3D Modelling of the In-Situ Stress Field in Nordland, Northern Norway

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GEOLOGICAL SURVEY OF NORWAY
- NGU -

COMSOL CONFERENCE
2017 ROTTERDAM
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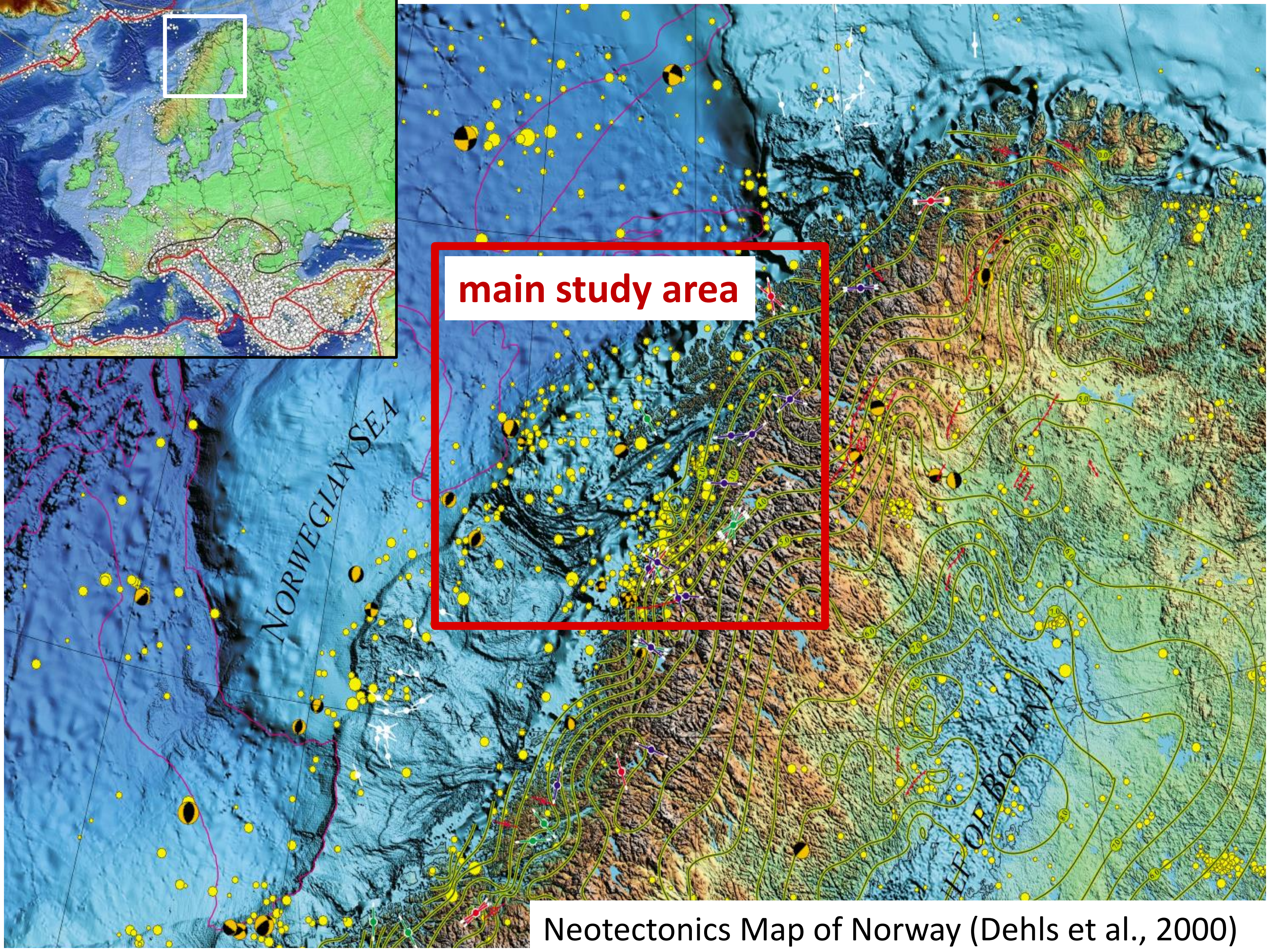
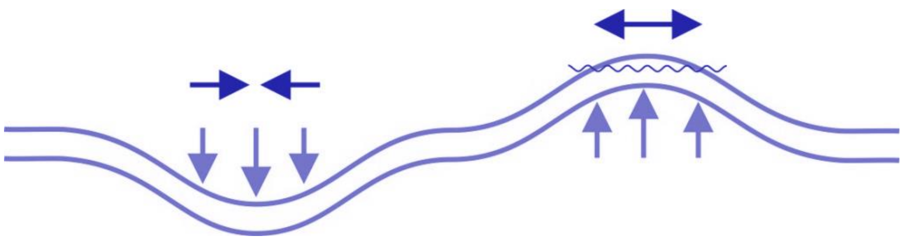


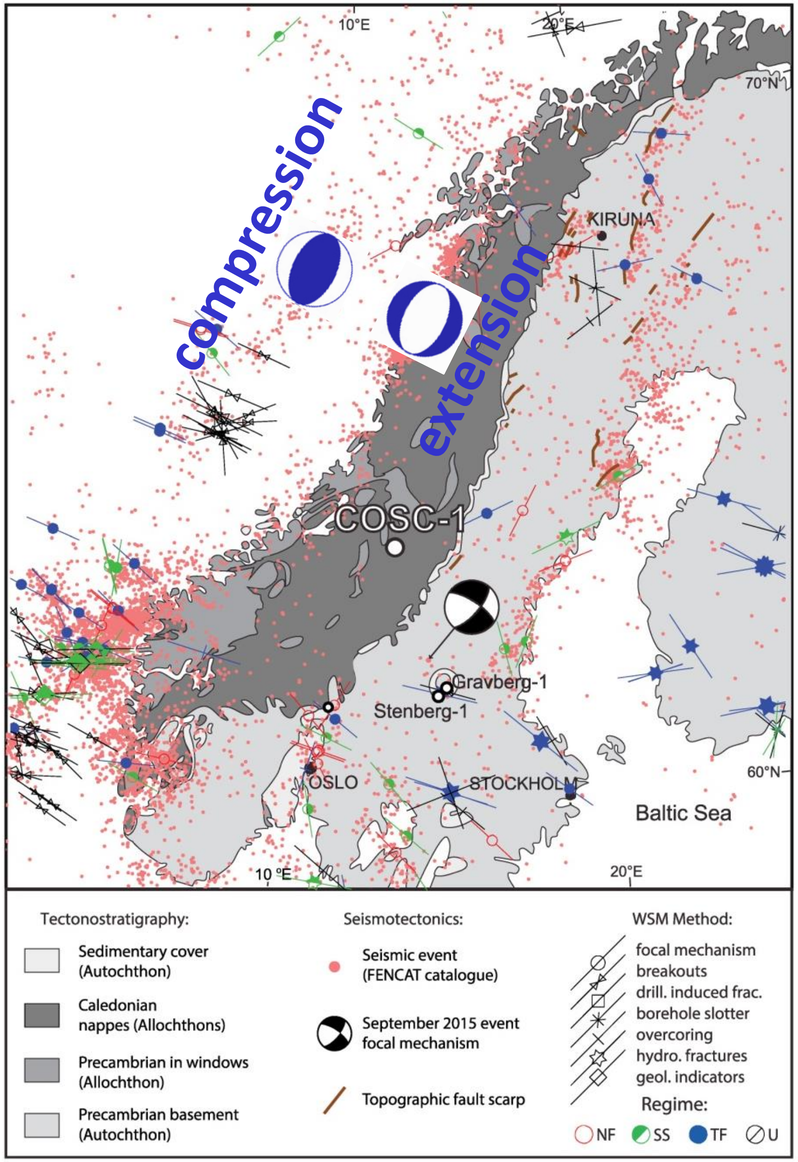
Neotectonics Map of Norway (Dehls et al., 2000)

Present-Day Stress Regime

- primarily WNW-ESE
- unaffected by Eurafrican collision
- compression offshore
- extension along coast

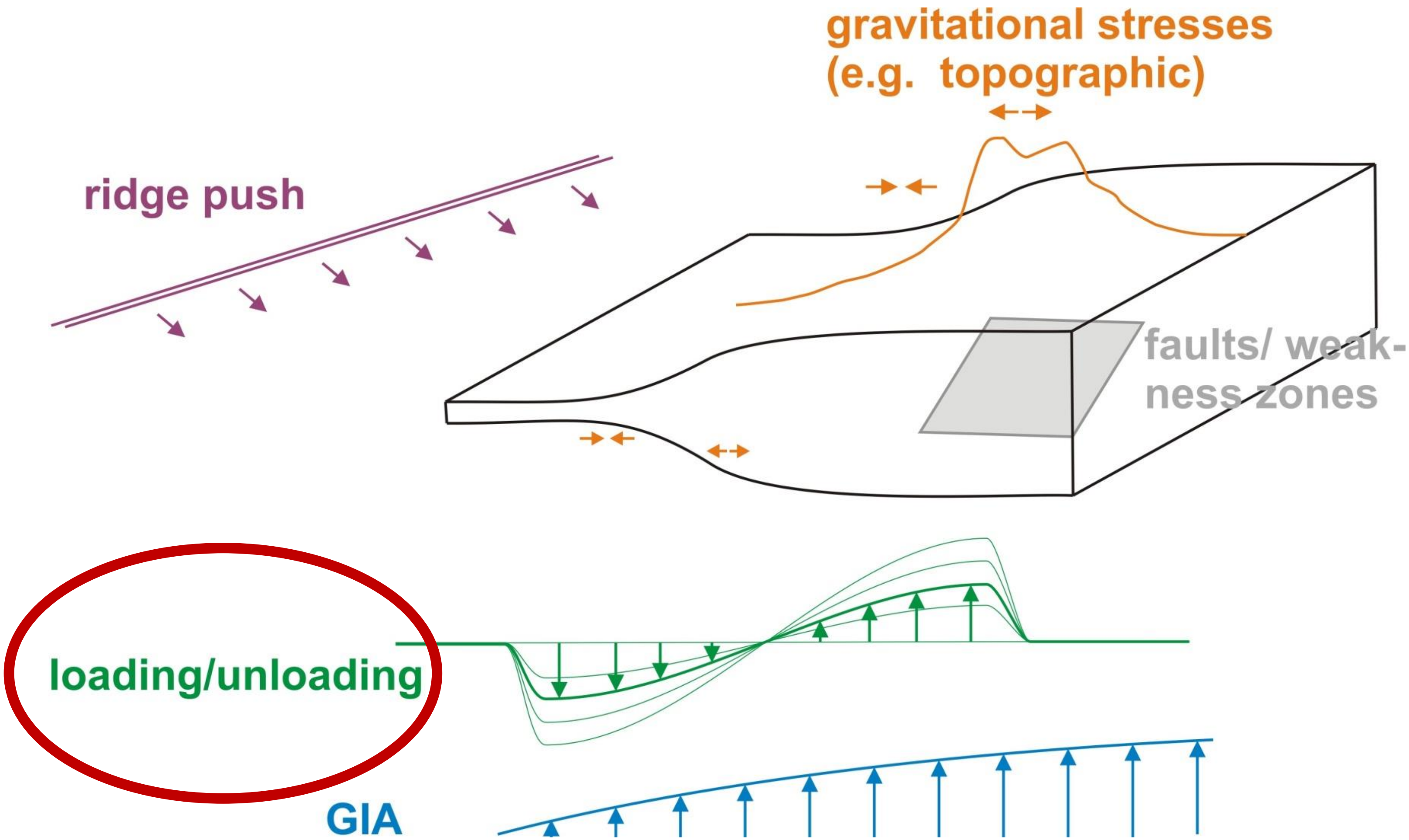
➢ Is seismicity linked to flexural effects of sediment re-distribution?





Wenning et al., 2017

Stress-Field Components

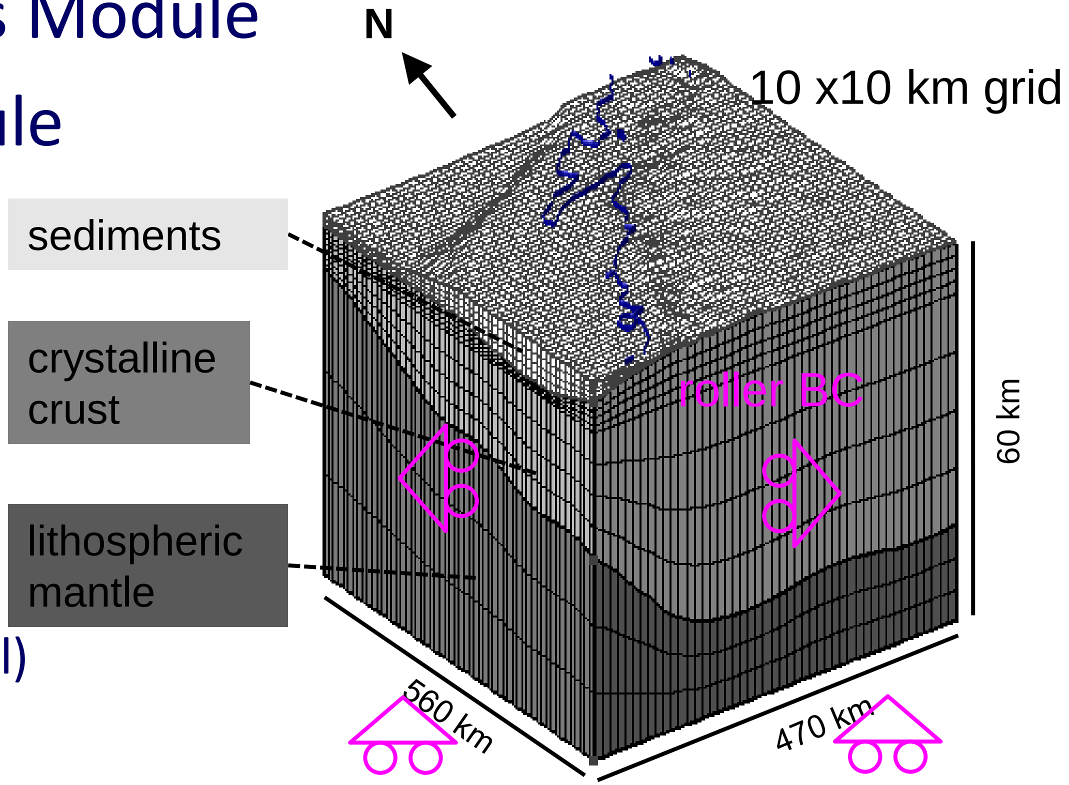


gravi-tational + ridge push + GIA + sed. load. = present-day stress field

Modelling Approach

3D finite element modelling with COMSOL Multiphysics®

- Structural Mechanics Module
- Geomechanics Module



3D model

Gravity (uniaxial compression)

Rheology (linear elastic)

Material properties (ρ, E, ν)

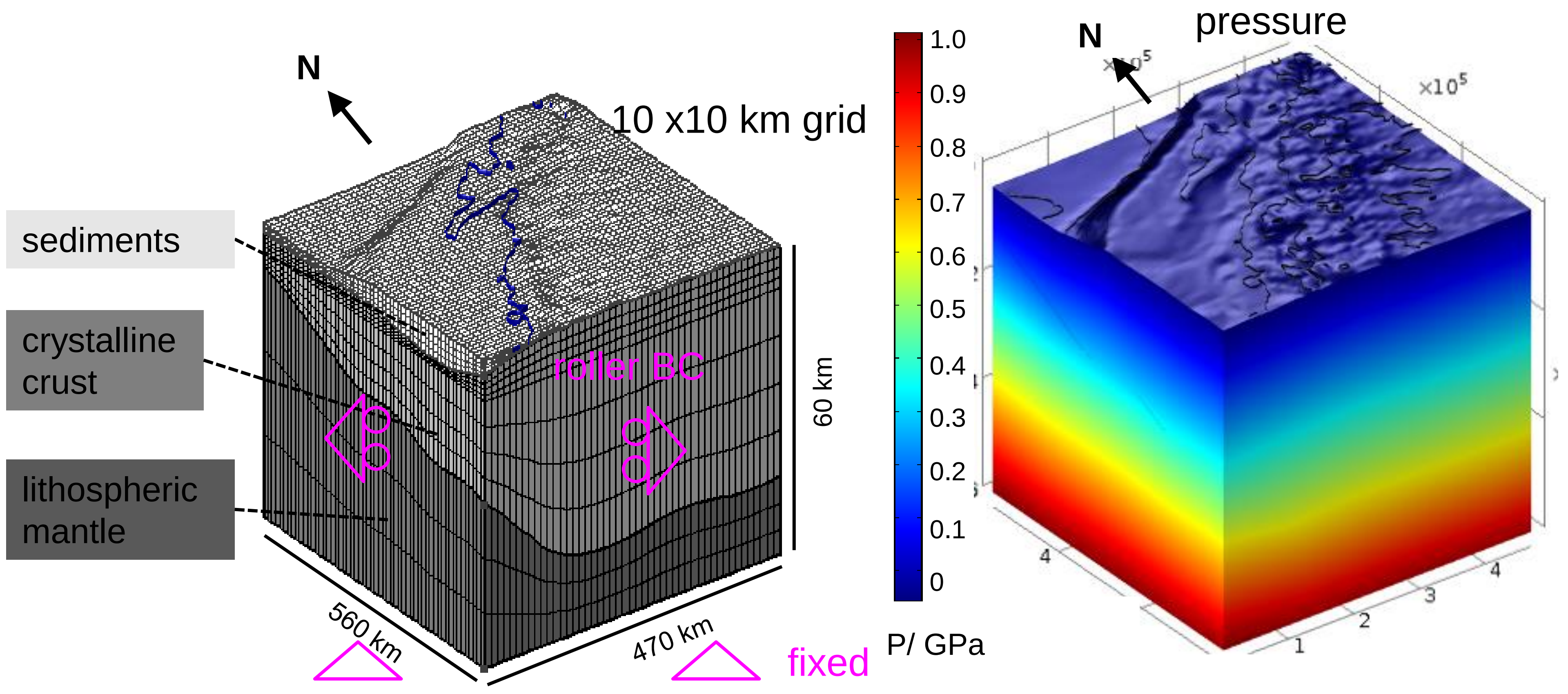
Boundary Conditions (basic model)

- roller BC @ sides
- roller BC @ bottom
- water load @ top

Material Properties

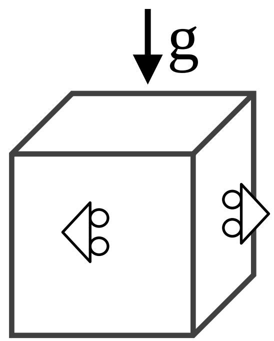
	Density	Rheology (linear elastic)
sediments	2700 kg/m³	E=40GPa, v=0.3
cryst. crust	2800 kg/m³	E=60GPa, v=0.3
lith. mantle	3300 kg/m³	E=70GPa, v=0.3

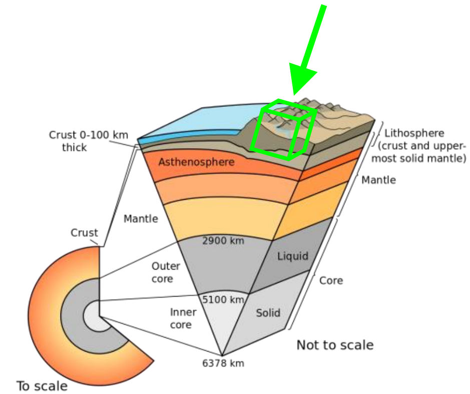
\+ water load & **gravity**



Modelling the Regional 3D Stress-Field

Model vs. **Earth**





Problem 1 – rheology

Model	Earth
elastic deformation	no deformation complex rheology

Problem 2 – background stress

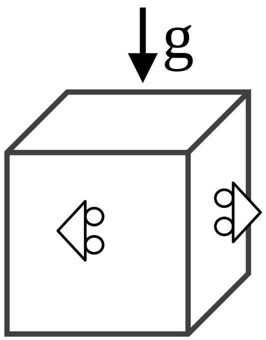
Model	Earth
tensile	near-lithostatic

Problem 3 – stresses at surface

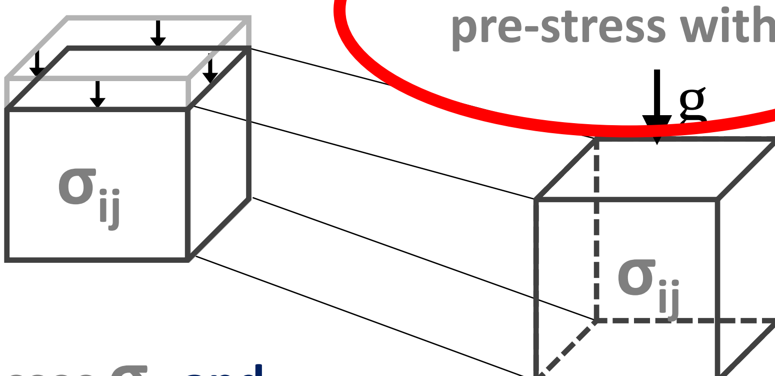
Model	Earth
poorly resolved	highly variable

Problem 1 – Displacement/Rheology

Model vs. Earth

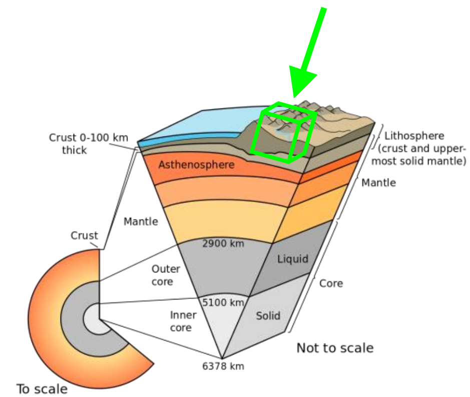


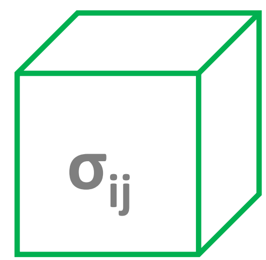
Solution1:
pre-stress with σ_{ij}



stresses σ_{ij} and **LARGE displacement**

stresses σ_{ij} and **negligible displacement**

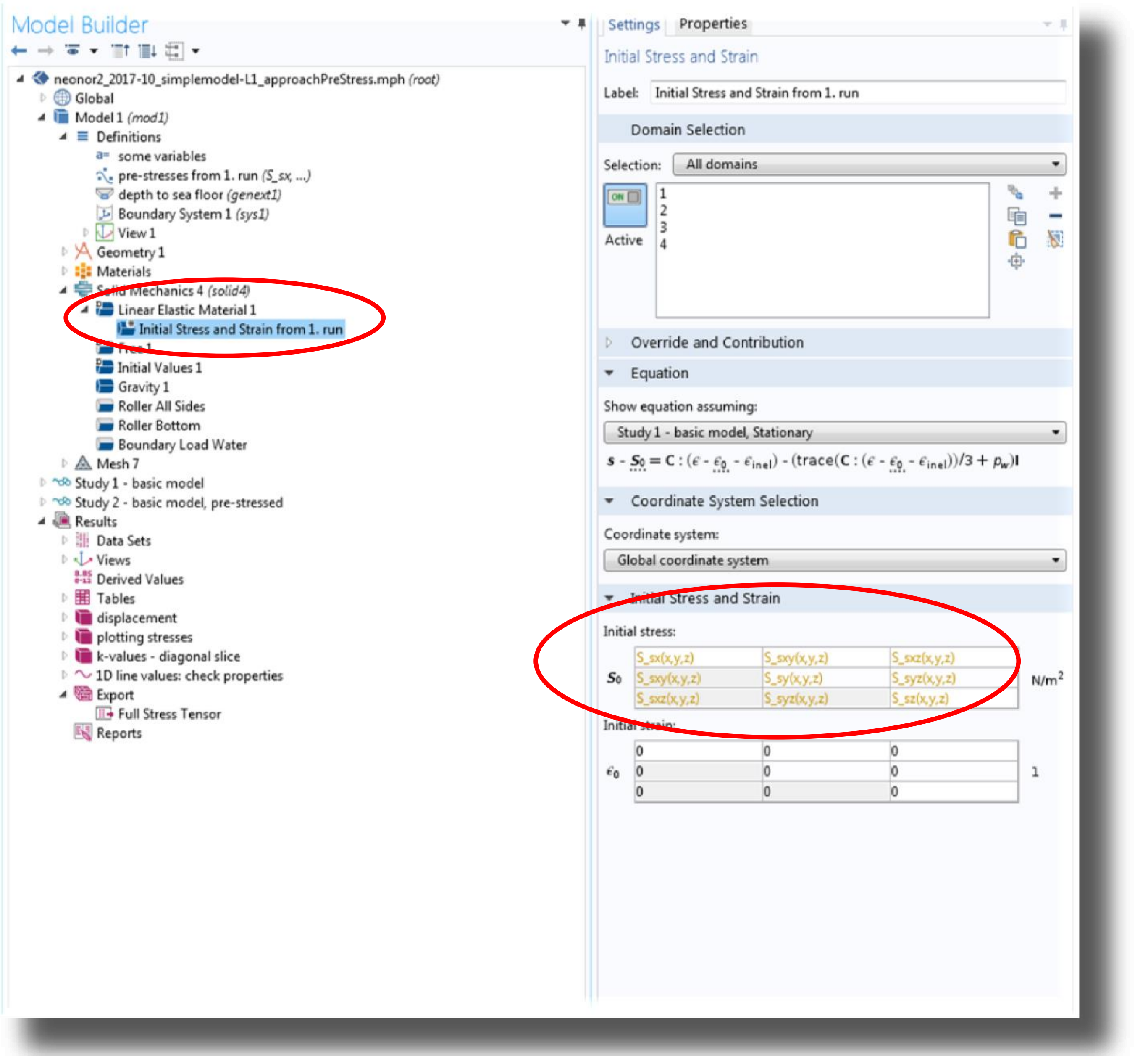




stresses σ_{ij} + **no displacement**

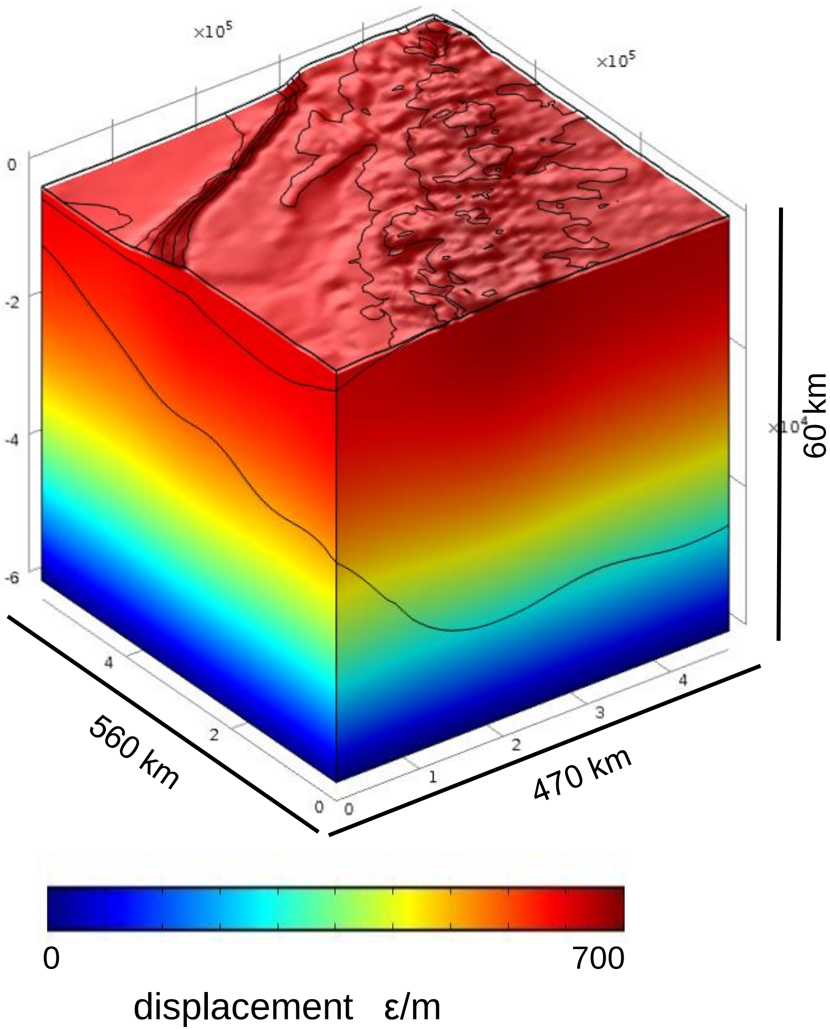
Basic Model – total displacement

0. run basic model
1. export full stress tensor
2. import stress tensor as interpolation function
3. use imported values as initial stress

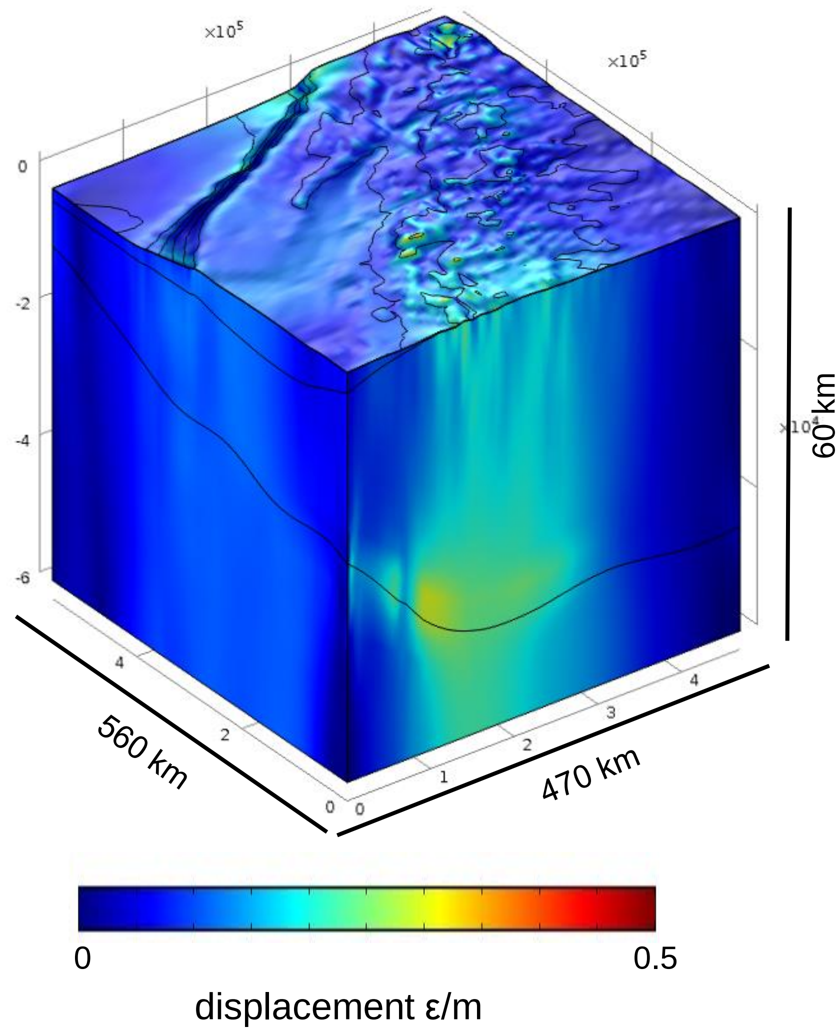


Pre-Stressing and Deformation

basic model



basic model with pre-stressing



Problem 2 – Background Stress

Model vs. Earth

linear elastic material

Young's modulus E

Poisson ratio v

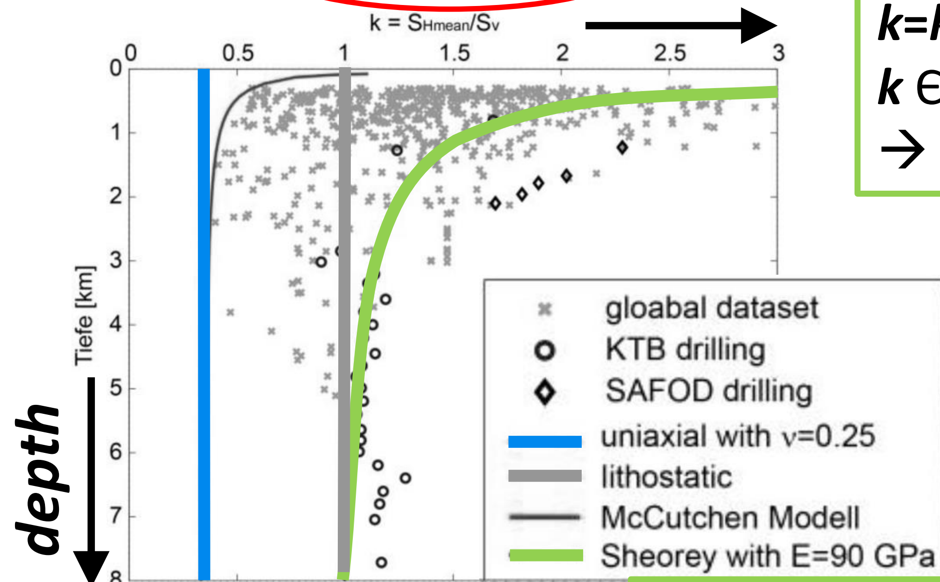
stresses in uniaxial compression

$\sigma_{xx} = k\,\sigma_{zz}$

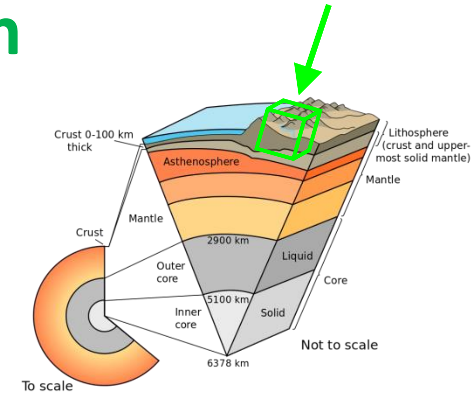
$k = \nu / (1 - \nu)$

$k = \text{const}$

$\sigma_z > \sigma_h$



Hegert and Heidbach, 2011



$k=k(z)$

$k \in [0.33, 3]$

$\rightarrow \nu \in [0.25, 0.75]$

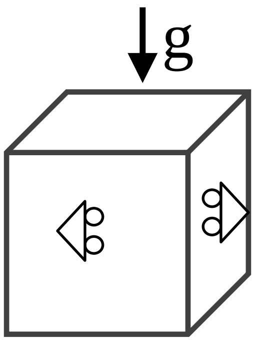
Sheorey, 1994

$k = 0.25 + 7 * E * (0.001 + 1/z)$

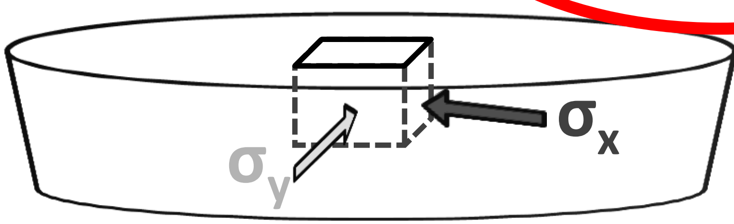
$k<1$, tension $k=1$, lithostatic $k>1$, compression

Solution 2 – Background Stress

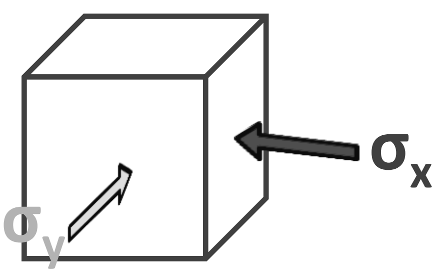
Model vs. Earth



Solution2:
1. embed model in box with tilted edges (spherical Earth)

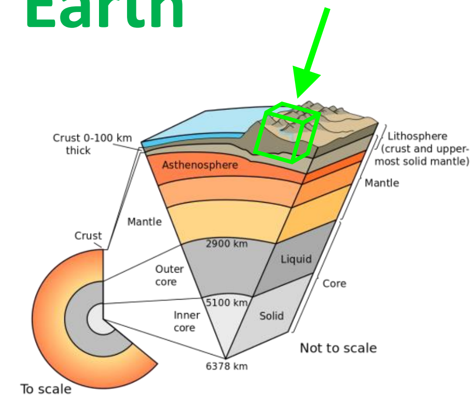


Sheorey Box



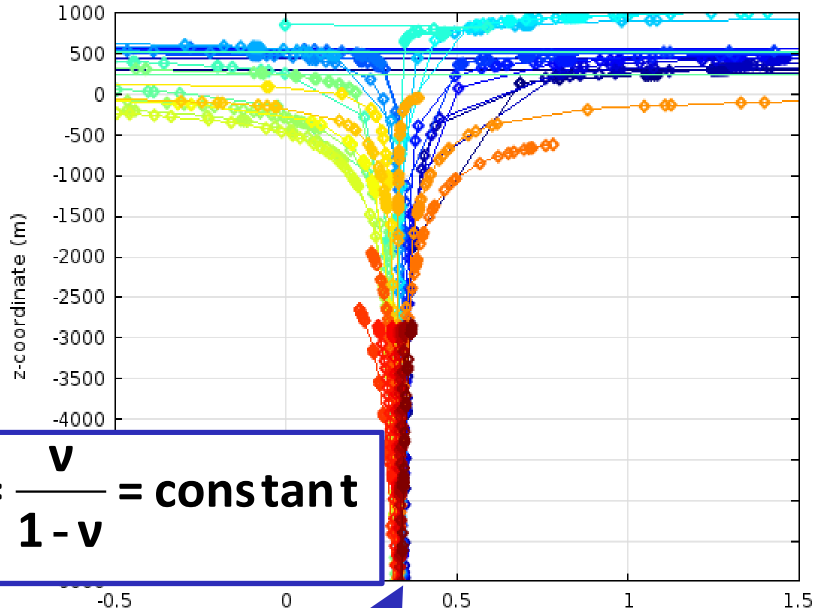
2. extract stresses within model box

3. apply these stresses as pre-stress on small box



Basic Model – Background Stress

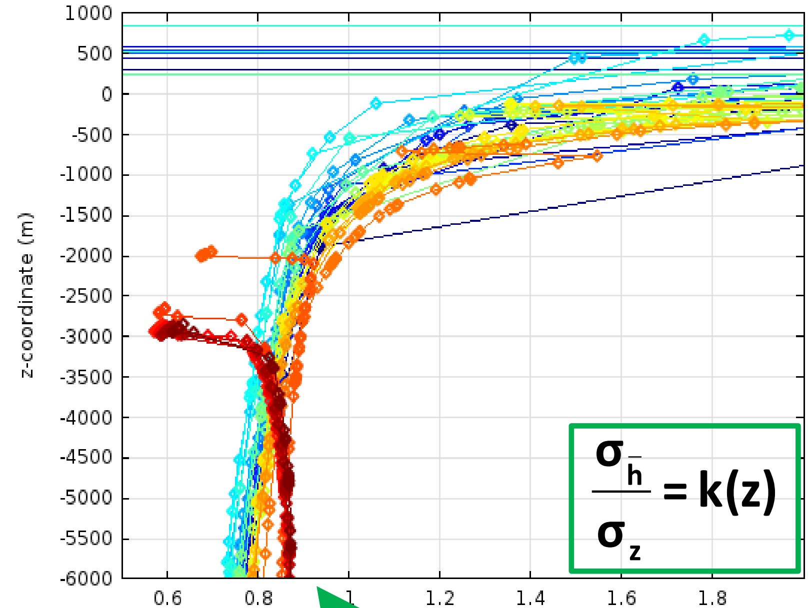
k(z) without Sheorey Box stresses



$$\frac{\sigma_h}{\sigma_z} = \frac{\nu}{1-\nu} = \text{constant}$$

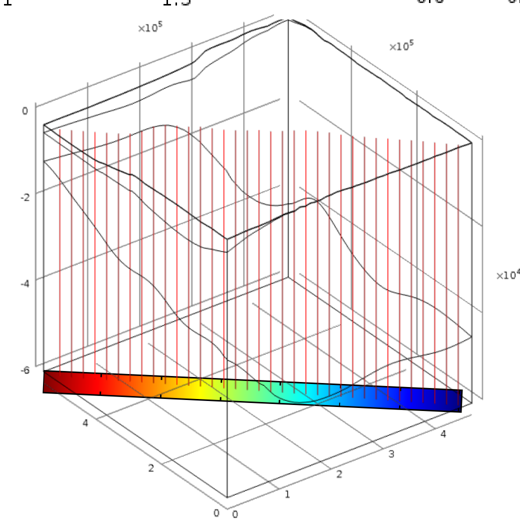
k_{deep}=0.33

k(z) with Sheorey Box stresses

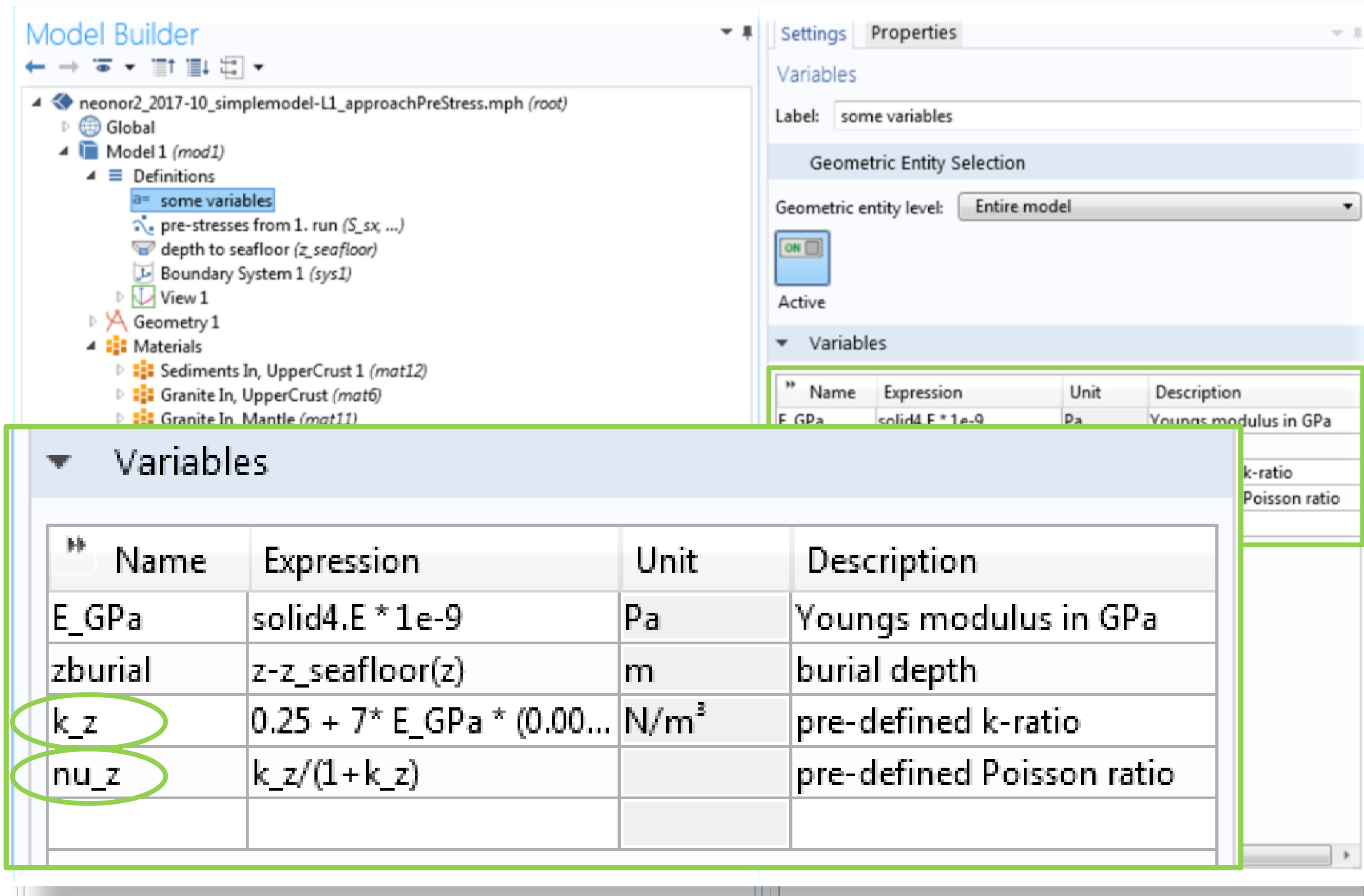


$$\frac{\sigma_h}{\sigma_z} = k(z)$$

k_{deep}≈0.8



Background Stress - Alternative solution



Name	Expression	Unit	Description
E_GPa	solid4.E * 1e-9	Pa	Youngs modulus in GPa
zburial	z-z_seafloor(z)	m	burial depth
k_z	0.25 + 7* E_GPa * (0.00...	N/m^3	pre-defined k-ratio
nu_z	k_z/(1+k_z)		pre-defined Poisson ratio

$k = 0.25 + 7 * E * (0.001 + 1/z)$

$\rightarrow \nu \in [0.25, 0.75]$

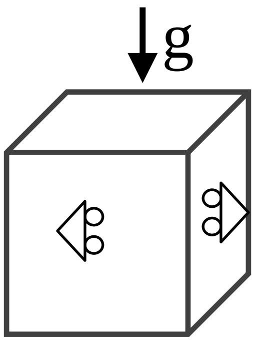
Sheorey, 1994

Background Stress - Alternative Solution

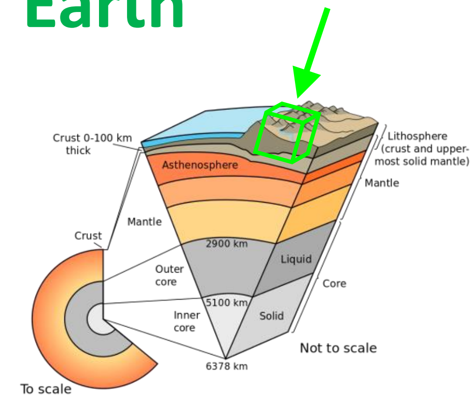
Model

vs.

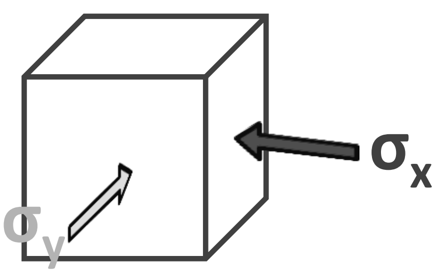
Earth



Solution2b:
1. run model with depth-dependent Poisson ratio

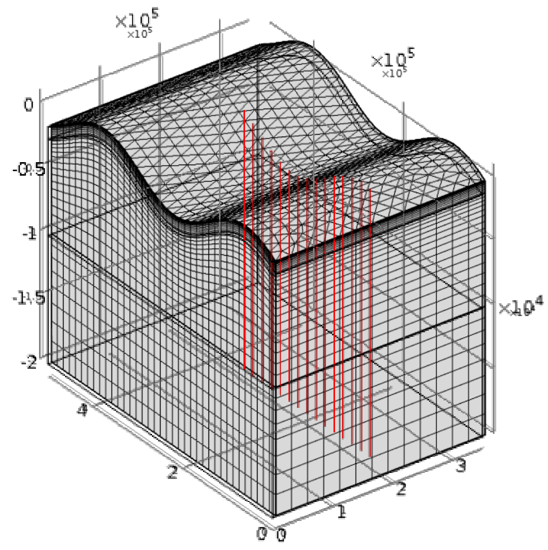


2. extract stresses within model box



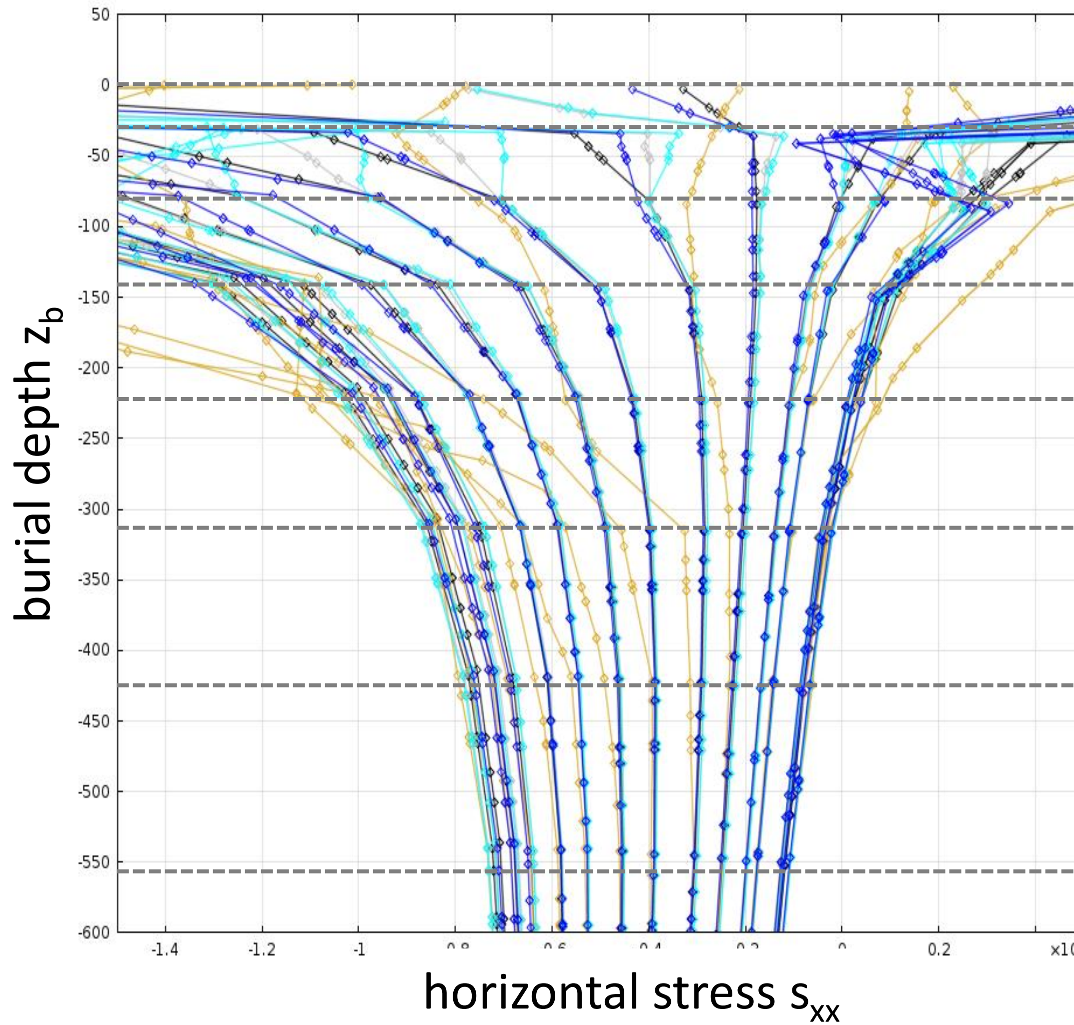
3. apply these stresses as pre-stress on small box (with constant Poisson ratios)

Problem 3 – Stresses @ Surface



test model

element number



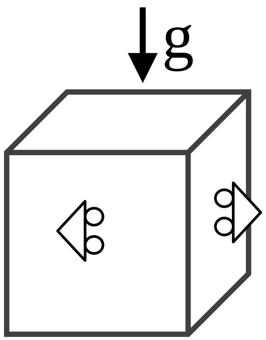
color: different resolution/data format

→ discard top three elements

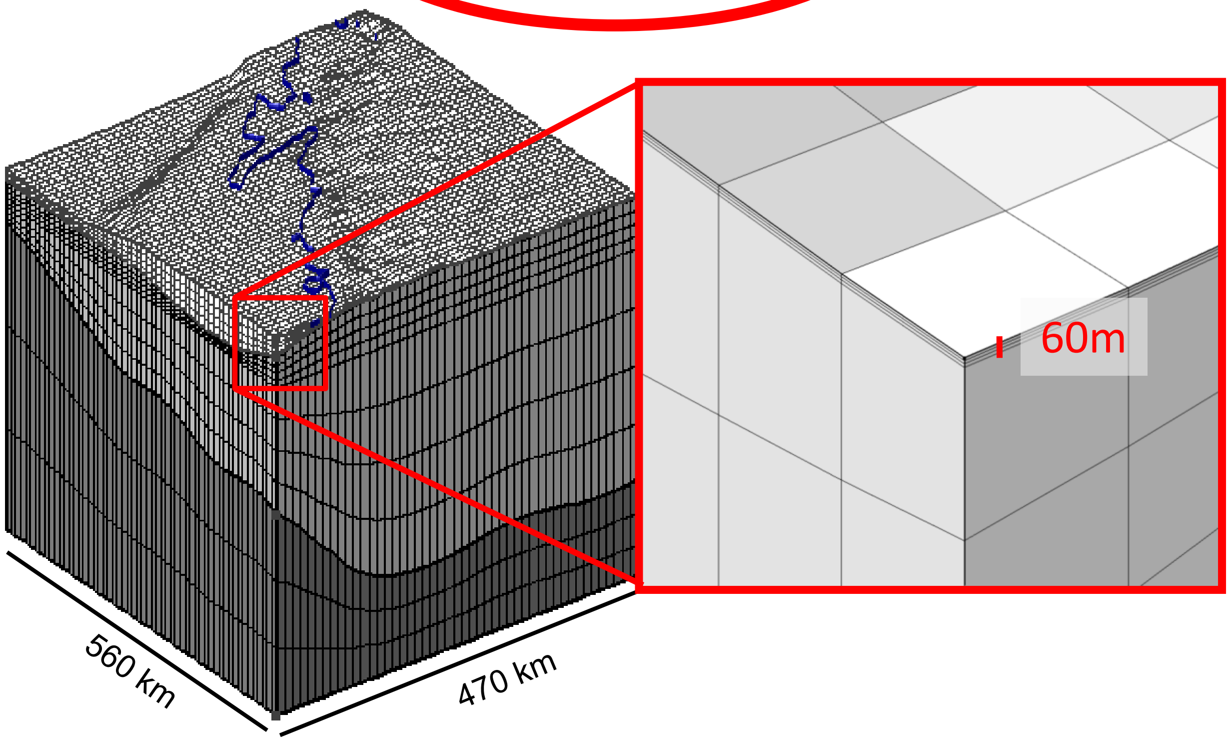
Problem 3 – Stresses @ Surface

Model

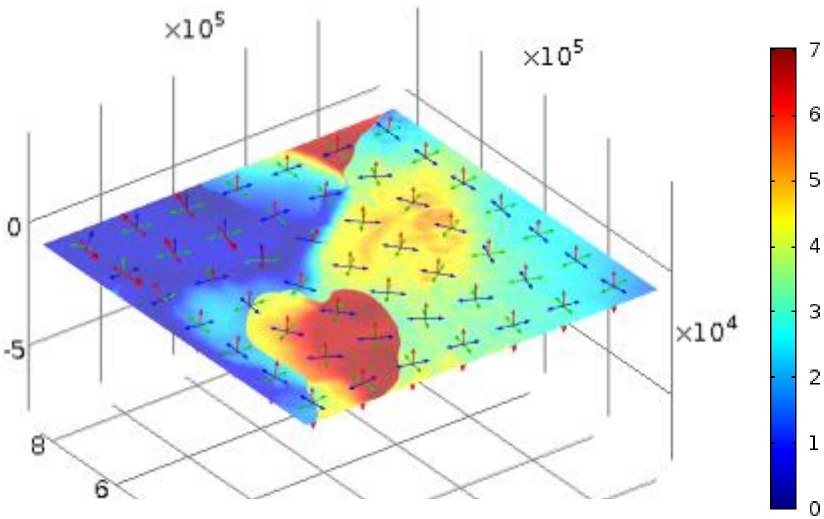
poorly resolved



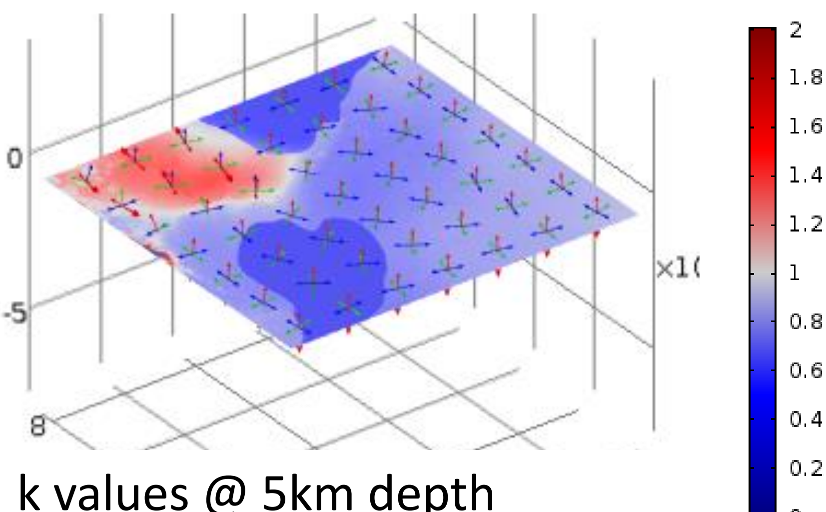
Solution3:
discard top three elements



Basic Model – Results and Summary



Von Mises stress @ 5km depth, principal stress direction



k values @ 5km depth

Problem 1: large elastic deformation

→ Solution: pre-stressing from initial run

Problem 2: background stress

→ Solution: use Sheorey box (or depth-dependent Poisson ratio)

Problem 3: surface stresses

→ Solution: discard top elements

Adding Stress Field Components

Gravitational Stresses (Topography, Moho,...)

- covered by ‘basic model’

Ridge Push

- boundary load @ side

Glacial Isostatic Adjustment

- pre-stresses from independent GIA model

Erosion/Sedimentation

- boundary load/deformation @ top

Existing Faults

- thin elastic layer from Geomechanics module


NORWEGIAN SEA
GULF OF BOTHNIA
Thank You