# GeoBlocks: Building blocks for the quantification of uncertainties in geological models

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17.03.2023

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# Background – Friedrich Carl

- Geosciences B.Sc. & M.Sc. in Tübingen
- Main focus: sedimentology, exploration
- Master thesis:
- ❖ Permeability measurements
- ❖ Petrophysical modelling in Petrel on core scale
- ❖ Fluid flow simulations in ECLIPSE
- Part of GeoBlocks since November 22

# Background – Jian Yang

| | |
|---|---|
| Bachelor Sc. | Petroleum Geology (China University of Petroleum)<br>• Thesis (in Karamay): Design of Carbonation and Permian Evaluation Wells in Dixi 106 Well Area |
| Master Sc. | Energy and Mineral Resources (RWTH Aachen University)<br>• Thesis: Guided Inversion in Virtual Reality |
| Work experience | Science assistant (CG3, RWTH Aachen University)<br>• Build guided inversion algorithm using external kriging and test the Tensorflow version of GemPy.<br>• Part of GeoBlocks since February 2023 |

# Background – Carlos Colombo

- **Electronic Engineering**, (Universidad Tecnológica Nacional)
- **Master in Oil & Gas Exploration and Production**, (Instituto Superior de la Energía)
- **MSc in Geophysics**,.(University of Aberdeen)

- **Work experience**:
  - 2003 – 2005: Field Engineer / Research Assistant in Scientific Station in Antarctica
  - 2006 – 2014: Operations Geophysicist
  - 2014 – 2018: Acquisition Geophysicist
  - 2018 – 2020: Processing Geophysicist
  - 2020 – 2022: Geoscientist / Junior Software Developer
  - 2022 – Present: Computational Geoscience Researcher, GeoBlocks (July 15$^{th}$, 2022)

# Background – Gabriela Gonzalez

| | |
|---|---|
| Bachelor | Geophysicist Engineering (Universidad Nacional Autónoma de México)<br>Thesis topic: Direct modelling potential methods |
| Master | MSc Geothermal Energy Systems (Hochschule Bochum)<br>Thesis topic: Wave simulation |
| Work experience: | 2012 – 2014: Follow-up oil & gas productions wells<br>2014 – 2019: Geomodelling oil & gas reservoirs<br>2019 – 2021: Geomodelling Ruhr district<br>2021 – 2023: Geoscientist Geological Survey NRW<br>March 2023: Part of GeoBlocks |

# Scientific objectives

- **Main objective:** creation of a workflow for geological modelling with a quantification of uncertainties

Substeps:

- Creation of test data sets from geological model analogues with high data quality & quantity (AP 2)
- Systematic analysis of the geological and geophysical input data regarding uncertainties and the influence of subjectivity on interpretations (AP 3)
- Review of the suitability of geological interpolation and modelling methods to model the spatial variability of host rocks (AP 4)
- Development of methods for the comparability of regions showing differences in the quantity and/or quality of subsurface data (AP 5)
- Development of approaches for the reduction of quantified uncertainties through intelligent sampling strategies to scientifically support the planning of follow-up work in the site selection process (AP 6)

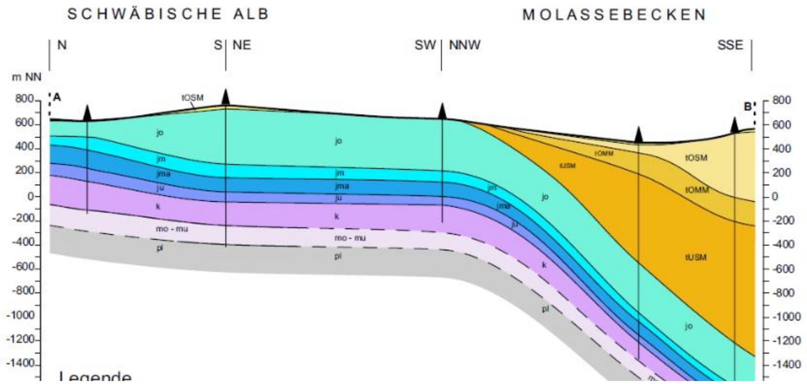
# Building Blocks for Model Development

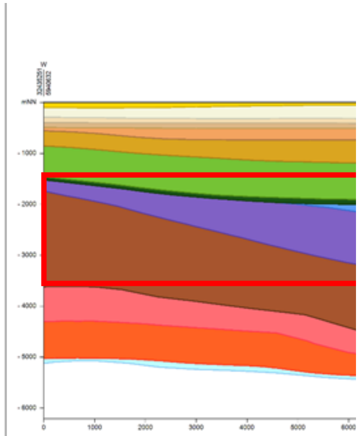
- A 3D geological model is a composite of geometrical elements & topological rules, decomposable into standard geometries (stacks of ±conformable layers, dome-shapes, sub-vertical layers etc.)
- A range of standard geometries can be pre-built as Building Blocks and adjusted stochastically to geophysical interpretations and borehole data after shape comparison
- Thus, the range of typical geometrical properties (thickness, dip angles, sinuosity, wavelength etc.) is needed
- Using the range of likely geometrical properties, the model uncertainty is provided
- The adjusted Building Block is introduced into the model and combined by topological rules with other Building Blocks

# Typical geometries for host rocks
# Claystones

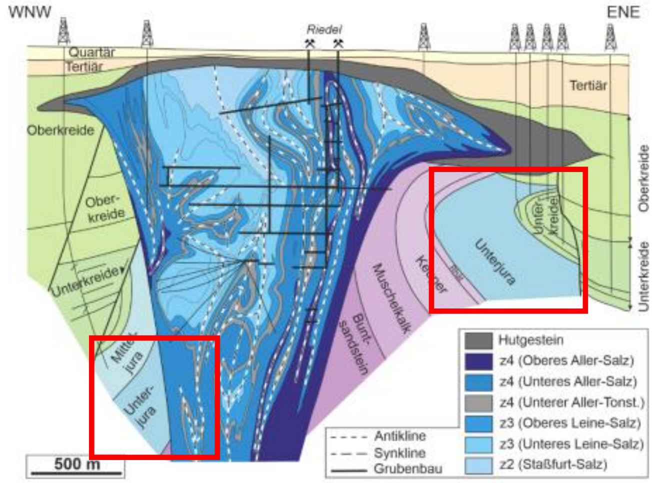
- Originally conformable layers (e.g. Northern Germany)
- Possibly dipping (Opalinus clay SW Germany)
- Possibly folded
- Possibly faulted

} Excluded in search of repository site



https://viewer.bge.de/?mode

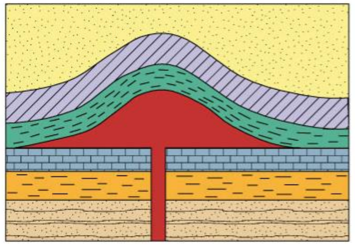


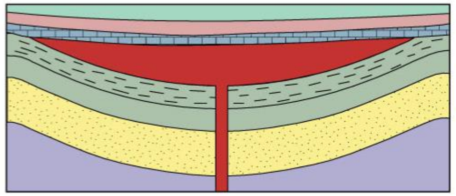

Example for folded and cut claystones in the viscinity of a salt structure (modified after Schachl, 1987)

# Typical Geometries for host rocks
# Plutonic rocks

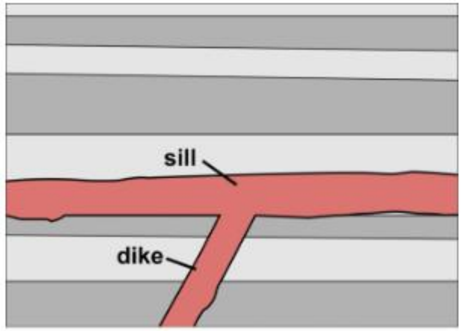
- Batholith: large irregular discordant intrusion >100 km²
- Stock: irregular discordant intrusion <100 km²
- Laccolith: concordant body with roughly flat base and convex top, usually with feeder pipe below
- Lopolith: concordant body with roughly flat top and shallow convex base, may have feeder pipe below
- Phacolith: concordant lens-shaped pluton typically occupying crest of anticline or trough of syncline
- Dike: relatively narrow tabular discordant body
- Sill: relatively thin tabular concordant body intruded along bedding planes

https://geology.com/rocks/igneous-and-volcanic-structures/



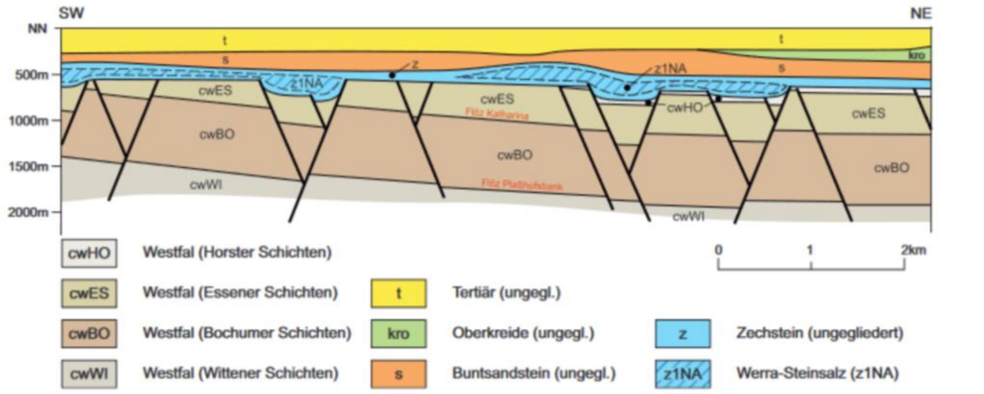
http://www2.ess.ucla.edu/~ejohnson/ess103a/4_1_intrus_str_peg.pdf



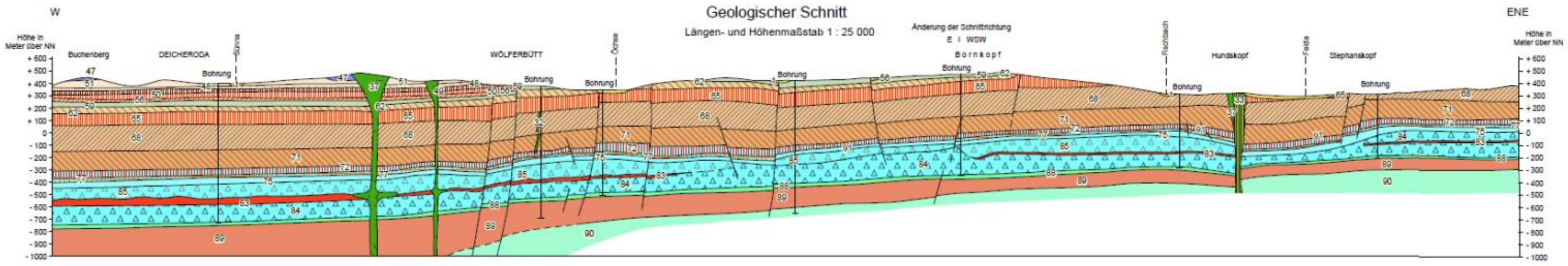

https://blogs.egu.eu/divisions/ts/2022/05/30/features-from-the-field-dikes-and-sills/

# Typical Geometries for host rocks
# Salt

- Originally conformable layering




Section through the Lower Rhine Basin (BASAL study, Reinhold et al., 2014)

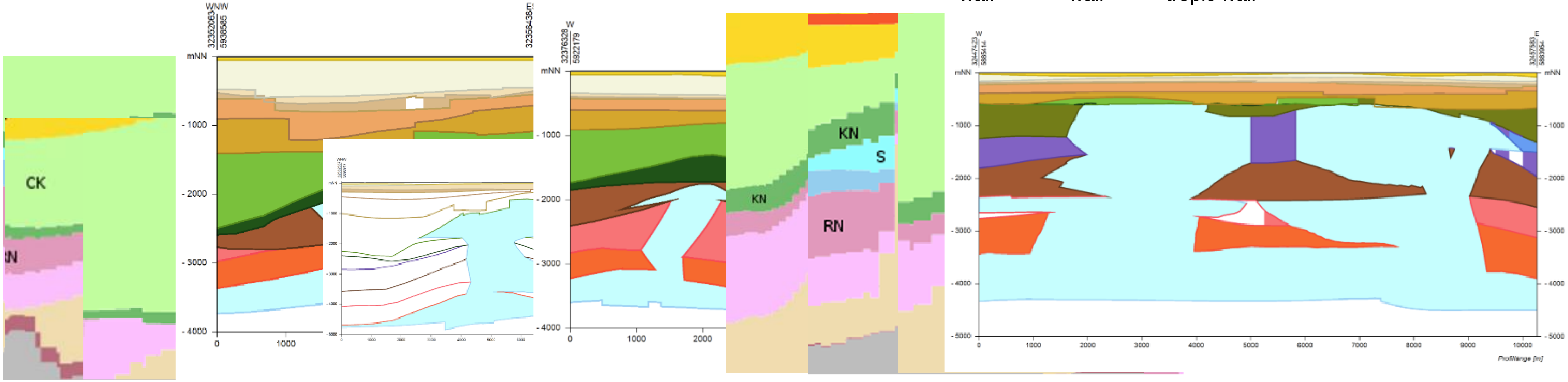



Section through the Werra Basin, Thuringia (GK25, Blatt 5226)

# Typical geometries for host rocks
# Salt

Twiss & Moores, 1992
Hudec & Jackson, 2007
https://www.dinoloket.nl/en/subsurface-models/map
https://viewer.bge.de/?model=Niedersachsen.GTA3D&filter=true

- anticline
- pillow
- low-amplitude roller
- diapiric stock
  - single-layered
  - multi-layered (salt wedges)
- diapiric salt sheet
- salt wall
  - broad base
    - high-amplitude roller
  - steep flanks
    - eroded wall
    - tapered wall
    - very aniso-tropic wall
- detached diapir
- complex shapes



# Current focus

**BGE**

Site identification

Define a **method for selection**, that can be adapted to the data that are available

**BGR**

Data set development

Fit GeoBlocks's collaboration purposes and methods

**GeoBlocks**

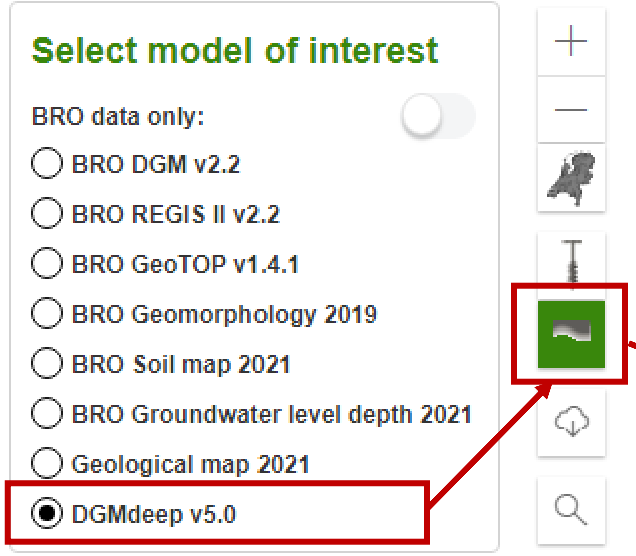
Idea generation

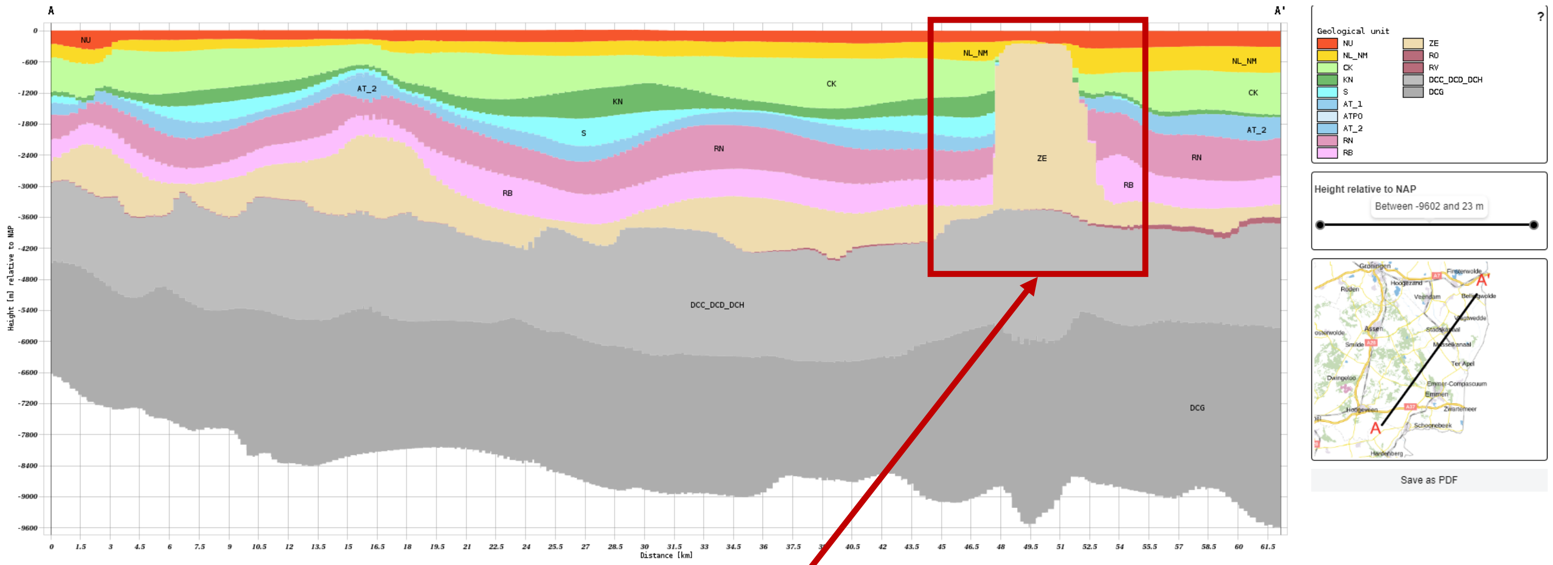
Build **example models** and build blocks for model development

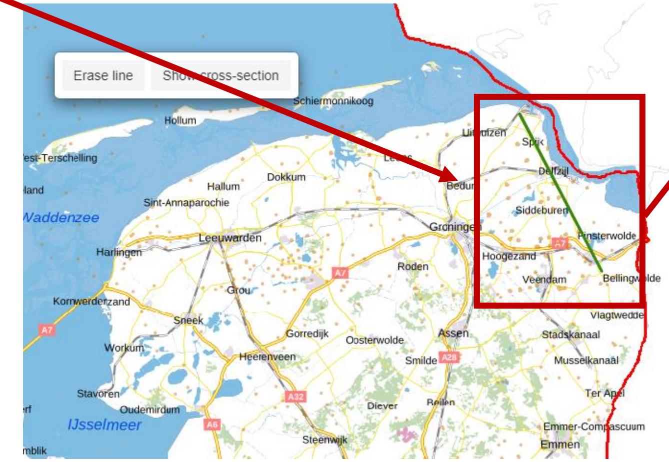
# Data acquirement of example model

**DINOloket**

*Data and Information on the Dutch Subsurface*

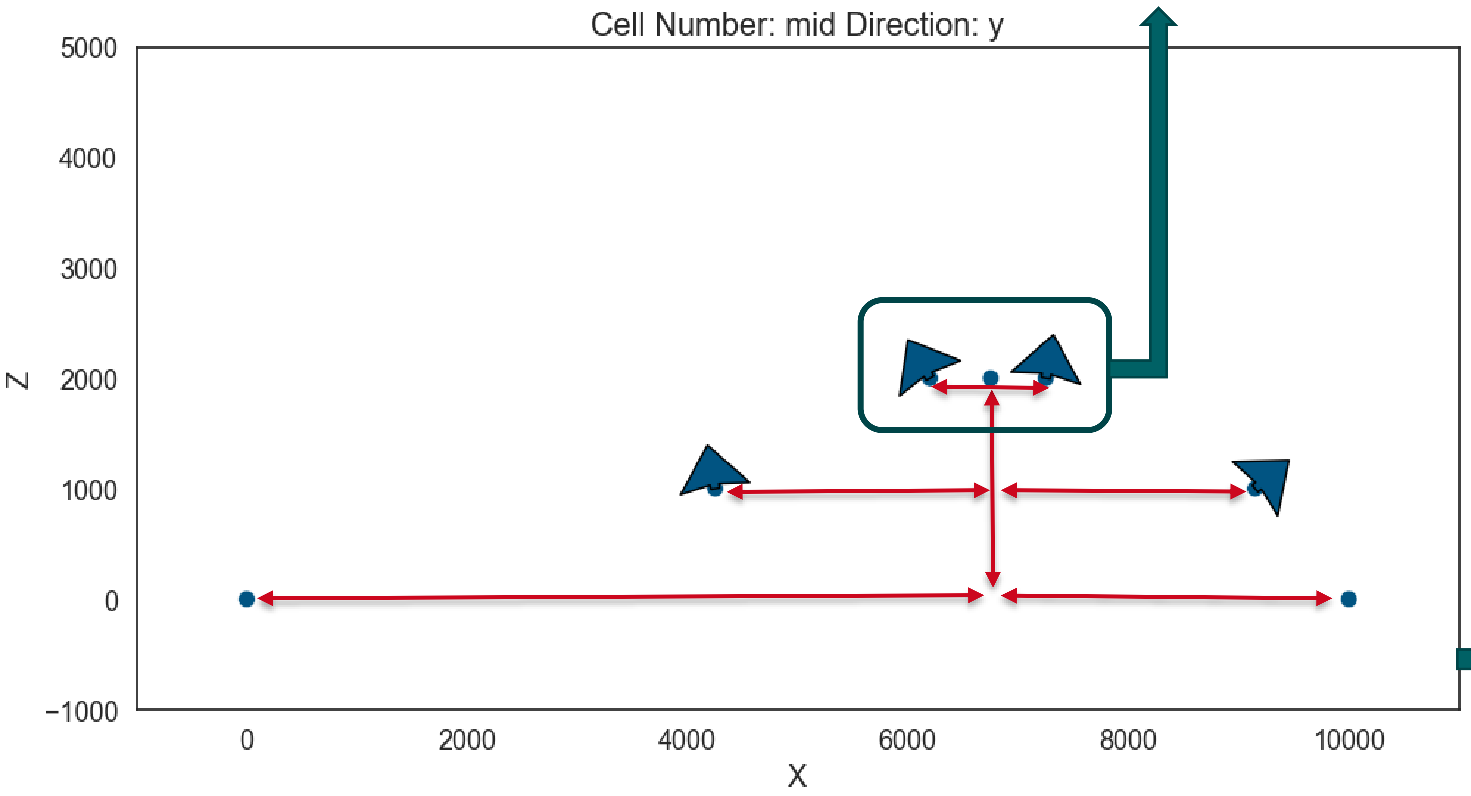


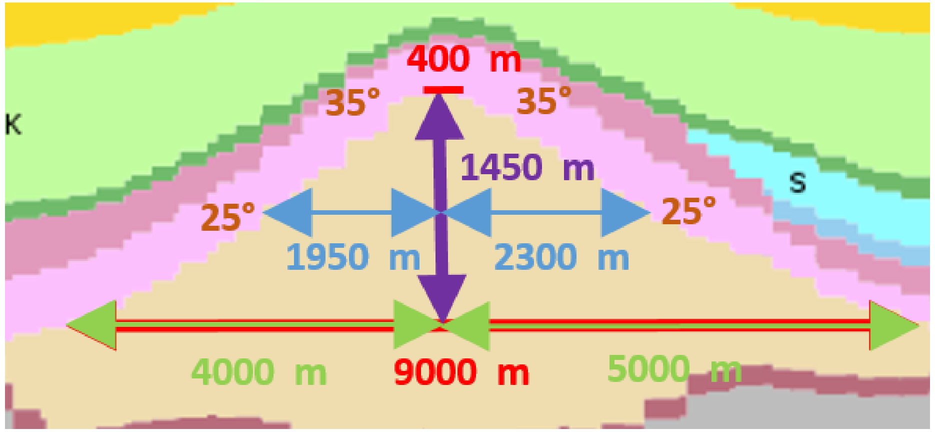



# Model parameters simple salt models (two slices 90° )

Assume we have a flat and asymmetry top




https://www.dinoloket.nl/en/subsurface-models/map

7 points in each slice
4 orientations in each slice

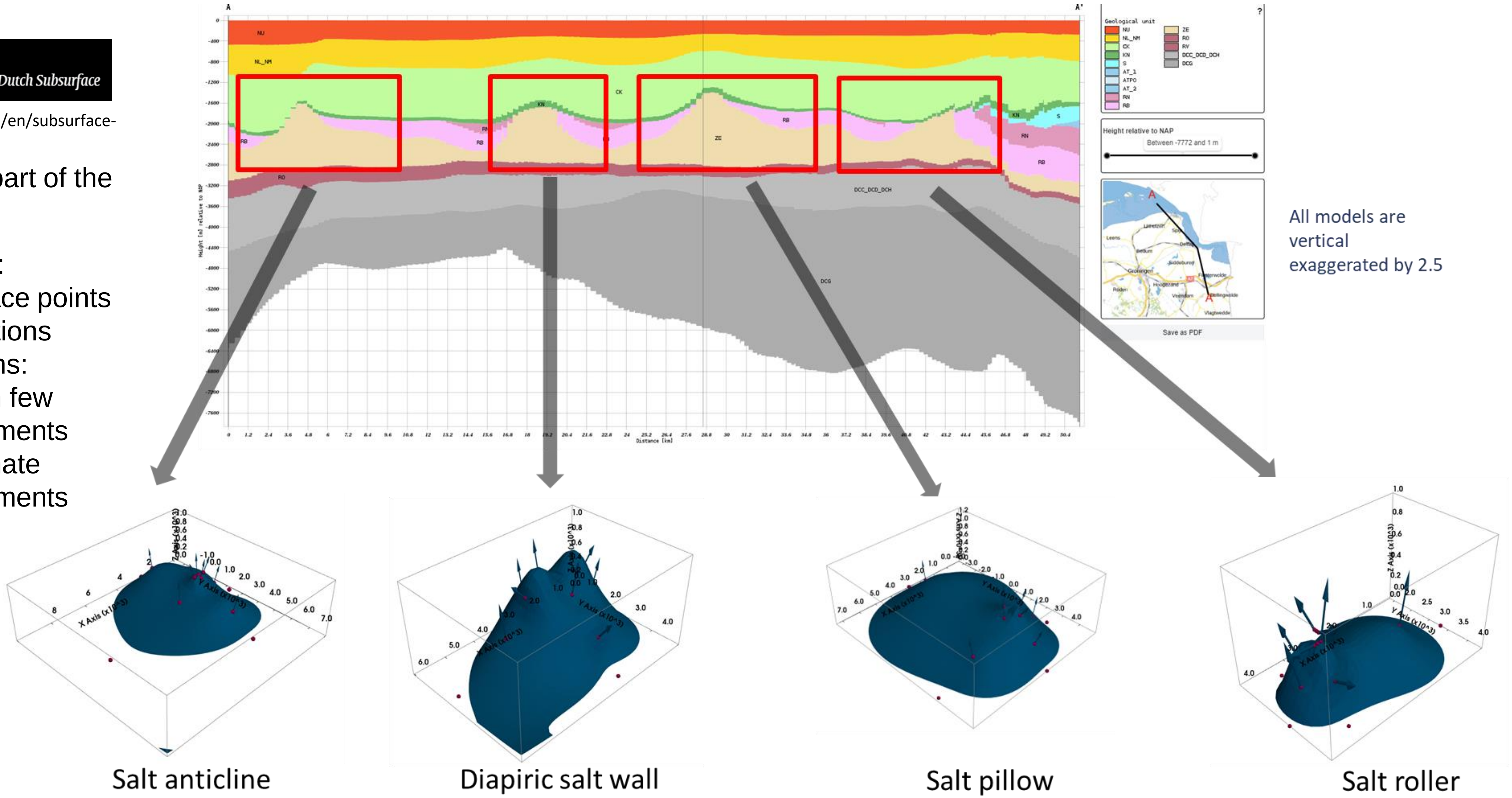
# Example salt models built by GemPy

**DINOloket**
*Data and Information on the Dutch Subsurface*

https:// www.dinoloket.nl/en/subsurface-models/map

North-eastern part of the Netherlands

- Measurements:
  - ❖ 14 interface points
  - ❖ 8 orientations
- Model limitations:
  - ❖ Based on few measurements
  - ❖ Approximate measurements




All models are vertical exaggerated by 2.5

# Example salt models built by GemPy

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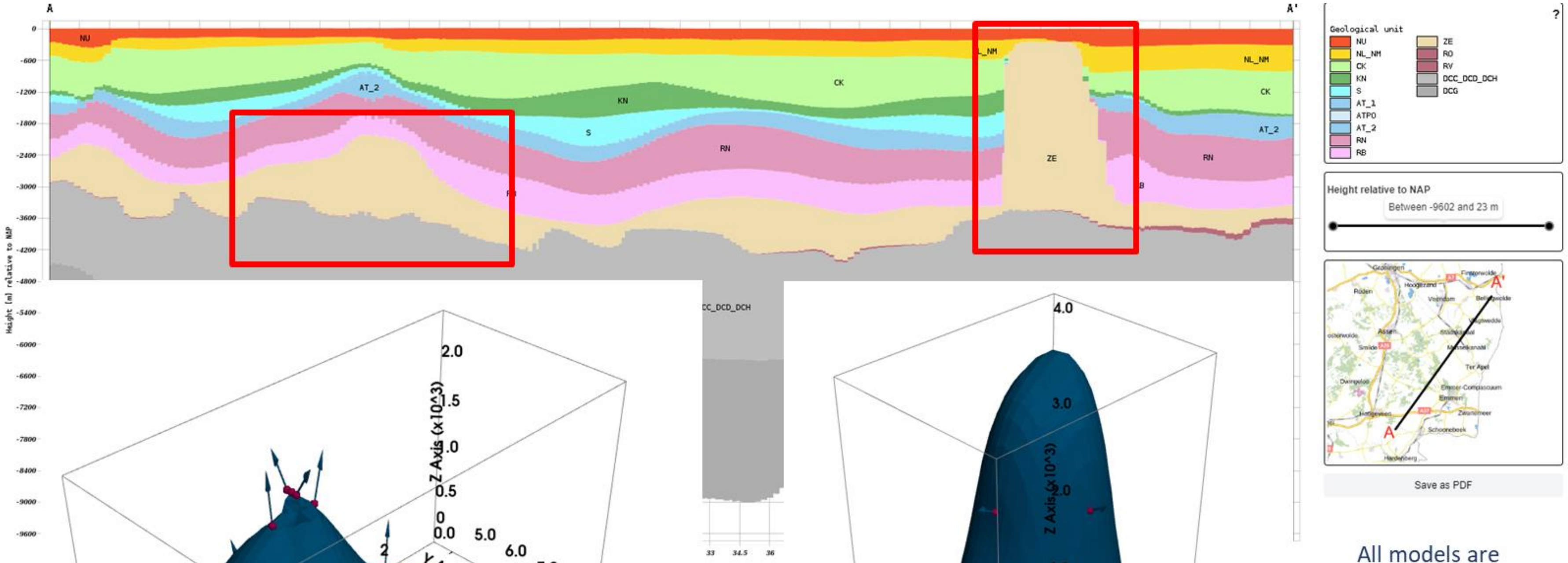
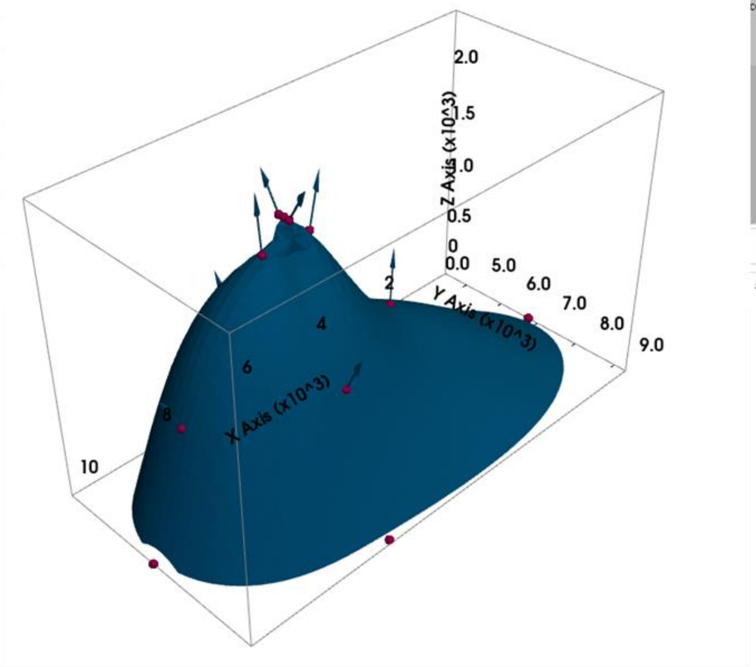
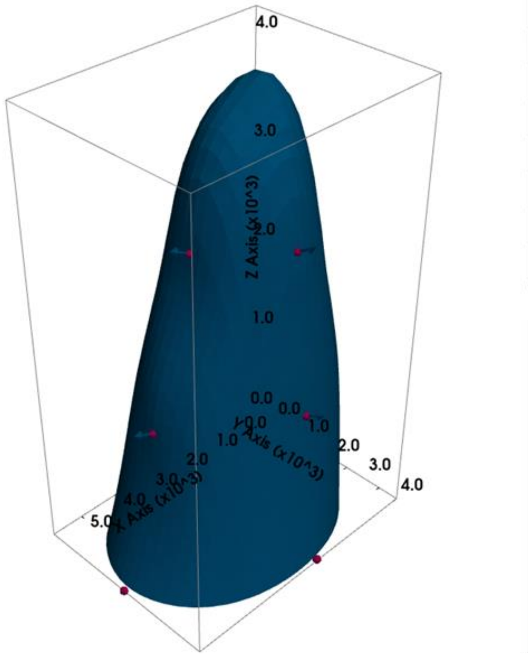



Salt pillow




Diapiric salt stock

All models are vertical exaggerated by 2.5



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# Example salt models built by GemPy

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*Data and Information on the Dutch Subsurface*

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North-eastern part of the Netherlands

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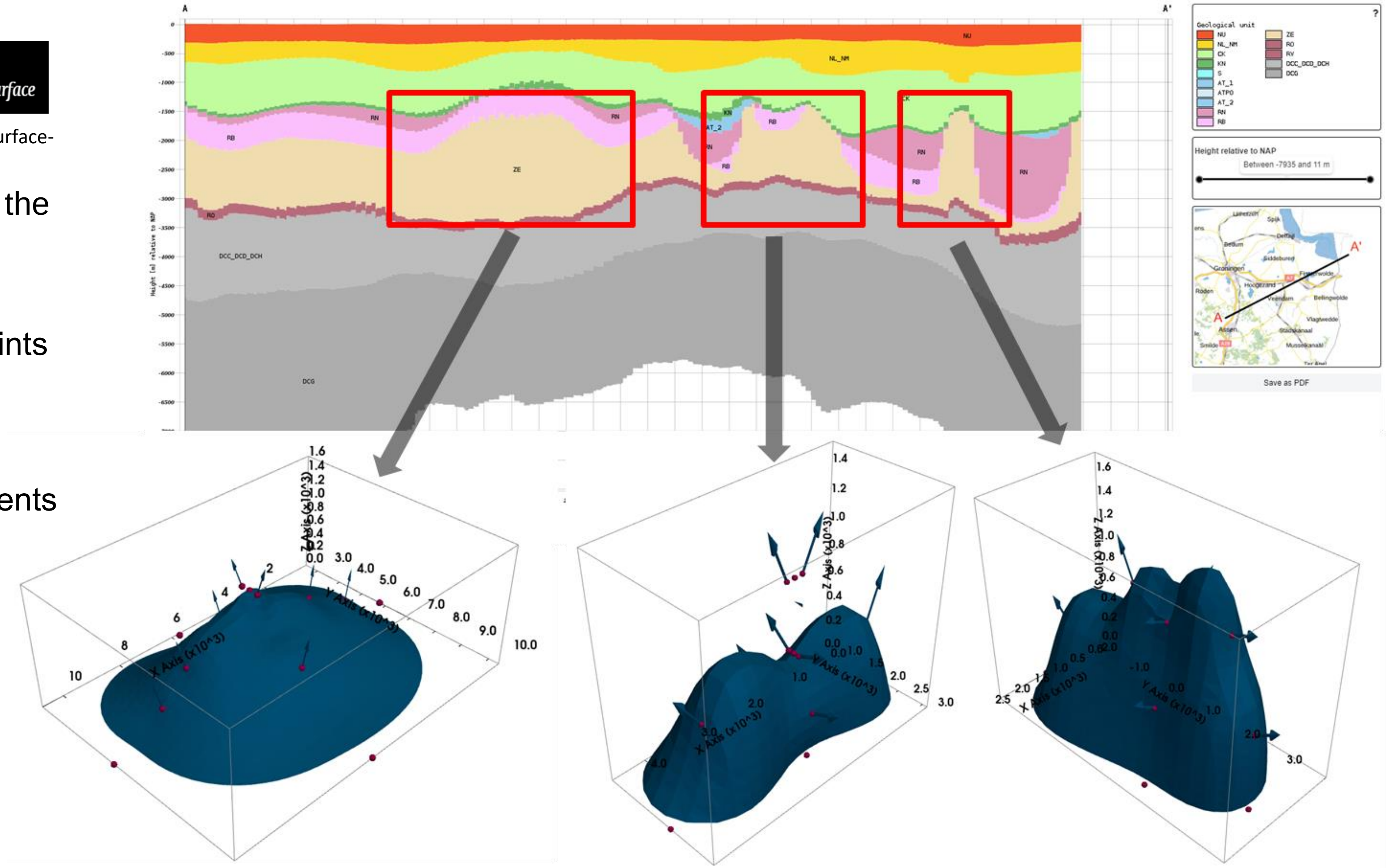
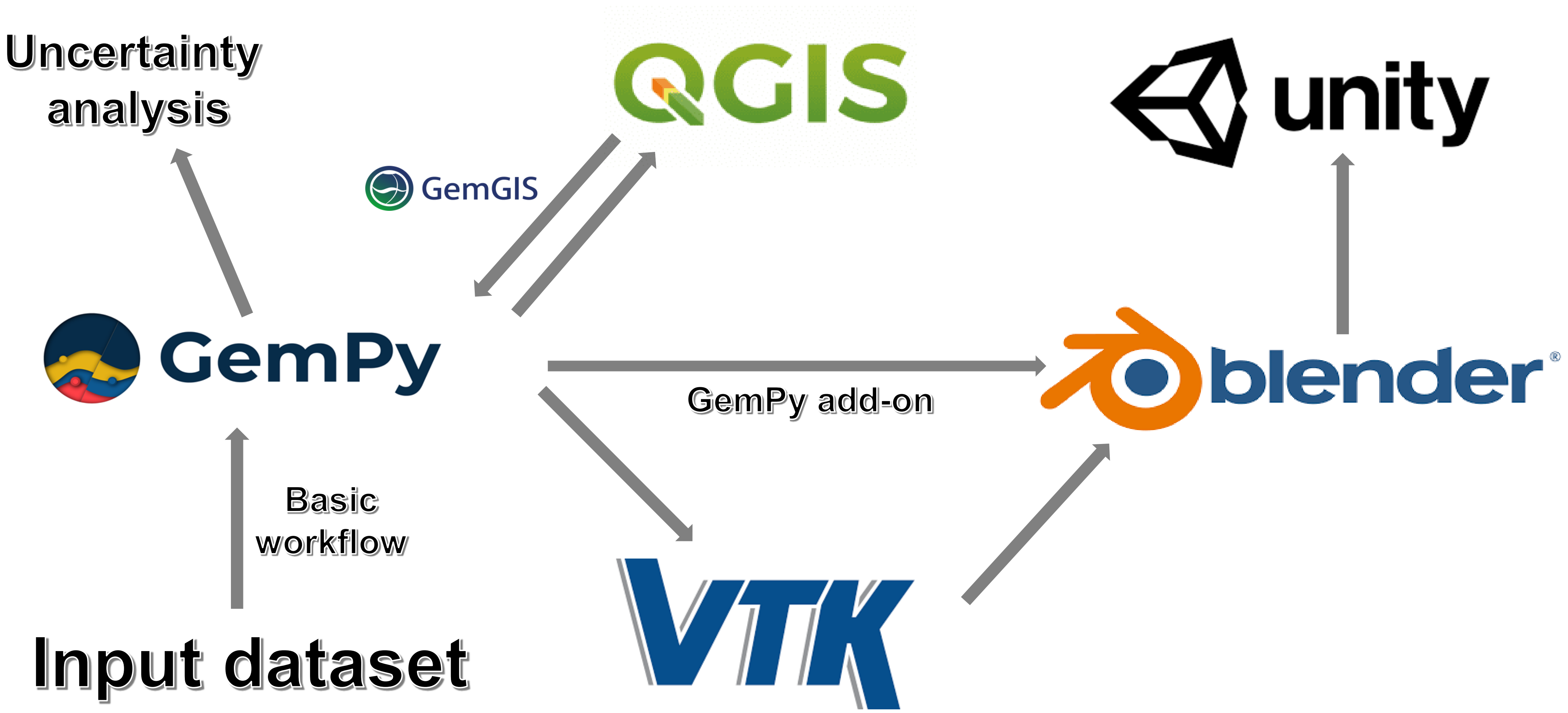



Salt anticline | Diapiric salt wall | Diapiric salt wall

All models are vertical exaggerated by 2.5

# Model processing by different software

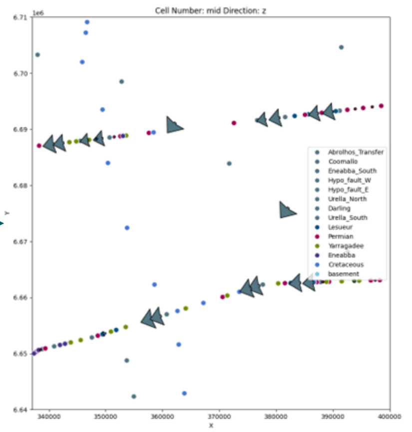


# Introduction of GemPy

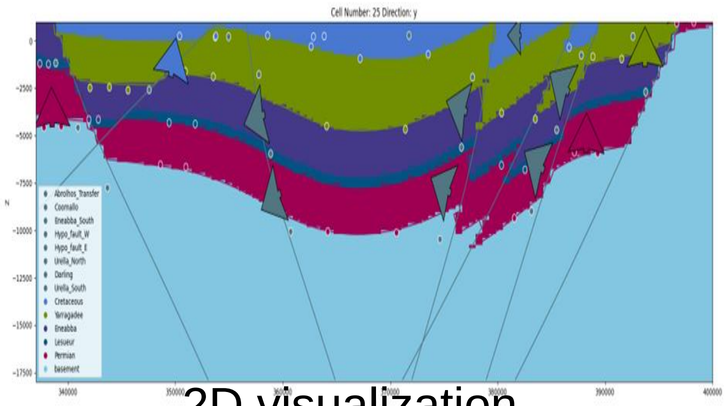
- GemPy – **Open-source** geological modelling python package
- Constructs 3D geological models ( folds, faults, unconformities)
- Potential-field interpolation algorithm based on **universal co-kriging**
- Full integration of stochastic geological modeling for **uncertainty analysis**

| X | Y | Z | formation |
| --- | --- | --- | --- |
| 0 | 1400 | 0 | S33 bottom |
| 1400 | 1400 | 2300 | S33 bottom |
| 1075 | 1400 | 2300 | S33 bottom |
| 1725 | 1400 | 2300 | S33 bottom |
| 500 | 1400 | 1150 | S33 bottom |
| 2250 | 1400 | 1150 | S33 bottom |
| 3000 | 1400 | 0 | S33 bottom |
| 1400 | -1500 | 0 | S33 bottom |
| 1400 | 1400 | 2300 | S33 bottom |
| 1400 | 3575 | 2300 | S33 bottom |
| 1400 | 2550 | 2300 | S33 bottom |
| 1400 | -1200 | 1150 | S33 bottom |
| 1400 | 3900 | 1150 | S33 bottom |
| [illegible]0 | 4500 | 0 | S33 bottom |

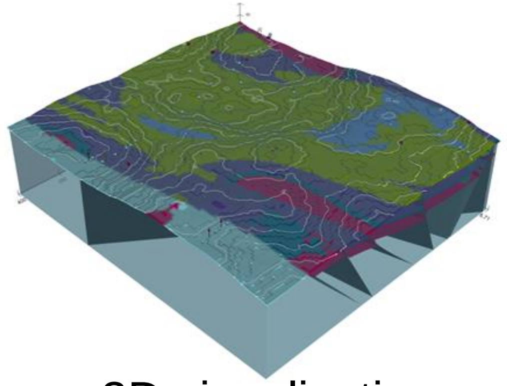
Input data




Compute model




2D visualization



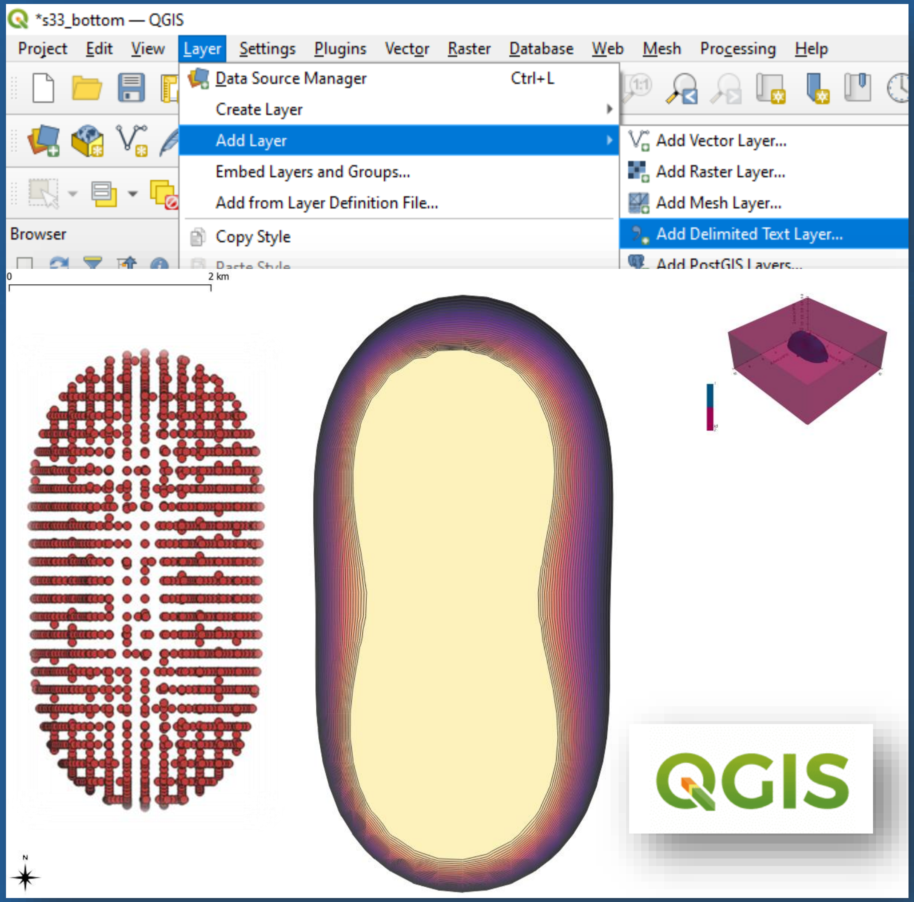
3D visualization


- Lajaunie, C., Courrioux, G. & Manuel, L. Foliation fields and 3D cartography in geology: Principles of a method based on potential interpolation. Math Geol 29, 571–584 (1997).
- de la Varga, M., Schaaf, A., and Wellmann, F.: GemPy 1.0: open-source stochastic geological modeling and inversion, Geosci. Model Dev., 12, 1–32, https://doi.org/10.5194/gmd-12-1-2019, 2019.

# Link between GemPy and GIS

Export of ***CSV*** file.
Can be used in GIS software, such as QGIS that supports viewing, editing, printing, and analysis of geospatial data.

- Output:
  - Grid
  - Surfaces
  - Kriging weights vector
  - Scalar field
  - Vertices
  - Geological map
  - Gradient

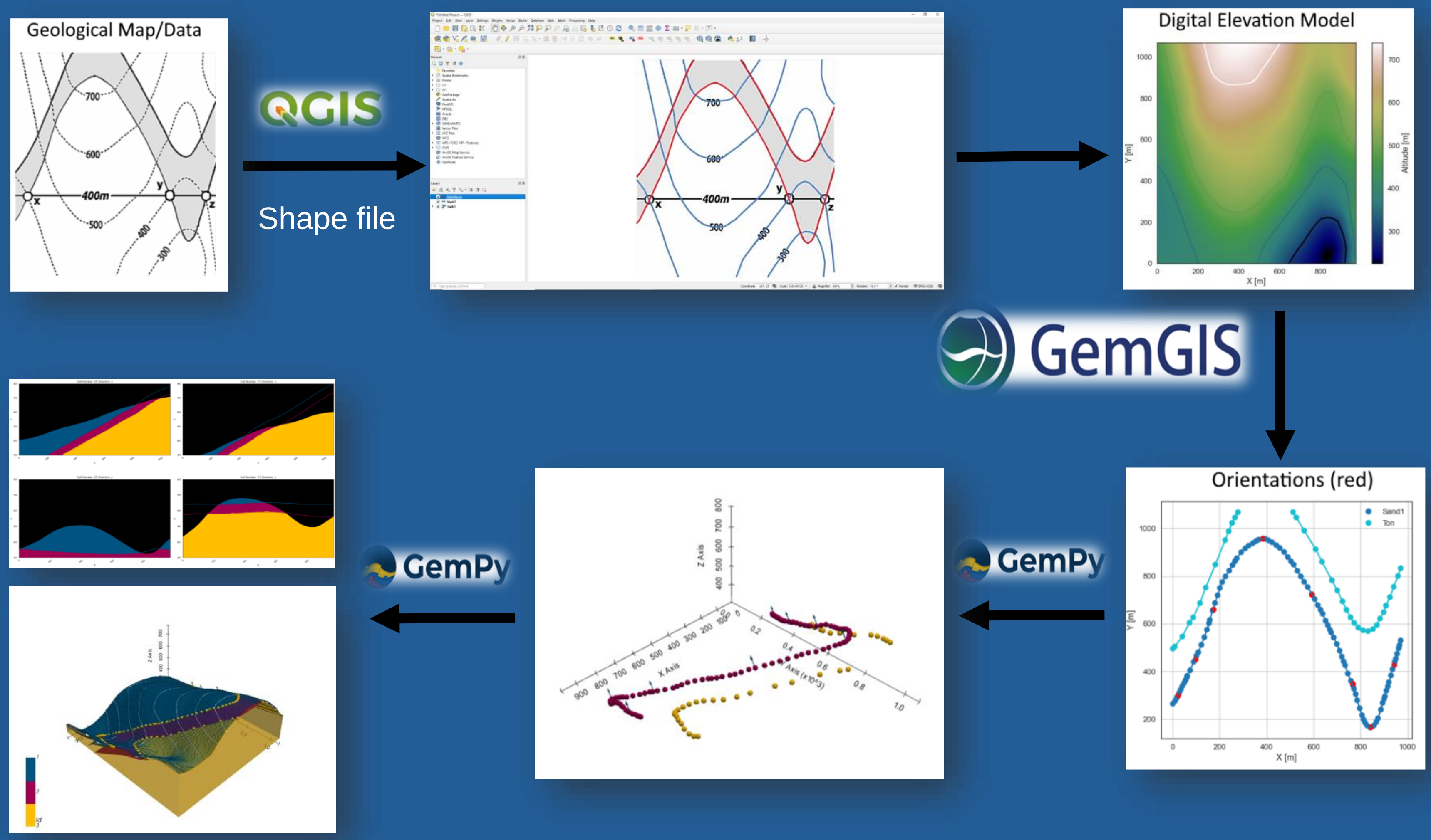



Input: Vertices of surface mesh
Method: contour level

# Link between GemPy and GIS

Geological map/data can be processed by GIS software such as QGIS to generate data for GemGIS.

GemGIS then will prepare data for Gempy to create 3D geological model.




QGIS

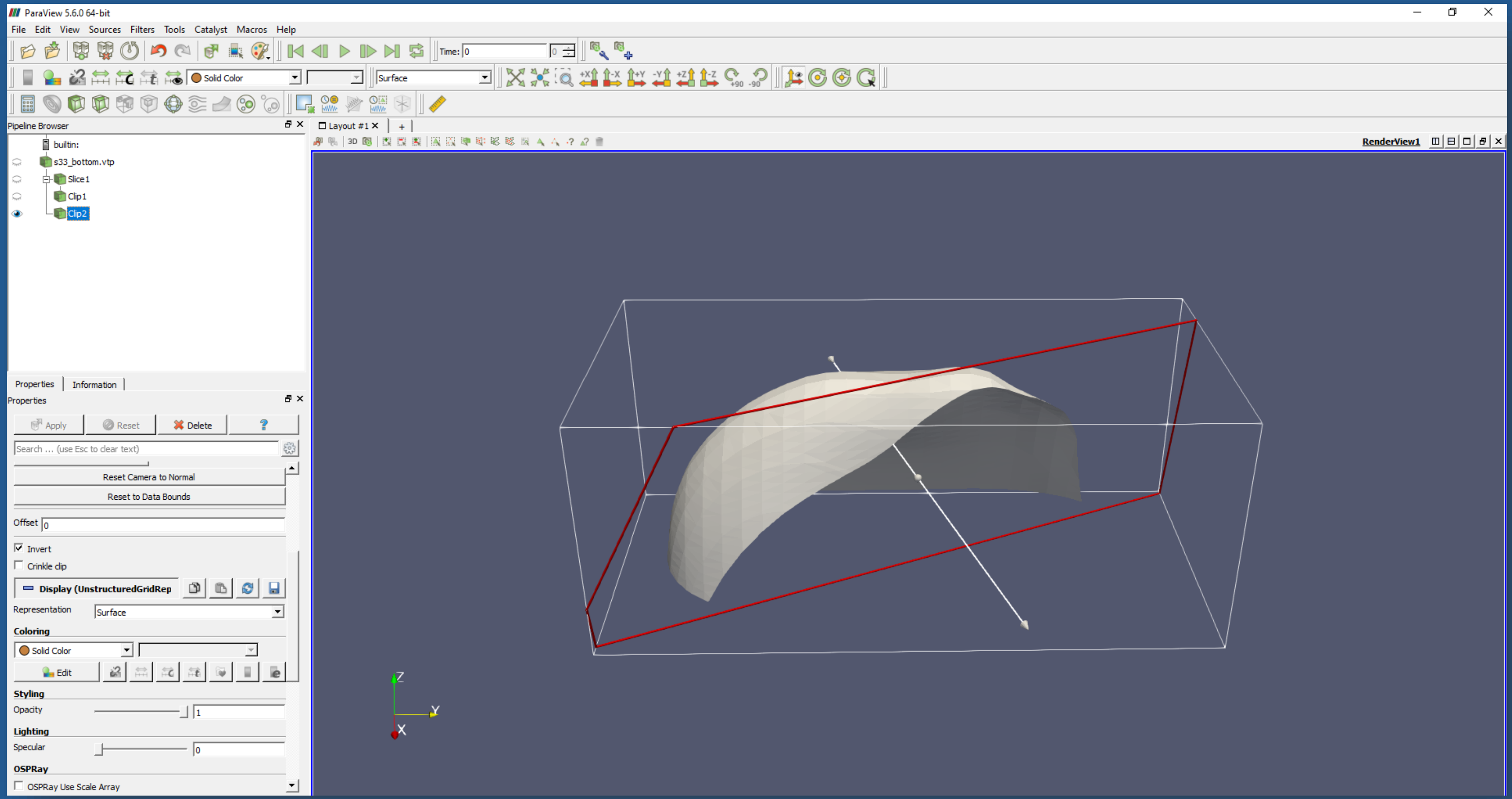
GemGIS

# Link between GemPy and VTK

Export of ***VTK*** file.
Can be used in Visual Toolkit software, such as Paraview that offers strong visualization capabilities and many output format.

VTK

ParaView




Input: .vtk file of surface
Method: cross-section

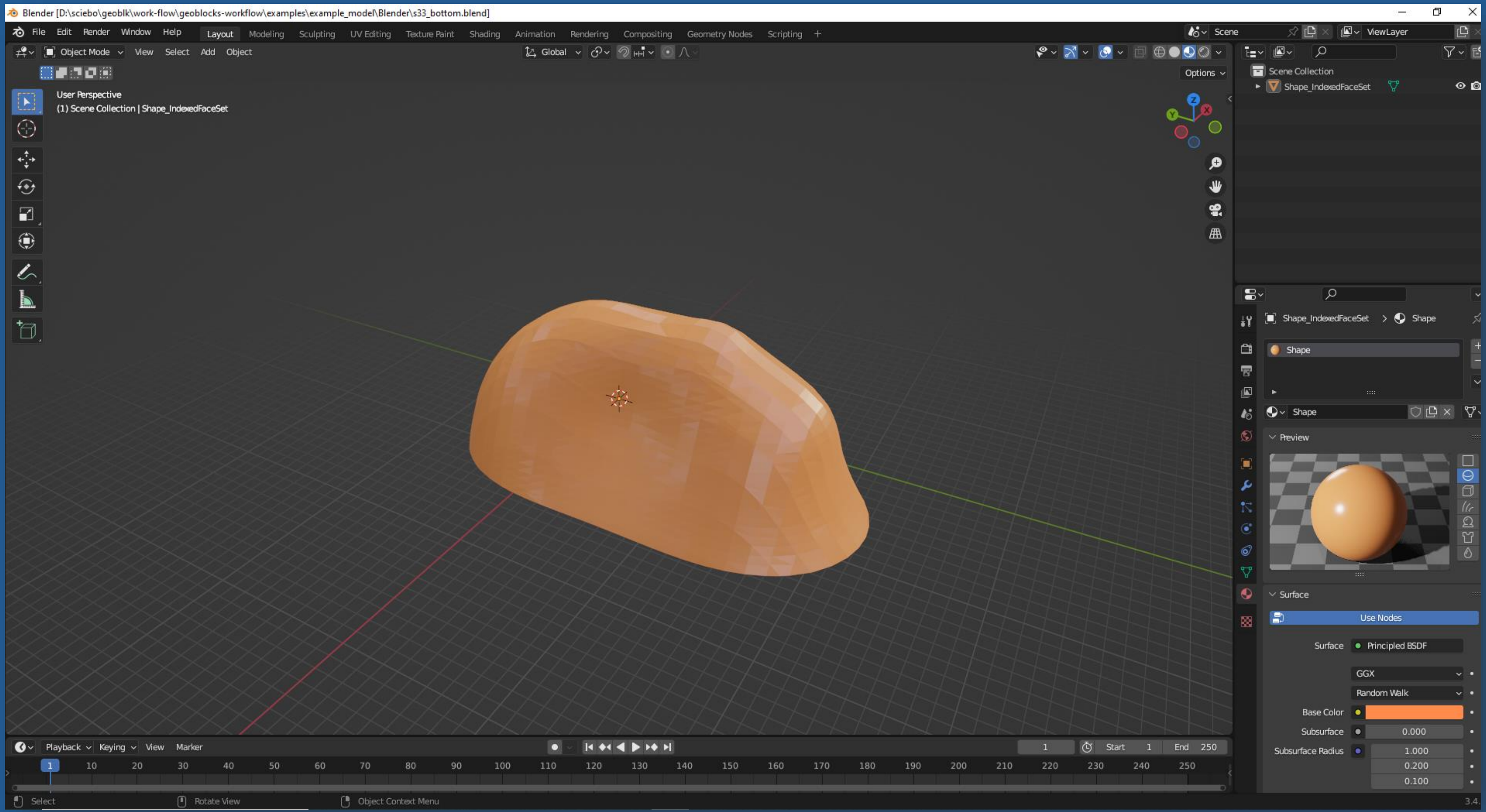
# Link between GemPy and Blender

Export of ***obj*** file. This triangulated surface meshes can be used in Blender for further processing.

We also developed a **blender add-on** which can directly create GemPy model in blender.

blender

- open-source
- animated films
- visual effects
- motion graphics
- virtual reality
- 3D-printe




Input: .obj file of surface
Method: rendering



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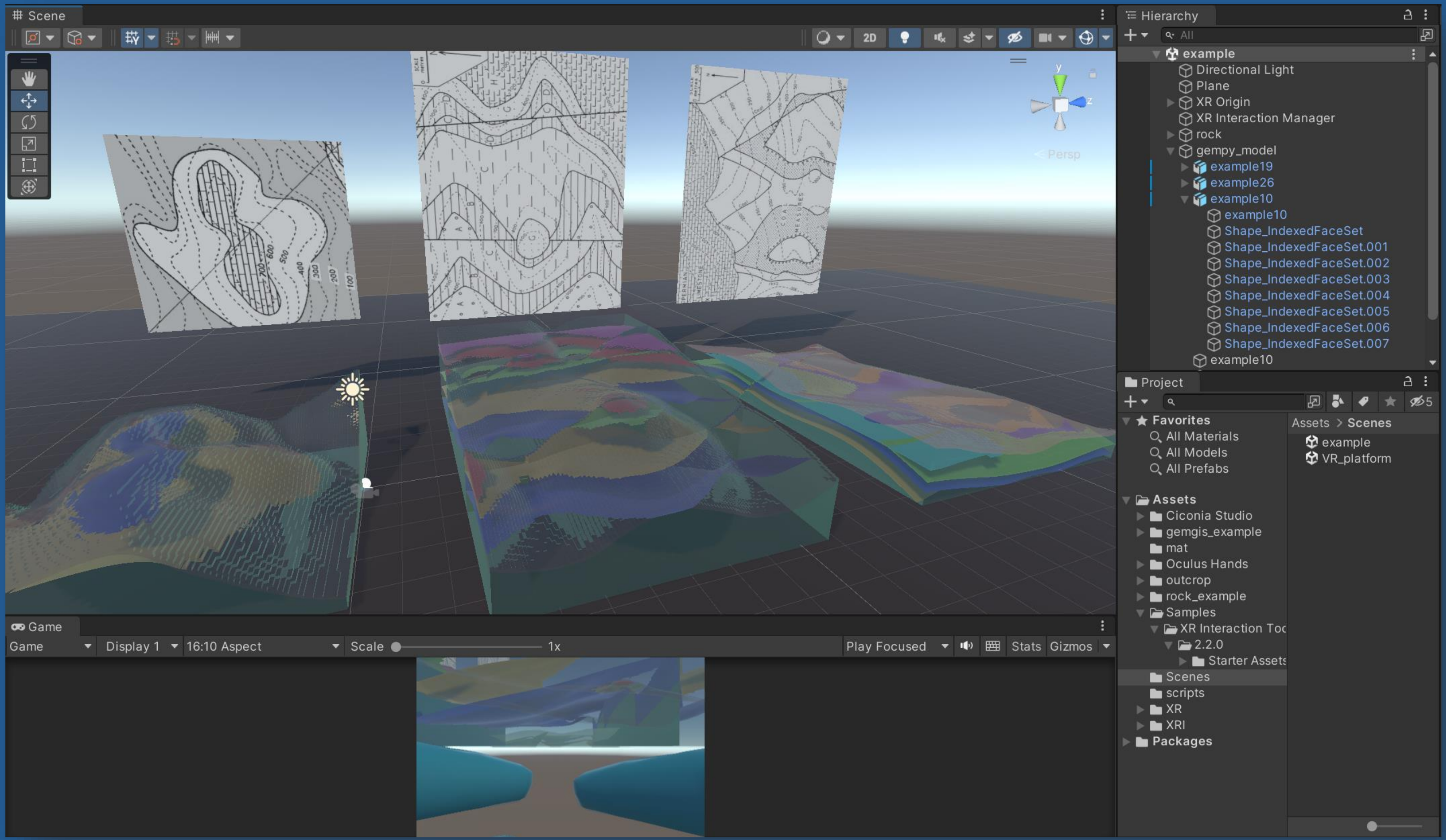
# Link between GemPy and Unity

Model from Blender can be imported into **Unity**, the 3D game engine where we can develop teaching software or visualization applications.

unity




NurGis VR geological teaching platform

# GeoBlocks Data Management Plan (DPM)

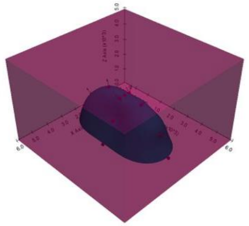
**Internally, we plan to build a GIS database (with QGIS) that allows all parties to easily visualise the data**

**Internal Applications Formats** → **Common Format**

**Maps**

| X | Y | Z | formation |
|---|---|---|---|
| 0 | 1400 | 0 | S33 bottom |
| 1400 | 1400 | 2300 | S33 bottom |
| 1075 | 1400 | 2300 | S33 bottom |
| 1725 | 1400 | 2300 | S33 bottom |
| 500 | 1400 | 1150 | S33 bottom |
| 2250 | 1400 | 1150 | S33 bottom |

**Tables**

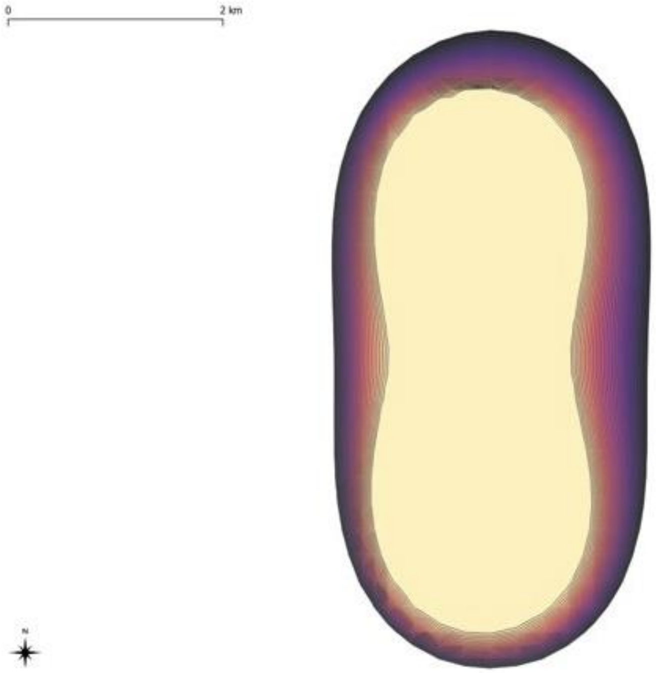


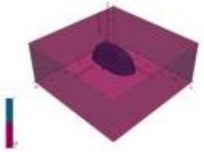
**Models**

## GIS DATABASE

## For QGIS or ESRI

## ArcGIS



QGIS



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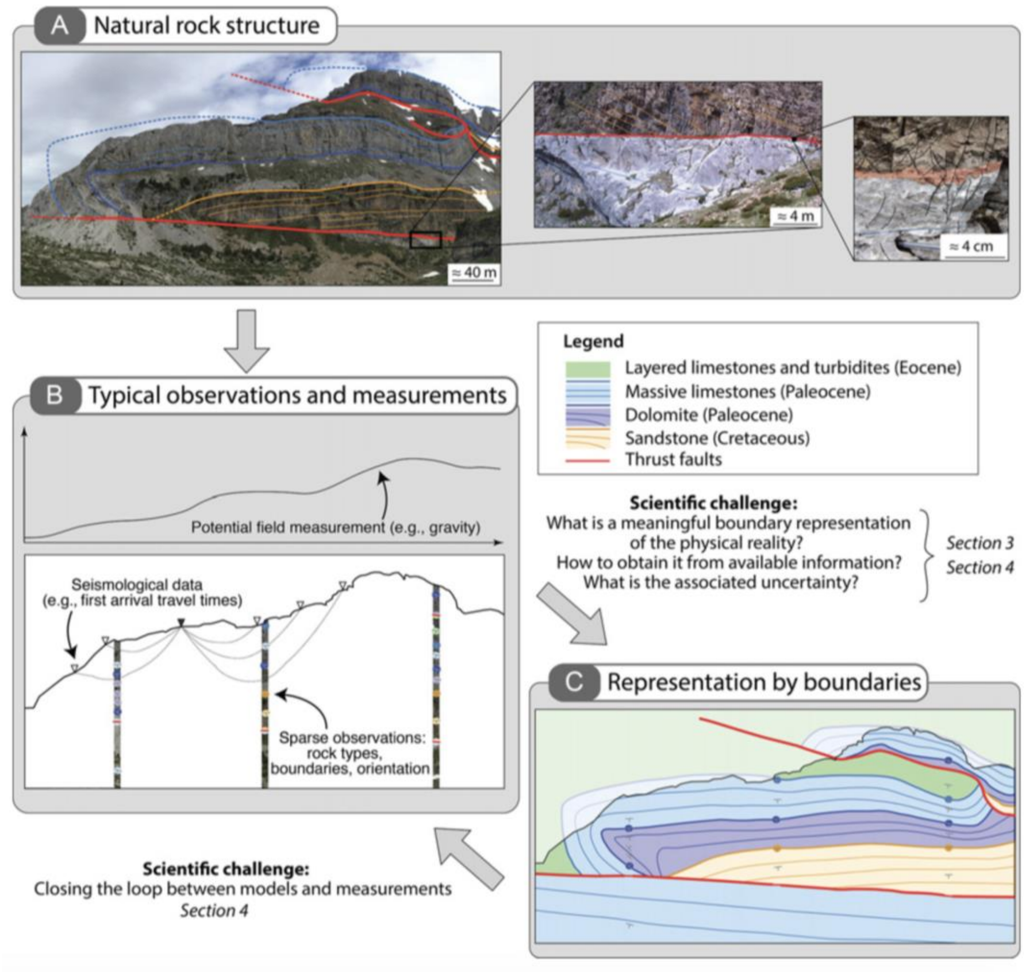
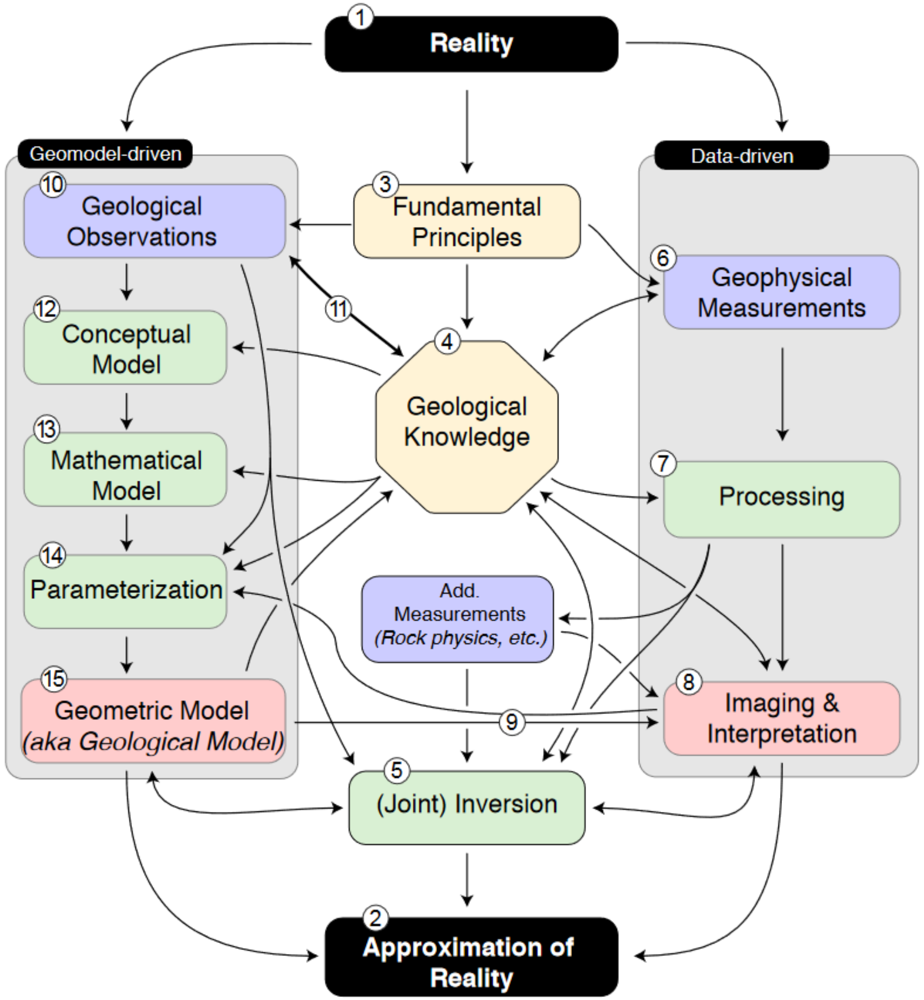
# Geomodelling Basic Concepts

**Interface detection is the key for modelling**

**One of goals of our team is to address uncertainty with probabilistic programing**



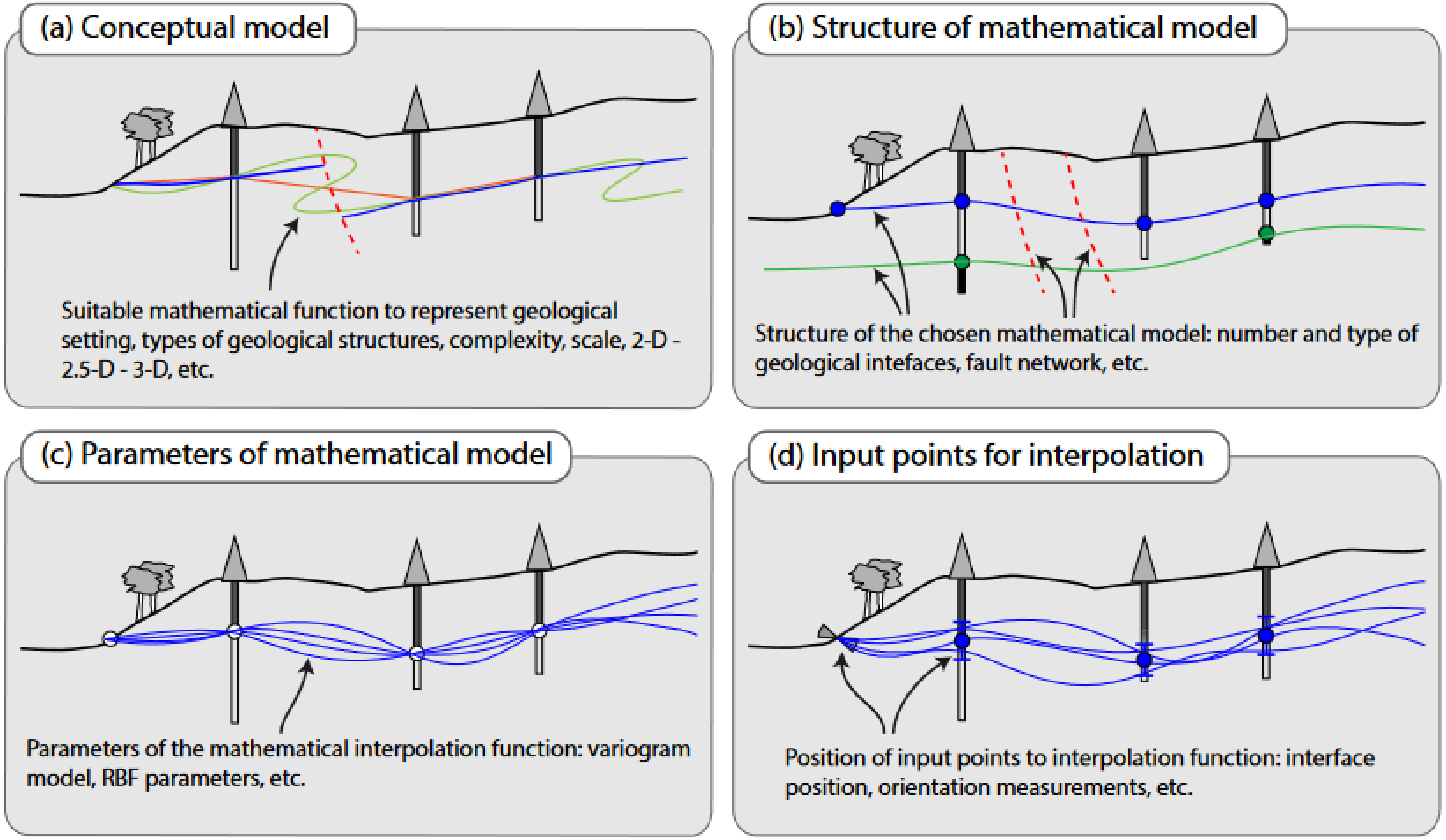




<u>Source</u>: Wellmann and Caumon, 2018

# Uncertainties found in Geomodelling

**General classifications (Wellmann et al., 2010, after Mann, 1993) applied to the case of structural Modelling:**

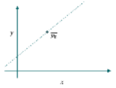
- **Type 1 (error, bias, and imprecision)**
  **Ambiguity of structure based on uncertainties in raw data.**
- **Type 2 (stochasticity, and inherent randomness)**
  **Uncertainty of interpolation and extrapolation away from know points.**
- **Type 3 (imprecise knowledge)**
  **Problem of incomplete knowledge of structures in subsurface.**

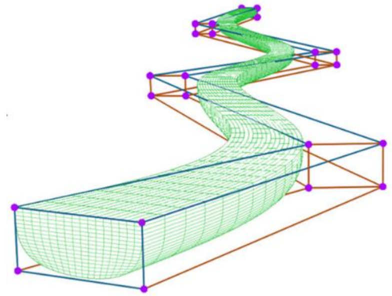



Source: Wellmann and Caumon, 2018

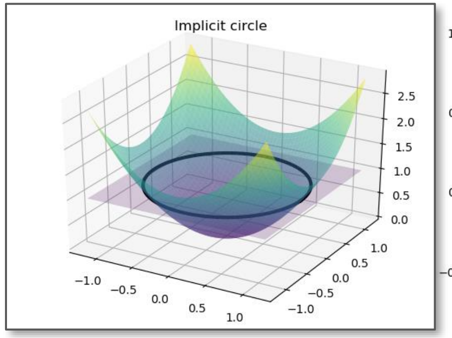
# Implicit vs. Explicit Geomodelling (Type 2 Uncertainties)

- **Explicit Methods**: directly building geological interfaces.
  - **How to represent a line?** $y = kx + b$
  - Usually linear estimators: e.g., kriging, inverse, natural neighbour.
  - Good for grids that include petrophysical modelling: e.g., Petrel, Gocad, RMS or Jewel Suite
  - For 3D geomodelling: TINs (linear approx.) or parametric surfaces (e.g., NURBS, higher order approx.).
  - Surfaces tend to intersect or leave gaps.
  - High user interaction and validation.
  - Better for difficult-to-model objects.

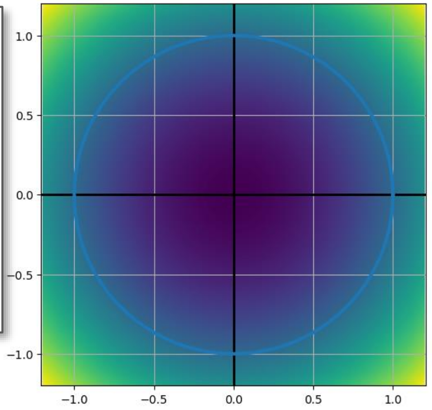




- **Implicit Methods**: scalar fields whose equipotential surfaces are the geological interfaces of interest.
  - **How to represent a line?** $Ax + By - D = 0$
  - Implicit surfaces (with iso-values) from sparse data points.
  - Meshless or mesh-based methods.
  - Require extra artificial data points with non-zero values, orientation measurement or forcing the gradient norm to be unitary.
  - Several surfaces can be modelled.
  - More flexible in representing more complex geometries.




$$x^2 + y^2 = r^2$$

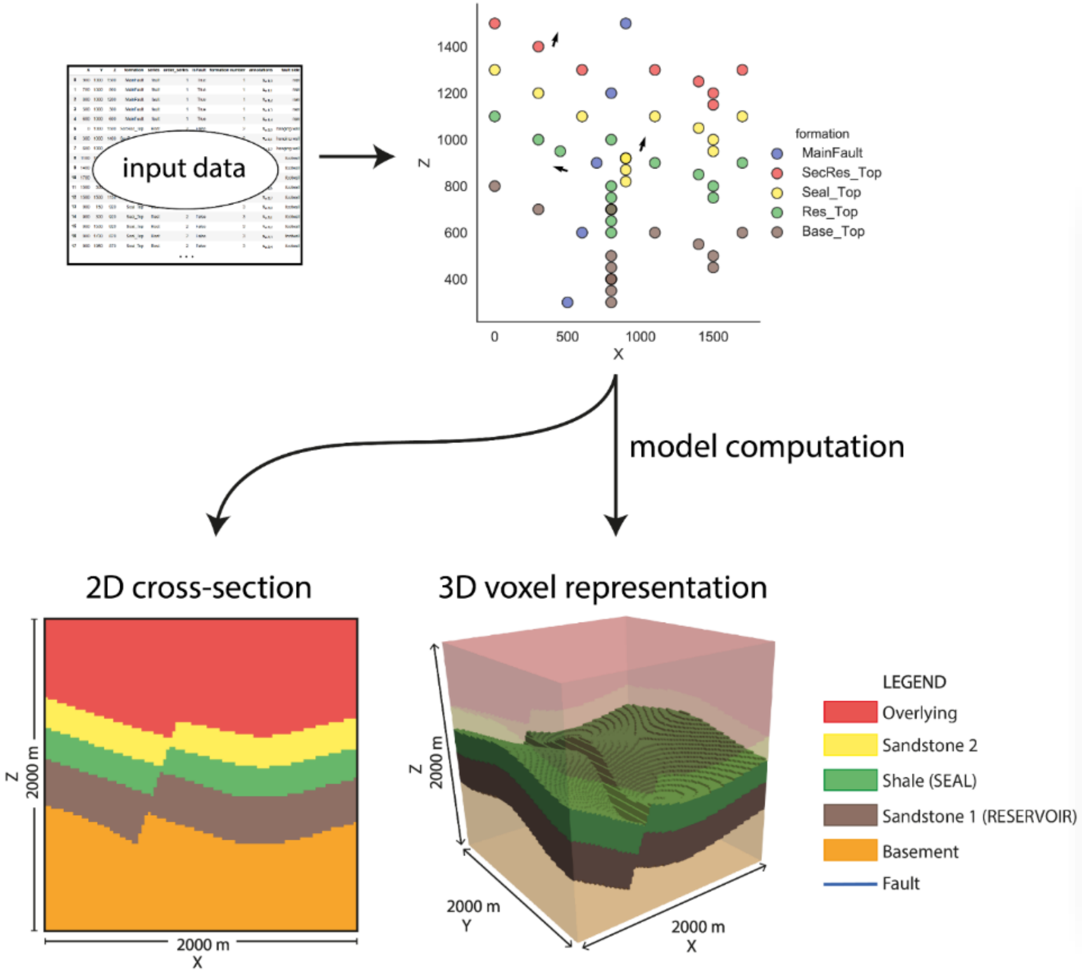



$$s(\mathbf{x}) = \sum_{i=1}^{I} c_i \chi_i(\mathbf{x}) + \sum_{l=1}^{L} d_l p_l(\mathbf{x})$$

**Scalar field for meshless methods**

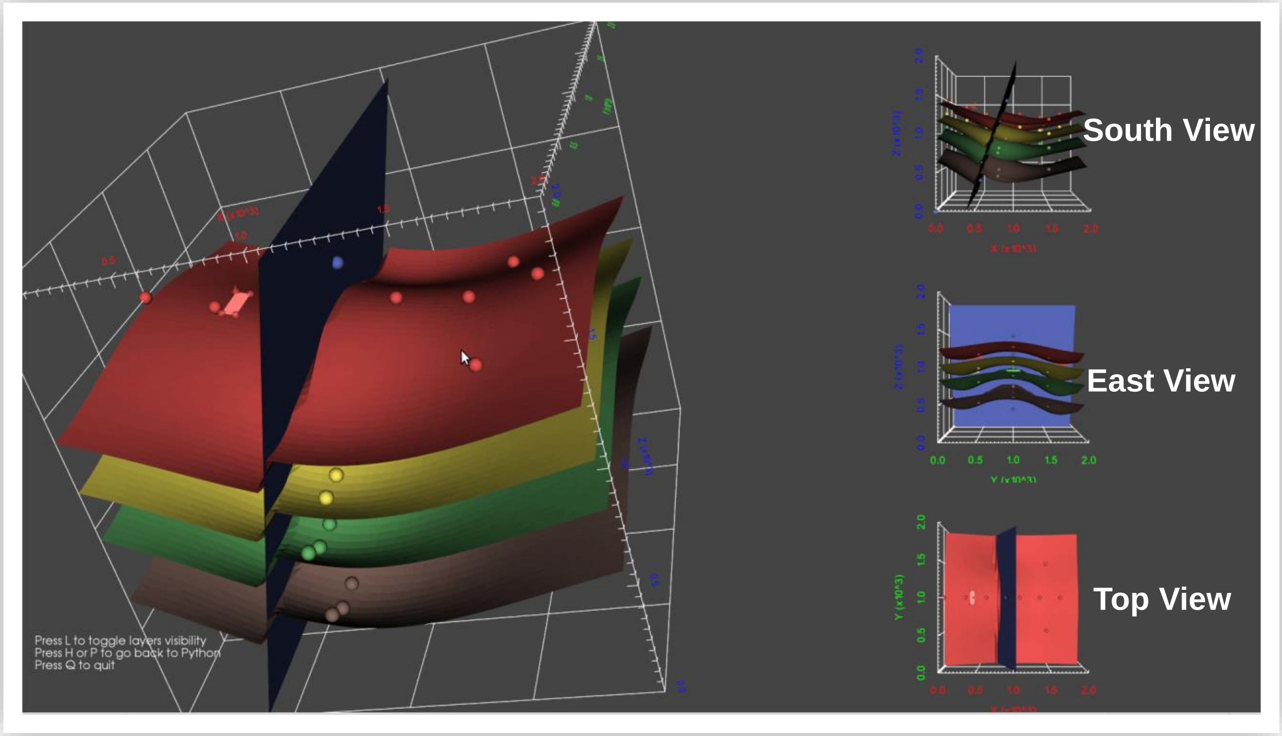
**Source: Wellmann, F. and Liang, Z., Structural Geological Models, WS 2022/23**

# GemPy – Implicit Geomodelling




Universal cokriging:

$$\begin{bmatrix} C_{\partial Z/\partial u,\partial Z/\partial v} & C_{\partial Z/\partial u,Z} & U_{\partial Z/\partial u} & F_{\partial Z/\partial u} \\ C_{Z,\partial Z/\partial u} & C_{Z,Z} & U_Z & F_Z \\ U'_{\partial Z/\partial u} & U'_Z & 0 & 0 \\ F'_{\partial Z/\partial u} & F'_Z & 0 & 0 \end{bmatrix} \begin{bmatrix} \lambda_{\partial Z/\partial u,\partial Z/\partial v} & \lambda_{\partial Z/\partial u,Z} \\ \lambda_{Z,\partial Z/\partial u} & \lambda_{Z,Z} \\ \mu_{\partial u} & \mu_u \\ \mu_{\partial f} & \mu_f \end{bmatrix} = \begin{bmatrix} c_{\partial Z/\partial u,\partial Z/\partial v} & c_{\partial Z/\partial u,Z} \\ c_{Z,\partial Z/\partial u} & c_{Z,Z} \\ f_{10} & f_{20} \\ f_{10} & f_{20} \end{bmatrix}$$




Source: Modified from Wellmann, F. and Liang, Z., Structural Geological Models, WS 2022/23

# Probabilistic Programming Languages

Probabilistic programming languages aims for reducing the representational gap between the representational capacity of probabilistic graphical models and the most innovative probabilistic models given by the AI, machine learning, and statistics community. *Source: Probabilistic Programing, Nov-15-2020, https://probabilistic-programming.org/, Accessed on Jan-12-2023.*

Probtorch (Probabilistic Torch, library for deep generative models that extends PyTorch, https://github.com/probtorch/probtorch)

Pyro (universal probabilistic programming language, https://pyro.ai/)

Python (programming language, https://www.python.org/)

PyTorch (open-source machine learning framework, https://pytorch.org/)

PyMC (probabilistic programming library, https://www.pymc.io/welcome.html)

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# Questions and Discussion