Towards a comprehensive European fault database for induced seismic hazard research

EGU2020-21420 Display D1607

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HIKE
Hazard and Impact Knowledge for Europe

EU Fault Database
Methods and Cases
Knowledge base

Author affiliations

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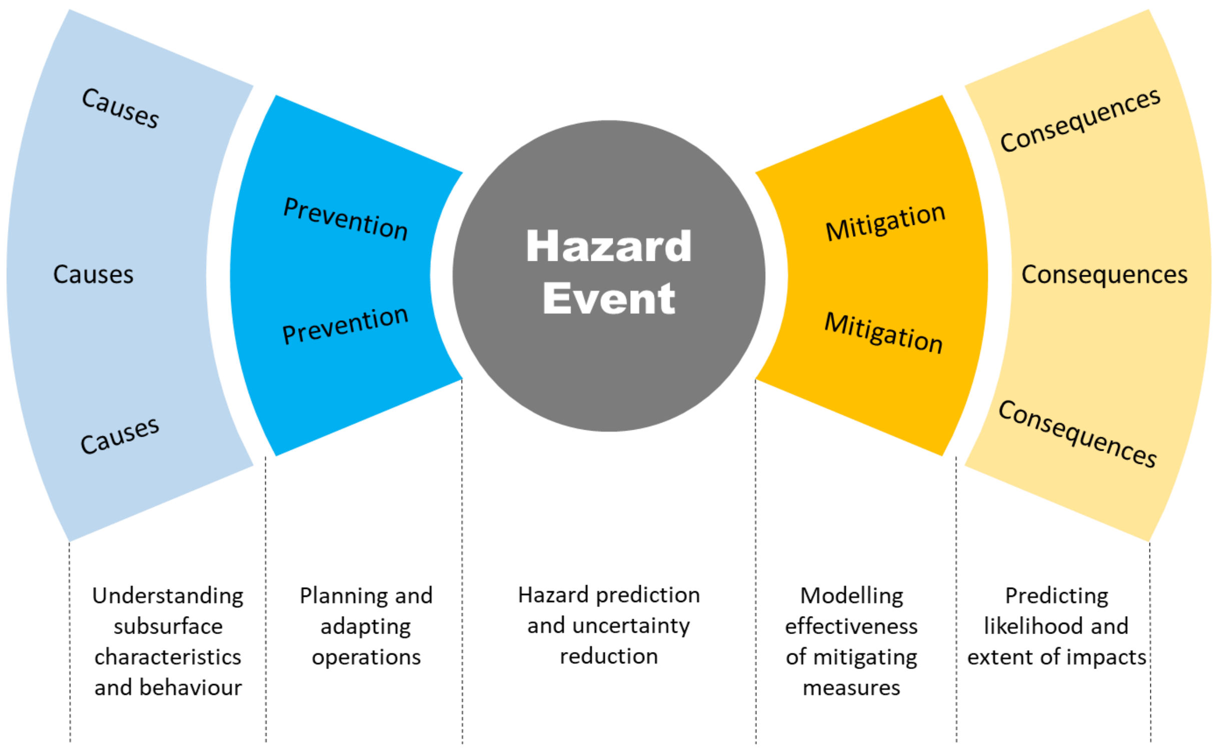
*: until 31-3-2020

GeoERA-HIKE project partners

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

HIKE Relevancy and Rationale



General Bow-Tie model for hazard and risk management

Subsurface activities in the vicinity of faults are a major cause for induced (anthropogenic) hazards

- Induced seismicity triggered by injection and extraction
- Leakage and migration during drilling and injection
- Instability in underground engineering

Hazard and risk assessments are key to prevent major impacts

- Physical en personal damage
- Premature cease of economic activities
- Failing societal support for subsurface activities securing climate goals and supply of energy and critical resources.

Fault data and knowledge is relevant for

- Cause-prevention assessment
- Designing adequate monitoring and early warning systems

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HIKE Relevancy and Rationale

Location of seismogenic faults based on the SHARE database (source: http://diss.rm.ingv.it/share-edsf/SHARE_WP3.2_Database.html)

Existing European fault databases and geological fault maps are primarily aimed at

- Seismogenic faults (e.g. SHARE fault database).
- Faults appearing at or near surface (e.g. OneGeology-EGDI)

Induced seismic hazard and risk assessments requires additional data on:

- Passive (yet capable) buried faults
- Fault geometry and characteristics at depth level of subsurface exploitation
- Behaviour of faults under influence of anthropogenic activities (e.g. fluid flow)

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Challenges

- Knowledge on passive and buried faults is dispersed over many different repositories.
- Accuracy, representation and attributes vary greatly between regions due to uneven access to data for accurate mapping, modelling and characterization of buried faults (e.g. seismic data, boreholes).
- Correlation and harmonization of faults is complicated by the variety of different geological and tectonic settings across Europe
- Characteristics and behaviour of many faults have changed significantly over geological time. This knowledge may be essential to understand and predict present-day characteristics.
- Use-cases have location-specific and stakeholder-dependent requirements in terms of level of detail, fault attributes and representation formats.

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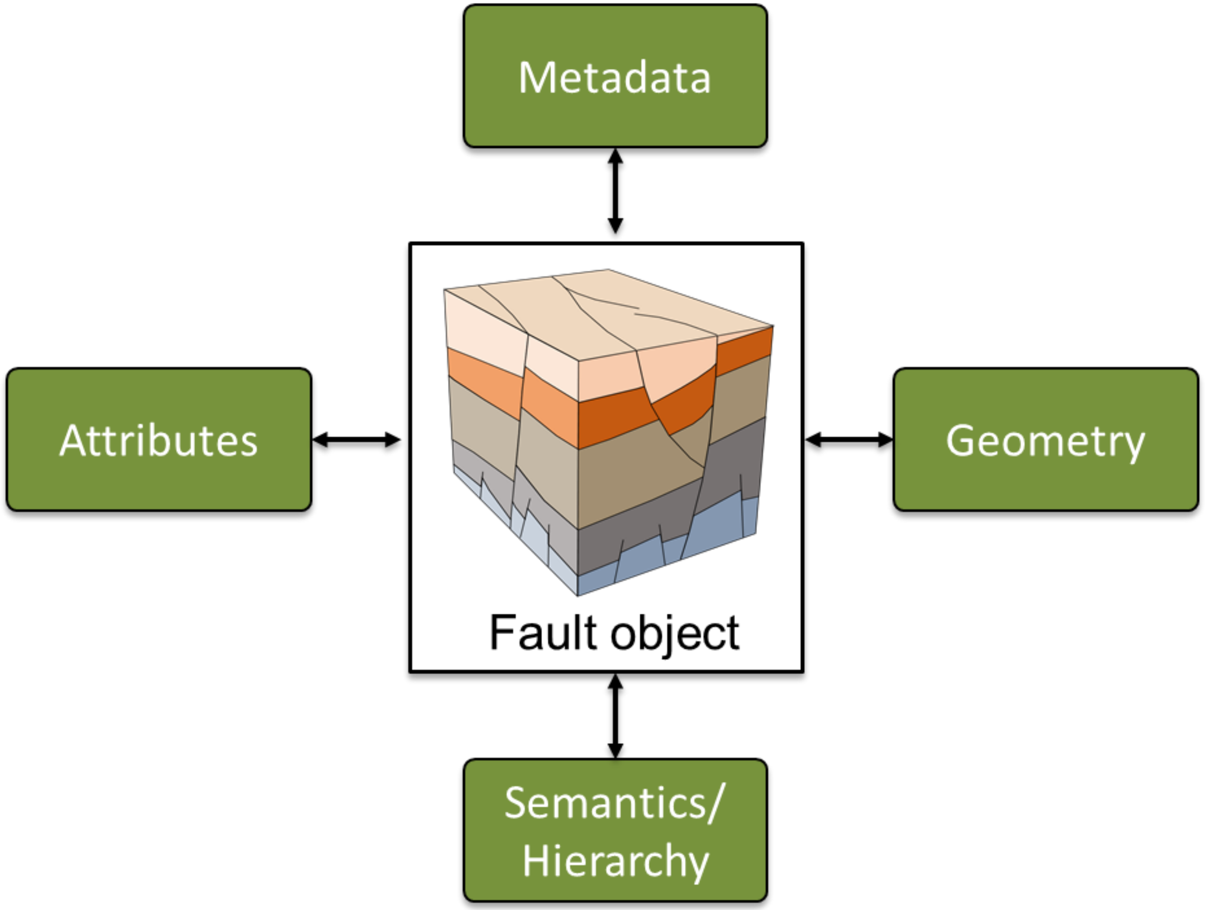
HIKE Objectives and Approach



Generalized concept of the HIKE Fault Database

Public fault data available at partner surveys

- Integrate with existing published data (e.g. seismogenic fault databases)
- Collaboration with other projects

Versatile fault database concept capable of dealing with heterogeneous sources

- Varying scales, representations, settings
- Contribute to different use-cases
- Updatable

Demonstration of use cases and assessment methods

- Test applications
- Advanced characterization
- Recommendations for improvement

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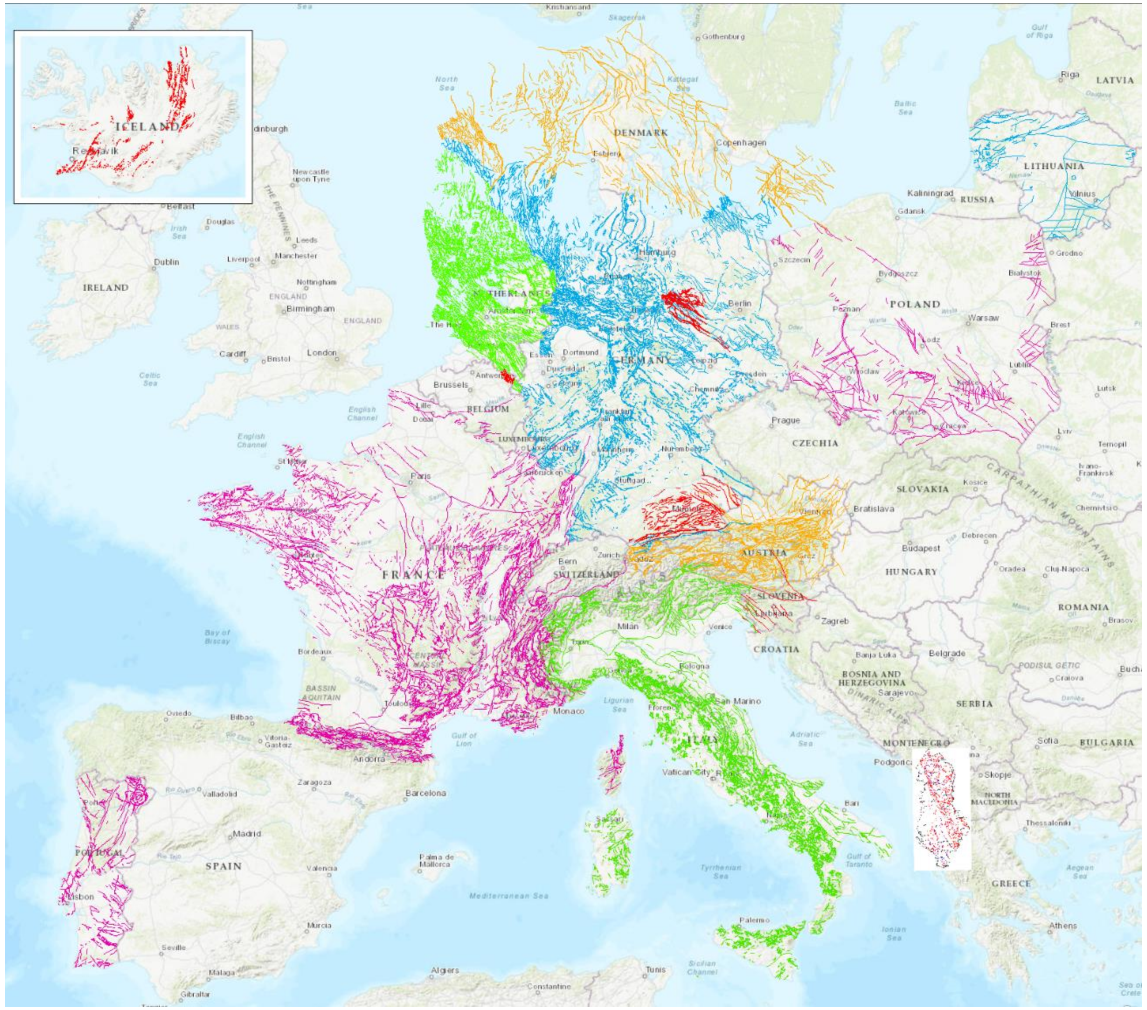
Fault data collection (in progress)



Overview of first round fault data collection in HIKE (per 15-12-2019)

Current inventory contains tens of thousands of faults from heterogeneous sources

Key attention points:

- Distinguish relevant faults for assessments
- Understand mutual fault relationships within larger tectonic framework
- Correlate faults across borders
- Integration across different scales
- Integrate different representations and formats (3D, 2D, multi-layer, source data)

Implementation of Structural Framework principles through semantic concepts:

- Incorporate fault information in a Structural Framework (cf. Barros et al., 2020 – GeoConnect3d) using a tectonic classification based on semantic concepts.

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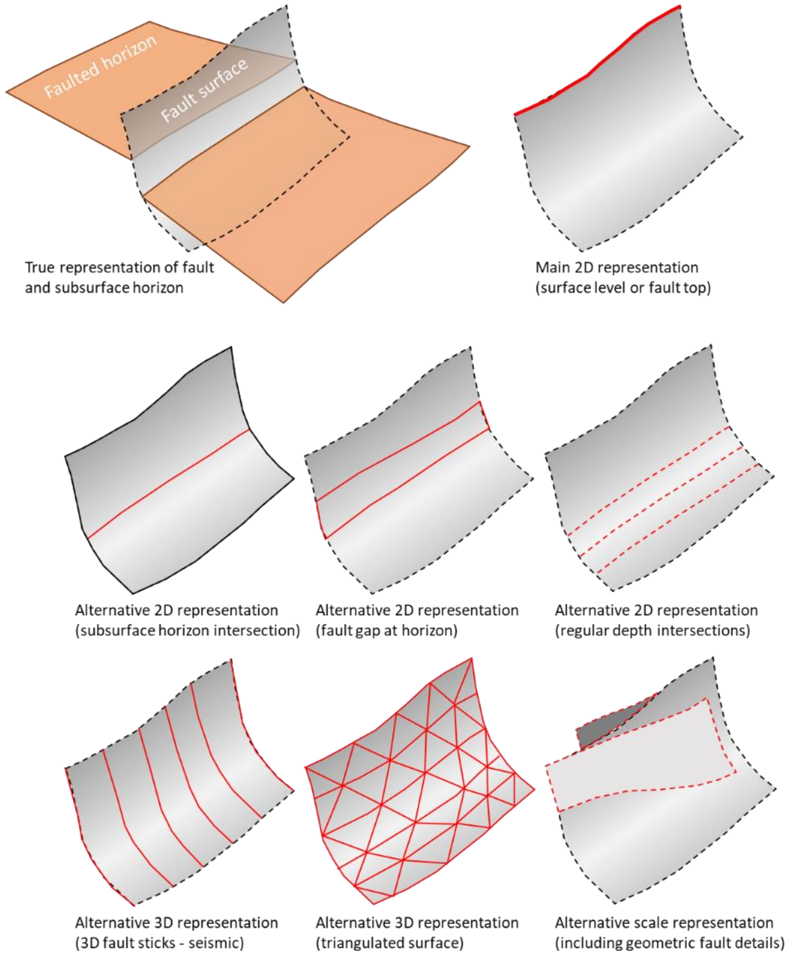
Fault geometries and attributes



Different 2D and 3D fault representations

Fault data is available in varying formats and styles of representation

- 2D Surface outcrop maps
- 2D subcrop maps at stratigrafic level
- 2D multilayer intersections at depth- and stratigraphic levels
- 3D model of fault surface
- Raw interpretation data (fault sticks, point sets)
- Special analytical representations

Possibility to integrate and disseminate multiple representation styles and formats

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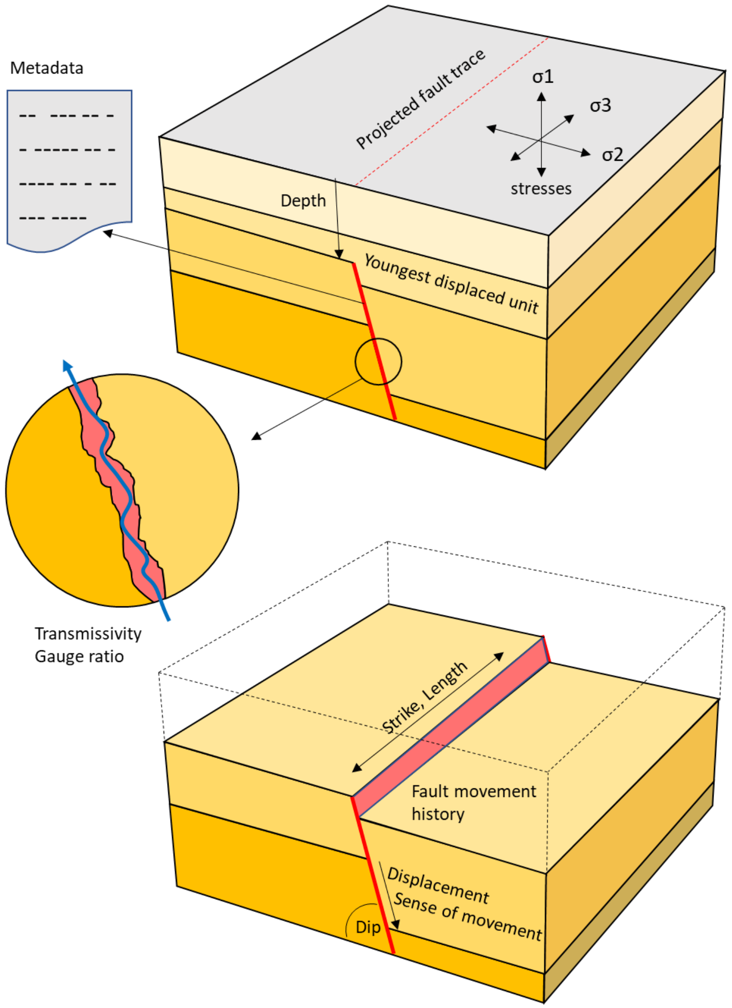
Fault geometries and attributes



Typical fault attributes for induced hazard assessment

Common set of attributes (partly mandatory, partly optional)

- Identification and meta-data parameters
- Geological and stratigraphic parameters
- Geometry-related parameters
- Physical characterization parameters
- Kinematic parameters and classification

Option to include user/stakeholder-specific parameters

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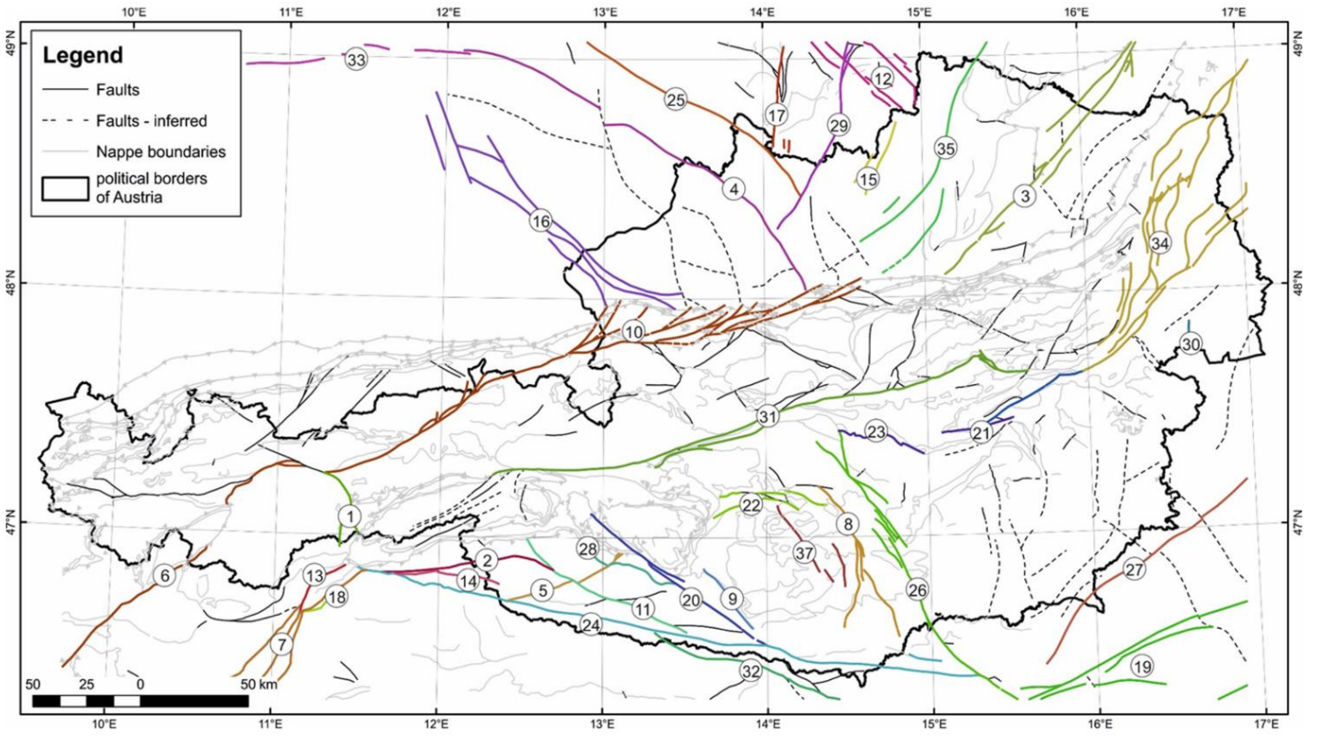
Development of the Semantic Concept: Austrian example



Overview of Austrian Fault Database with semantic classification of tectonic boundaries (Hintersberger et al., 2017)

The Austrian Fault Database provides the basic concepts for implementing the semantic classification of tectonic boundaries

- Hierarchical fault classification framework with narrower (child) and broader (parent) relationships
- Naming with multi-lingual support
- Link to scientific literature and citations
- Cross-border correlations (e.g. Germany and Italy) using "related" definitions
- Online viewer with attribute browser

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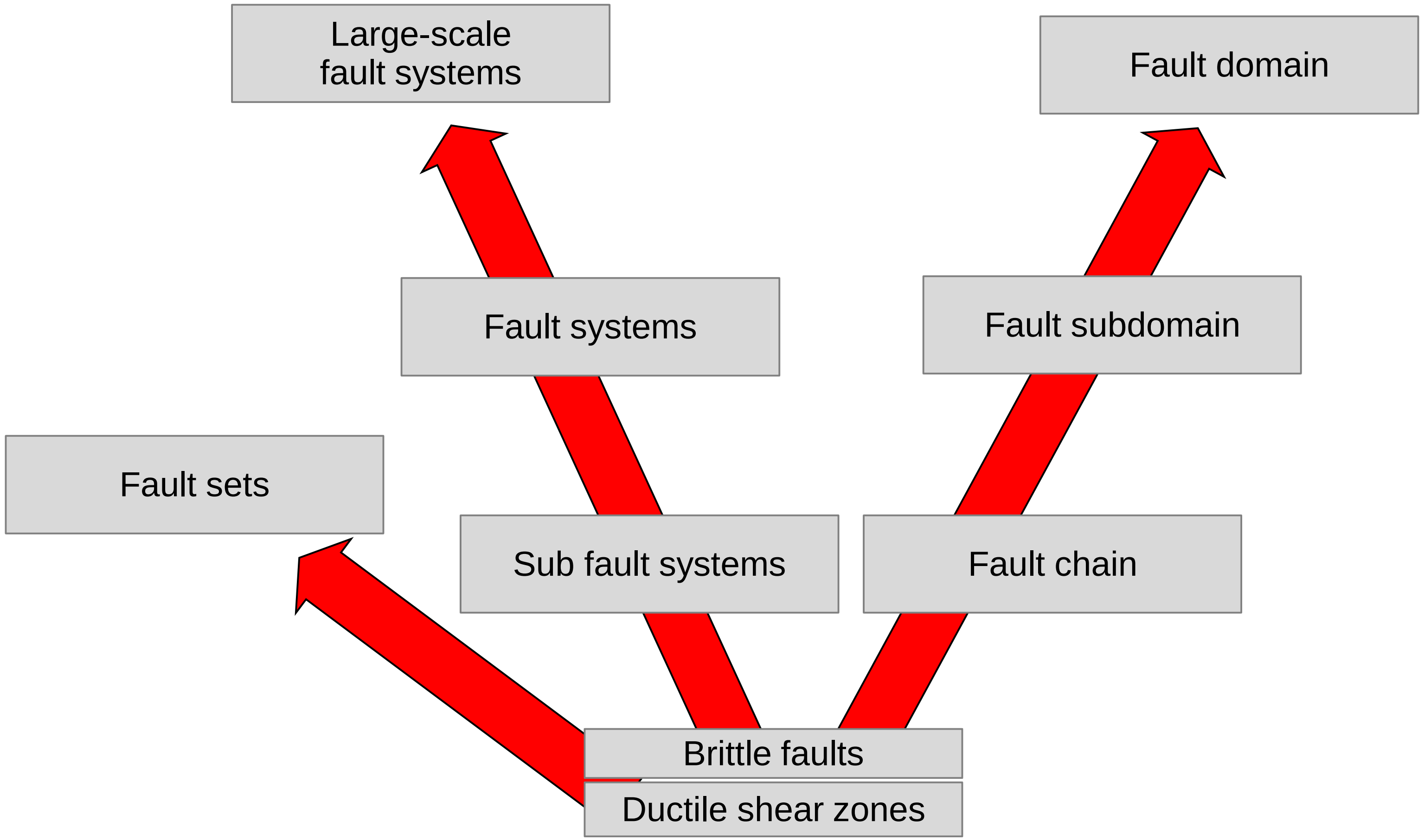
Semantic concept: Classification framework

The classification framework provides different hierarchically ordered elements depending on the tectonic and geological setting.

The elements can be mixed (e.g. fault systems and fault sets)

The elements can be cross-correlated, e.g. a defined **fault system** may be (cor)related to a **fault chain** in an other region



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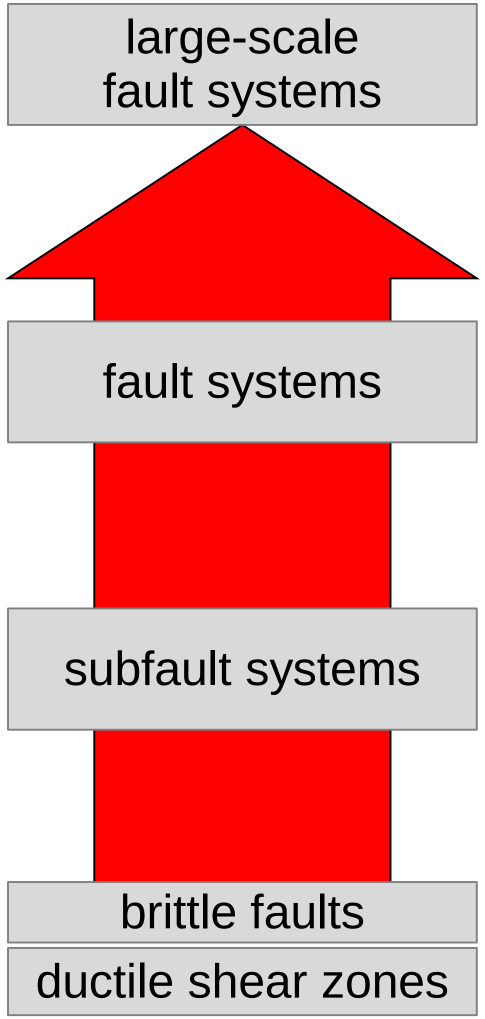
Semantic concept: example definition in Austrian fault database



Kouřim-Blanice-Kaplice-Rodl LFS

Kouřim-Blanice FS

① Kouřim SFS

② Blanice-Graben SFS

Rodl-Kaplice FS

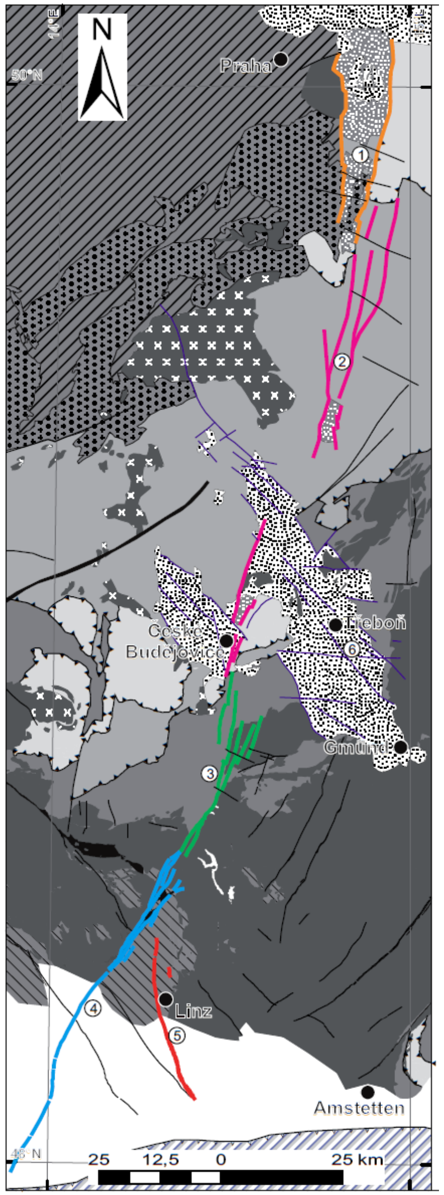
③ Kaplice SFS

④ Rodl SFS

⑤ Haselgraben SFS

Jáchymov FS

⑥ Třeboň and Budějovice SFS



Hintersberger et al., 2017

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Austrian fault database example: semantics concepts and attributes

Semantic description

Geological Survey of Austria — Home About Feedback EN

Vienna Basin Fault System

URI: http://resource.geolba.ac.at/structure/190 ⇒ RDF download

Wien-Becken-Störungssystem de Vienna Basin Fault System en
Wiener Becken-Störungssystem (set) de
GBA Status: official use

The almost 200 km long, NNE-SSW trending, rhomboetric Vienna Basin consists of mostly NE-SW striking oblique left-lateral strike-slip faults at its eastern margin and NNE-SSW trending listric normal faults compensating E-W extension (Decker, 1996). It extends from Gloggnitz at its southern end via the recent flood plain of the River Danube between Vienna and Hainburg at its widest point towards Zilina in the North. Formation of the Vienna Basin Fault System started due to pull-apart subsidence during the Badenian at around 16 Ma and lasted until 9 - 8 Ma (Decker, 1996; Peresson & Decker, 1997; Hölzel et al., 2010). Quaternary reactivation is indicated by dissected Pleistocene terraces and Quaternary basins (Decker et al., 2005, Beidinger & Decker, 2011).

— Decker, K.; Peresson, H. & Hinsch, R. (2005): *Active tectonics and Quaternary basin formation along the Vienna Basin Transform fault.- In: Quaternary Science Reviews 24, Nr. 3-4, S. 307-322* - [Catalog]
— Decker, K. (1996): *Miocene tectonics at the Alpine Carpathian junction and the evolution of the Vienna basin. - Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich 51, 33-44* - [PDF] - [Catalog]
— Hölzel, M., Decker, K., Zámolyi, A., Strauss, P. & Wagreich, M. (2010): *Lower Miocene structural evolution of the central Vienna Basin (Austria). - Marine and Petroleum Geology 27, 3, 666-681*
— Beidinger, A. & Decker, K. (2011): *3D geometry and kinematics of the Lassee flower structure: Implications for segmentation and seismotectonics of the Vienna Basin strike-slip fault, Austria. - Tectonophysics 499, 1-4, 22-40* - [Catalog]
— Peresson, H. & Decker, K., (1997): *Far-field effects of Late Miocene subduction in the Eastern Carpathians: E-W compression and inversion of structures in the Alpine-Carpathian-Pannonian region. - Tectonics 16, 1, 38-56.* - [Catalog]

Concept relations

broader	Mur-Mürz-Vienna Basin-Vah Large-scale Fault System
narrower	Aderklaa-Bockfliess Fault Leopoldsdorf Fault Matzen Fault Engelhartstetten Fault Markgrafneusiedl Fault Nussdorf Fault Bisamberg Fault Lassee Fault Poysbrunn Fault Pirawarth-Hochleiten Fault Schrattenberg Fault Steinberg Fault Pottendorf Fault

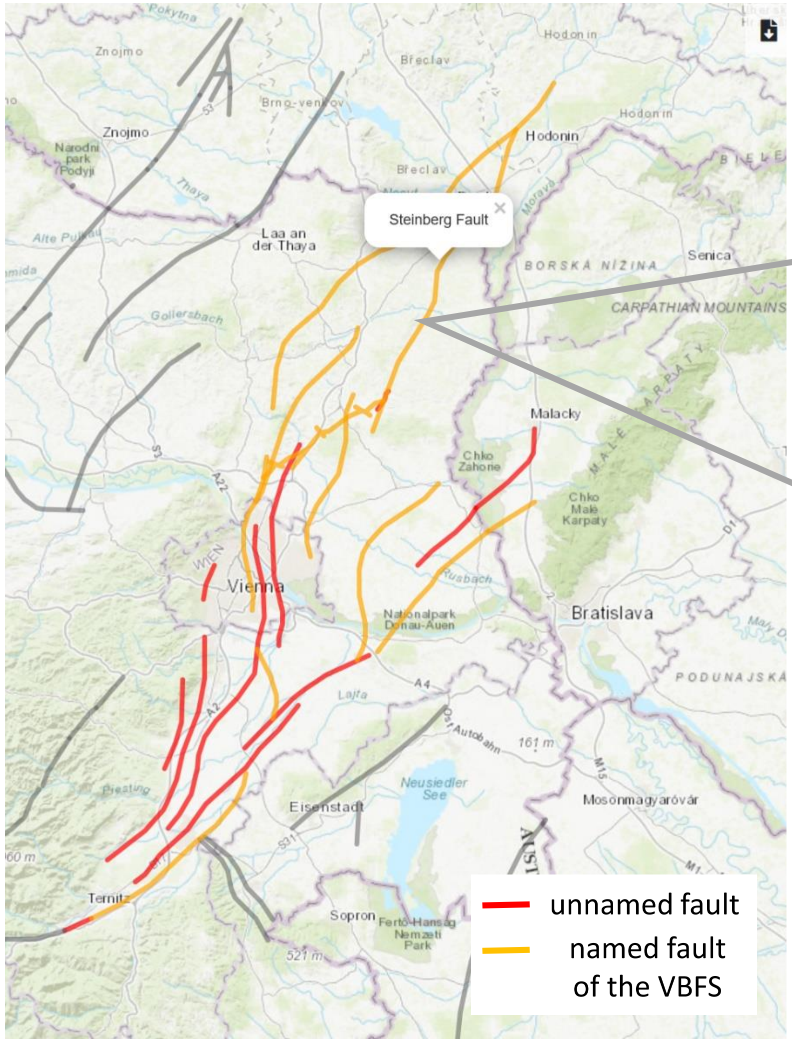
thesaurus — Search for... Go!

Applications: Network diagram · Database queries · Structure Viewer

Geologic Structures (subject)

The Theme Geologic Structures includes linear and planar predominantly deformation structures in geologic maps. Shear sense indicators and fold structures are also covered by this theme.

Fault geometry



Attributes attached to fault geometry (WMS data)

WMS Data:

OBJECTID	354
NummerderStörung	10340
SHAPE	Polyline
FEATURE_ID	102
Klassifizierung	Störung
Bezeichnung	Steinberg-Störung
synonymeBezeichnung	Steinbergbruch; Steinberg Fault
Großstörungssystem	Mur-Mürz-Wien-Becken-Vah-Großstörungssystem
Störungsystem	Wien-Becken-Störungssystem
Teilstörungssystem	Null
Störungbzw.Scherzone	Steinberg-Störung
Kurzreferenz	Beidinger and Decker, 2011; Decker et al., 2005; Kovac et al., 2004
THESURL	http://resource.geolba.ac.at/structure/203

LinkedData:

Steinberg-Störung

Diese NNE-SSW streichende, steil nach ESE einfallende Störung verläuft von Groß-Schweinbarth über Zistersdorf, Neusiedl an der Zaya bis nördlich von Breclav (CZ; Kovac, 2004). Der E-Block wurde während des Miozäns um rund 5 km abgeschoben. Im Quartär wurde die Störung vermutlich zeitgleich mit anderen Störungen im Wiener Becken abschiebend reaktiviert. (Decker et al., 2005; Beidinger & Decker, 2011)

in ..Wien-Becken-Störungssystem

Decker, K.; Peresson, H. & Hinsch, R. (2005): Active tectonics and Quaternary basin formation along the Vienna Basin Transform fault.- In: Quaternary Science Reviews 24, Nr. 3-4, S. 307-322

thesaurus.geolba.ac.at

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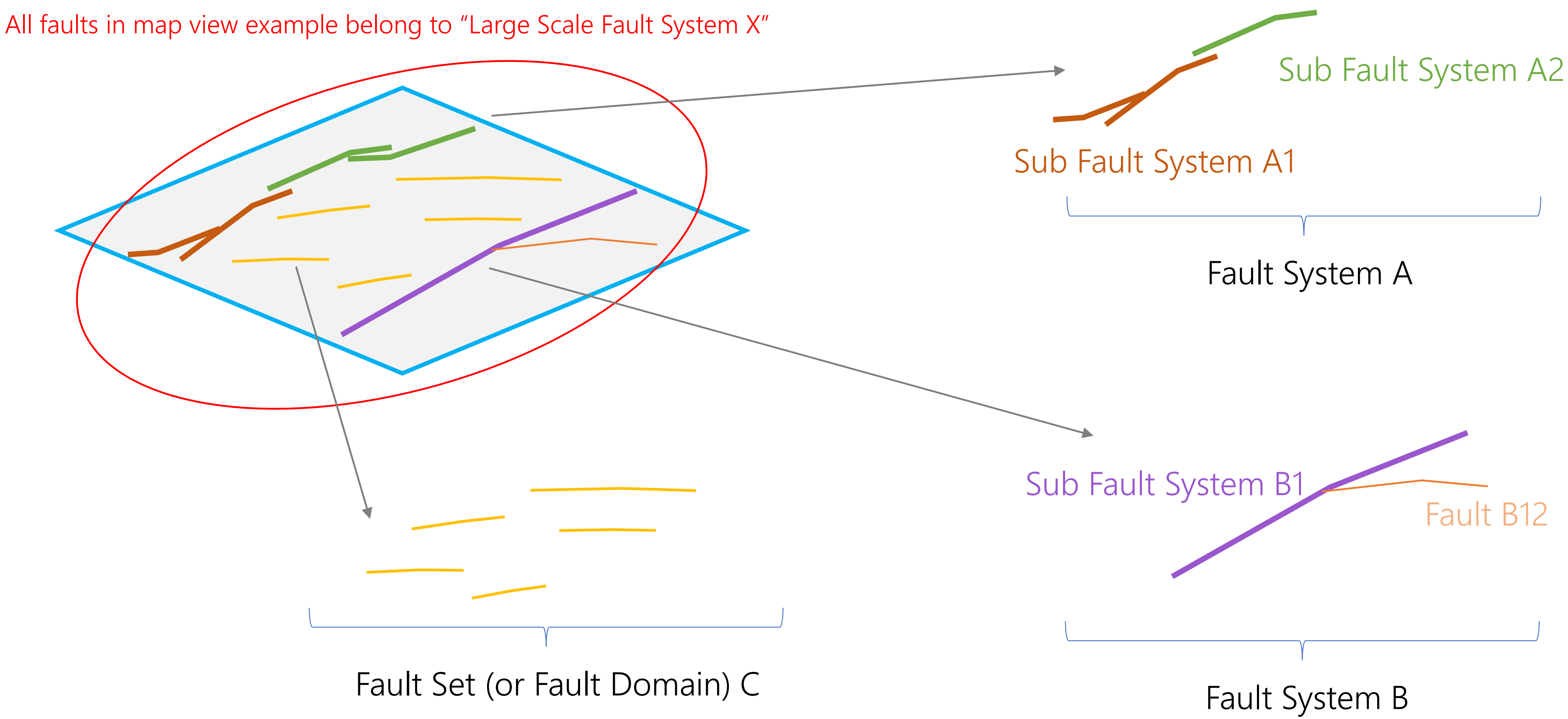
Semantic concept: hierarchical classification



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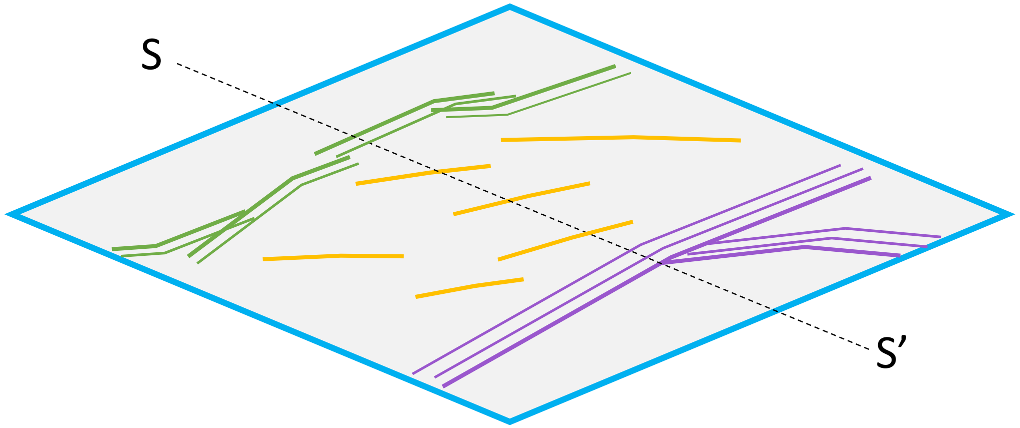
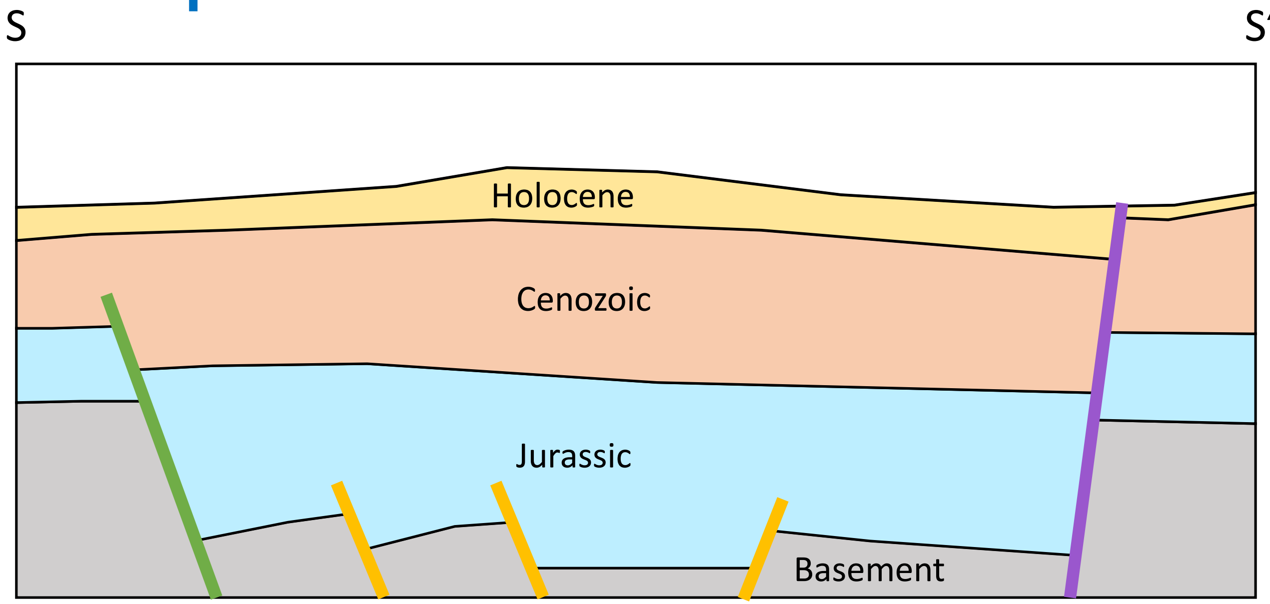
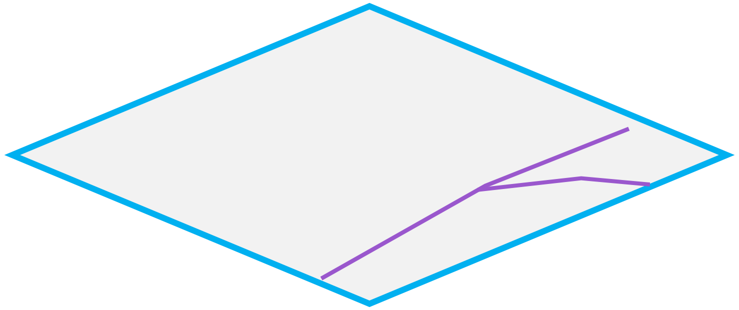
Semantic concept: linking multiple depth levels

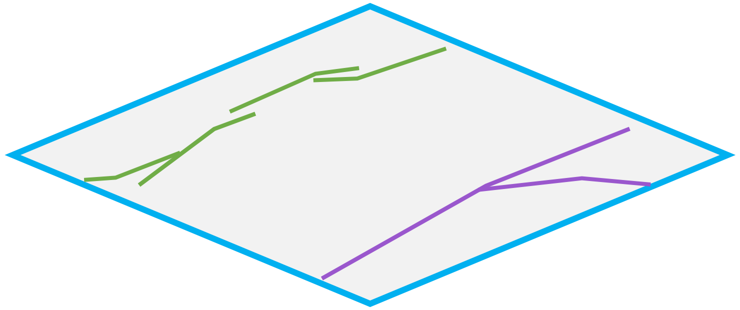
All intersections shown in one map view



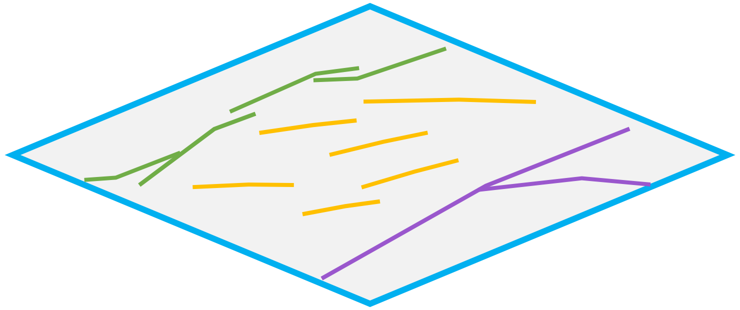




Holocene intersection



Cenozoic intersection



Jurassic intersection

The semantic classification determines the position in the structural framework (and thus the link to tectonic development). The fault attribute values determine the depth/stratigraphic intersection

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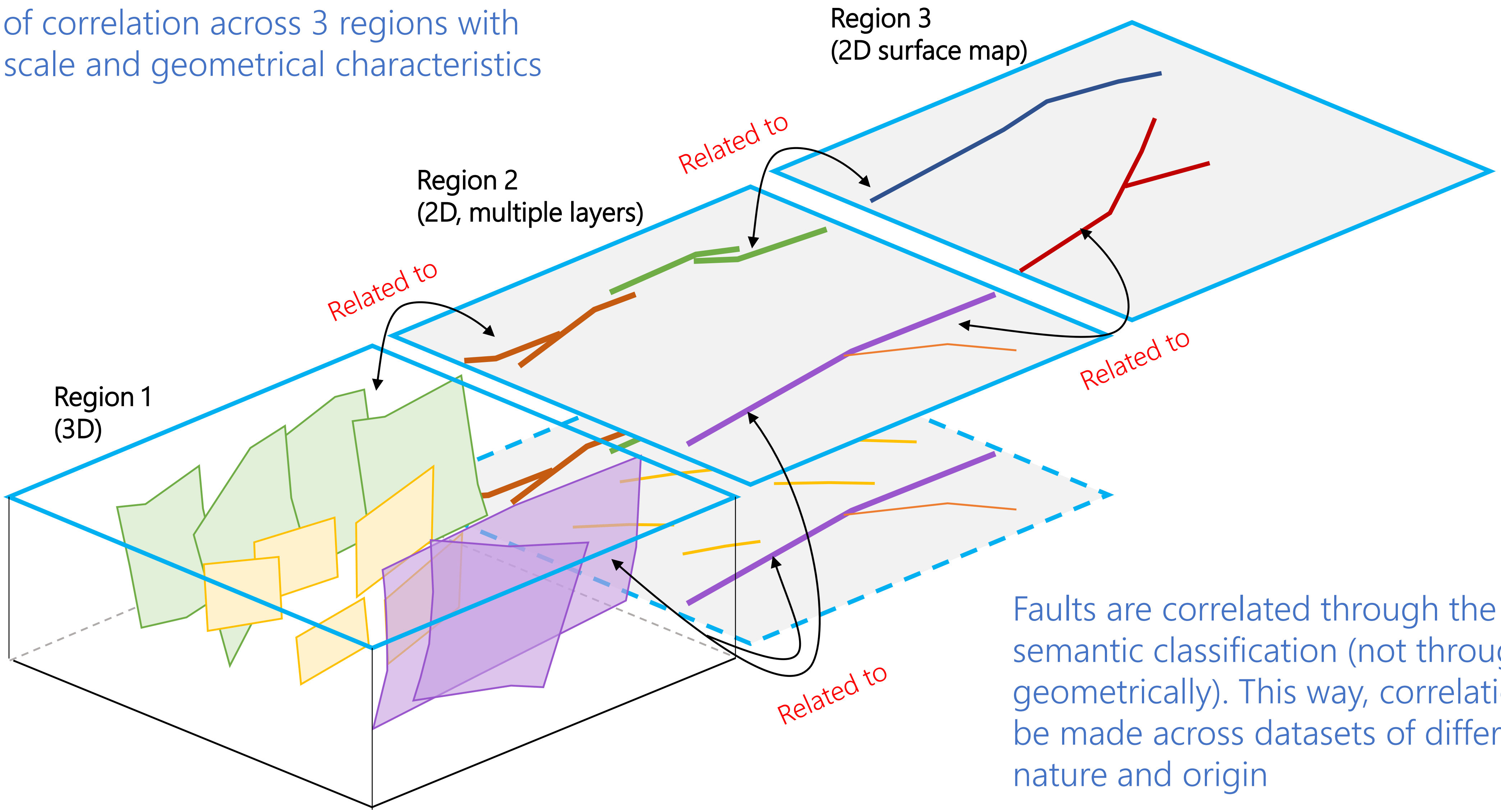
Semantic concept: regional correlation

Example of correlation across 3 regions with different scale and geometrical characteristics



Faults are correlated through the semantic classification (not through geometrically). This way, correlations can be made across datasets of different nature and origin

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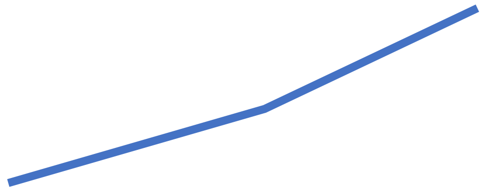
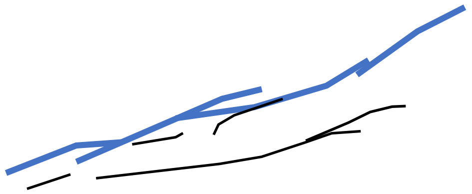
Semantic concept: linking faults at multiple scales

1:5.000.000



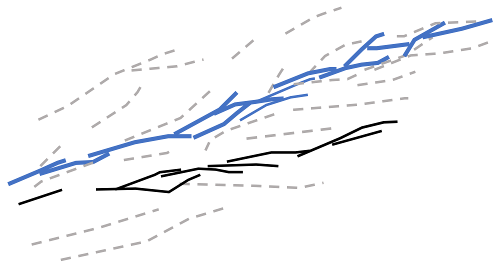
Only major fault systems with macro-regional relevance. Defined in low detail

1:500.000



Faults and fault systems with national/regional relevance. More detail is shown

1:50.000



Faults and fault systems with local relevance. All minor faults at high detail

Fault domain X

- Large Scale Fault System A
- Sub Fault System B
- Fault Set C

Faults that are mapped at different scales still share the same semantic concept definition. This ensures correct linking of the same faults across different datasets. In the example, Large Scale Fault System "A" is defined in all datasets, yet the geometry varies with the mapping scale.

The scale factor is attached as attribute to the geometry (i.e. can be selected for visualization)

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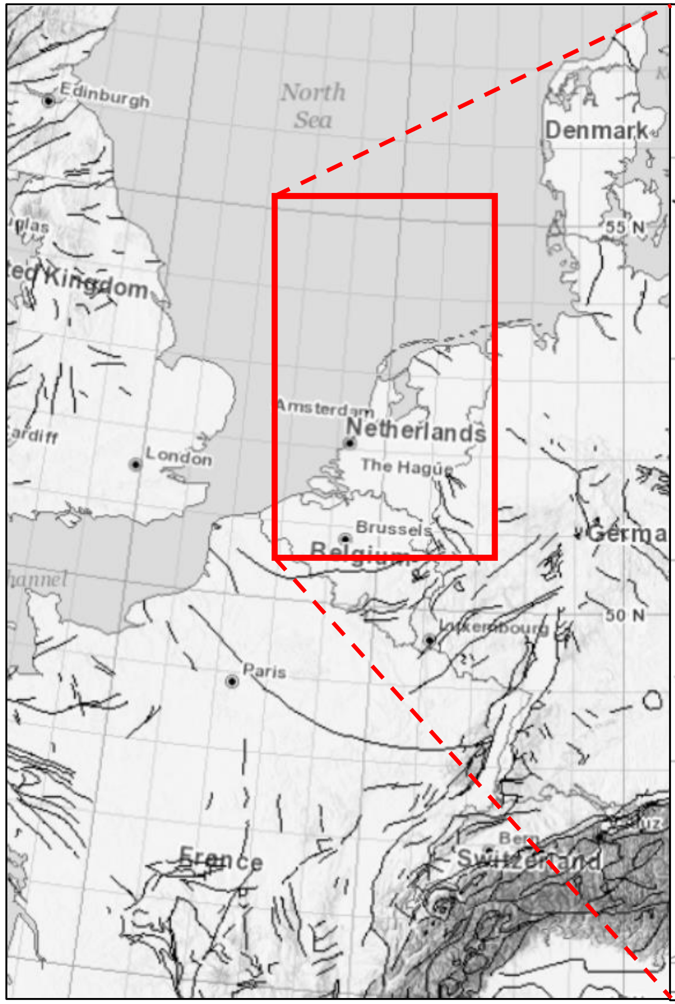
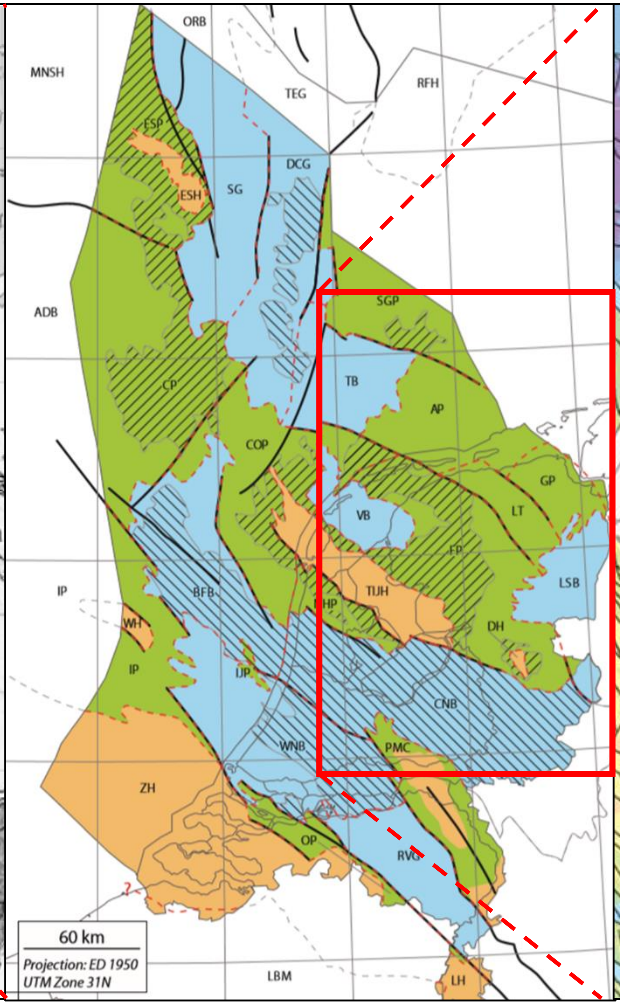
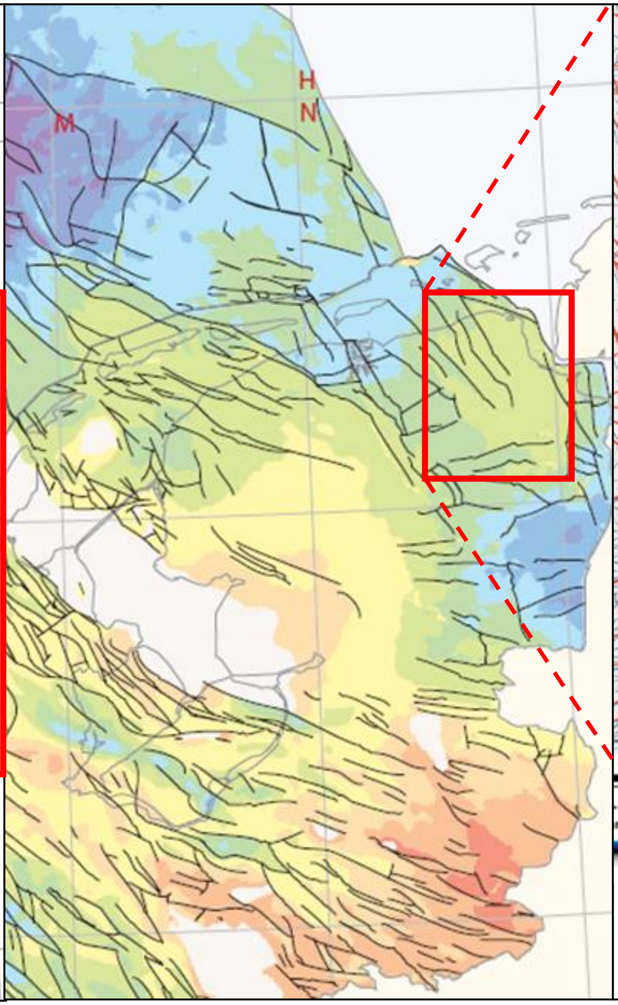
Use case: Integrating varying mapping scales and purposes



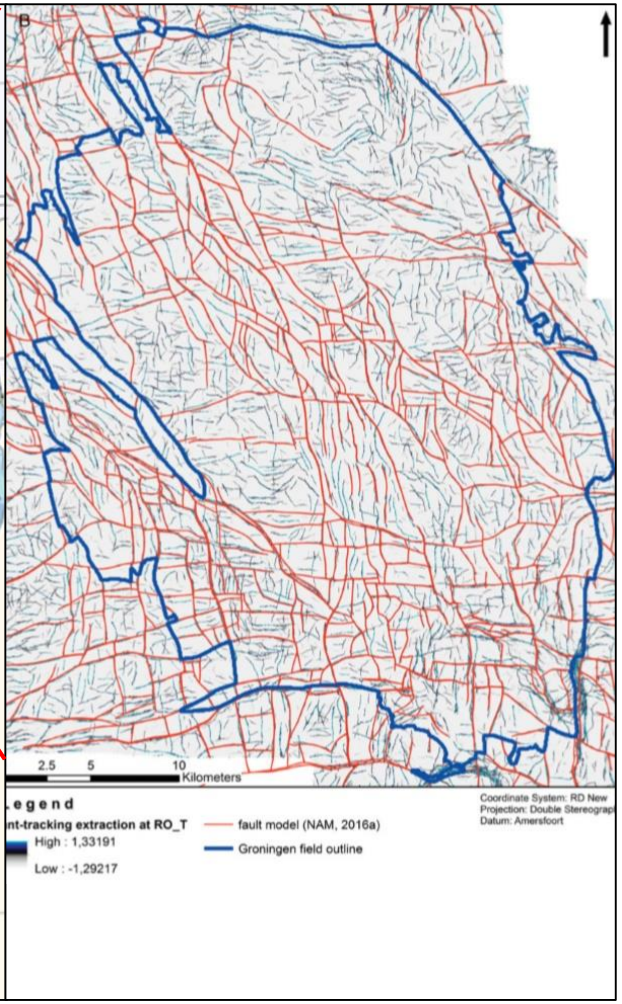
OneGeology EU surface level fault map (IGME5000)



Netherlands structural elements and boundary faults (Kombrink et al. 2012)



Netherlands on- and offshore fault mapping, base Permian level (Duin et al. 2006)



Detailed fault mapping in the Groningen gas field (Kortekaas et al. 2018). Induced seismicity assessment

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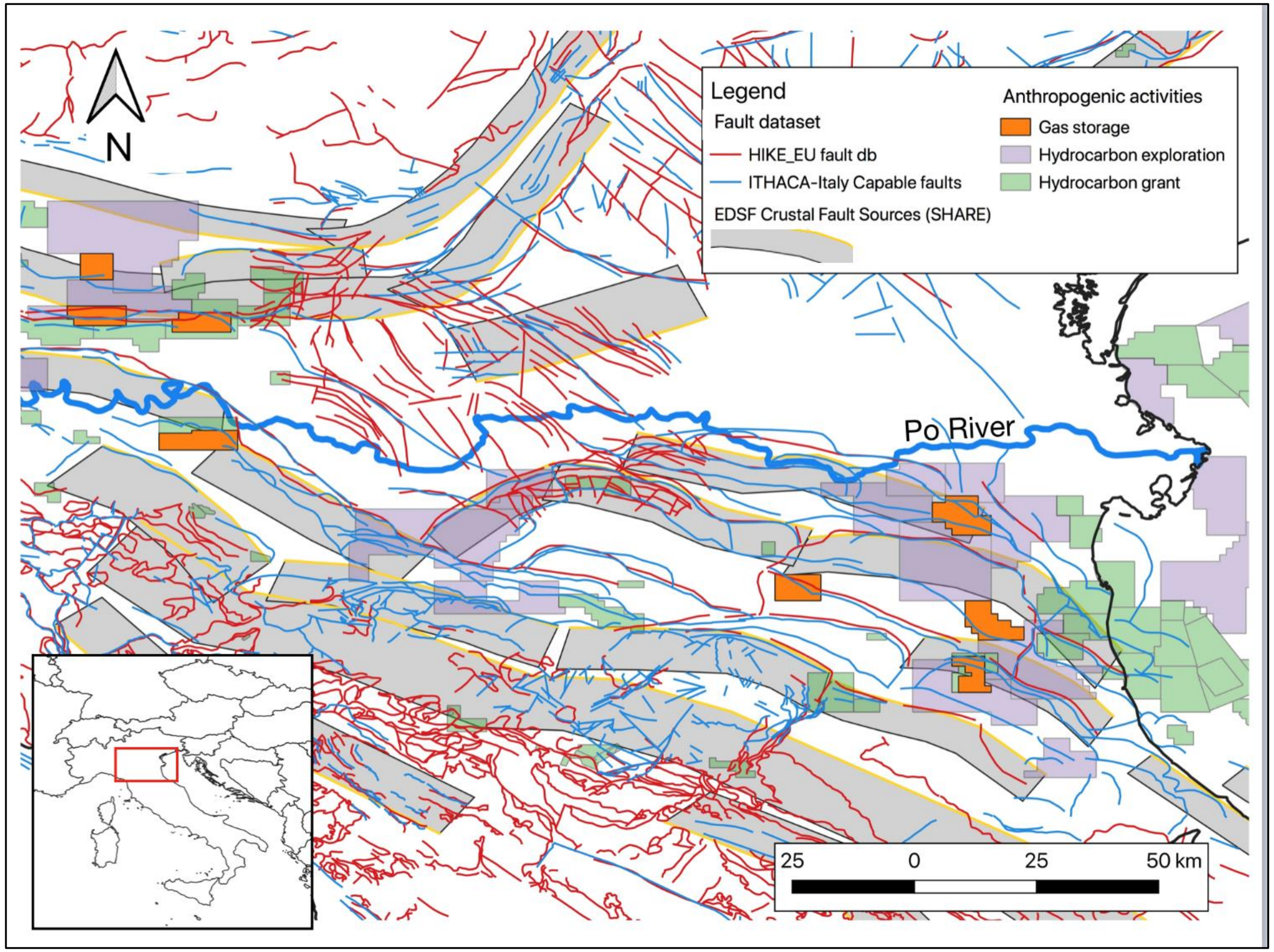
Use case: integrating different databases and applications



Di Manna et al., 2020

Assess relationship between passive, capable and seismogenic faults

- Linking three databases (SHARE, ITHACA and HIKE)
- Linking different scales and depth levels
- Subsurface activities near passive and capable faults, influenced by connected seismogenic faults

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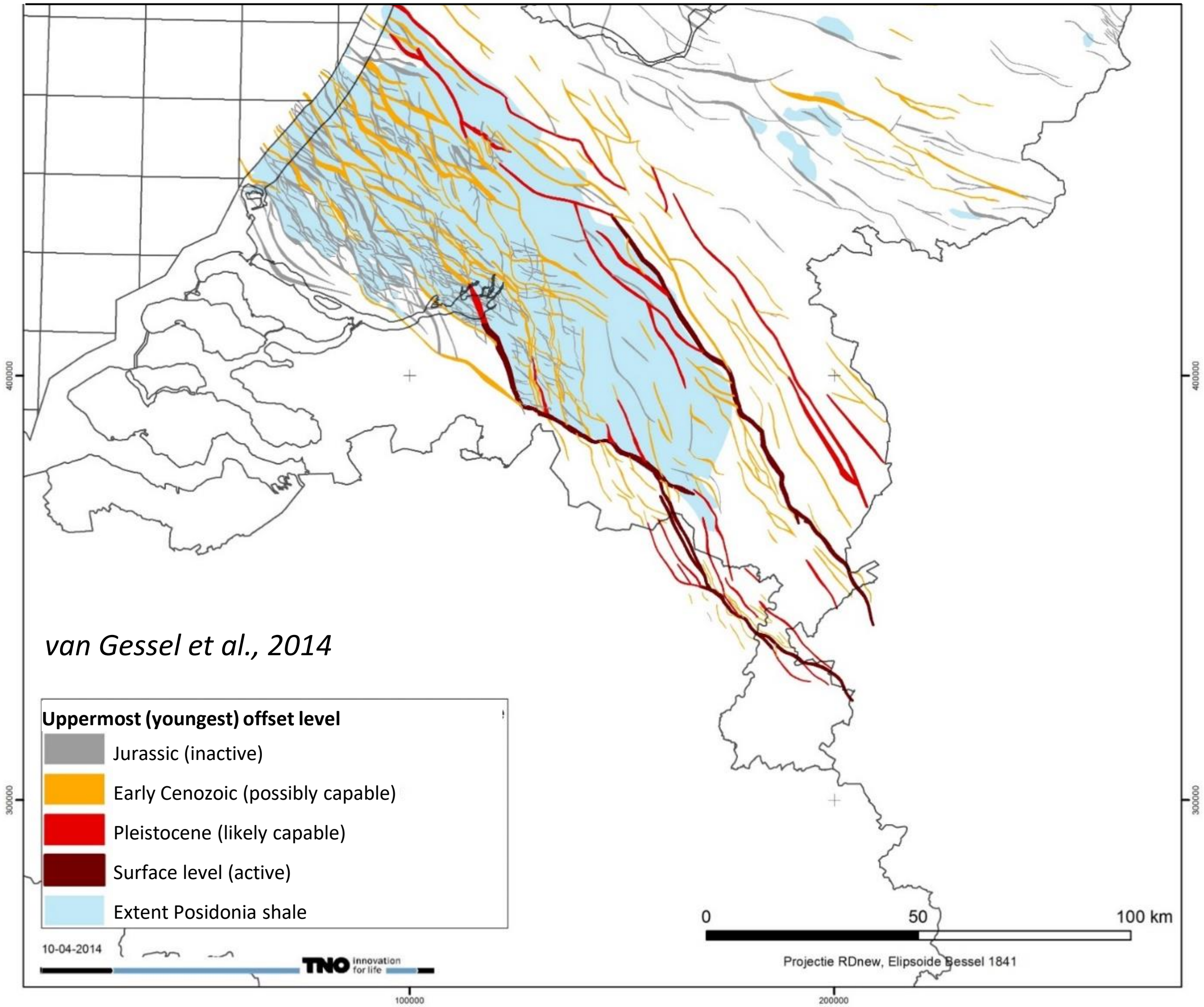
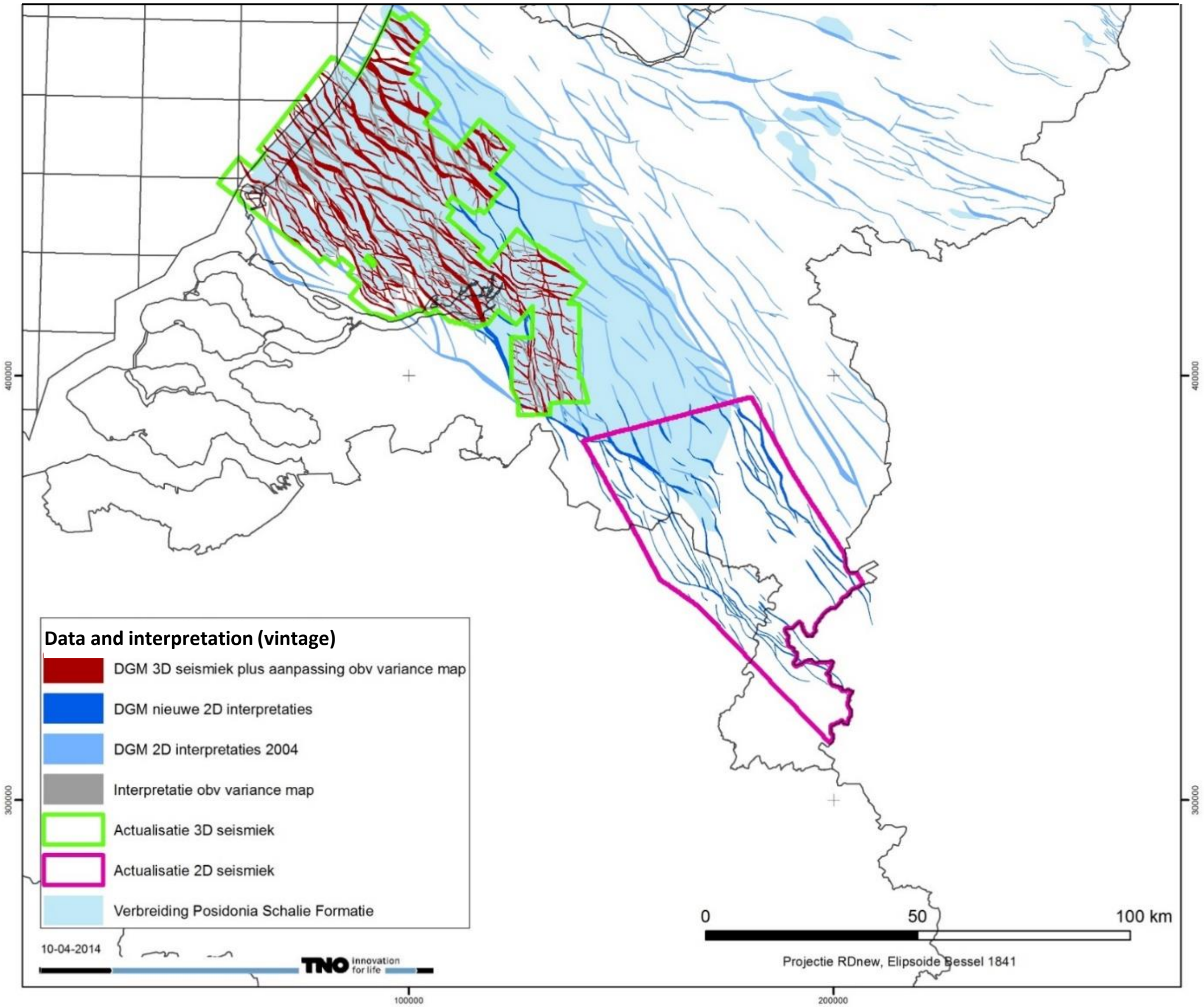
Use case: example fault classification Netherlands





The red faults in the left map are labeled as large fault systems in the semantic concept scheme and delimit major structural elements (Roer Valley Graben). Active surface faults extend westward into buried faults at Pleistocene level. The quality of fault interpretation (right map) depends on data availability (2D vs 3D seismic) and the vintage of interpretation/modelling

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Use case: testing various applications and method studies

score	basement connected	inter-well pressure communication	re-injection pressure [MPa]	circulation rate [m³/h]	epicentral distance to natural earth-quakes [km]	epicentral distance to induced seismicity [km]	distance to fault [km]	orientation of fault in current stress field	net injected volume [1000 m³]
10	yes	no	> 7	> 360	< 1	< 1	< 0.1	favorable	> 20
7	possible	unlikely	4 - 7	180-360	1 - 5	1 - 5	0.1 - 0.5	shearing possible	5 - 20
3	unlikely	likely	1 - 4	50-180	5 - 10	5 - 10	0.5 – 1.5	shearing unlikely	0.1 - 5
0	no	yes	< 1	< 50	> 10	> 10	> 1.5	locked	< 0.1

Example of a seismic hazard assessment scoring protocol (QCON & IF-Technology 2016: Defining the Framework for Seismic Hazard Assessment in Geothermal Projects V0.1 Technical Report)

Uncertainty reduction in localizing seismic events (NL, DK, IS)

Relation between faults and surface deformation (IT)

Fault sealing in storage and injection (PL)

Seismicity in storage (FR)

Alternative methods to detect and characterize buried faults (AT, DE)

Applying the fault database in seismic hazard assessment protocols (NL)

Link with expert reports and source data repositories related to induced hazard and impact research (HIKE Knowledge Share Point)

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HIKE European Fault Data Base summary:

- Compilation of existing (available) and new fault data from national mapping programs and assessments
- Seismogenic, capable and passive faults
- Intergration of various sources, representation styles, formats, scales
- Standard attribute and meta-data specification
- Implementation of structural framework classifications through semantic concept definitions
- Interface to existing fault repositories (e.g. SHARE/EPOS)
- State-of-art use cases and test applications

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References:

Slide 3: Image extracted from the online SHARE fault database viewer (http://diss.rm.ingv.it/share-edsf/sharedata/SHARE_WP3.2_Map.html)

Slide 9 & 11: E. Hintersberger, C. Iglseder, R. Schuster and B. Huet, 2017. The new database “Tectonic Boundaries” at the Geological Survey of Austria. Jahrbuch der Geologischen Bundesanstalt 157(1-4):195-207

Slide 12: Snapshot of the online Austrian fault database viewer (https://thesaurus.geolba.ac.at)

Slide 17-a Snapshot of the ONE-Geology surface fault map (IGME-5000) (http://www.europe-geology.eu/onshore-geology/geological-map/onegeologyeurope/)

Slide 17-b: H. Kombrink, J.C. Doornenbal, E.J.T. Duin, M. den Dulk, S.F. van Gessel, J.H. ten Veen & N. Witmans, 2012: New insights into the geological structure of the Netherlands; results of a detailed mapping project. Netherlands Journal of Geosciences — Geologie en Mijnbouw | 91 – 4 | 419 - 446 | 2012

Slide 17-c: E.J.T. Duin, J.C. Doornenbal, R.H.B. Rijkers, J.W. Verbeek & Th.E. Wong, 2006. Subsurface structure of the Netherlands – results of recent onshore and offshore mapping. Netherlands Journal of Geosciences — Geologie en Mijnbouw | 85 – 4 | 245 - 276 | 2006

Slide 17-d: M. Kortekaas & B. Jaarsma, 2018. Improved definition of faults in the Groningen field using seismic attributes. Netherlands Journal of Geosciences — Geologie en Mijnbouw |96 – 5 | s71–s85 | 2017

Slide 19: S.F. van Gessel, G. Remmelts, K. van Thienen-Visser, J. ten Veen, 2014. Geologische evaluatie potentieel gasvoerende schalielagen: karakterisatie van breuken en afdekkend pakket. Report TNO 2014 R10187

Slide 20: S. Baisch, C. Koch, H. Stang, B. Pittens, B. Drijver, N. Buik2, 2016: Defining the Framework for Seismic Hazard Assessment in Geothermal Projects V0.1 Technical Report, QCON & IF-Technology)

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Hazard and Impact Knowledge for Europe

EU Fault Database

Methods and Cases

Knowledge base

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