IG(M)AS (+) – A rather long history

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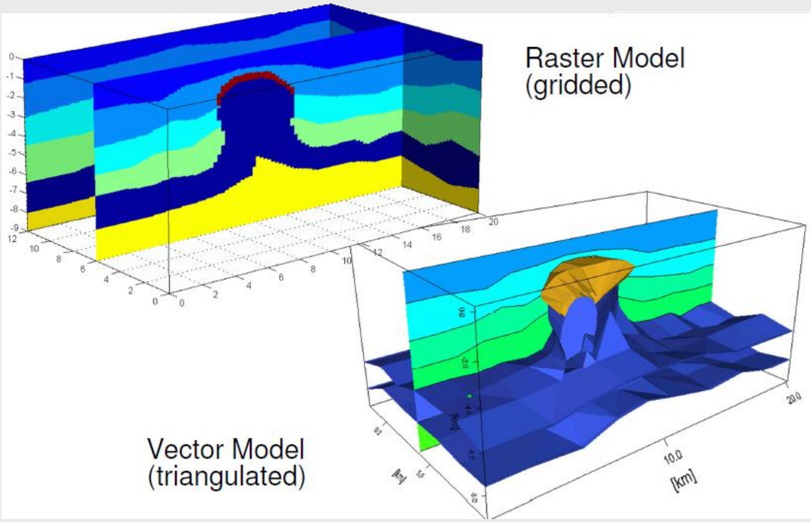

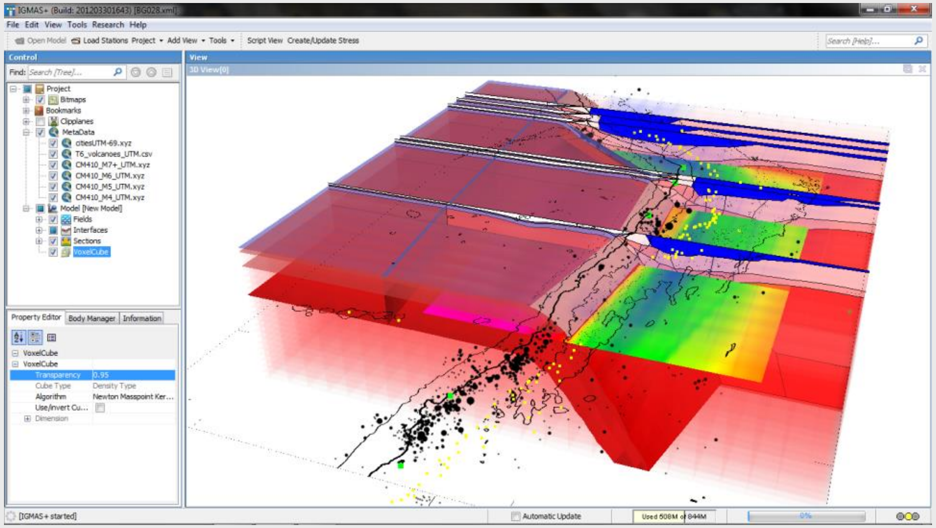

Analytical solution of the volume integral for polyhedra (Götze 1976)

IGAS development started on a mainframe in Fortran (SEG)

IGMAS moved to PC

IGMAS code upgraded (C++)

IGMAS+ project Wintershall/Statoil (JAVA)

End of Transinsight

Donation to GFZ

1970 1980 1990 2000 2010 2020

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IGMAS+ – a tool for interdisciplinary 3D potential field modelling of complex geological structures

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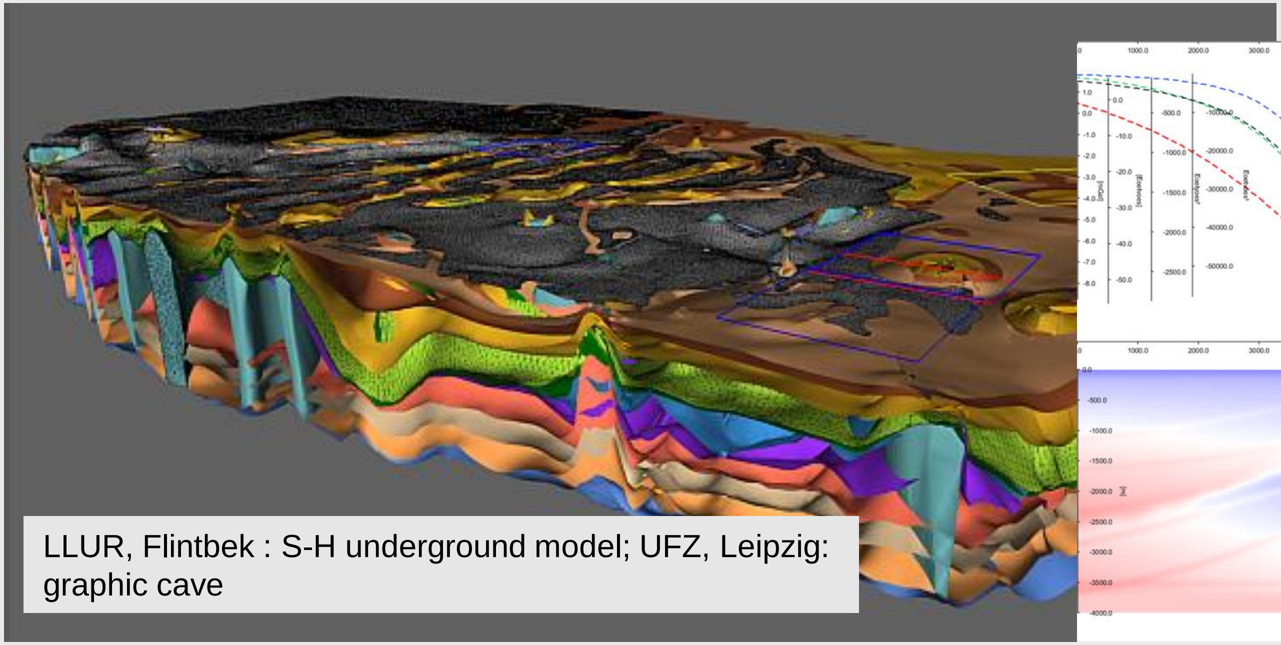
OUTLINE:

- Modelling at different scales and under independent constraints,
- Facilities for 3D modelling
  fast algorithms for gravity & magnetic and their gradients
- Interpretation tools
  edge effects, variable densities, stress, 3D plotting
- Outlook (next) & references
  Thermal modelling, petrology, uncertainty/sensitivity

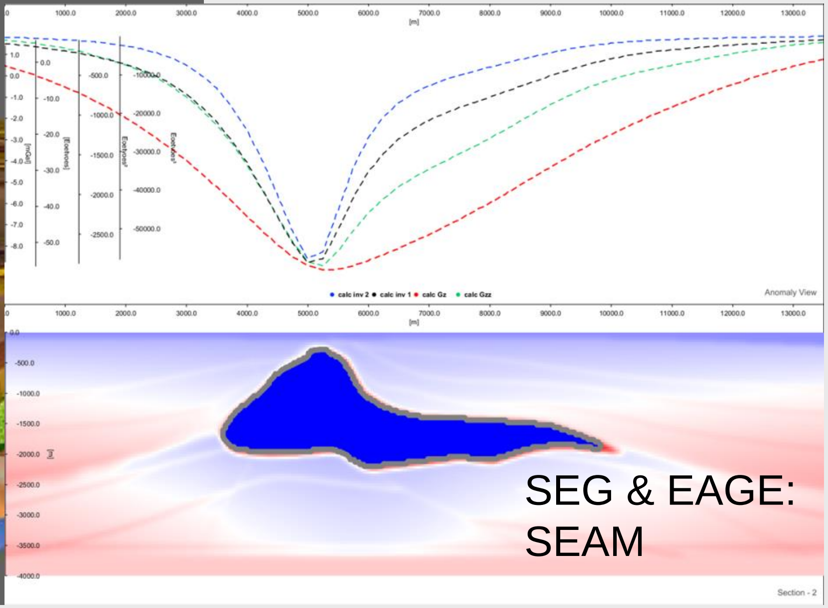
Motivation

Modelling software should be:

- **F**ast, interactive & robust,
- **F**orward and inverse modelling,
- **U**ser friendly for use in *complex model environments* and
- **A**vailable for *Grav/Mag* fields *and their gradients*.



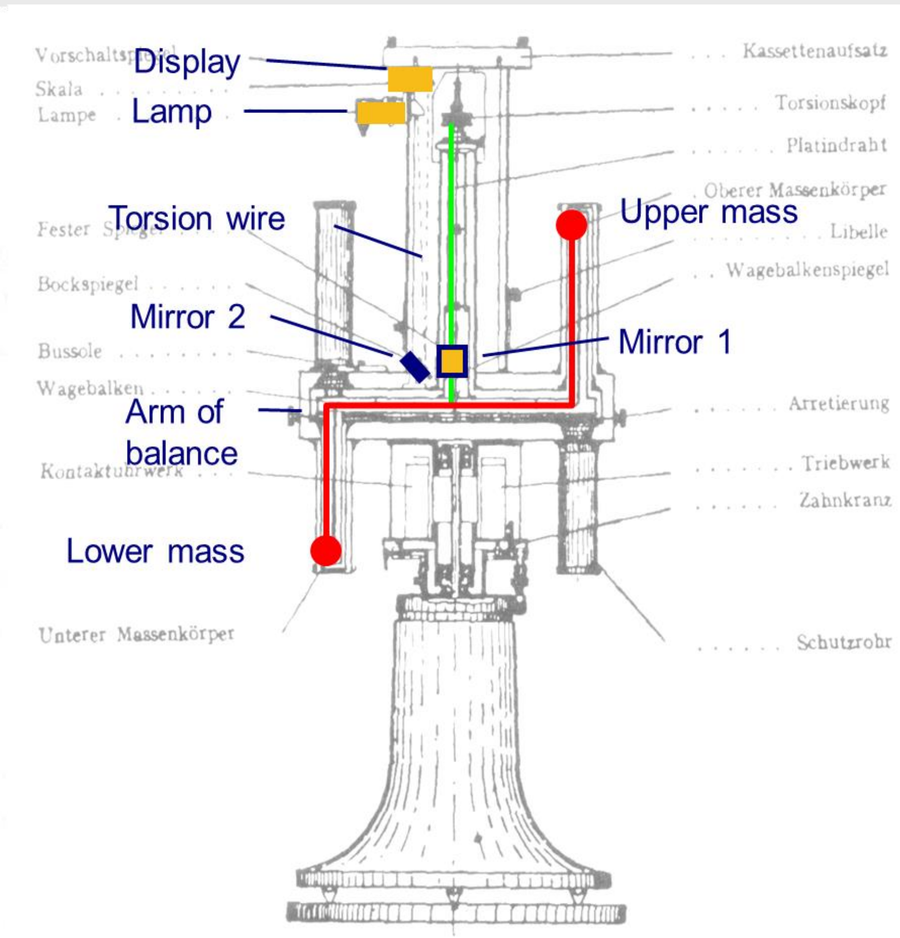
LLUR, Flintbek : S-H underground model; UFZ, Leipzig: graphic cave



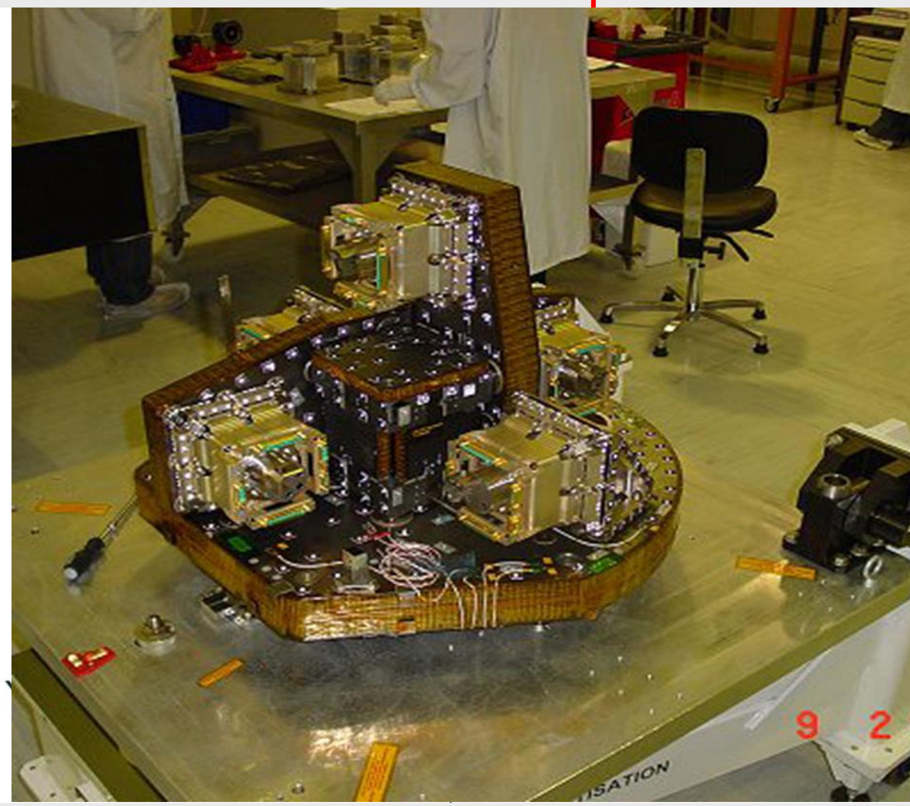
SEG & EAGE: SEAM

Different scales: tosion balance vs. GOCE

Principle: Torsion balance



Principle: GOCE gradiometer



Modelling at macro - medium – micro - scale

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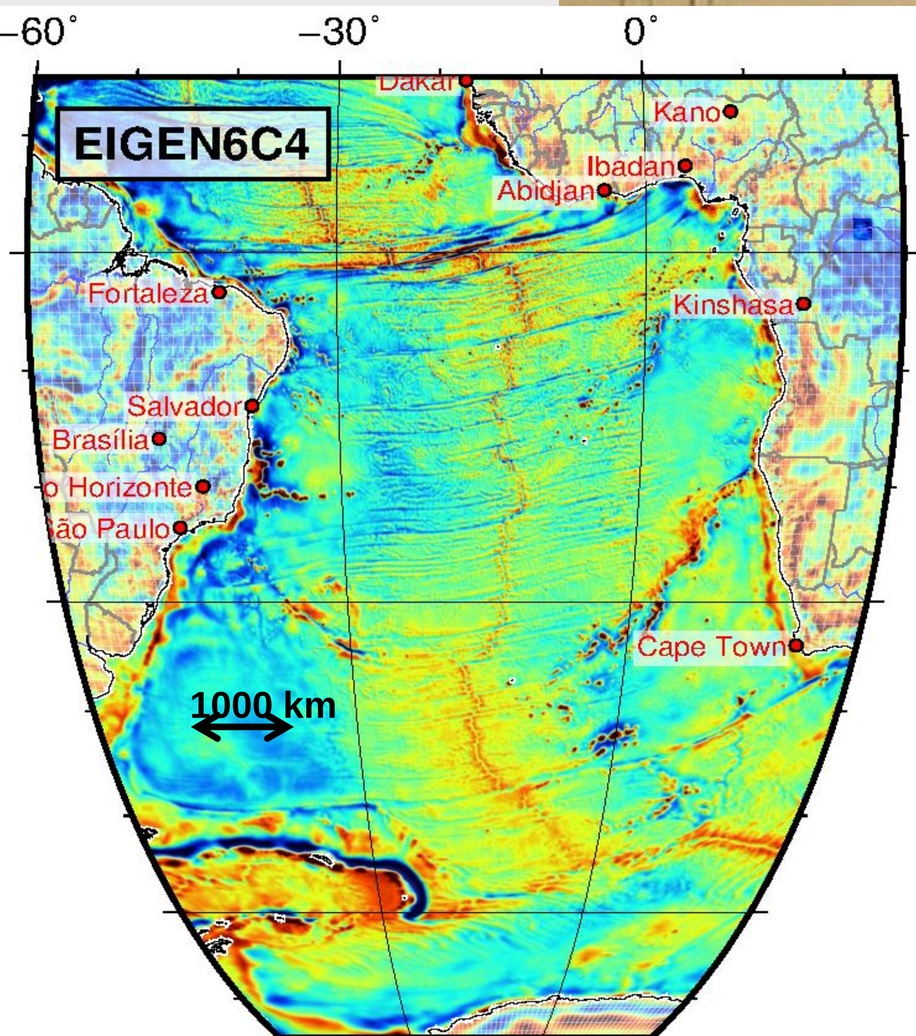
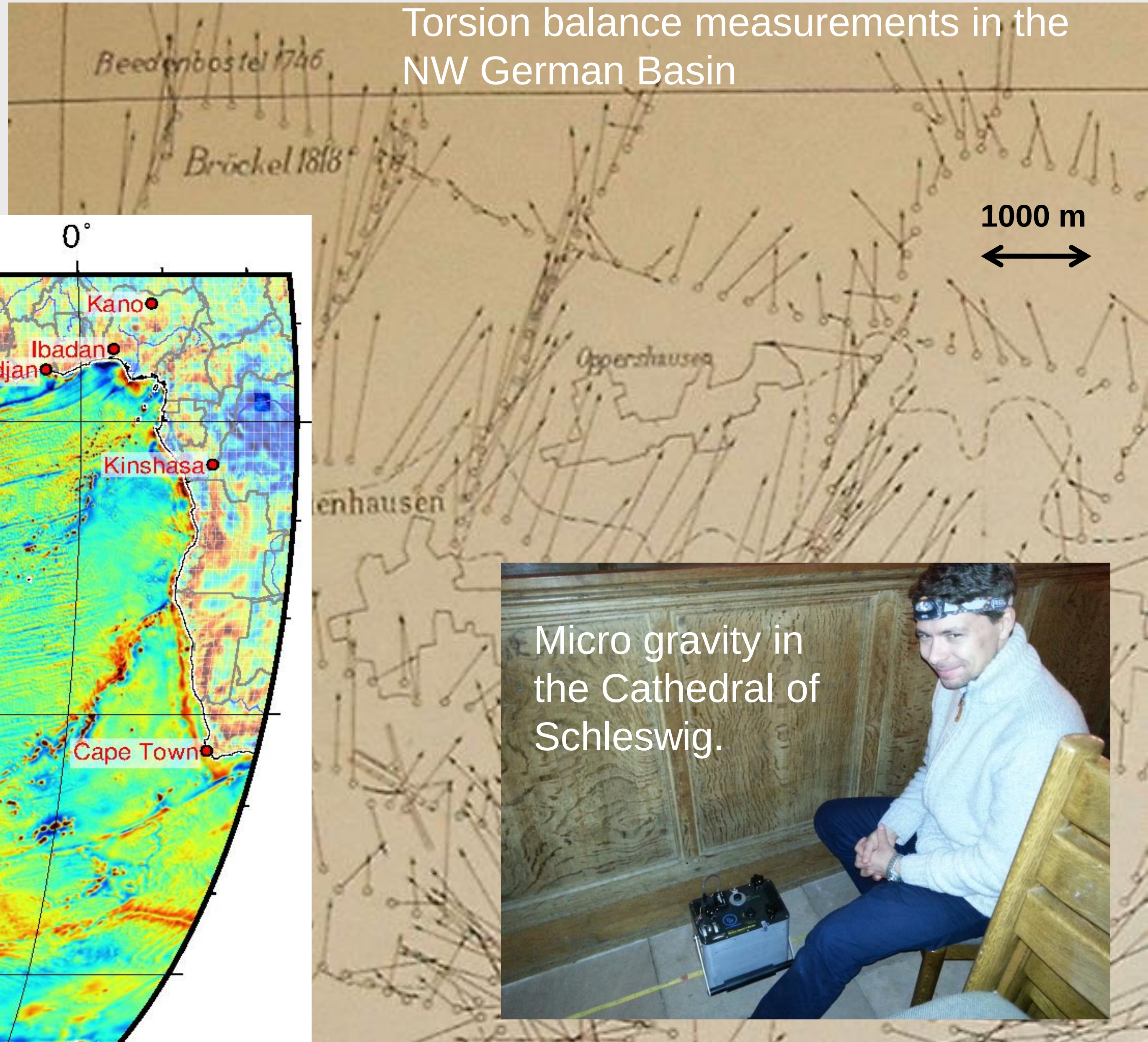


Torsion balance measurements in the NW German Basin

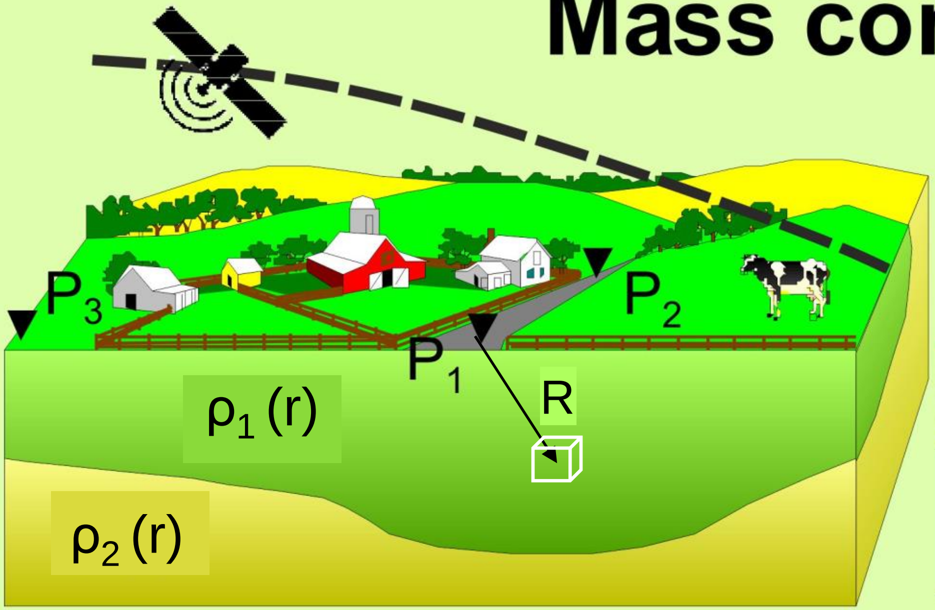


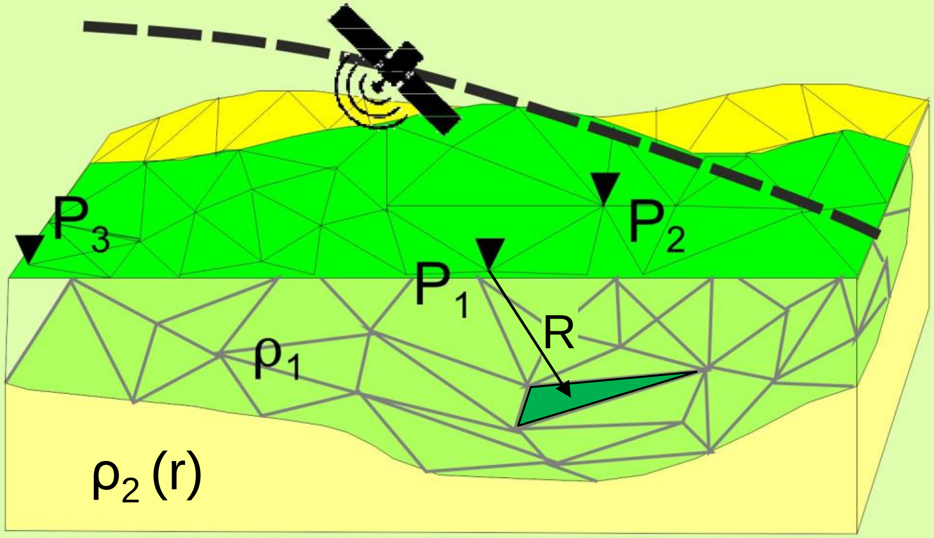
Micro gravity in the Cathedral of Schleswig.

Facilities for 3D modelling

- fast algorithms for gravity & magnetic and their gradients

Mass continuum





$$g_{(P)} = f \iiint_V \frac{\rho(r)\, dv}{r^2}$$

$$g_{(P)} = f\rho \oint\!\!\oint_S \cos(n,z) \frac{ds}{r^2}$$

Final mathematical formulas

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$$U = \frac{f\,\rho}{2} \sum_{t=1}^{m} SIGN(D)_t\, D_t \left[\sum_{v=1}^{3} SIGN(d)_{tv}\, d_{tv}\, LN_{tv} + D_t \sum_{v=1}^{3} SIGN(d)_{tv}\, ARC_{tv} \right]$$

Potential

$$U_i = f\,\rho \sum_{t=1}^{m} \cos(\vec{n}_t, \vec{e}_i) \left[\sum_{v=1}^{3} SIGN(d)_{tv}\, d_{tv}\, LN_{tv} + D_t \sum_{v=1}^{3} SIGN(d)_{tv}\, ARC_{tv} \right]$$

3 Gravity field components

$$U_{3\,j} = f\,\rho \sum_{t=1}^{m} \cos(\vec{n}_t, \vec{e}_3) \left[\sum_{v=1}^{3} \cos(\vec{n}_{tv}, \vec{e}_j)\, LN_{tv} + SIGN(D)_t \cos(\vec{n}_t, \vec{e}_j) \sum_{v=1}^{3} SIGN(d)_{tv}\, ARC_{tv} \right]$$

6 Gravity gradients

$$H_j = RJ_j \sum_{t=1}^{m} \cos(\vec{n}_t, \vec{e}_j) \left[\sum_{v=1}^{3} \cos(\vec{n}_{tv}, \vec{e}_j)\, LN_{tv} + SIGN(D)_t \cos(\vec{n}_t, \vec{e}_j) \sum_{v=1}^{3} SIGN(d)_{tv}\, ARC_{tv} \right]$$

3 Magnetic field components

Further reading: Götze 1976; Götze & Lahmeyer, 1988; Götze 2017

3D Interpretation tools

edge effects, variable densities, stress, 3D plotting

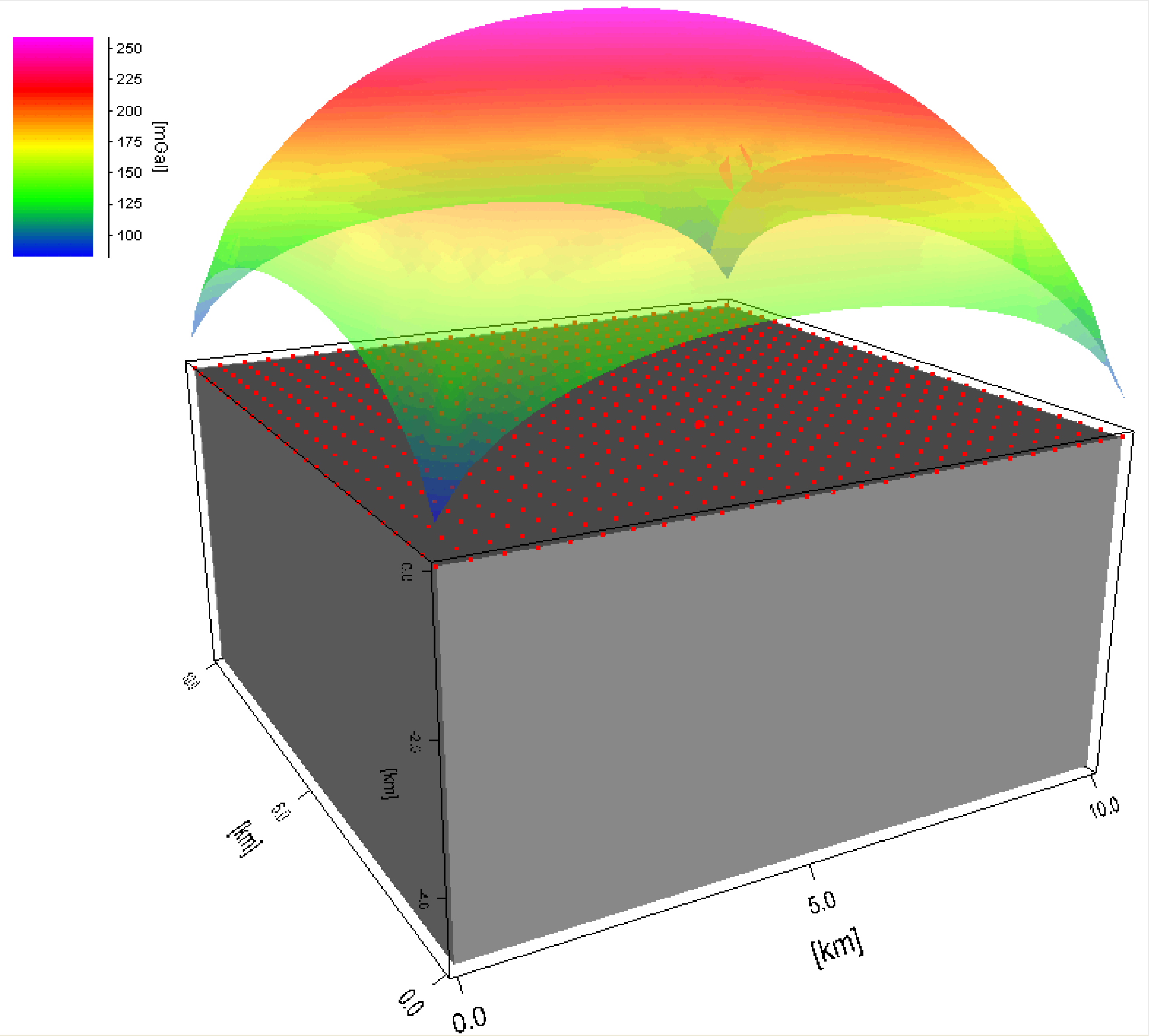
Handling edge effects – here of a cube

A text book example

and

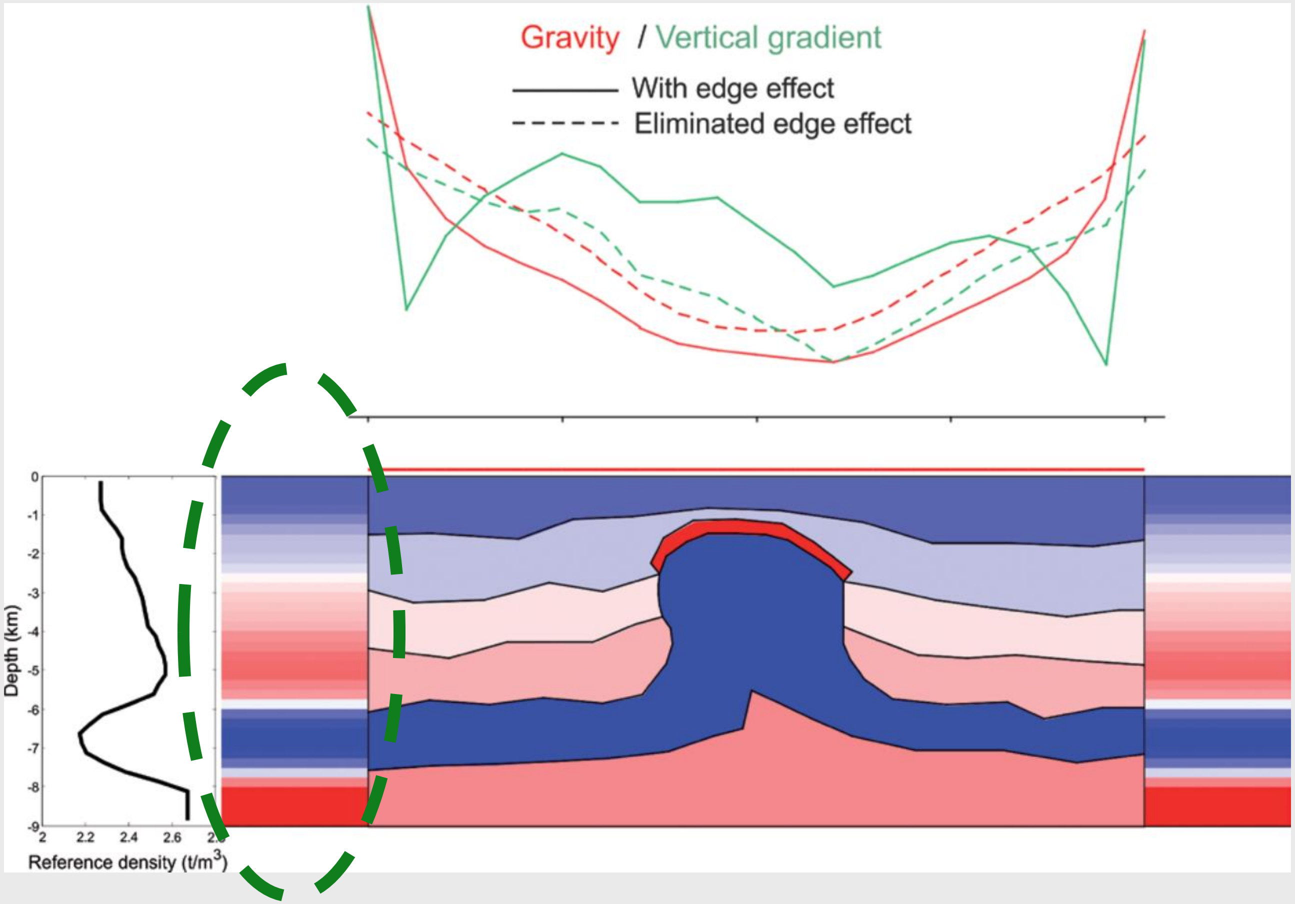
our solution

V
V
V



Handling of edge effects

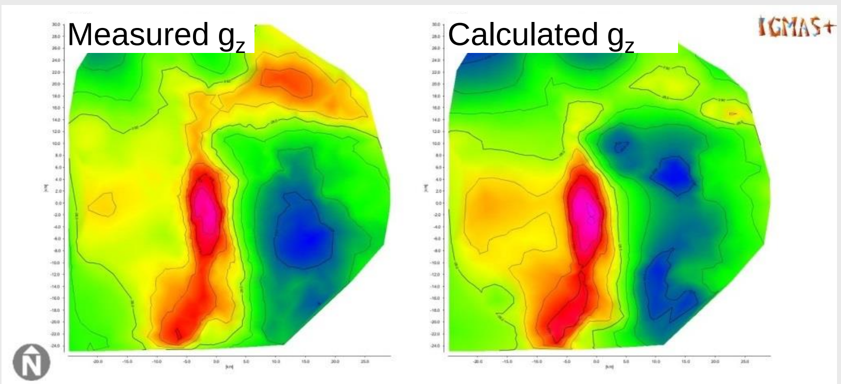
- **Our solution: Handling of edge effects in 3D modelling by calculation of a depth-density function which surrounds the density model** (Schmidt, 2010)**.**

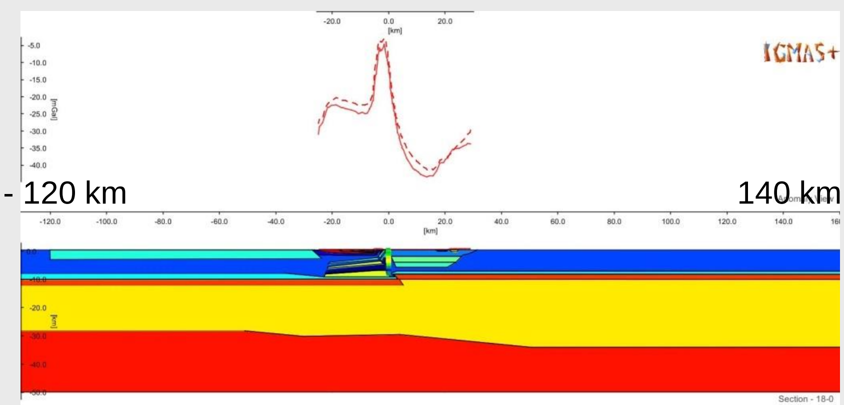


Handling edge effects

Edge effects in 3D modelling

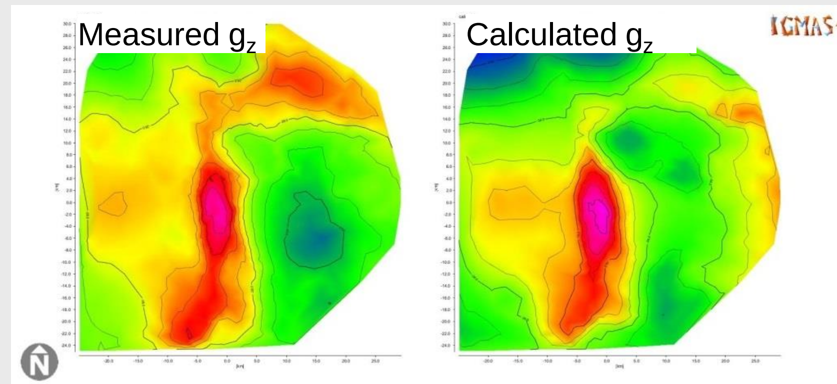
Conventional - extended geometry
(e.g. approx. 5 000km)

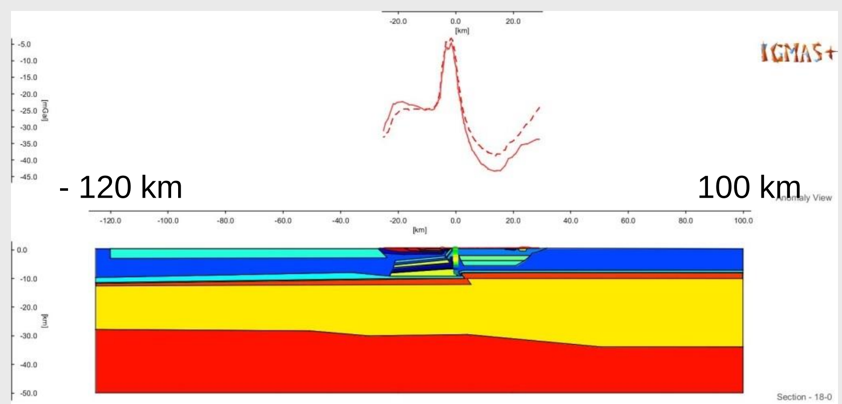




<< - 5 000 km
5 000 km >>

Automatic edge effect reduction



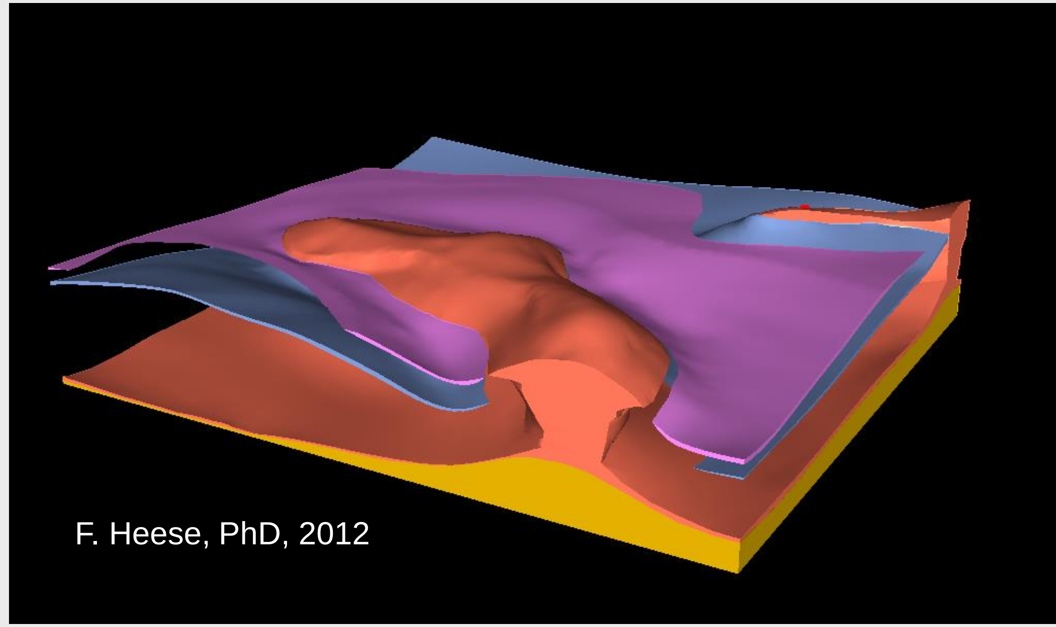


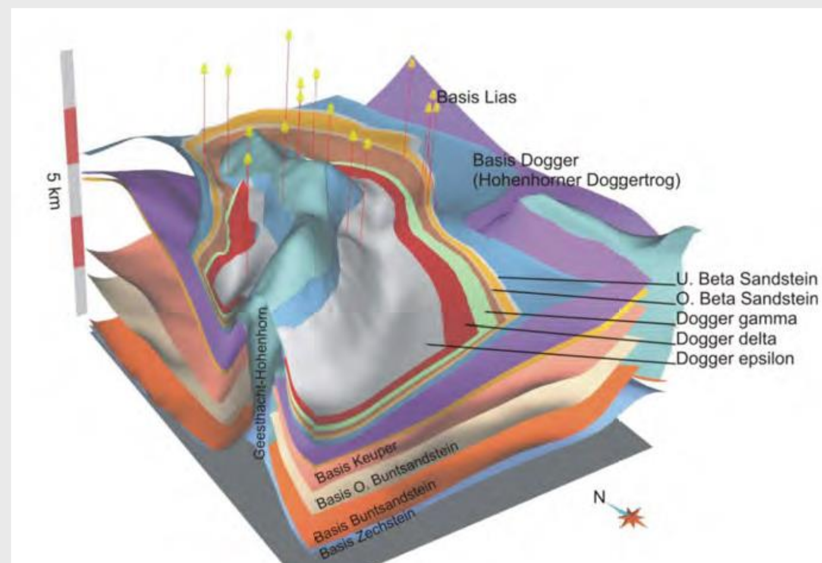
~ - 120 km
100 km

Geometry of geological structures

Complicated models describe:
Salt structures -
500 000 triangels and
even more.

Often the layers very
thinn and models consist of
numerous layers
(up to 30).


F. Heese, PhD, 2012



Salt dome Geesthacht, K. Altenbrunn, PhD, 2014

Other approaches of 3D
modelling:
GOCAD
PETREL

The medium scale: Gifhorn Trough – NWGB

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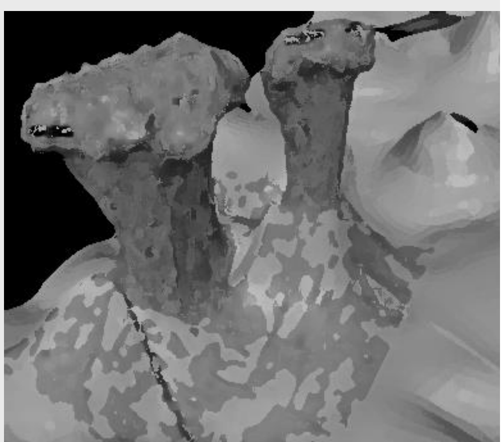
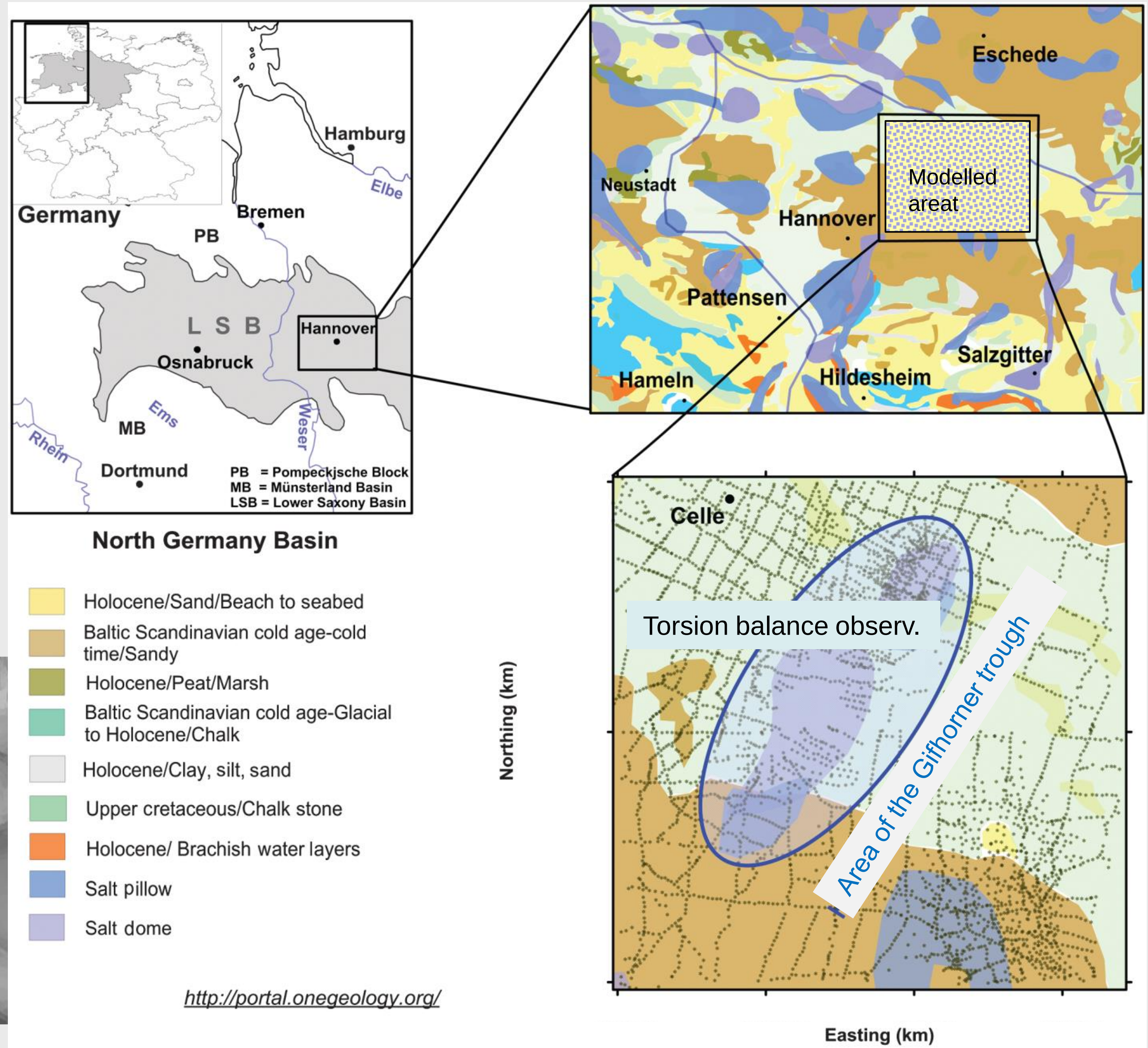
Research area

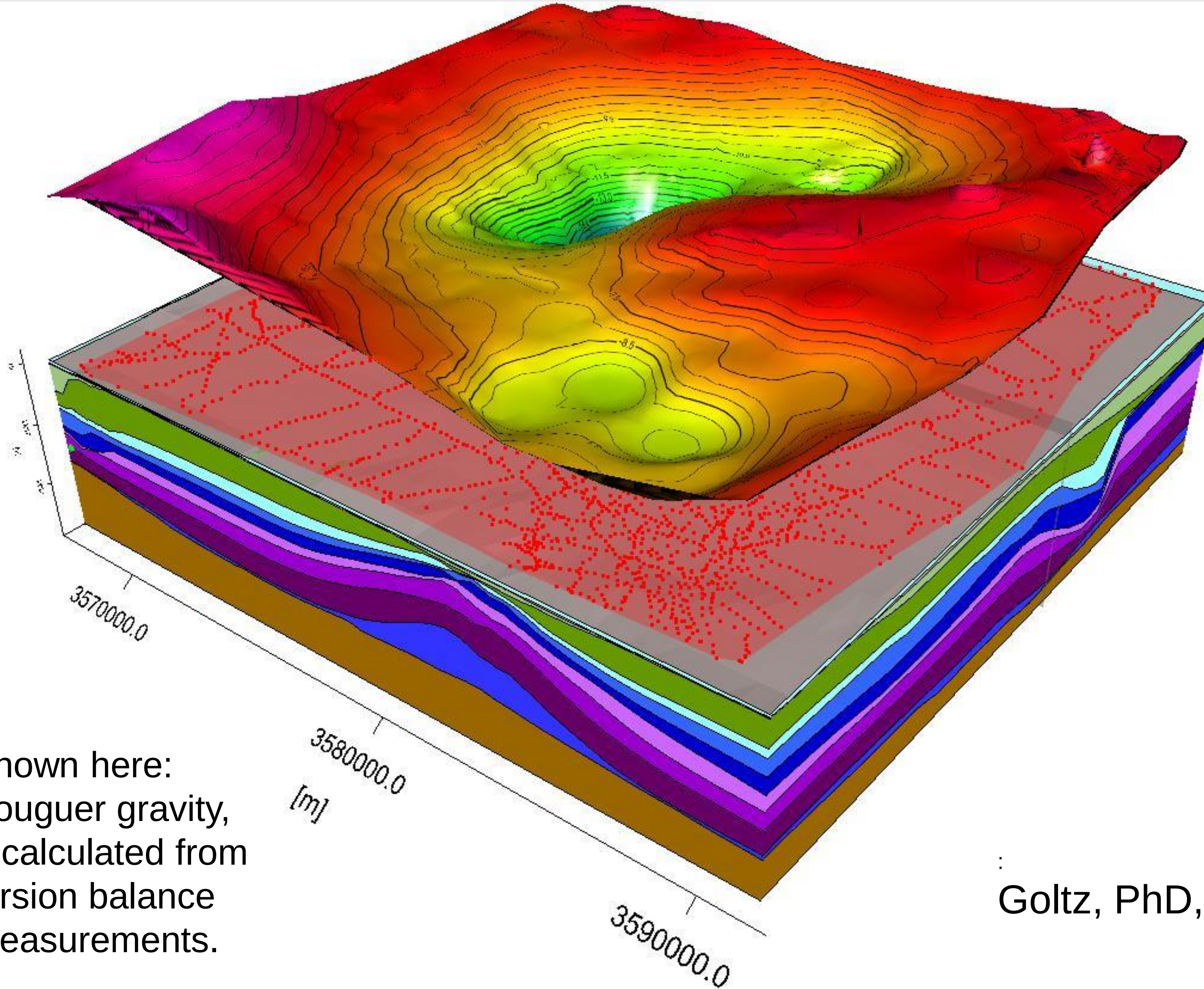
and
locations of
Torsion balance
observations.

Number of **gradients**:
~7 600
out of 22 000
… of **curvature**:
~ 3 700
out of 17 000.





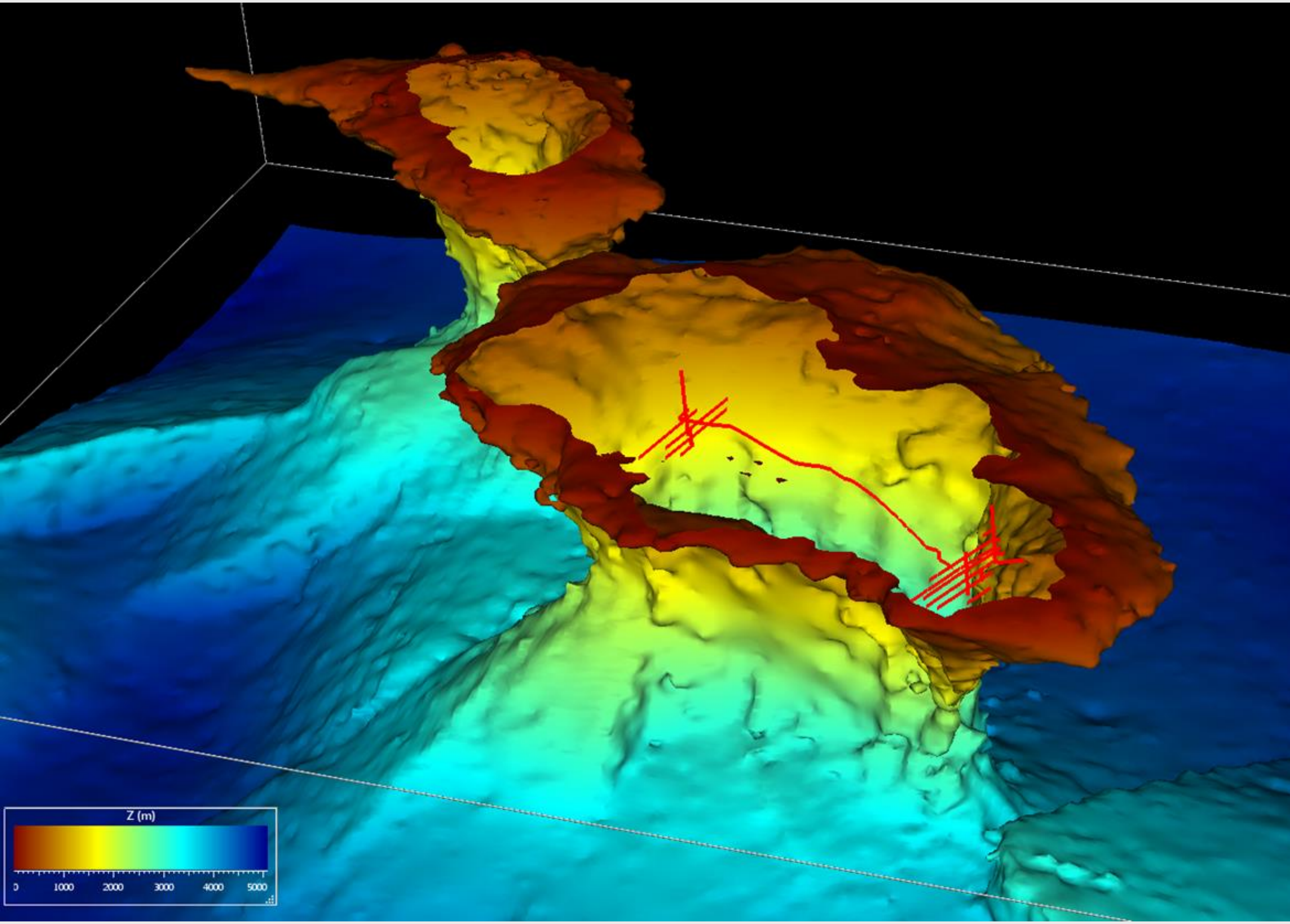
Define constraints from Geology



Shown here:
Bouguer gravity,
recalculated from
torsion balance
measurements.

Goltz, PhD, 2001

Modelling of salt domes in the Gifhorn Trough



264 subsurface gravity data

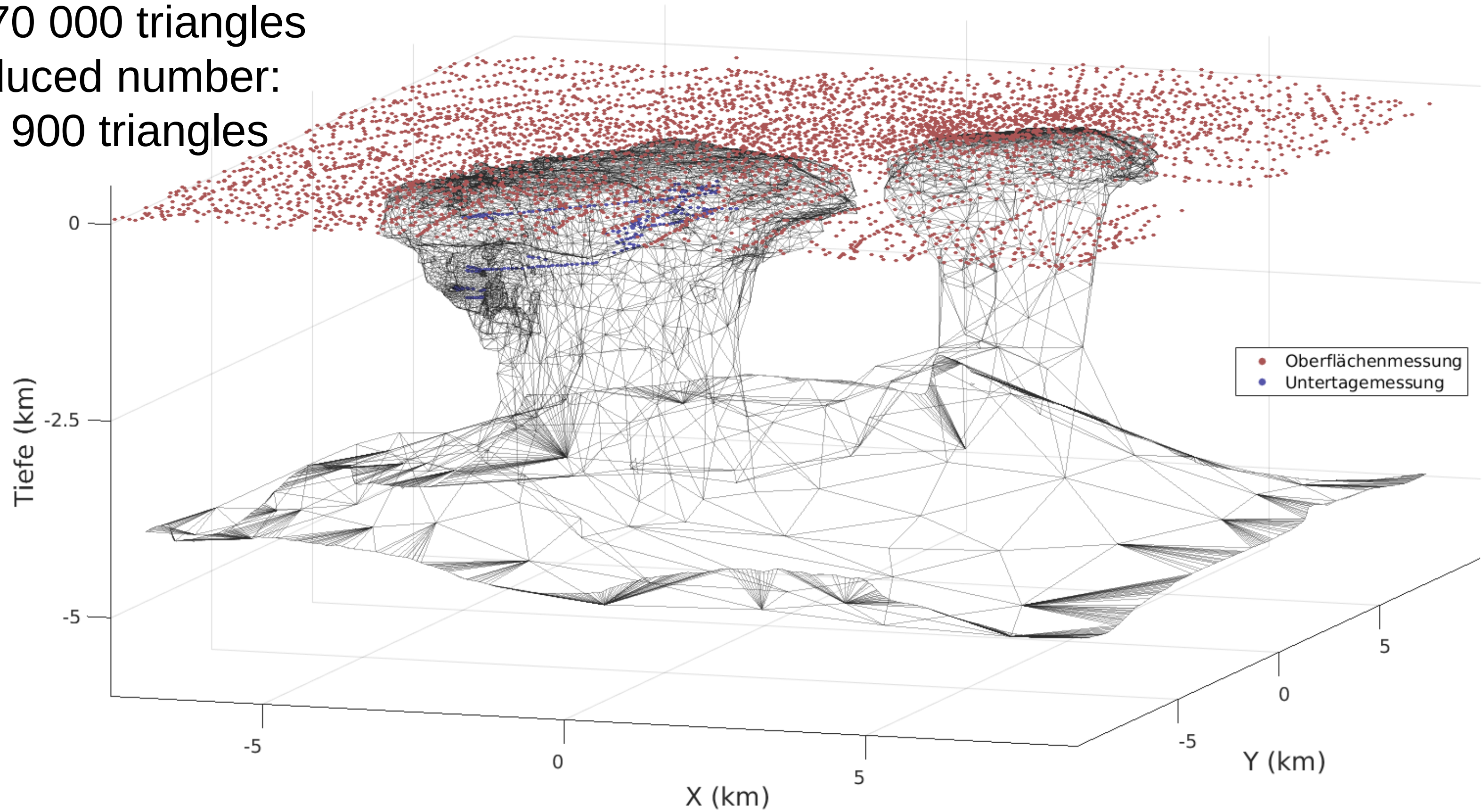
S_{zmax} = -1 457,30 m b.s.l.

Data base: gravity BEB & CAU

The task: How to verify / test a salt structure provided by a **3D seismic survey** using **existing old gravimetric data** (gravity, torsion balance).

Optimize 3D models by reduction of triangles

Original number:
370 000 triangles
Reduced number:
13 900 triangles



Parameter reduction: here reduction of triangles – without loss of gravity effect which is smaller than 1 % … (Götze, Schmidt & Menzel, 2017)

3D modelling of gravity & gradients

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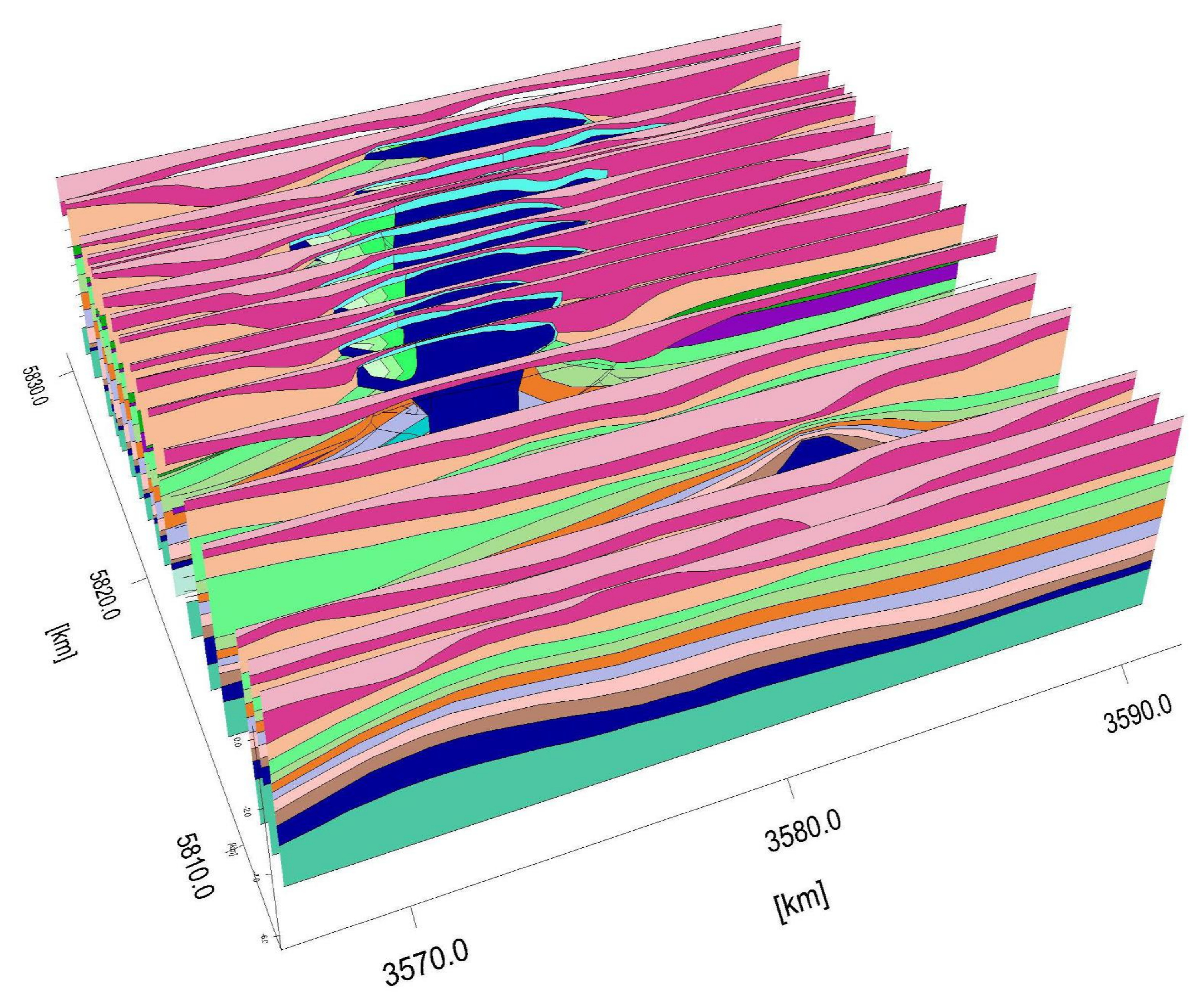

Salt dome is modelled by **17 vertical cross sections** **- to define the 3D model structure of a salt dome.**

Dubey et al., 2014

3D modelling, gravity & gradients simultaneously

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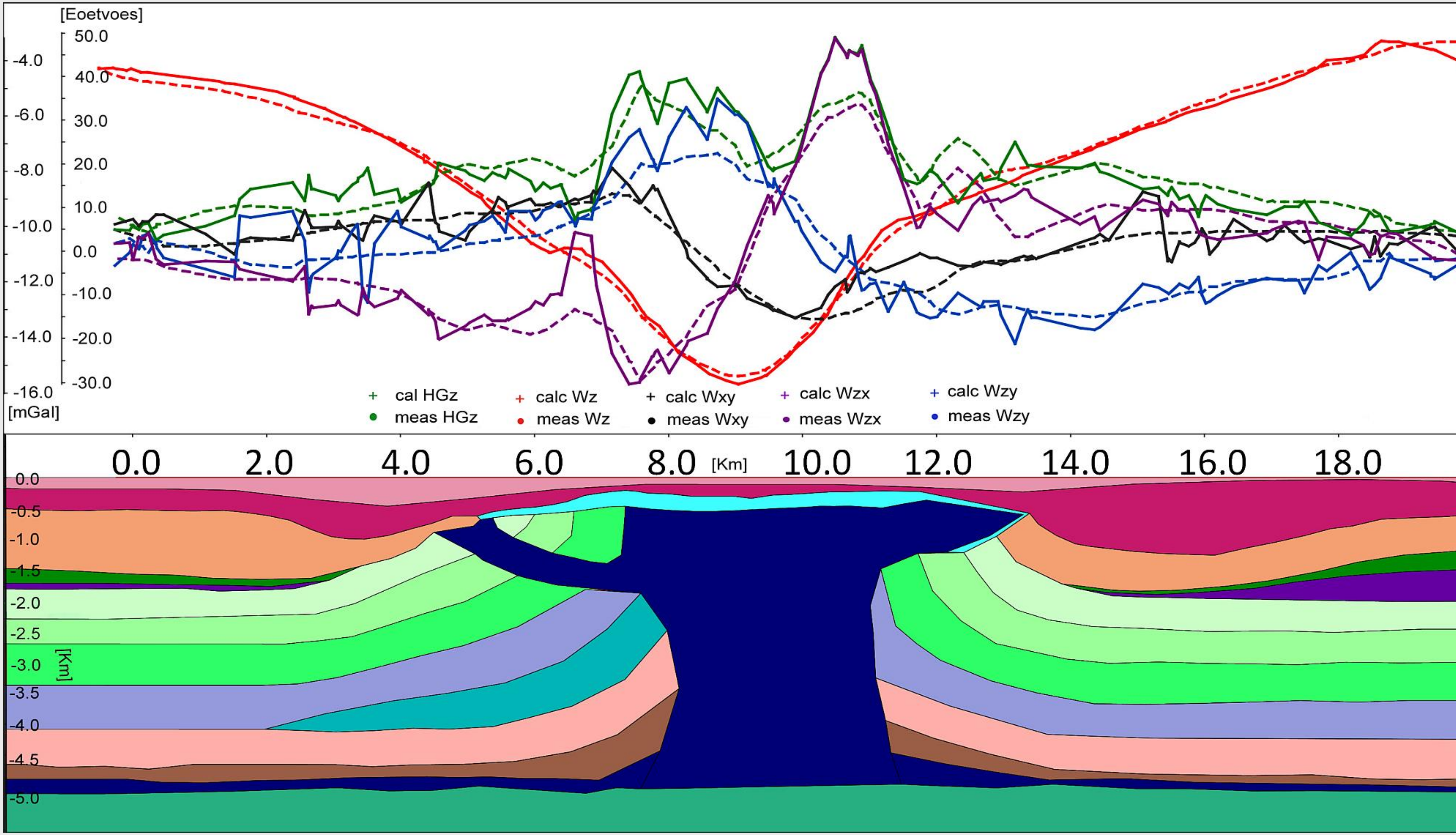
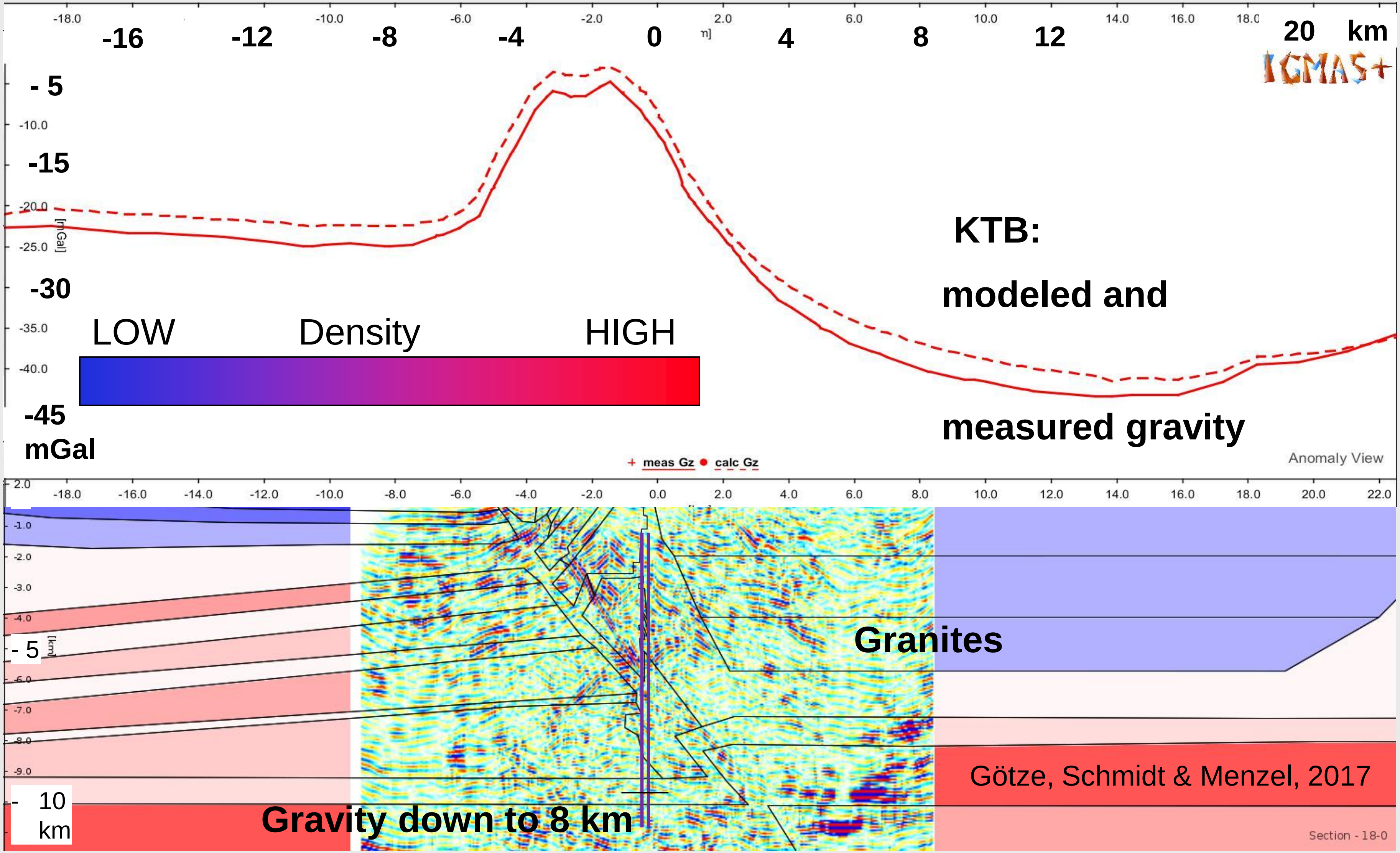


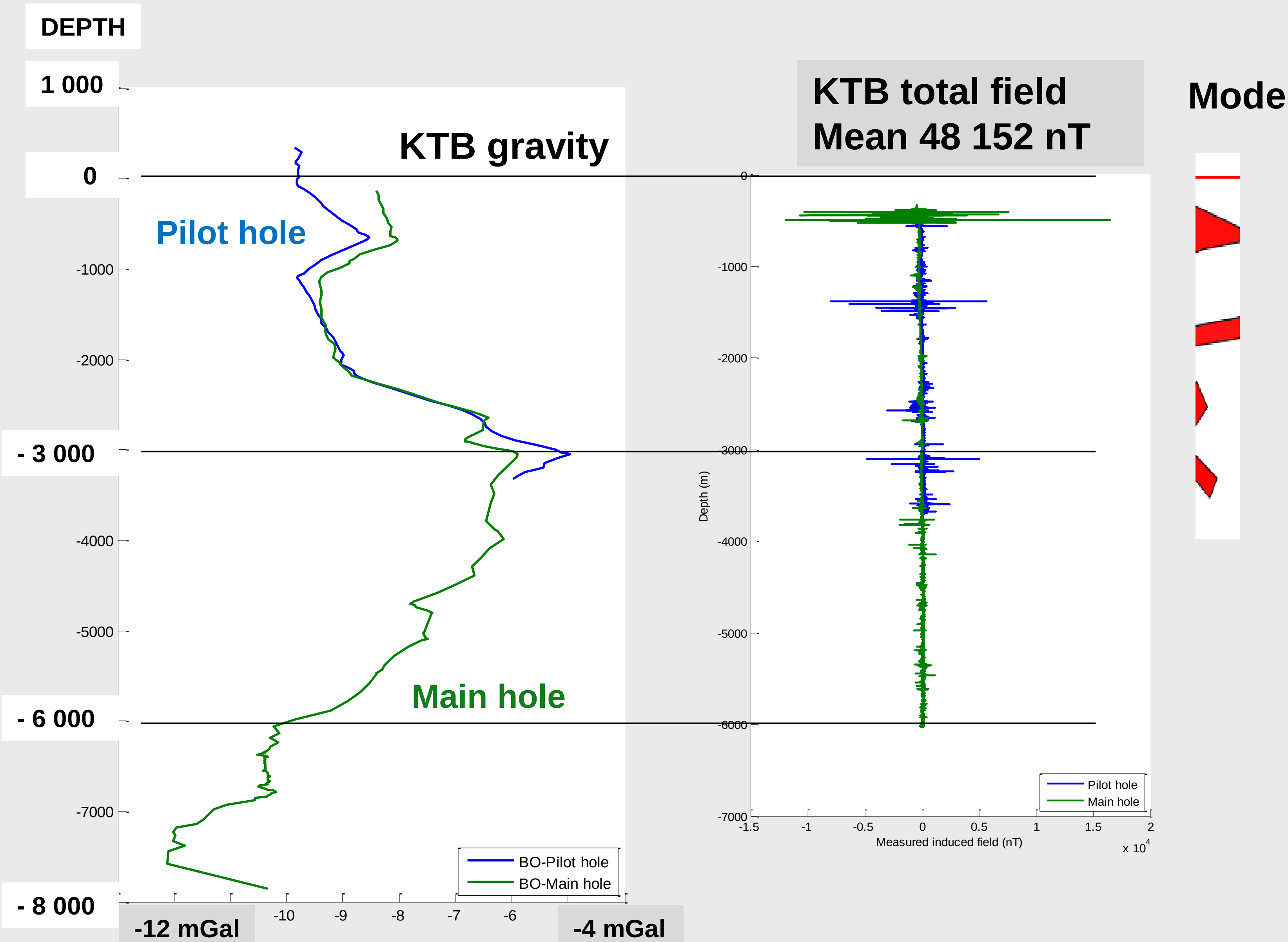
Not for interactive manipulation, …. but for inversion …

(Dubey et al., 2014)

Constraints from reflection seismic data



KTB borehole gravity and magnetics



Modelling against background densities

Conventional modelling:

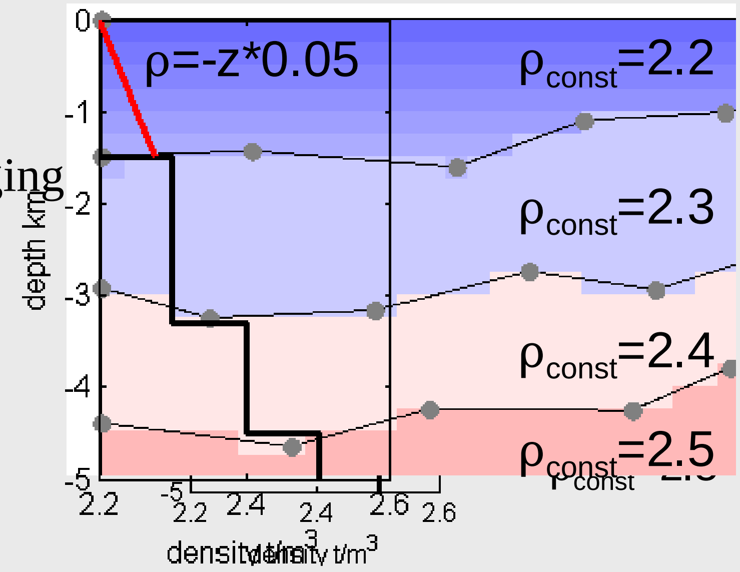
$$measured - error = calculated = \sum_{i=1}^{n} \rho_i P_i$$

Hybrid modelling:

$$measured - error = calculated = \sum_{i=1}^{n} \rho_i P_i + \sum_{i=1}^{n} f_i V_i$$

with

P_i = Polyhedroneffect of body i (for density 1)
V_i = Voxeleffect of body i, that is the sum of all voxels with variable density belonging to body i
ρ_i = Constant density of body i
f_i = Voxelfactor of body i
n = total number of bodies



Schmidt et al., 2010

Modelling against background densities

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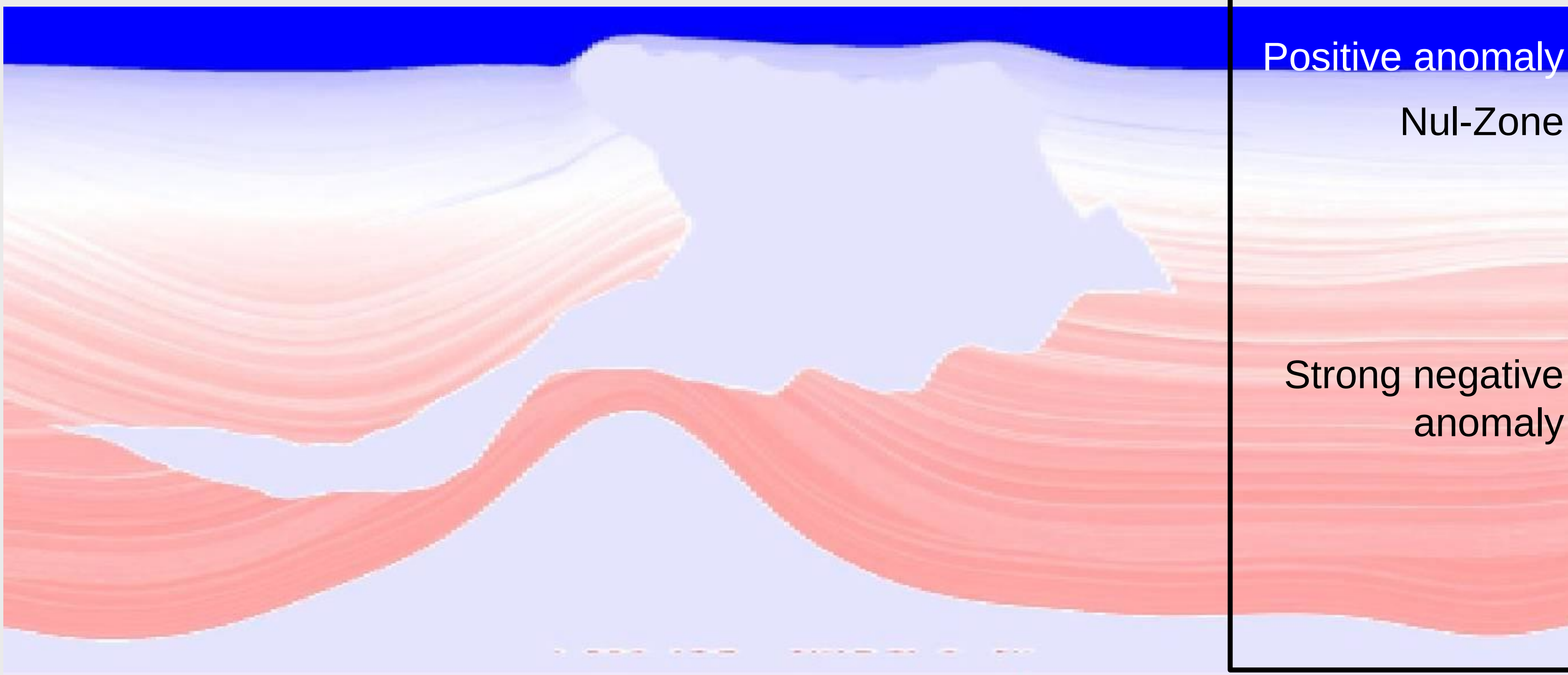
Colors: densities low high

Densities of the Background model causes:



3D - SEAM of EAGE & SEG: transferring a velocity model into a 3D density model.

Alvers et al., 2015

Hybrid model by voxels and polyhedrons

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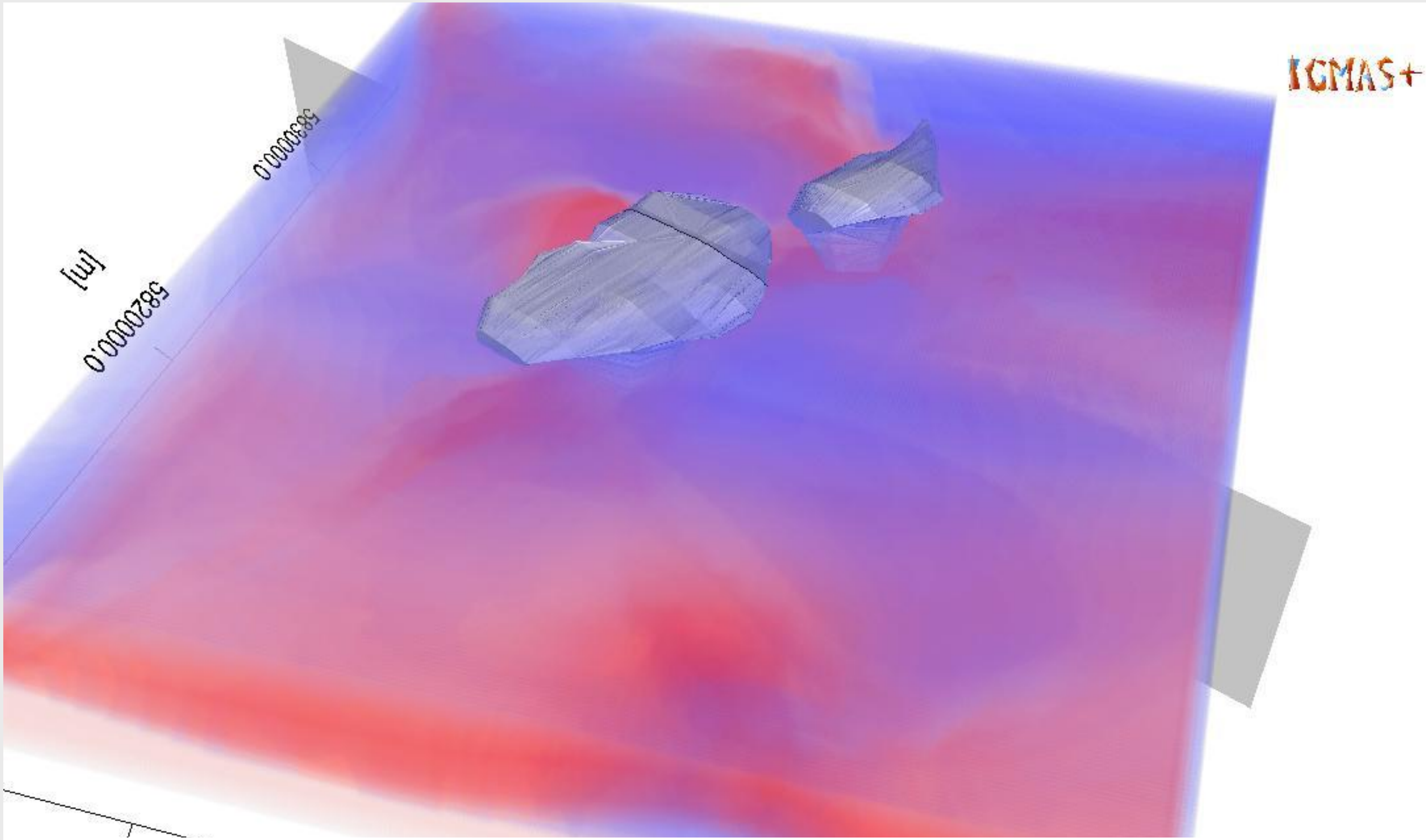

The complete 3D velocity model of the Gifhorn Trough – transferred into a 3D voxel density model which surrounds the fixed density polyhedron model of the salt dome.

The advantage of variable densities

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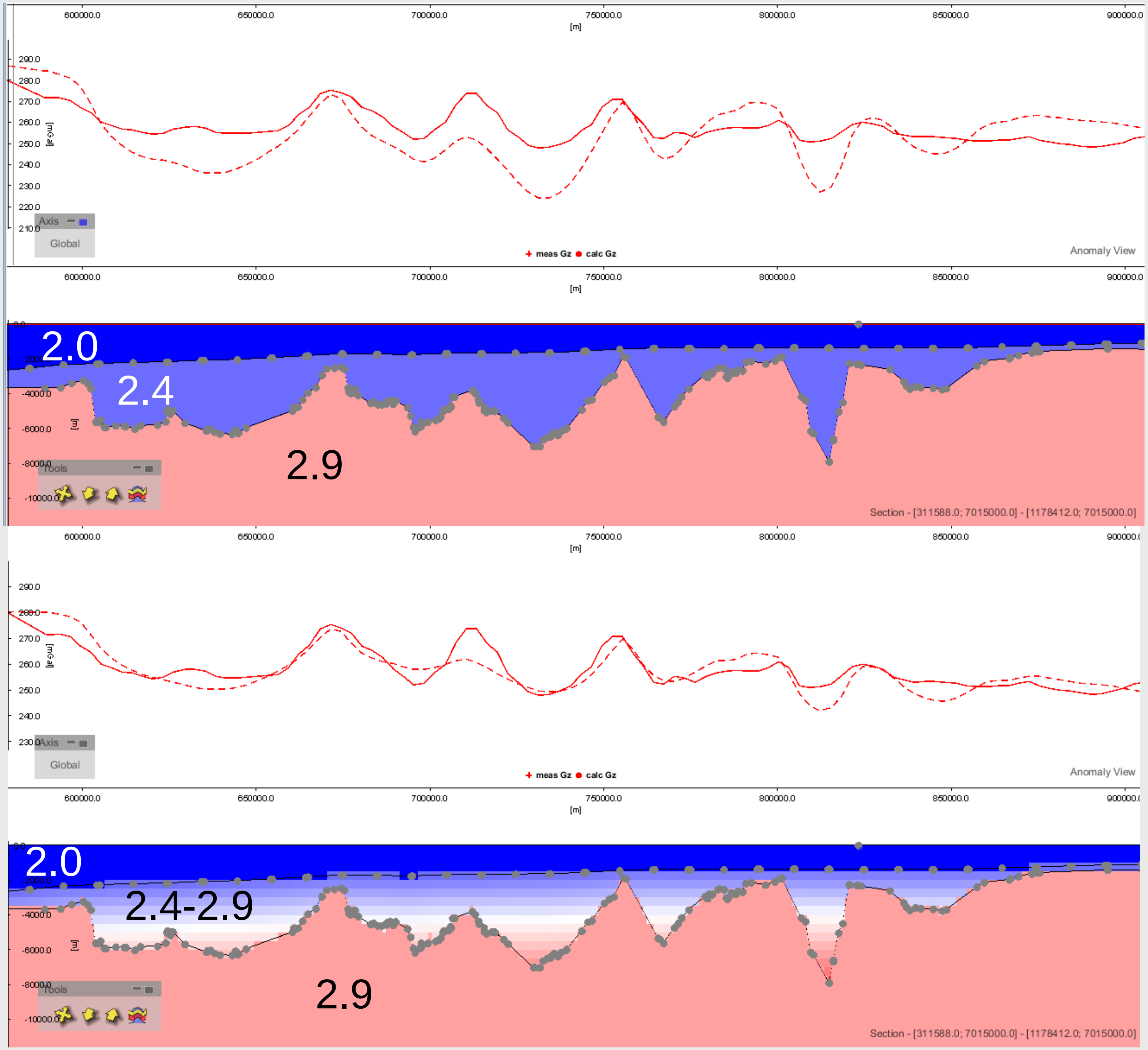
Capel & Faust Basin
Offshore Australia

Vert. Exaggeration: 5



The improvement of the adaptation of measured and modelled gravity by introducing a stratified density distribution in the Earth's crust

Vertical stress & Gravitational Potential Energy

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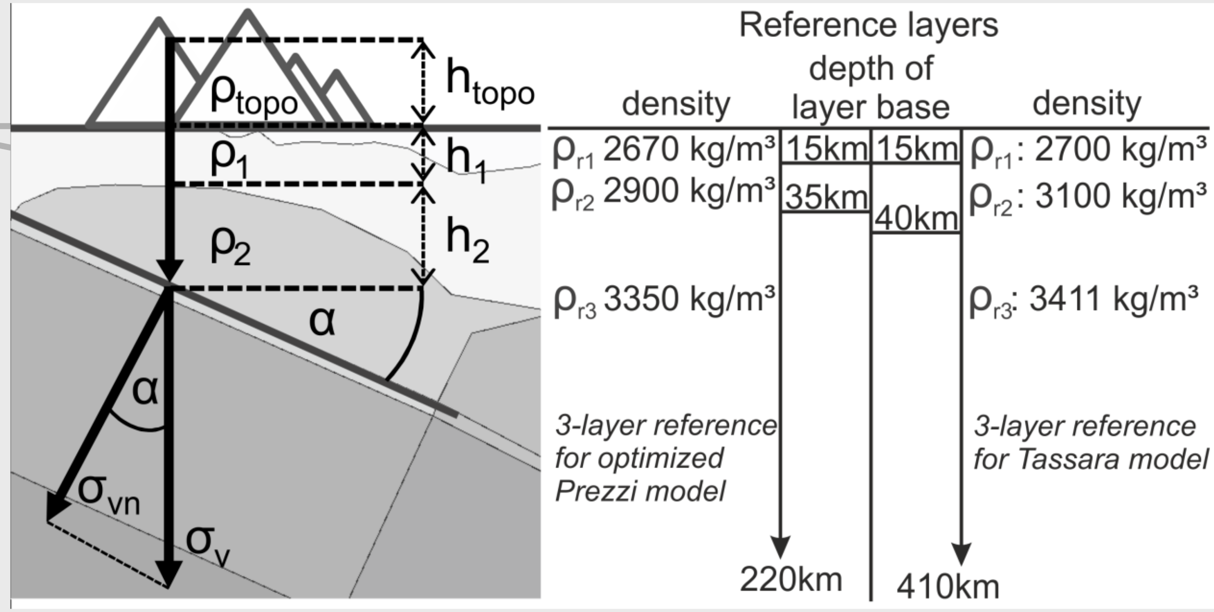

Normal stress:

$$\sigma_n = \sigma_v \cdot \cos\alpha + \sigma_h \cdot \sin\alpha$$

Refer also to Tassara (2010), and **Gutknecht, PhD, 2015**

Vertical stress anomaly:

$$\Delta\sigma_v = \gamma \cdot \left(\rho_{topo} h_{topo} + (\rho_1 - \rho_{r1})h_1 + (\rho_2 - \rho_{r2})h_2 + \cdots\right)$$

Normal component of the vertical stress anomaly:

$$\Delta\sigma_{vn} = \Delta\sigma_v \cdot \cos^2\alpha$$

GPE per unit area of a lithospheric column is given as:

$$GPE = \int_{-h}^{L} \rho(z)\gamma L \, dz - \int_{-h}^{L} \rho(z)\gamma z \, dz = -\int_{-h}^{L} \sigma_v(z) \, dz$$

Relative stress below salt body

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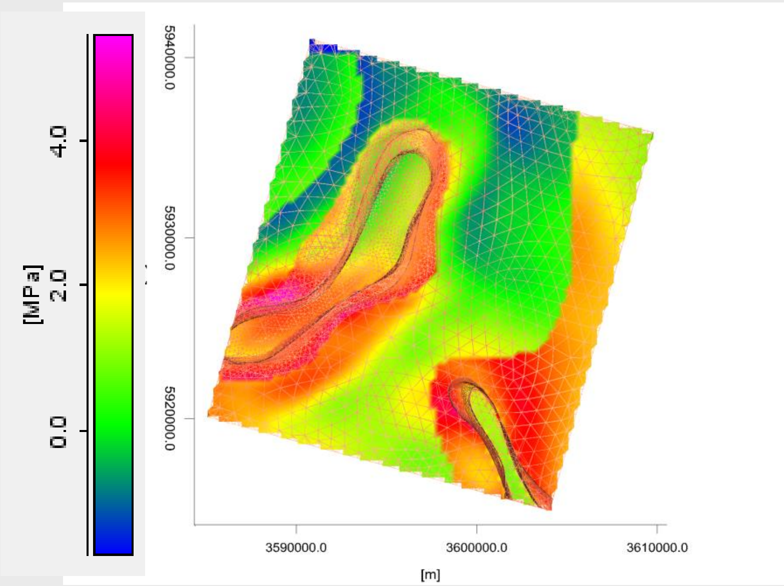
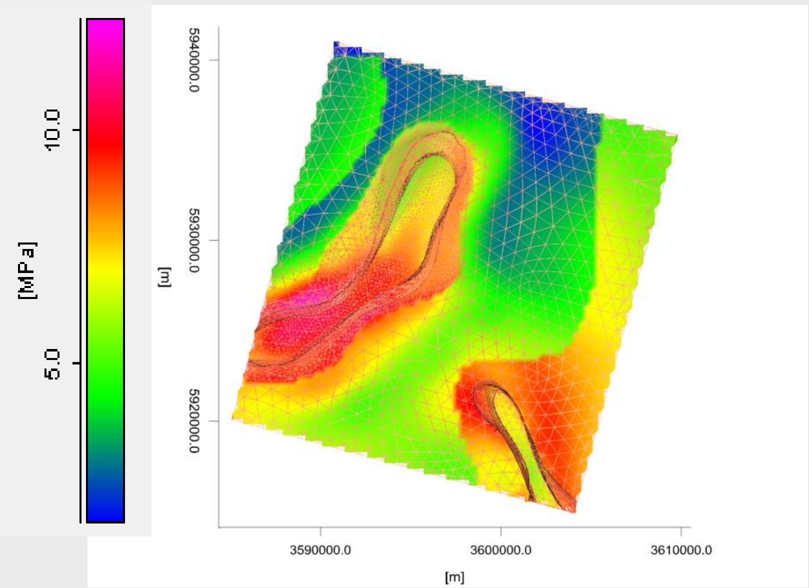
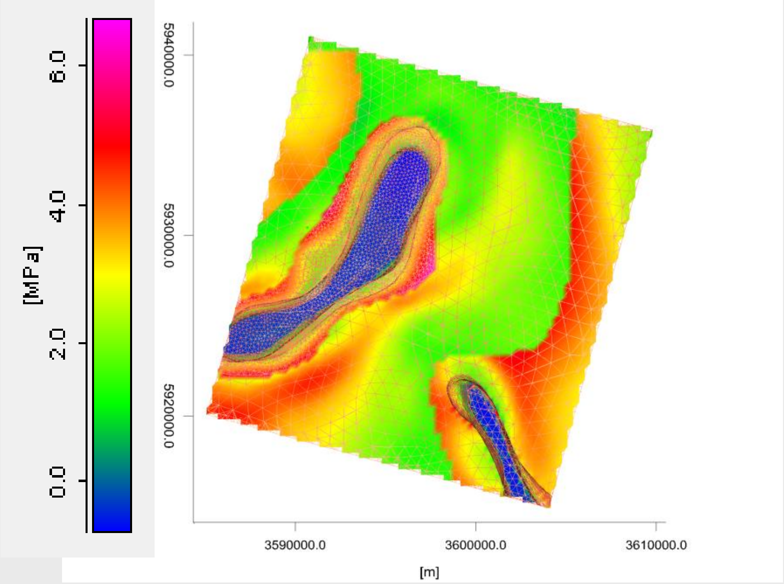
Reference density 2.3 t/m³ | Reference density 2.5 t/m³

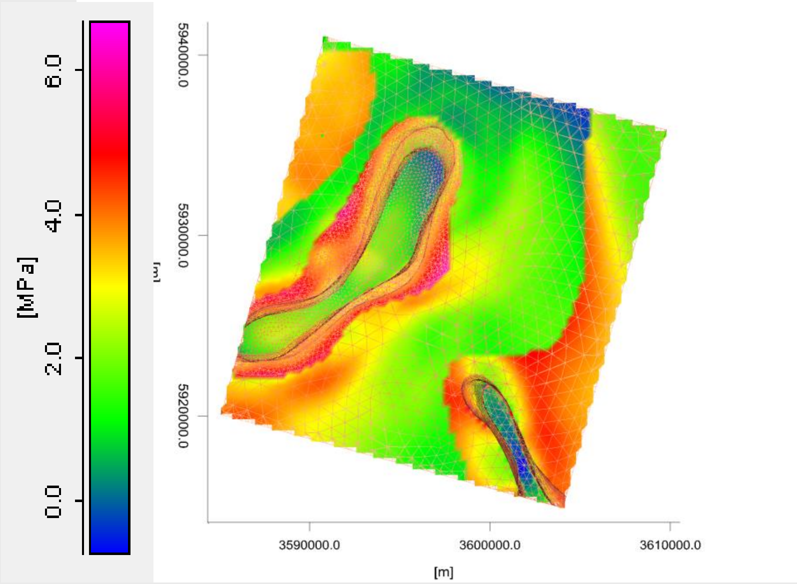
Constant depth (5450 m)





At bottom salt





Plot interface: 3D plotter – IGMAS software

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Lowcost 3D plotting by IGMAS+ plotter software Interface.

… after approx. 22 hours

Plot interface: 3D plotter – IGMAS software

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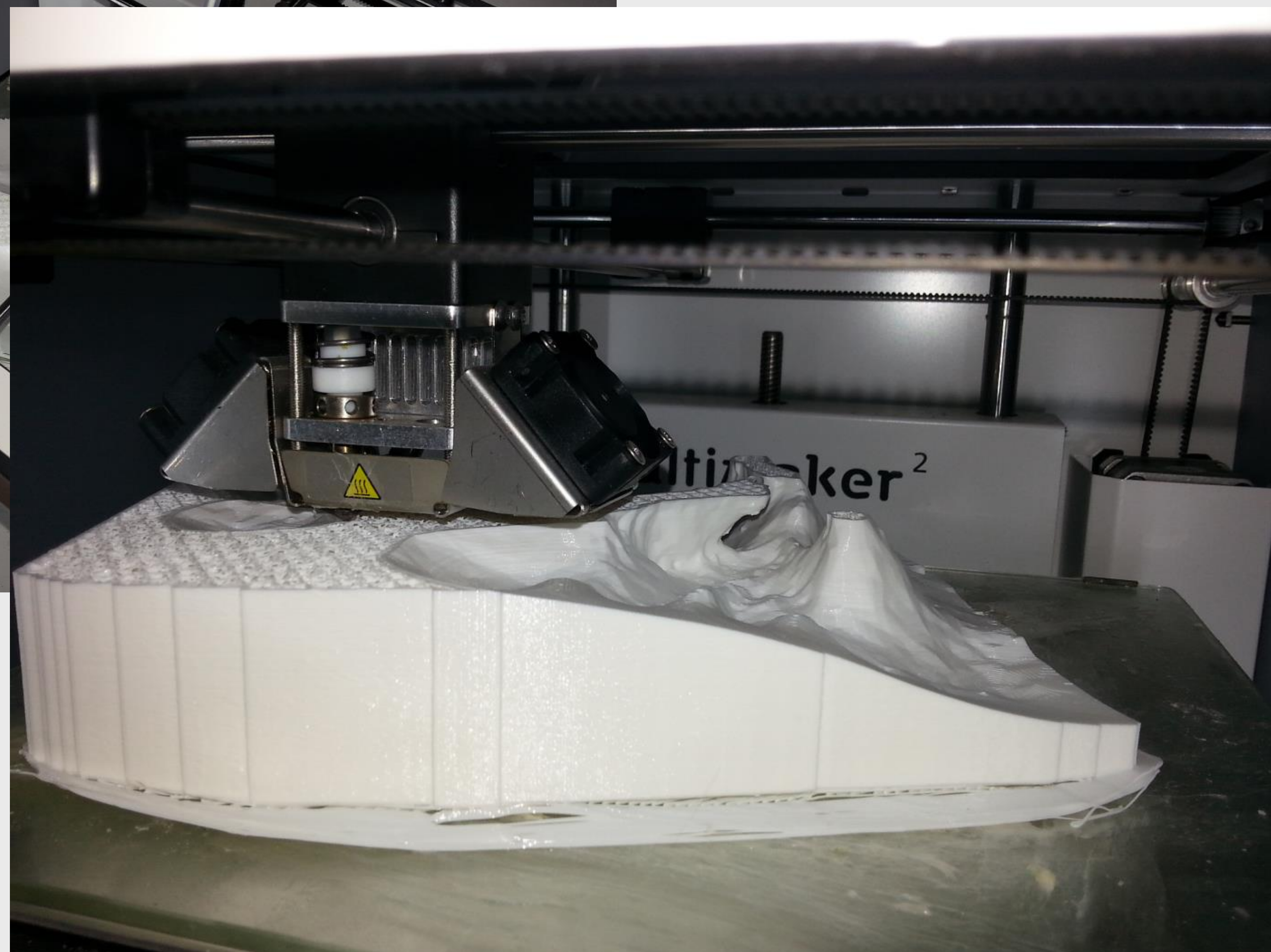

Lowcost 3D plotting by IGMAS+ plotter software Interface.

… after approx. 22 hours

Plot interface: 3D plotter – IGMAS software

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The making of a 3D plot of a density model in the NW German Basin.

The big scale:

Alpine Region

Southern Central Andes

Northern Patagonian Massif

Eastern Alps: constraints from refraction & reflection data

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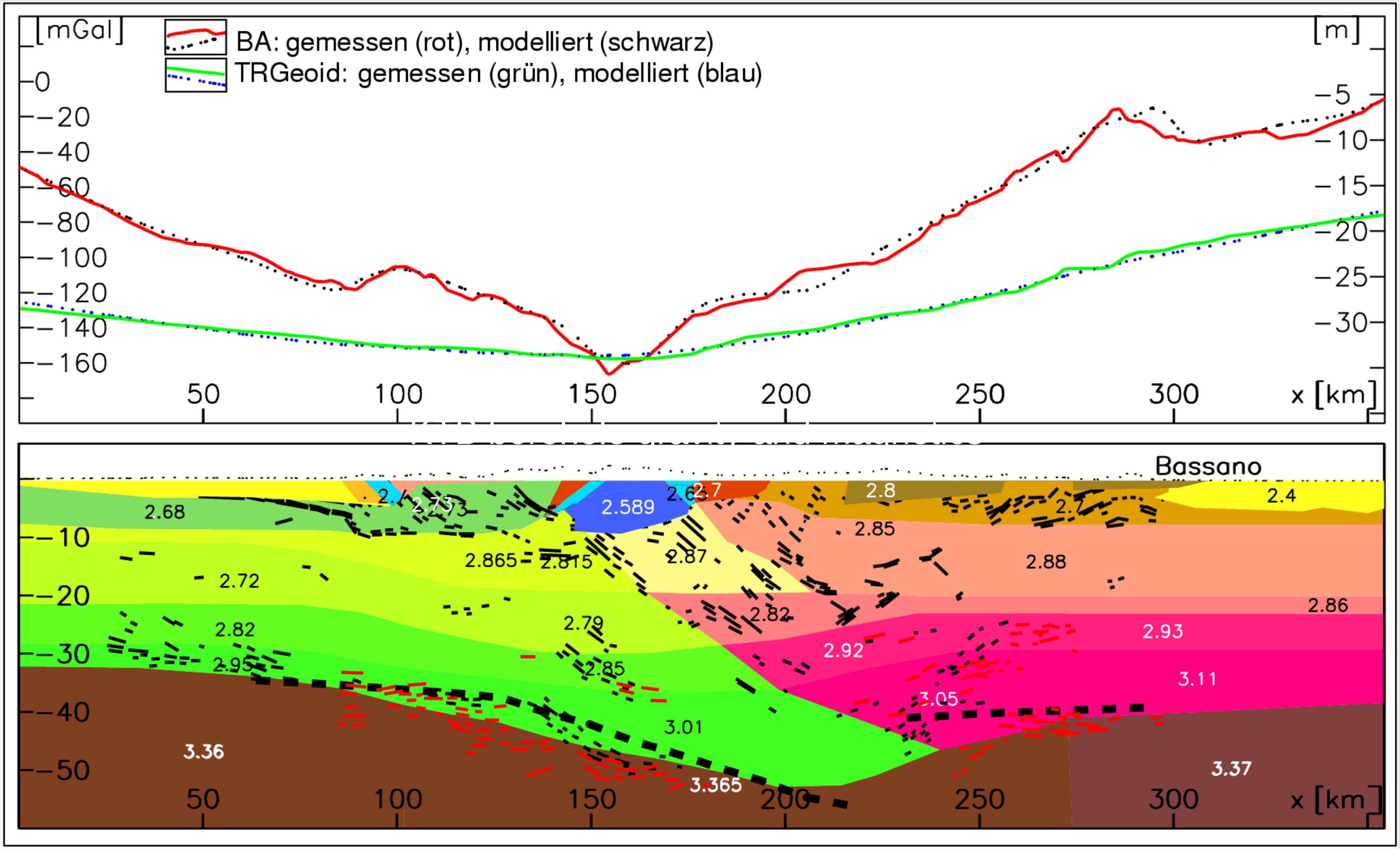


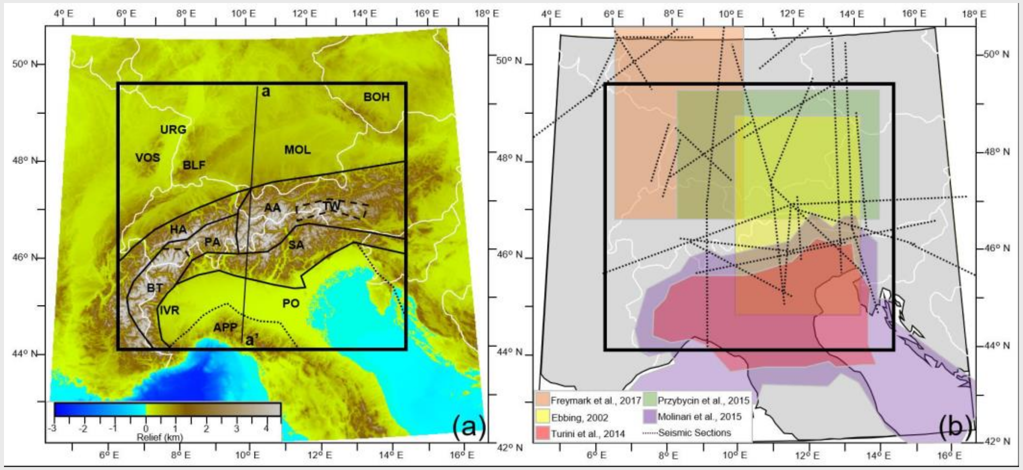
J. Ebbing, PhD, 1992

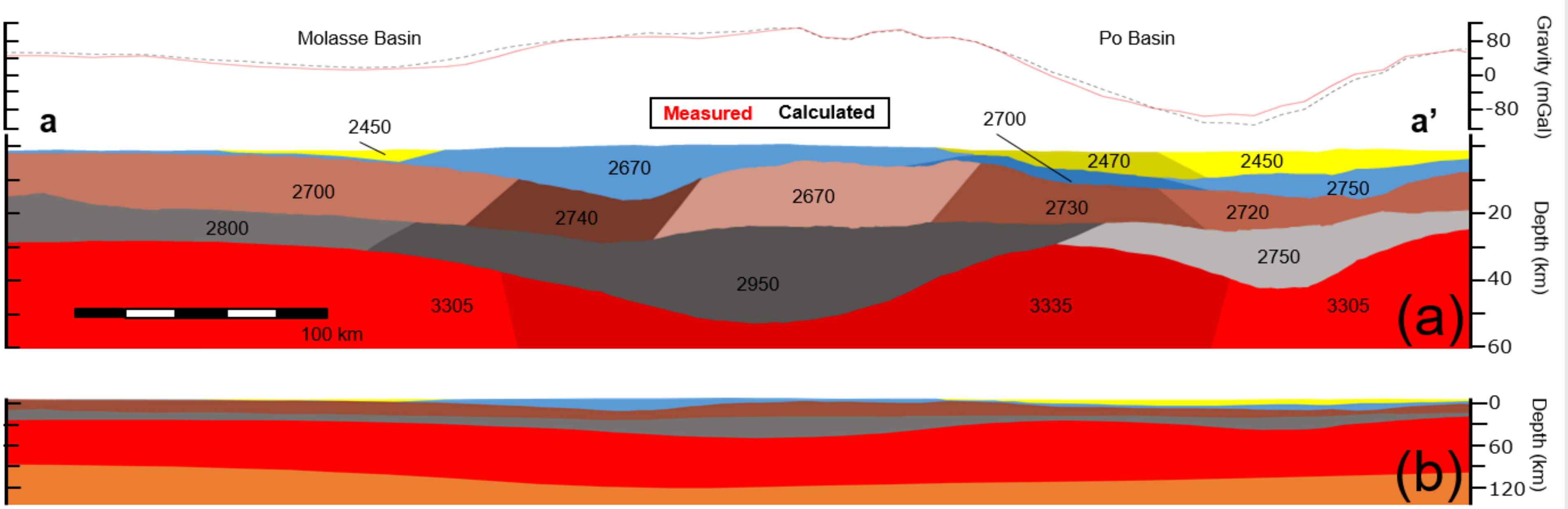
Eastern Alps: constraints from refraction & reflection data

Cameron Spooner et al. (2019):

N-S cross-section along aprox. of 10° latitude of a constrained density model.

Reddish colors: Upper mantle





Southern Central Andes: seismically and gravity-constrained 3D lithospheric model

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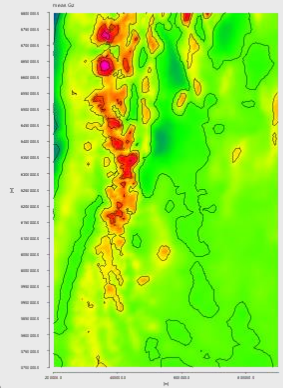
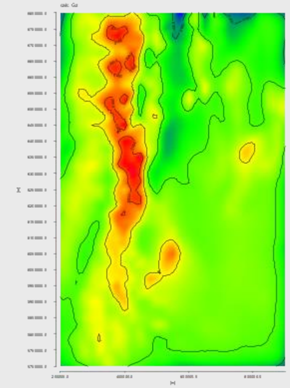
Rodriguez Piceda et al. (2020, under review):

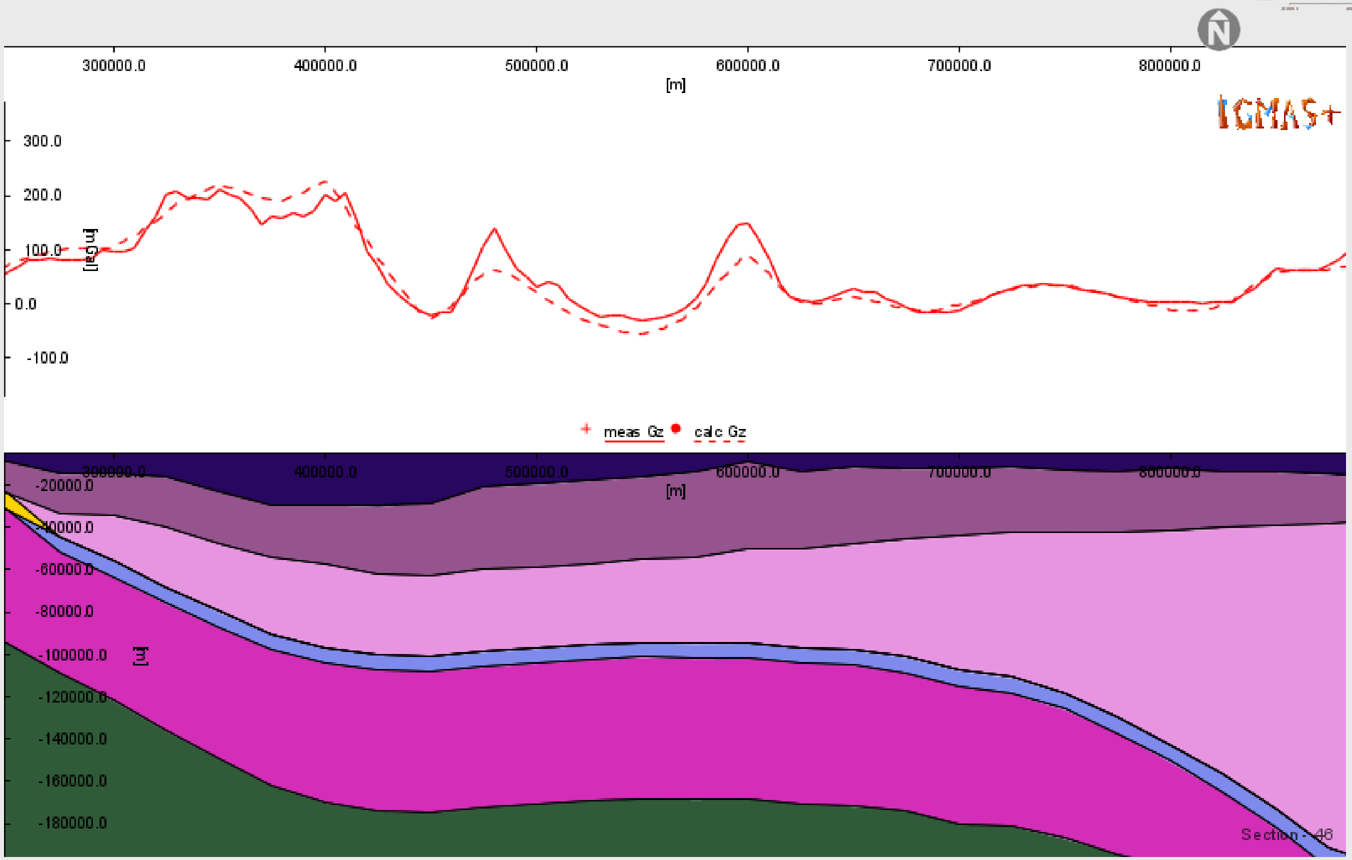
- Extension: 700 km (E-W)*1100 km (N-S)
- Depth: 200 km
- Lateral resolution: 25 km
- Distance between working sections: 25 km
- Bodies with constant density (except lithospheric mantle)

Measured gravity

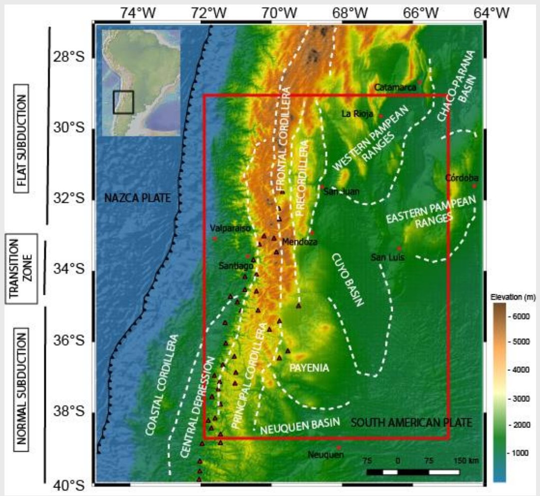


Modelled gravity





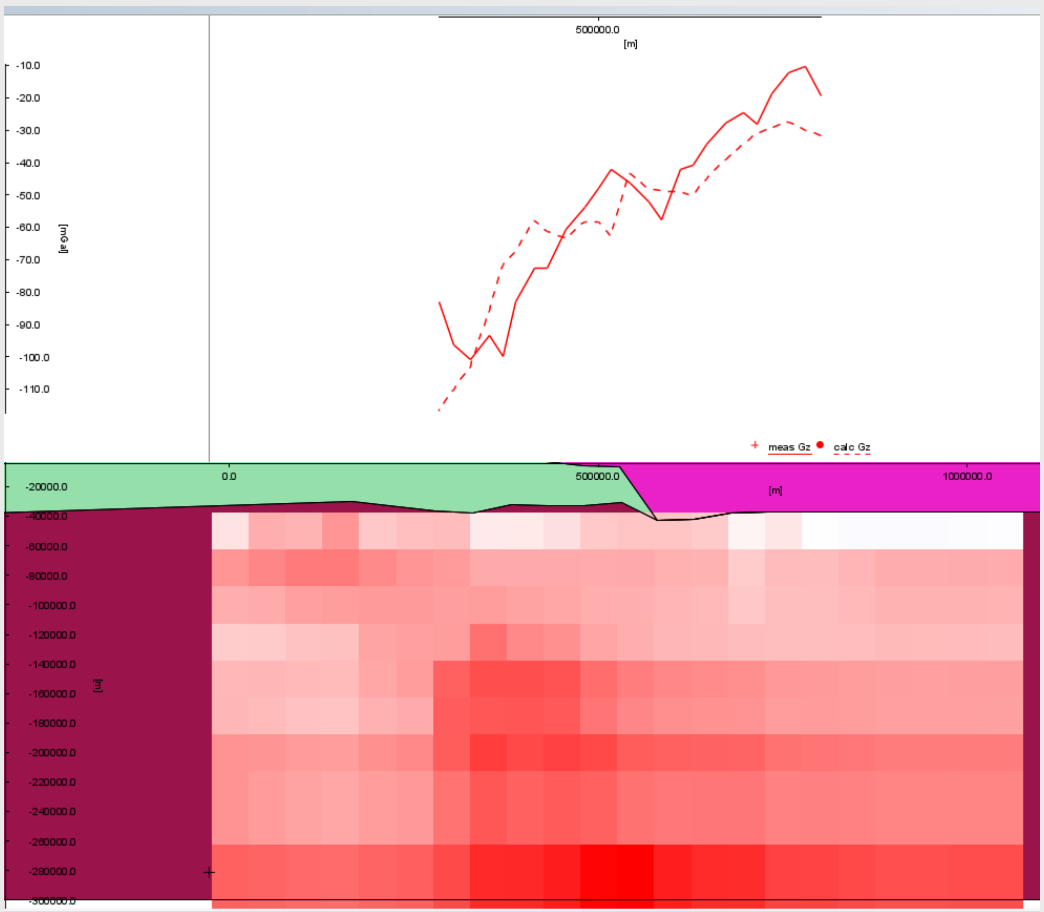
Layers	Density [kg/m3]
Water	1030
Oceanic Sediments	2300
Continental Sediments	2400
Upper Continental Crust	2800
Lower Continental Crust	3100
Continental Mantle	from conversion of Vs *
Oceanic Crust - Basalt	2900
Oceanic Crust - Eclogite	3200
Mantle Slab	3340
Oceanic Mantle	from conversion of Vs*

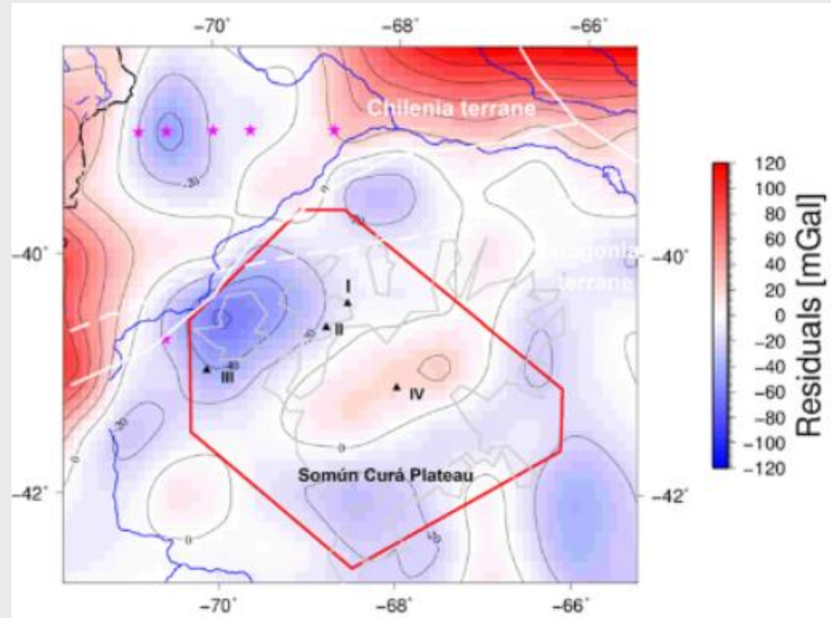


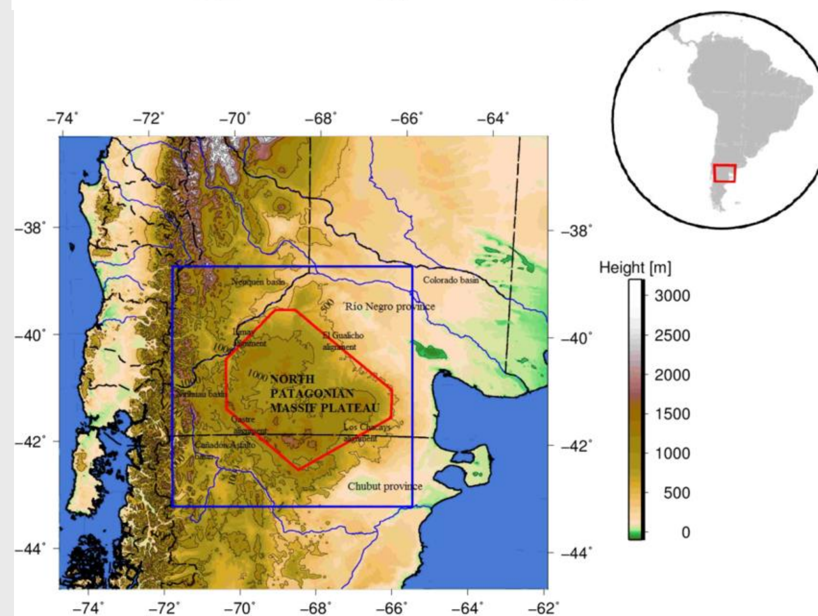
North Patagonian Massif: gravity-constrained 3D lithospheric model

Gomez Dacal et al. (2017):

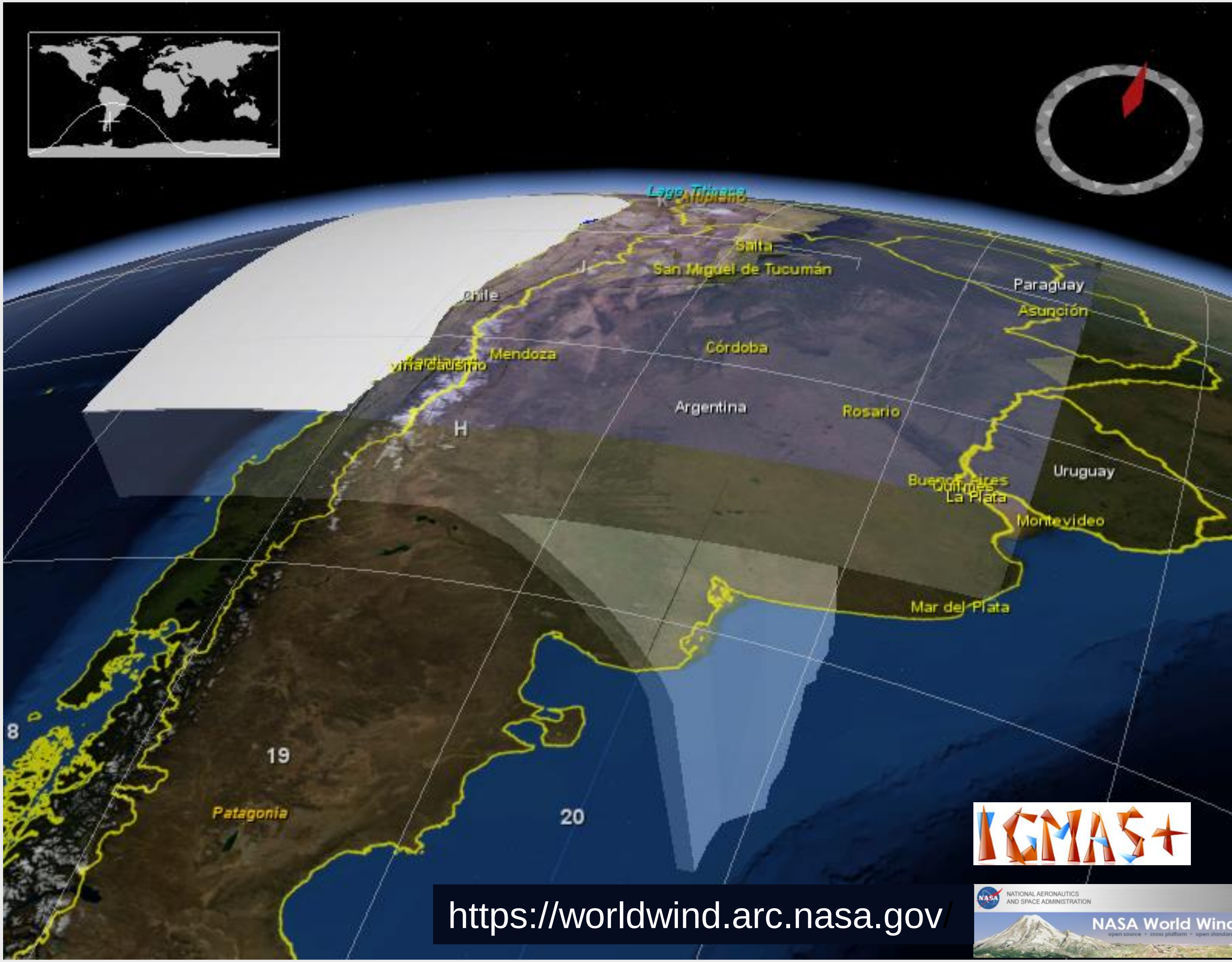
- Extension: 500 km (E-W)*500 km (N-S)
- Depth: 200 km
- Lateral resolution: 0.5°
- Distance between working sections: 50 km
- Tomographic models were used to create a voxel cube



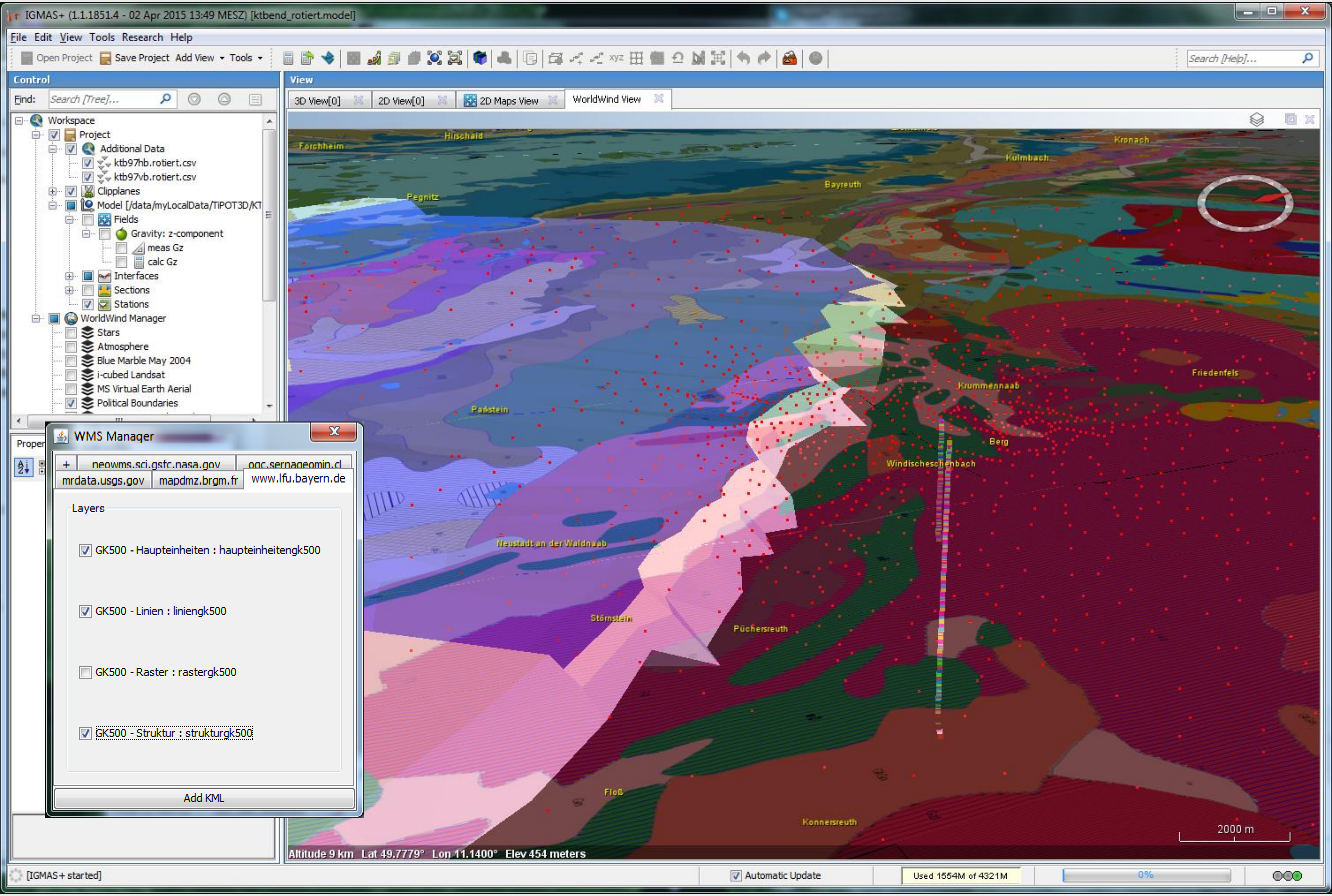




Spherical modelling - visualization



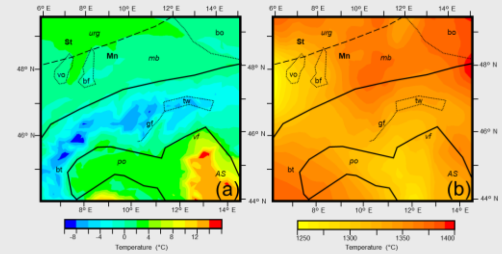
Use of free Web Mapping Services



Outlook (next):

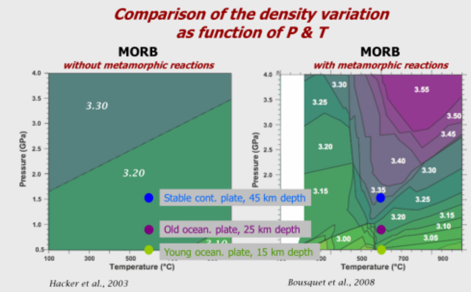
Interface to thermal modelling,

e.g. Przybycin et al. (2017), Spooner et al., under review



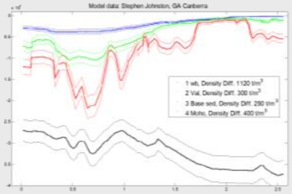
Rock petrology &

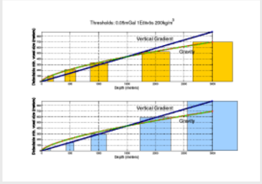
e.g. Wind (2015), Oalmann et al. (2019)



Uncertainty/sensitivity

e.g. Schmidt pers. com., Wellmann & Caumon, 2017





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