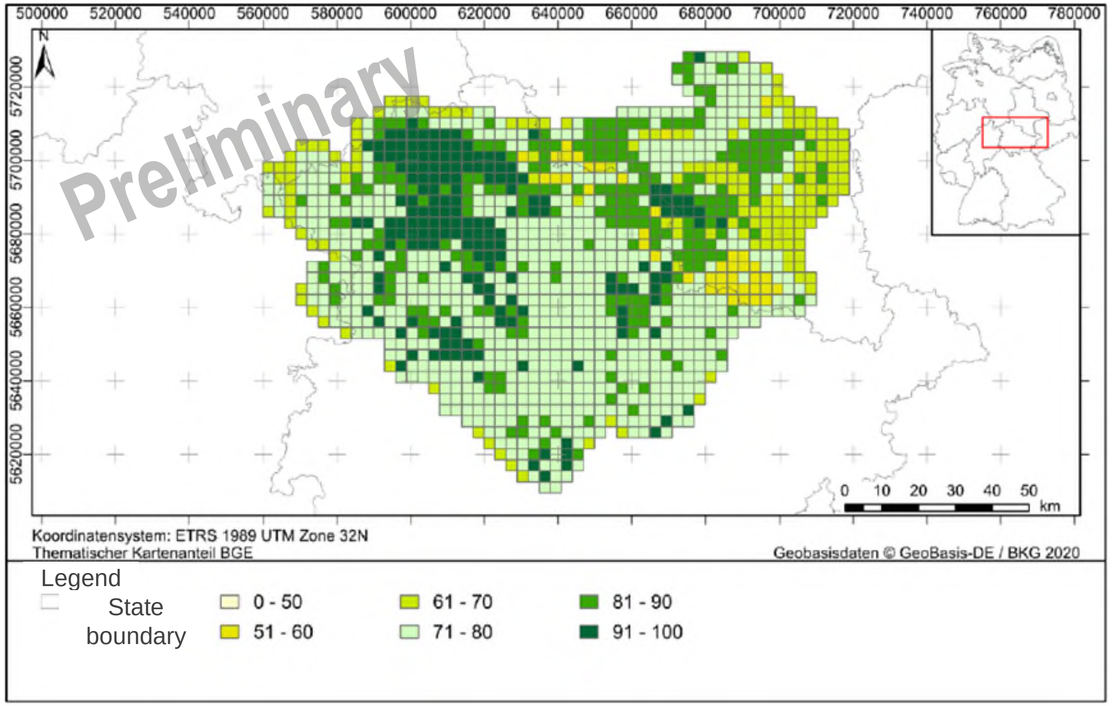
THE AGGREGATED DEGREE OF CONFIDENCE

Geological complexity				
Complex	Moderate	Simple		Data quantity and quality
85	90	95	Very good	
70	80	90	Good	
50	65	80	Mod-erate	
30	50	70	Poor	
5	30	60	Very poor	



- The aggregated degree of confidence

Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

Source: BGE

DEGREE OF CONFIDENCE: DETAILED AND AVERAGE

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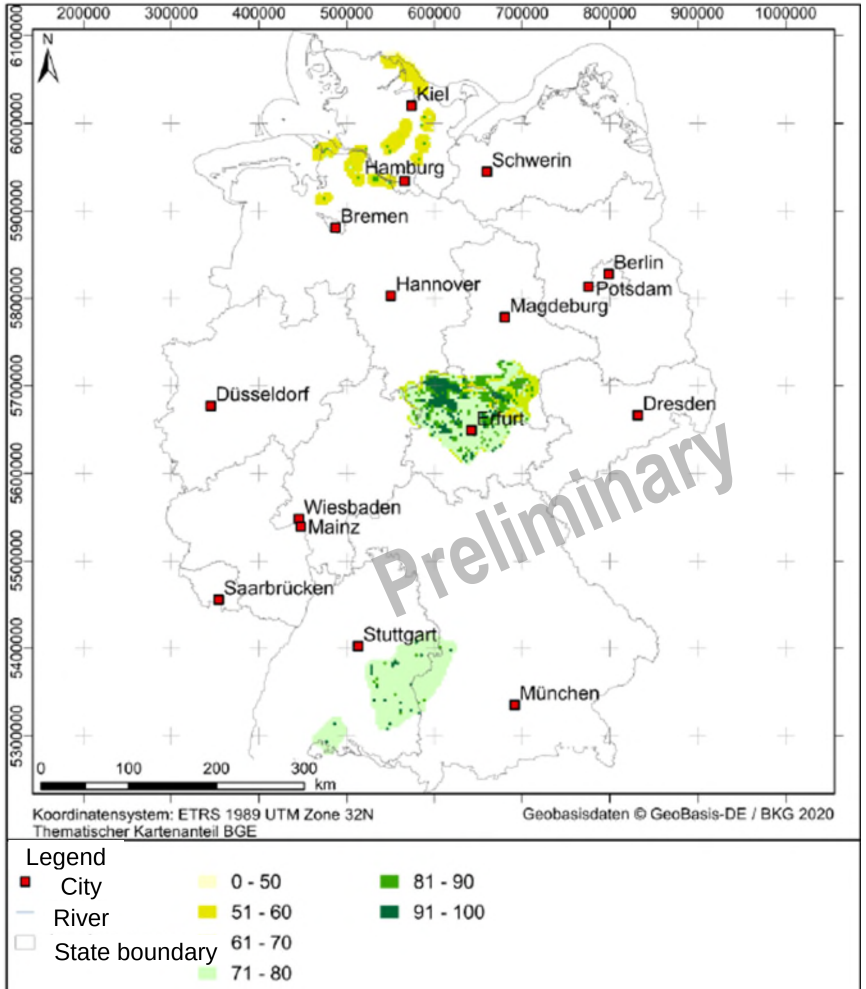
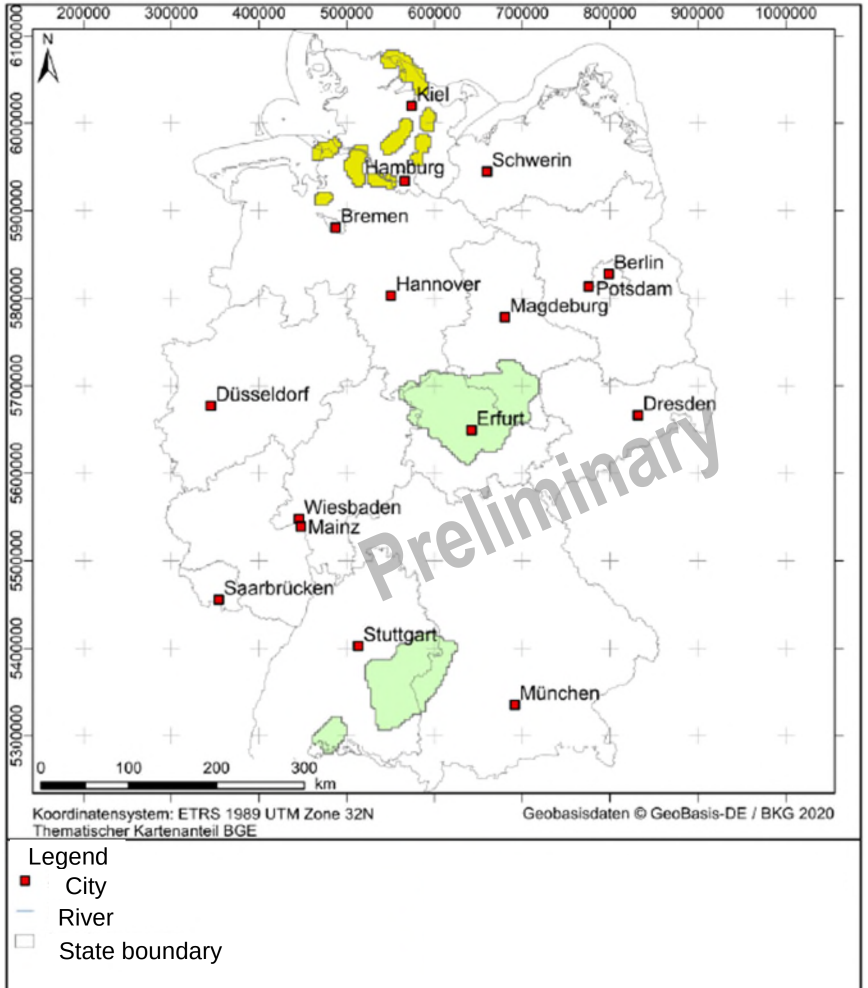


Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.



Note: The degree of confidence and its color scale do not reflect the degree of suitability as a site region.

Source: BGE

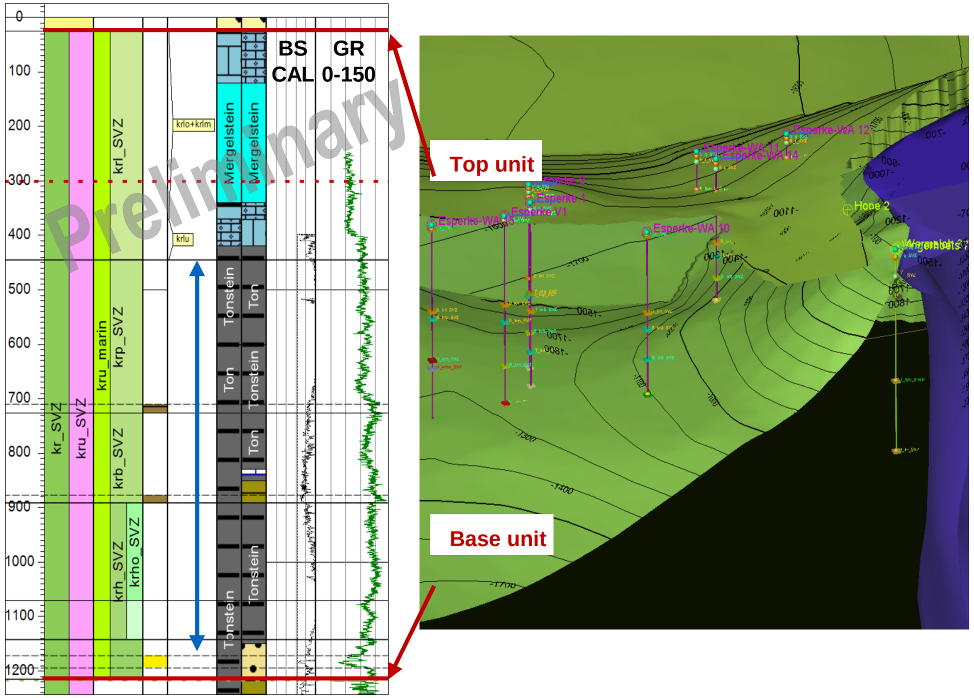
THE QUANTITATIVE METHOD

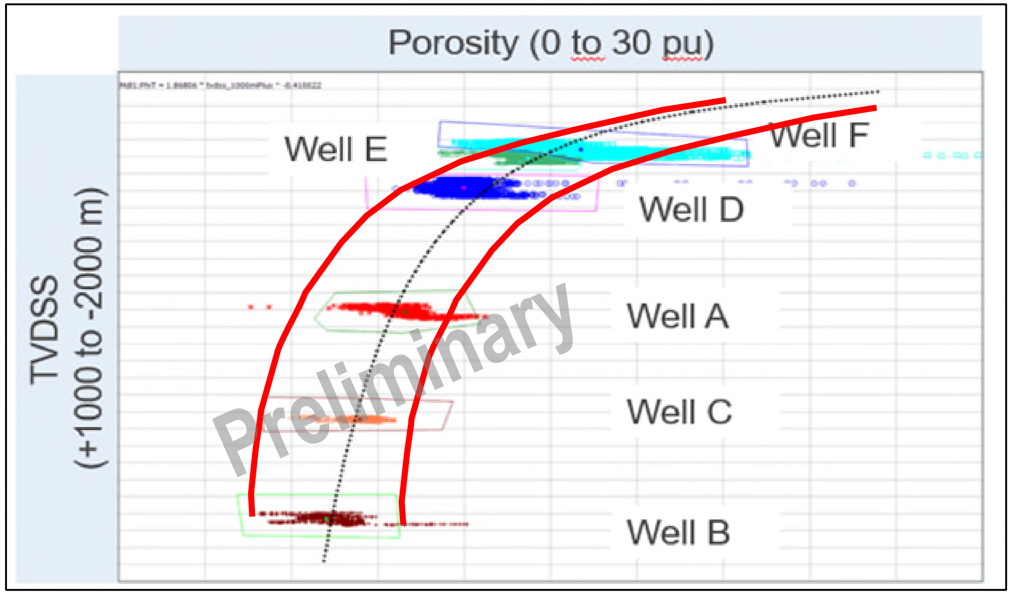
03

THE QUANTITATIVE METHOD

- **Quantifies ranges** of key parameters (e.g. thickness, porosity, etc.) and is applied on smaller, high-potential areas, assessing their robustness in terms of safety requirements

- E.g. applied in 3D-geomodels and during the transport simulation via statistical and geostatistical methods





Uncertainty envelopes for the porosity-depth relation

Source: BGE

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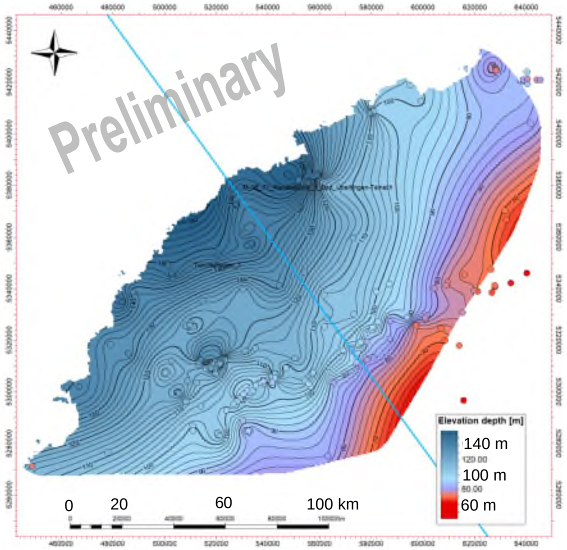
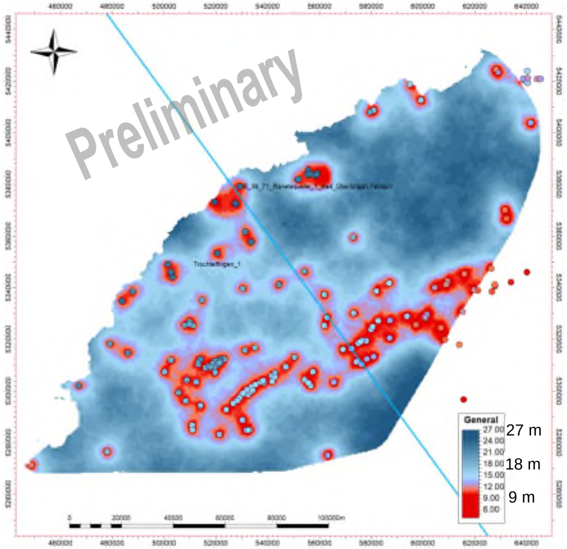
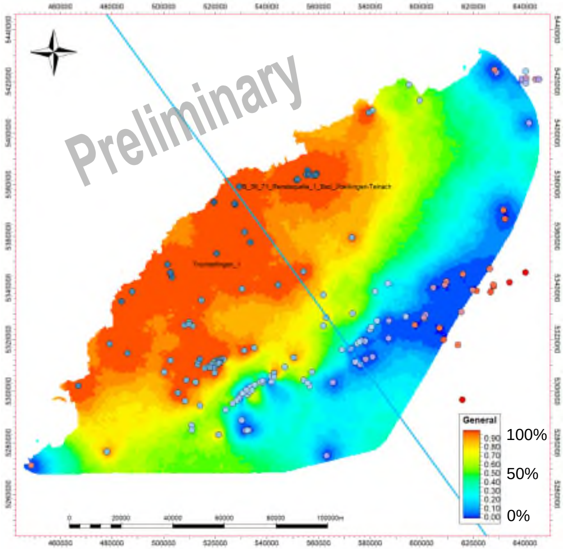
ASSESSMENT OF THE THICKNESS UNCERTAINTY



True vertical thickness (TVT) (m)

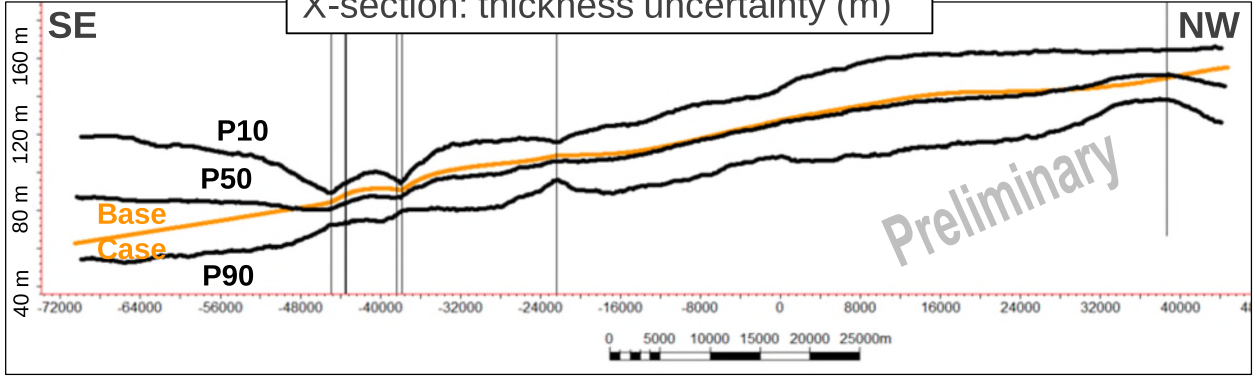


Thickness uncertainty (m)



Probability map of TVT being below a certain threshold (%)

X-section: thickness uncertainty (m)



- Using statistical and geostatistical methods, e.g. Kriging or Monte Carlo simulation

Source: BGE

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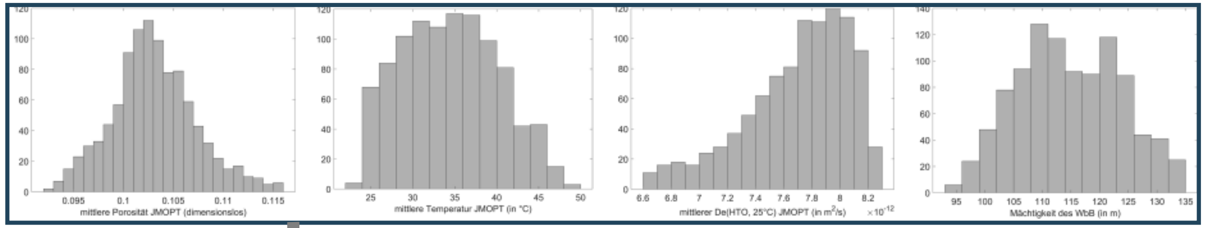
IMPACT OF PARAMETER UNCERTAINTY RANGES ON THE SIMULATED TRANSPORT DISTANCE: THE WORKFLOW FOR CLAYSTONE

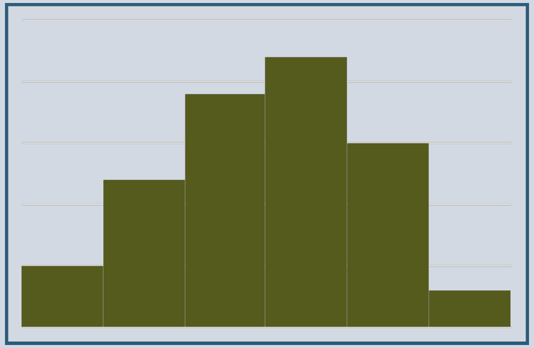


Estimating uncertainty ranges for relevant parameters

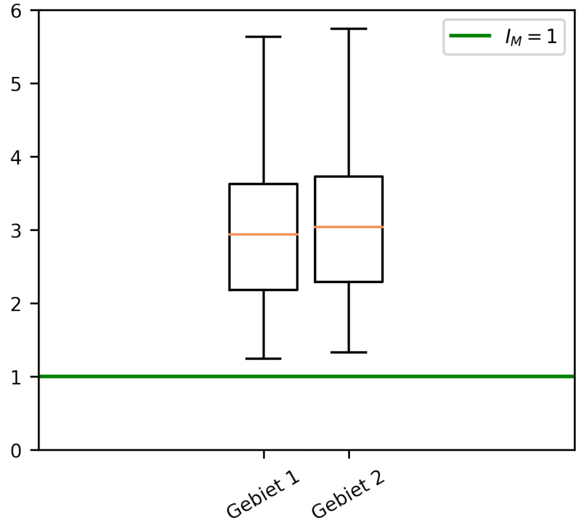
Sensitivity analysis

Sampling (e.g. Monte Carlo)

Radionuclide-transport simulation



Distribution of the transport distance



Source: BGE

SUMMARY

04

SUMMARY

BUNDESGESELLSCHAFT FÜR ENDLAGERUNG

- Subsurface uncertainties are assessed when relevant for the decisions within preliminary safety assessment
- Scale-dependent methods for assessing the subsurface uncertainties are used, depending on the goal:

1. The semi-quantitative method:
   - is used for the screening of large areas
   - allows a consistent uncertainty-weighted comparison of regions characterized by different data and geological complexity
2. The quantitative method:
   - is used on small, high-potential areas in order to assess their robustness in terms of safety requirements
   - is performed in 3D-geological models and the transport simulation via statistical and geostatistical methods
3. Geological risk elements (e.g. faults) potentially impacting the safety requirements, which are not included in the best estimate or in any other uncertainty realization, are recorded in the geological risk register

REFERENCES

- Peter Rose (2001) Risk Analysis and Management of Petroleum Exploration Ventures. AAPG Methods in Exploration Series, No. 12