LITHOFLEX WORKSHOP

24-25 JUNE 2008

StatoilHydro Research Centre Rotvoll – Trondheim – Norway

StatoilHydro

LithoFLEX

Course Program

Day 1 Morning- theory (9:00-11:30)
9:00-9.-15: Welcome

9.15-10:15: **Part I: Theoretical background for gravity studies (CB)**
Theoretical background for gravity forward and inverse calculation by Parker approach. Role of the minimum wavelength in inversion. Parameter trade-off. Sensitivity study of parameters. Grace derived gravity field; GOCE satellite

10:15-10.30: Coffee

10:30-11:30: **Part II: Density-depth functions (JE)**
Density-depth functions in general and for sediments. Velocity-depth relation. Compaction models.

Day 1 Afternoon- practical (12:30-16:00)

12:30-13:15

-Data preparation. Useful grid sampling. Geosoft and Surfer Grid formats (JE)

14:00-…

Areas to be calculated: West Siberian Basin.

Introduction to grids: sediment, topography, gravity anomaly, Bouguer anomaly, Moho, seismic sections (Vyssotski). Sediment forward calculation. Testing different density-depth functions. Moho forward gravity calculation, Testing of parameters, gravity residual calculation

(2 - Backup example: South China Sea)

Day 2 Morning- theory (9:00-11:30)
9:00-9:30: **Part III Introduction to isostasy (SW)**

9:30-10:15: **Part IV Isostatic anomalies and basin evolution (JE)**
isostatic anomalies, local isostasy, Pratt model, McKenzie-rifting, Backstripping

10:15-10.30: Coffee

10:30-11:30: **Part V Regional flexure modelling (CB)**
Regional flexure modelling, full plate and broken plate model, Te constant and variable, Forward and inverse flexure calculations, Necessary constraints: crustal thickness and equivalent load, relative importance of internal loads and topographic loads (CB).

Day 2 Afternoon- practical (12:30-15:00)
equivalent total load calculation. Synthetic topographic generation. Flexure forward calculation. Continue flexure forward calculation, testing role of parameters. Flexure inverse calculation on a synthetic case.

Final Discussion.

Isostasy and flexural rigidity, for what is it good for?

Motivation Gravity, Moho

History about Isostasy

Flexural rigidity

Method Old: Spectral methods

New: software LITHOFLEX

Application Andes

Motivation: get insides into Earth's crustal architecture

- *Crust*

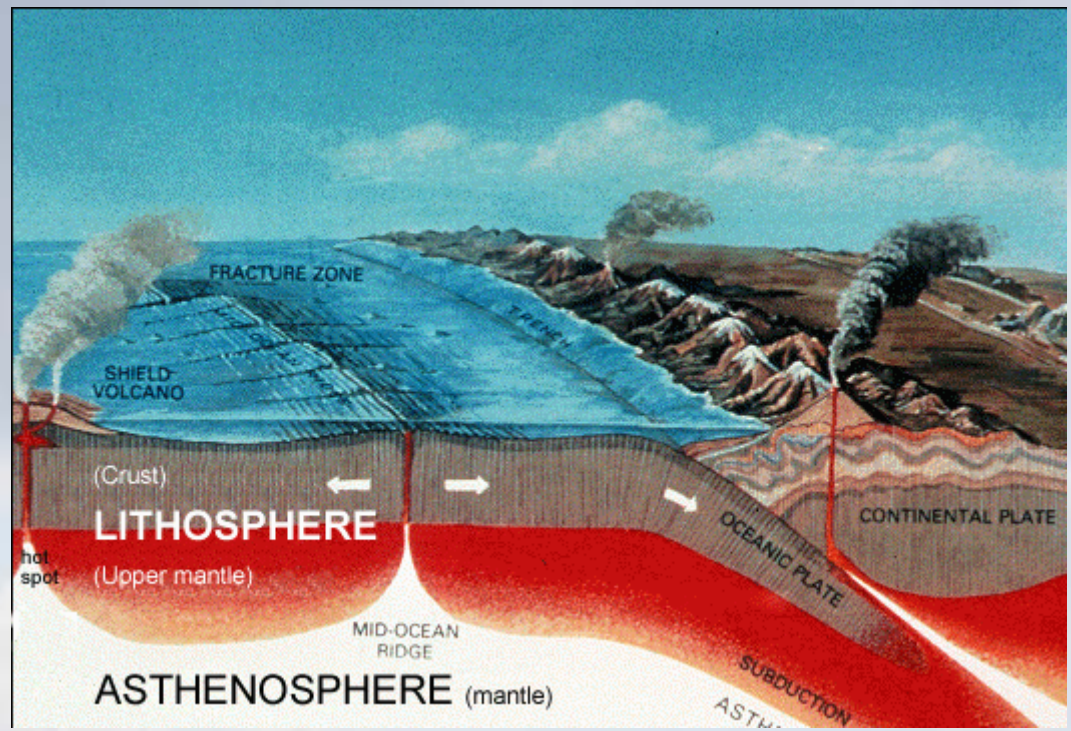
5km-35km, upper crust 2.67

lower crust 2.95

- *Mantle*

viscous fluid

upper mantle: 3.3



How? Use Gravity

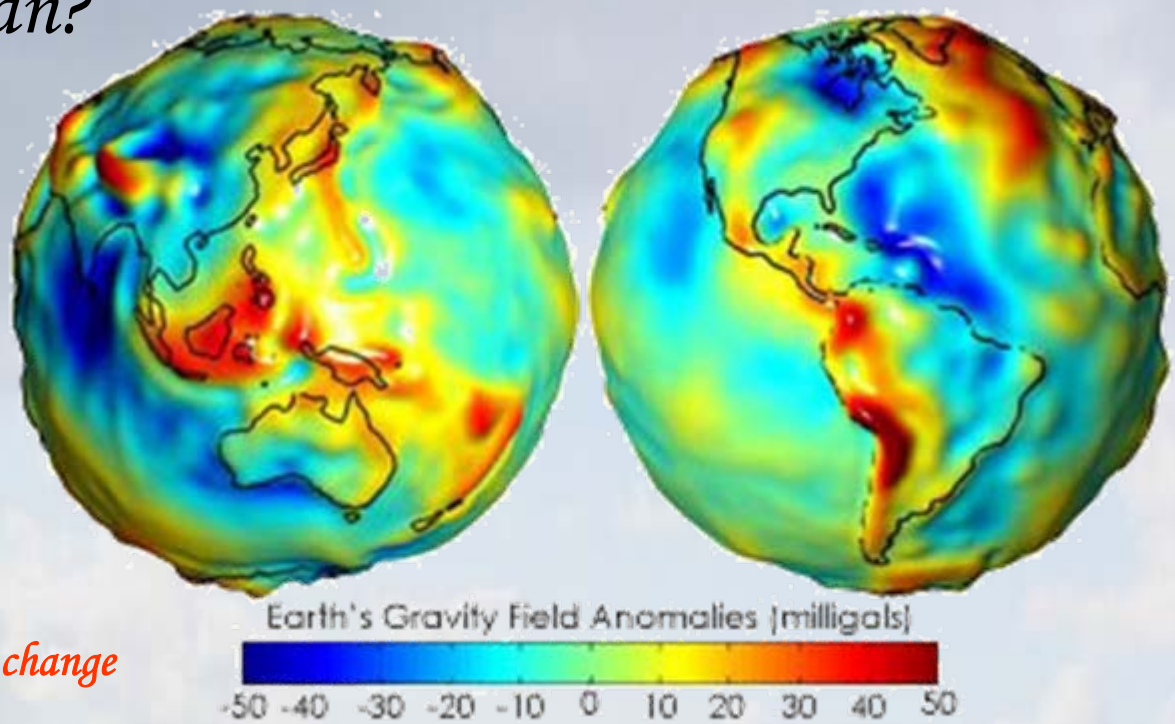
- *What does it mean?*

$g = 9.81\ m/s^2$

sphere/const. density

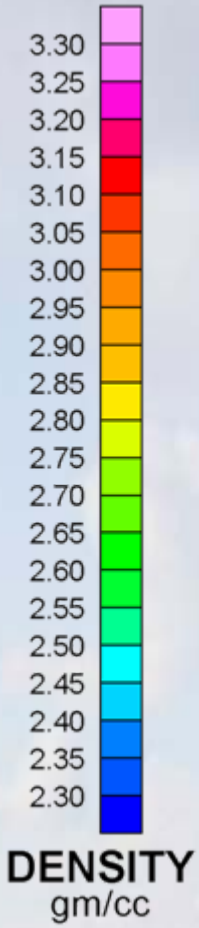
$1mGal = 10^{-5} m/s^2$

anomaly due to geometry/density change



3D gravity modelling

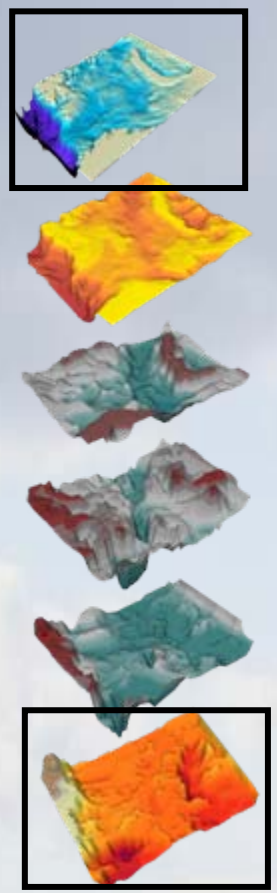
- Build 3D modell, change geometry, density
- Fit modelled gravity to observed gravity
- Use some constrains



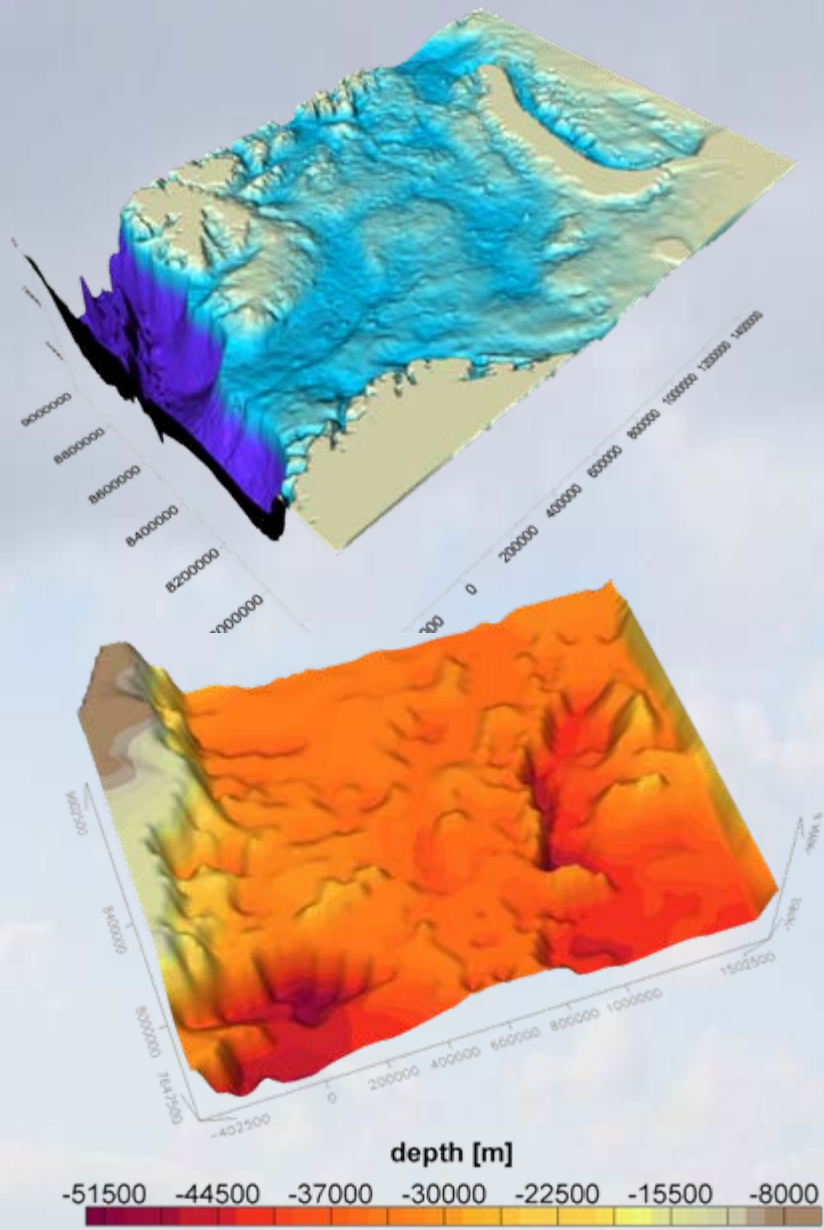
3D gravity modelling

- Small wave length: sediments
- Intermediate wave length: basement / lower crust
- Long wave length: Moho

- Topo



- Moho



But: long stretched sedimentary basins produce also long wave length!!

Next Motivation: Find Moho !

Moho

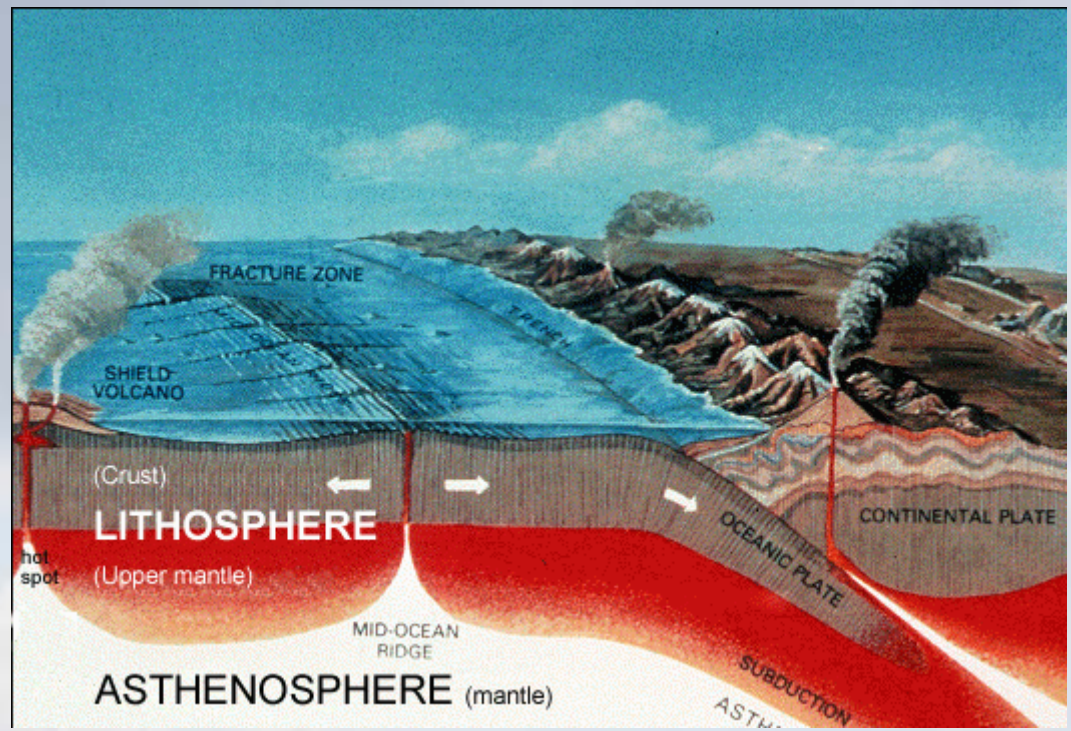
Andrija Mohorovičić

- *first detected 1909*

Seismic:

transition zone

p-wave velocity incr.



Boundary between Crust and Mantle,

which no one has ever seen …

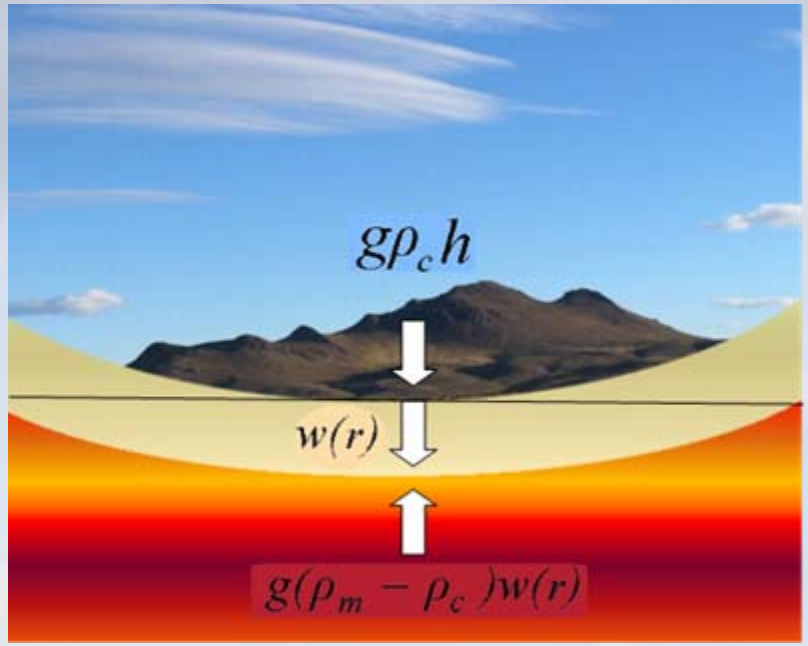
Moho

- *What does it mean?*

Seismic: transition zone p-wave velocity increase

Gravity: density contrast between 2.95 and 3.3

Isostasy: surface of equilibrium

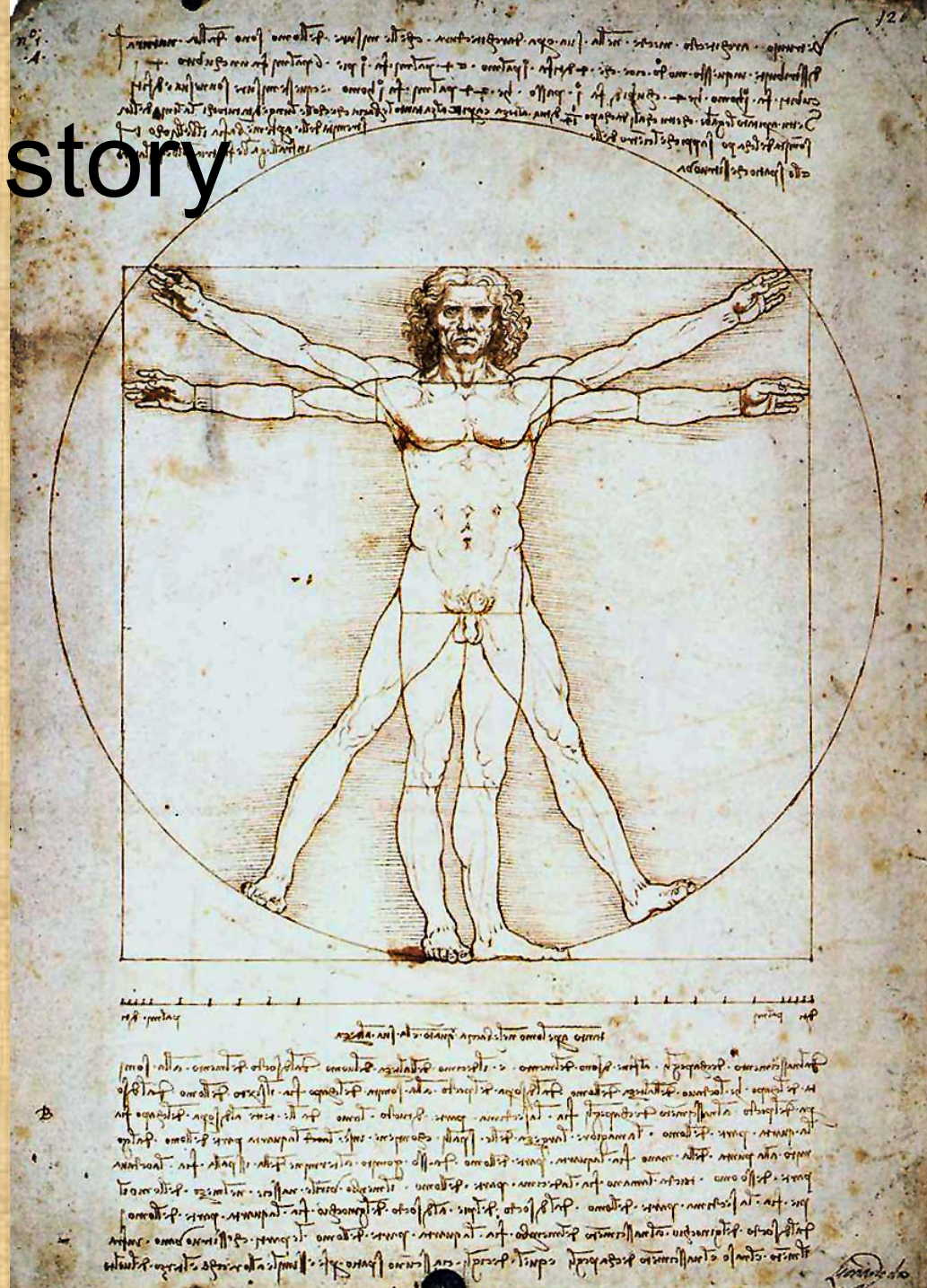


$\Rightarrow$ *use Gravity/Isostasy in areas of less seismic coverage*

Isostasy → back to history

History

Leonardo da Vinci (1452-1519)

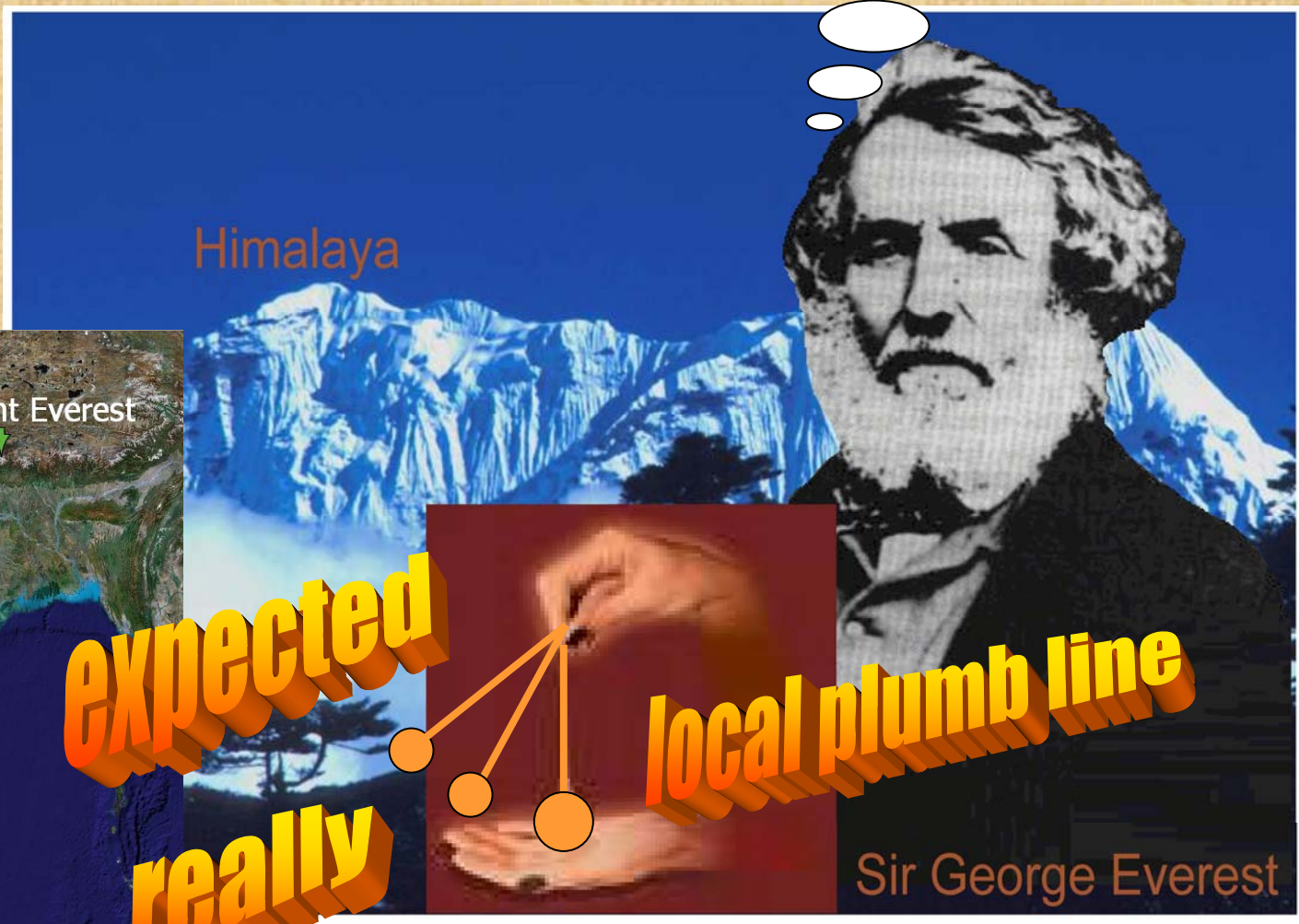


from 15 to the 19 century

land measurements India

Why 1/3 discrepancy?

Measurement of the meridian degree length India (1840-1859)



somewhere

mass deficit

expected

really

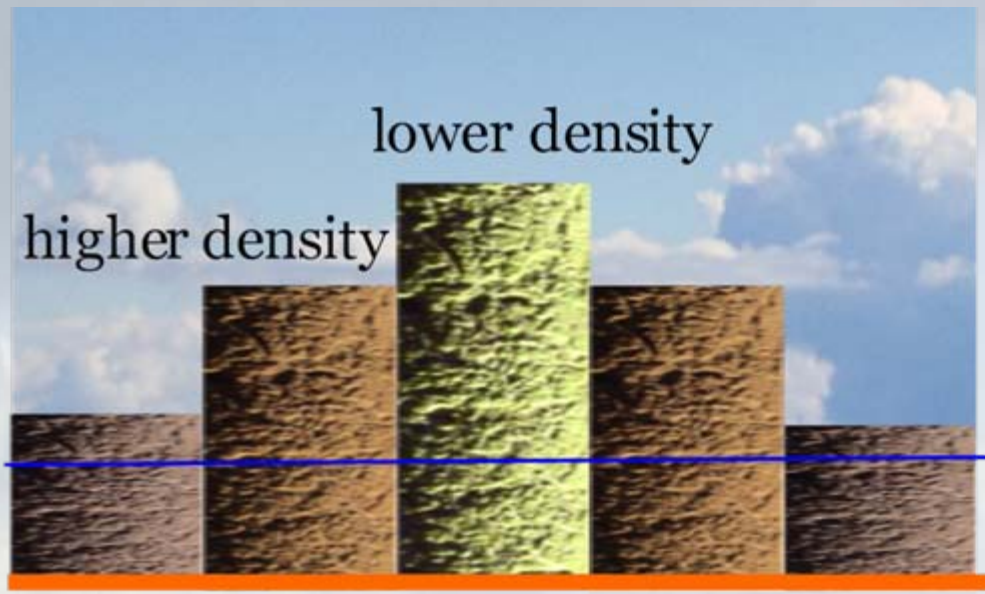
1 open question

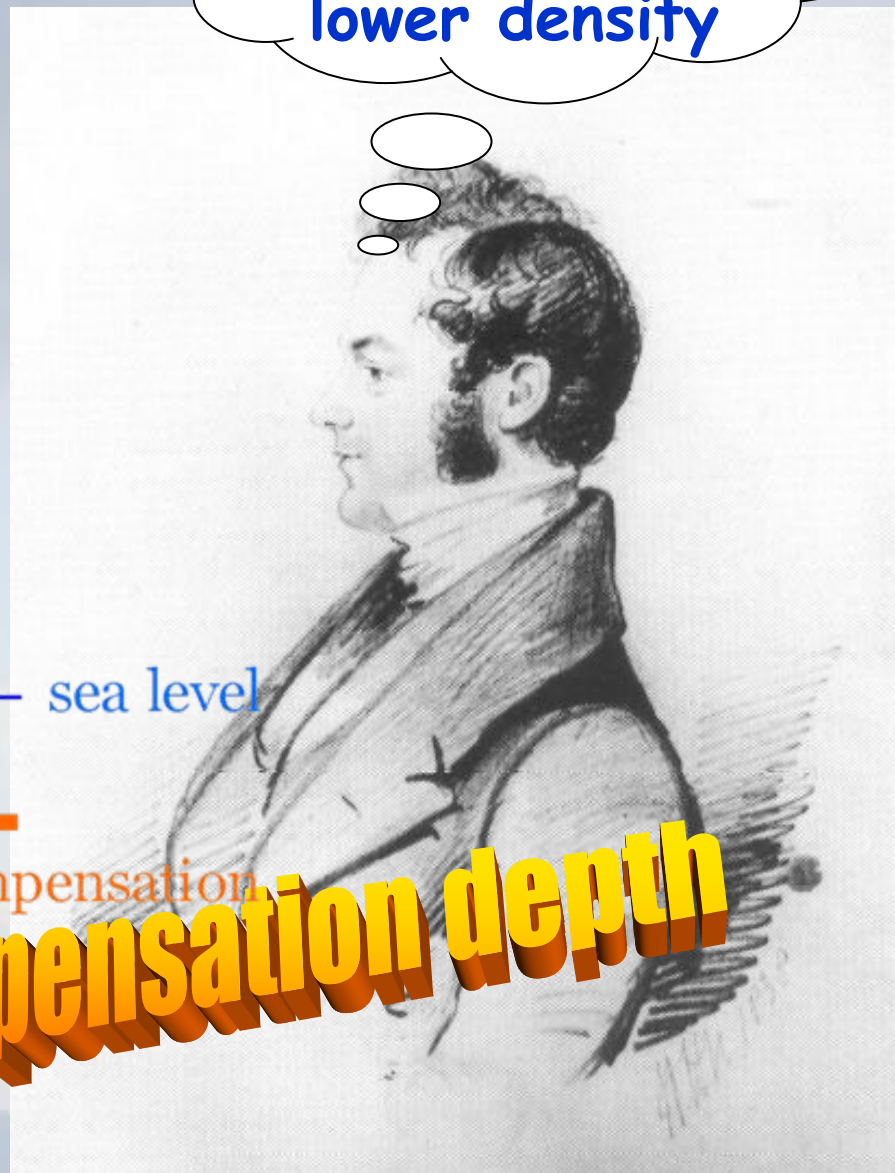
3 answers

History

John Henry Pratt
(1809-1871)

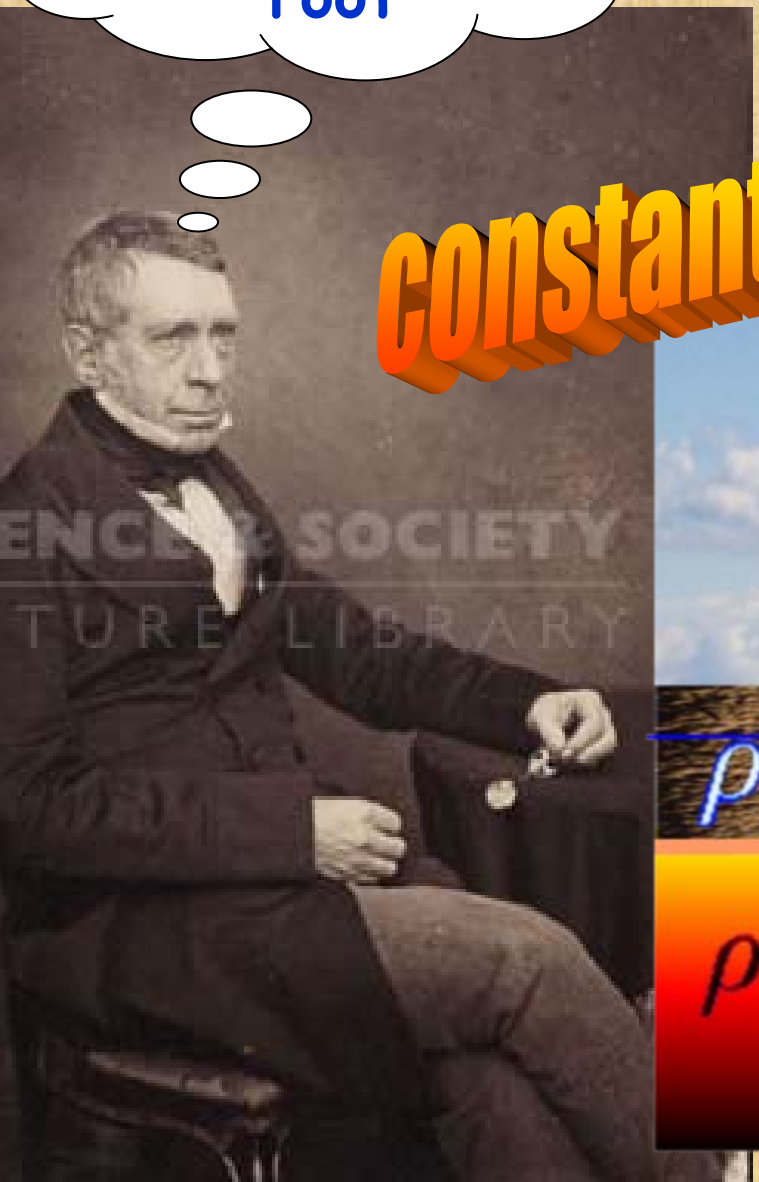
mass deficit because of lower density





constant compensation depth

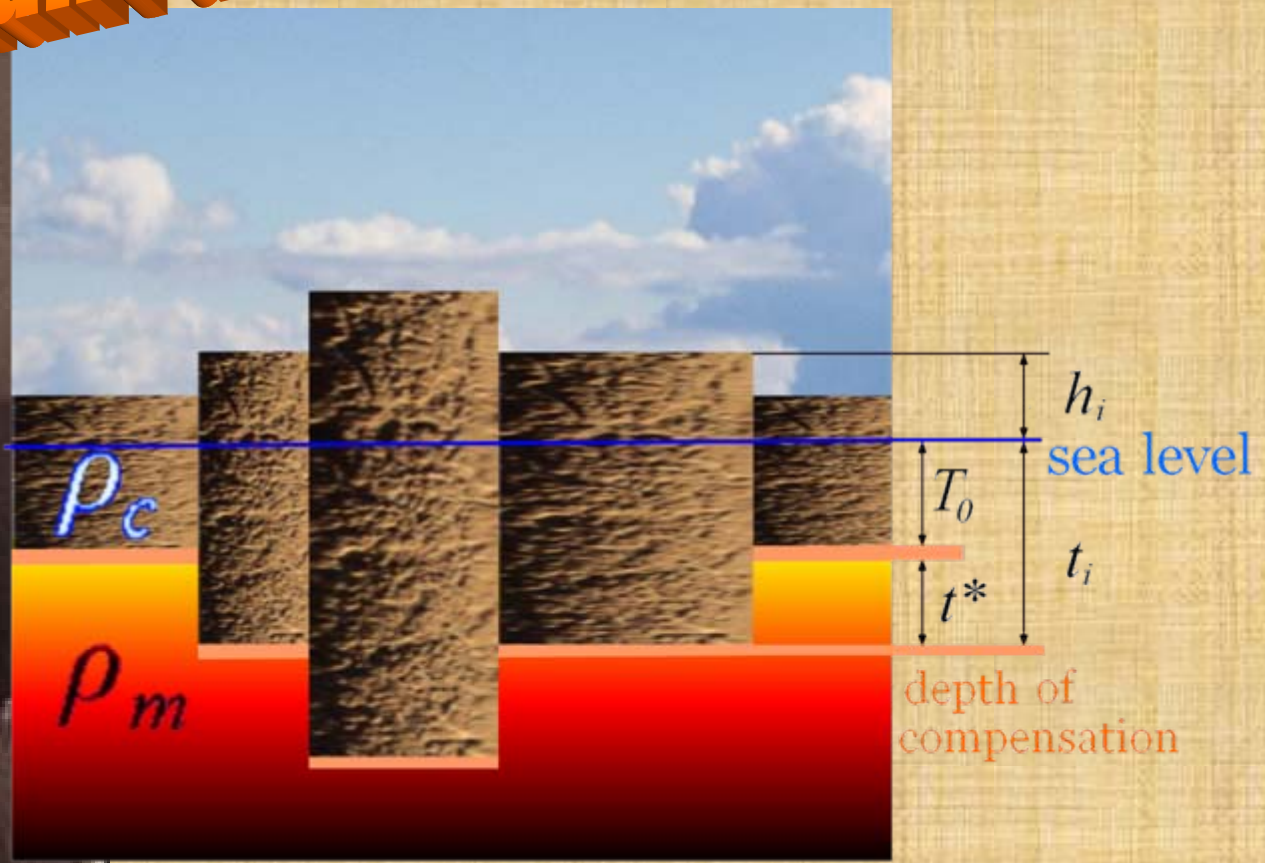
mass deficit because of root



Sir George Biddell Airy

(1801-1892)

constant density



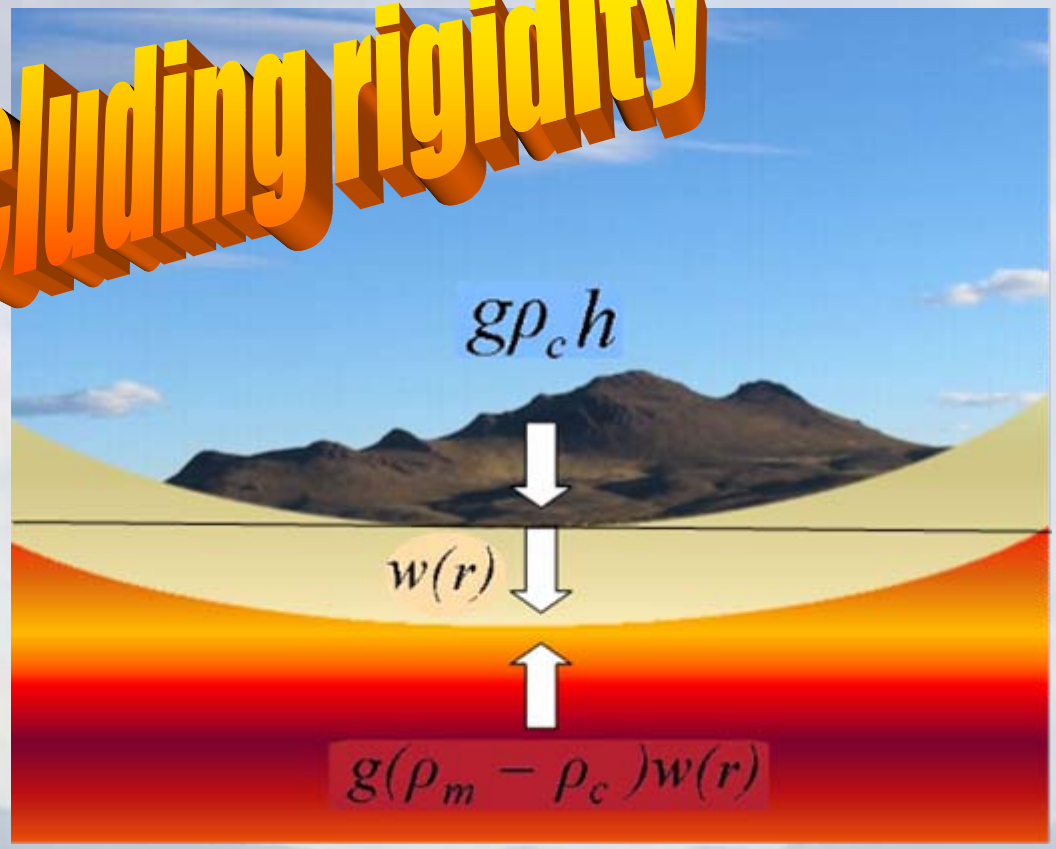
Vening

mass deficit because of root ... yes, but more regional

g-Meinesz

(1887-1966)

including rigidity



- *local compensation*

  Pratt and Airy model

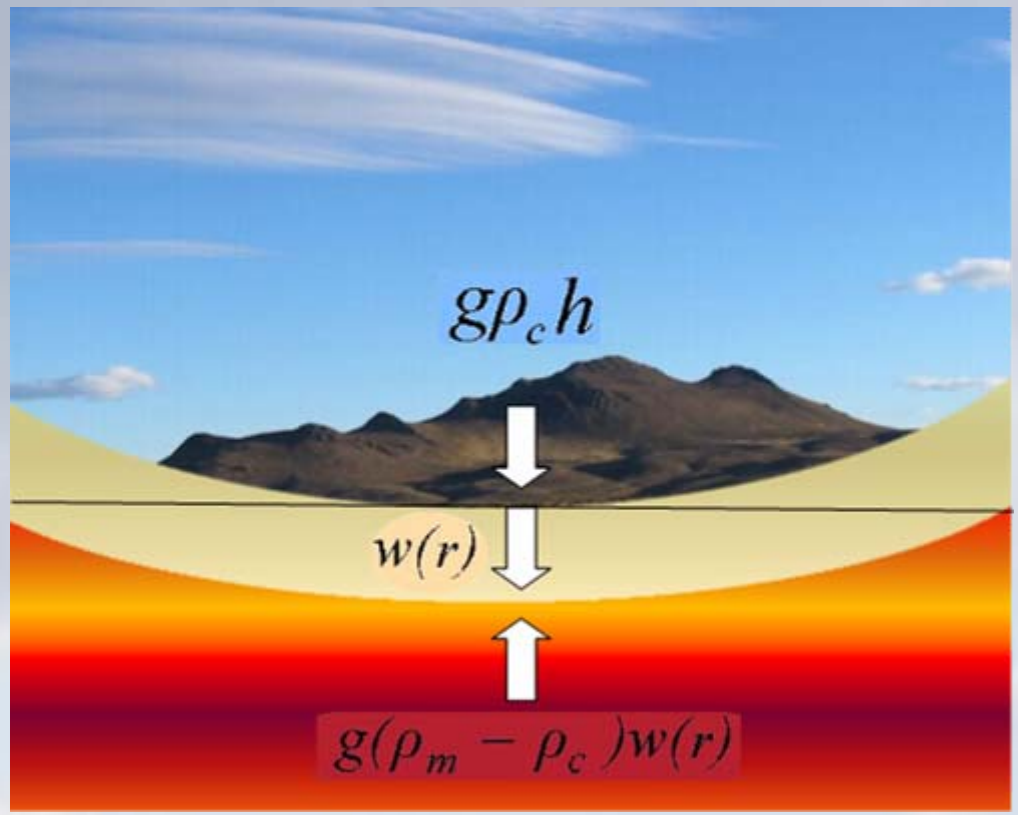
- *regional compensation*

  Vening-Meinesz model

Isostasy

- *What does it mean?*

iso stasis = equal standing

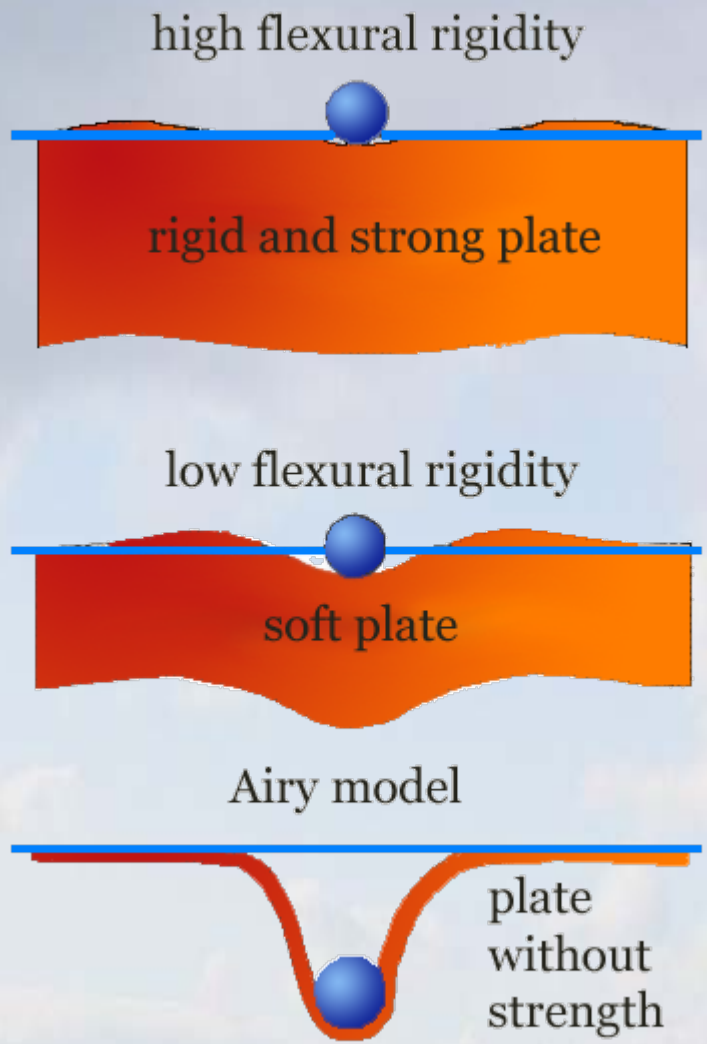


Vening-Meinesz isostasy

Flexural rigidity

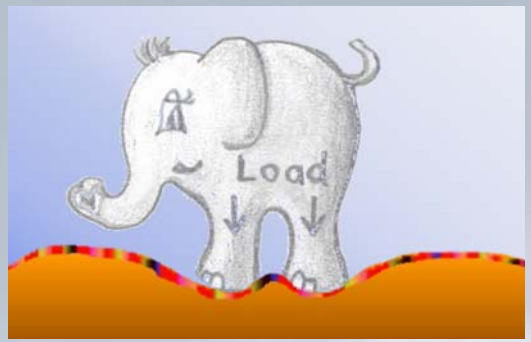
- *What does it mean?*

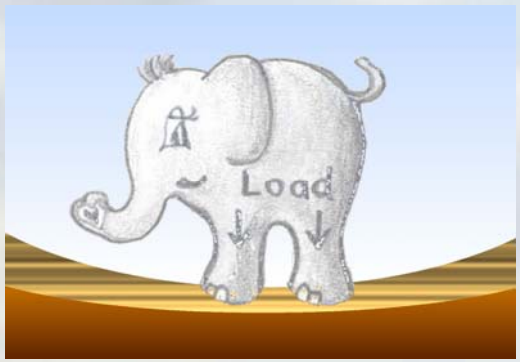
behaviour of a body against a deformation

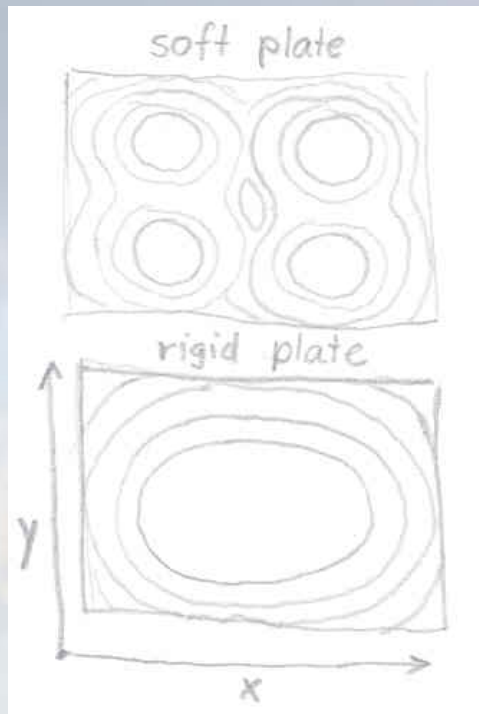


Flexural rigidity

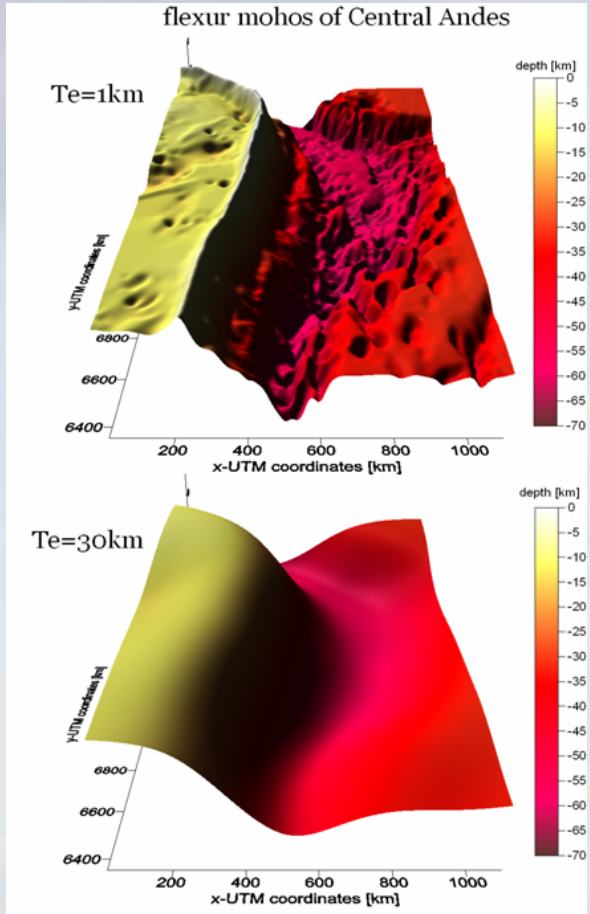
derrived from known load and moho





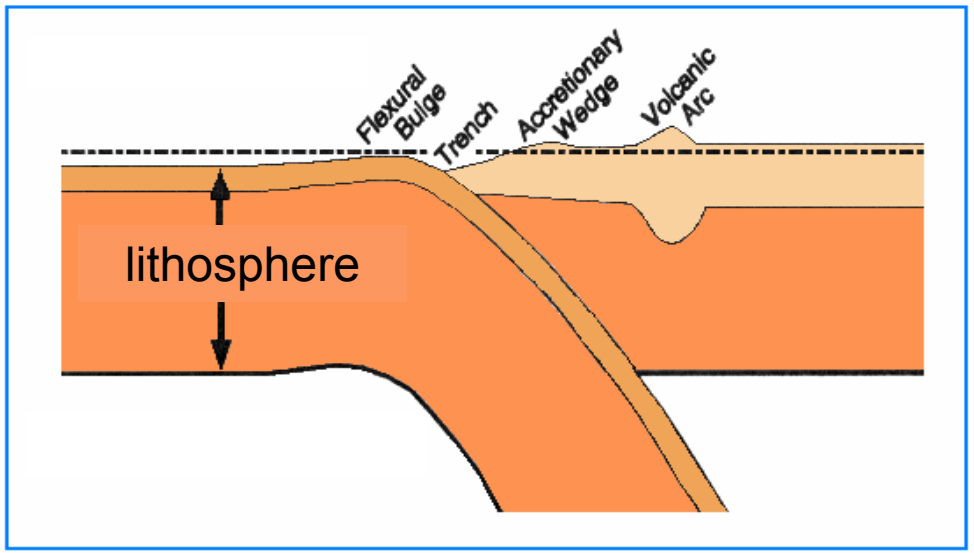


Look at pattern

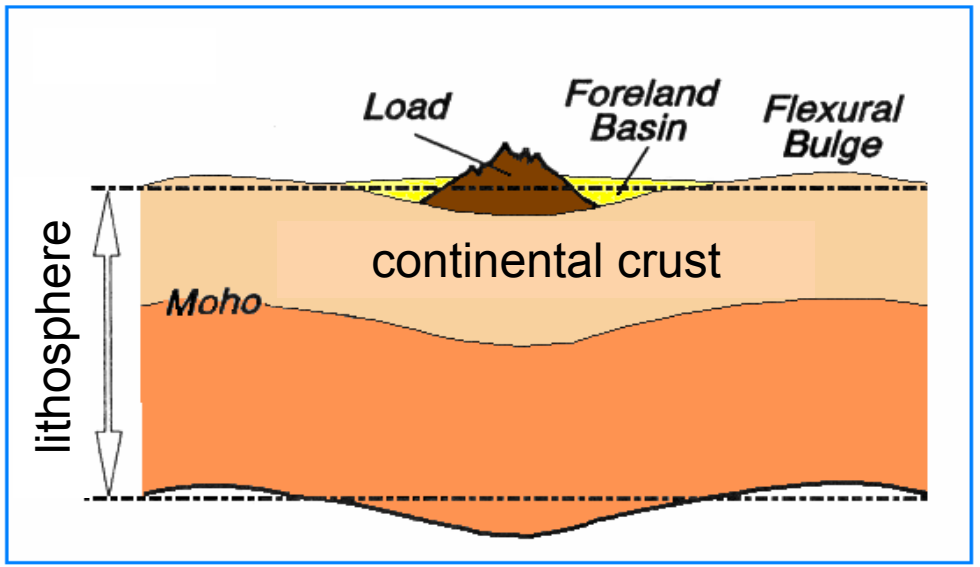


rigid ity

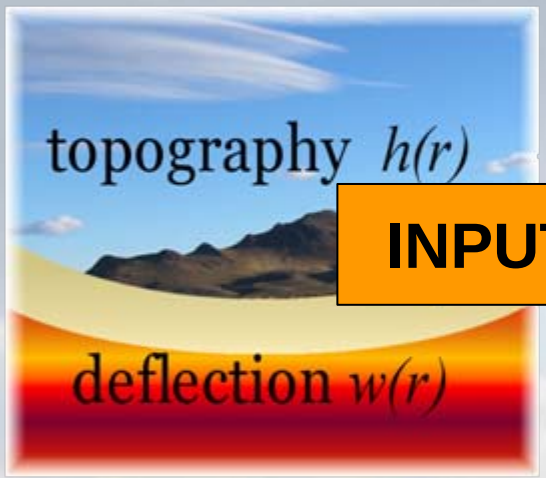
subduction zone



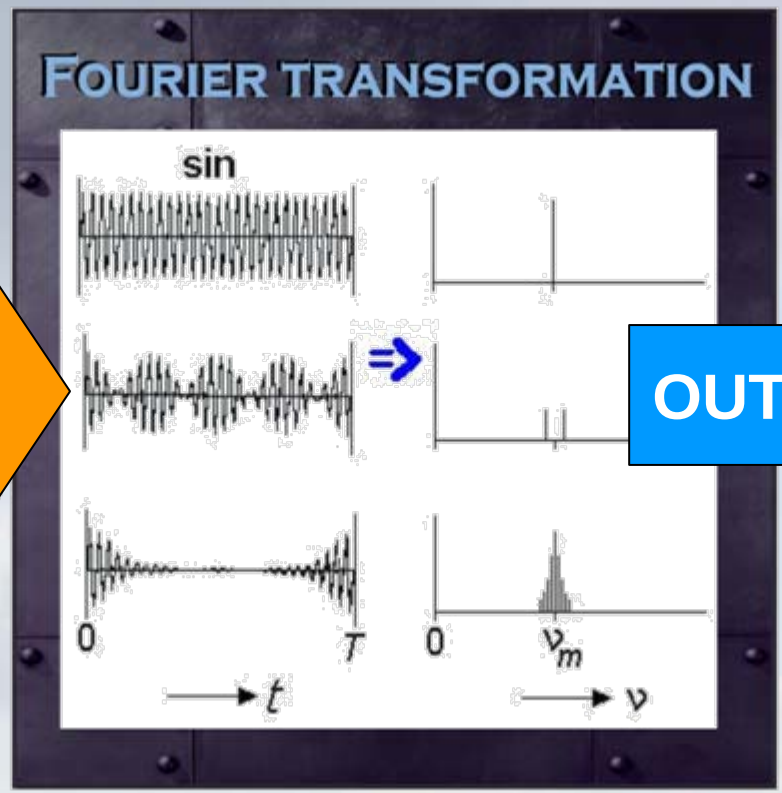
mountain



Spektral method



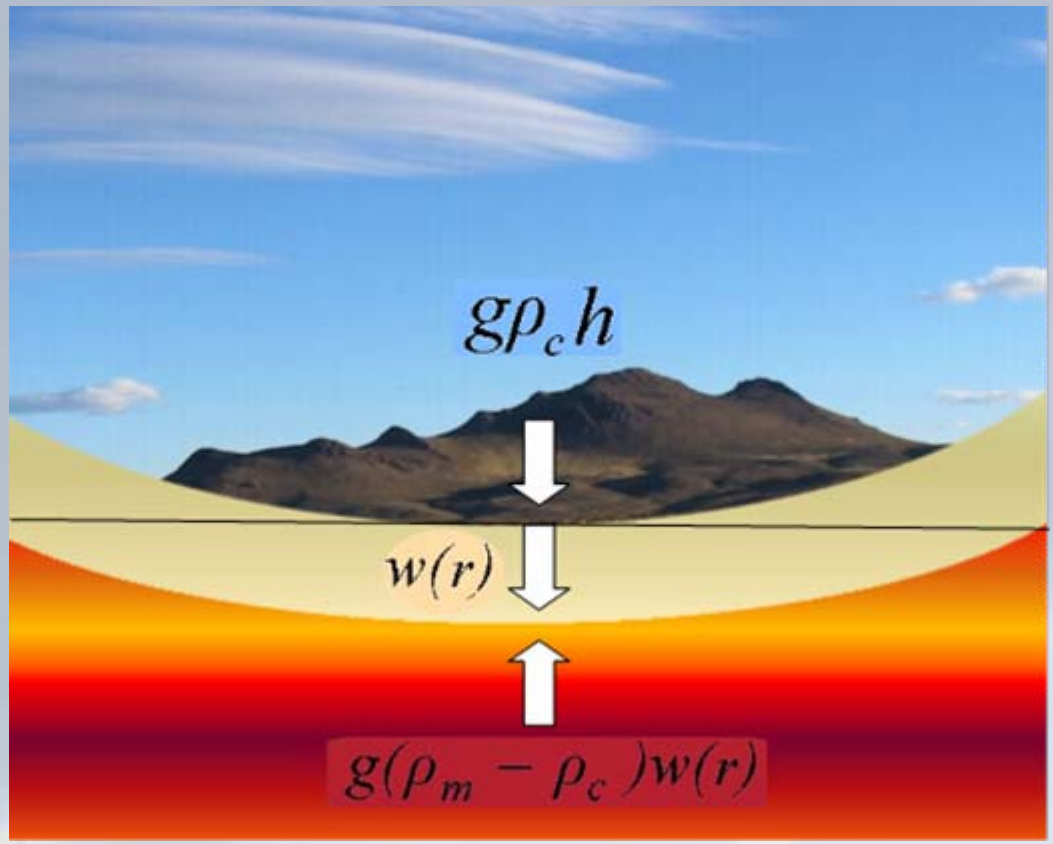
INPUT



OUTPUT

Fourier transform of topography
$FT[h(r)]=H(k)$

Fourier transform of deflection
$FT[w(r)]=W(k)$



$$w_0 = \frac{P}{8(\rho_m - \rho_k)g \cdot \beta^2}$$

$$w(x,y) = \frac{P}{2\pi\beta^2(\rho_m - \rho_c)g} \cdot \left\{ \begin{array}{l} \frac{(r_{x,y})^2}{2^2} \cdot \ln(r_{x,y}) - \frac{(r_{x,y})^6}{2^2 \cdot 4^2 \cdot 6^2} \cdot \left(\ln(r_{x,y}) - \frac{5}{6} \right) + \ldots \\ + \frac{\pi}{4} \left(1 - \frac{(r_{x,y})^4}{2^2 \cdot 4^2} + \frac{(r_{x,y})^8}{2^2 \cdot 4^2 \cdot 6^2 \cdot 8^2} - \ldots \right) \\ \ldots - 1.1159 \cdot \left(\frac{(r_{x,y})^2}{2^2} - \frac{(r_{x,y})^6}{2^2 \cdot 4^2 \cdot 6^2} + \ldots \right) \end{array} \right\}$$

$$w(x,y) = \frac{P}{2\pi\beta^2(\rho_m - \rho_c)g} \sqrt{\frac{\pi}{2}} \frac{e^{-(r_{x,y})\sqrt{\frac{1}{2}}}}{\sqrt{(r_{x,y})}} \left\{ \sin\left((r_{x,y})\sqrt{\frac{1}{2}} + \frac{\pi}{8} \right) - \frac{1}{8(r_{x,y})} \sin\left((r_{x,y})\sqrt{\frac{1}{2}} + \frac{3\pi}{8} \right) + \ldots \right\}$$

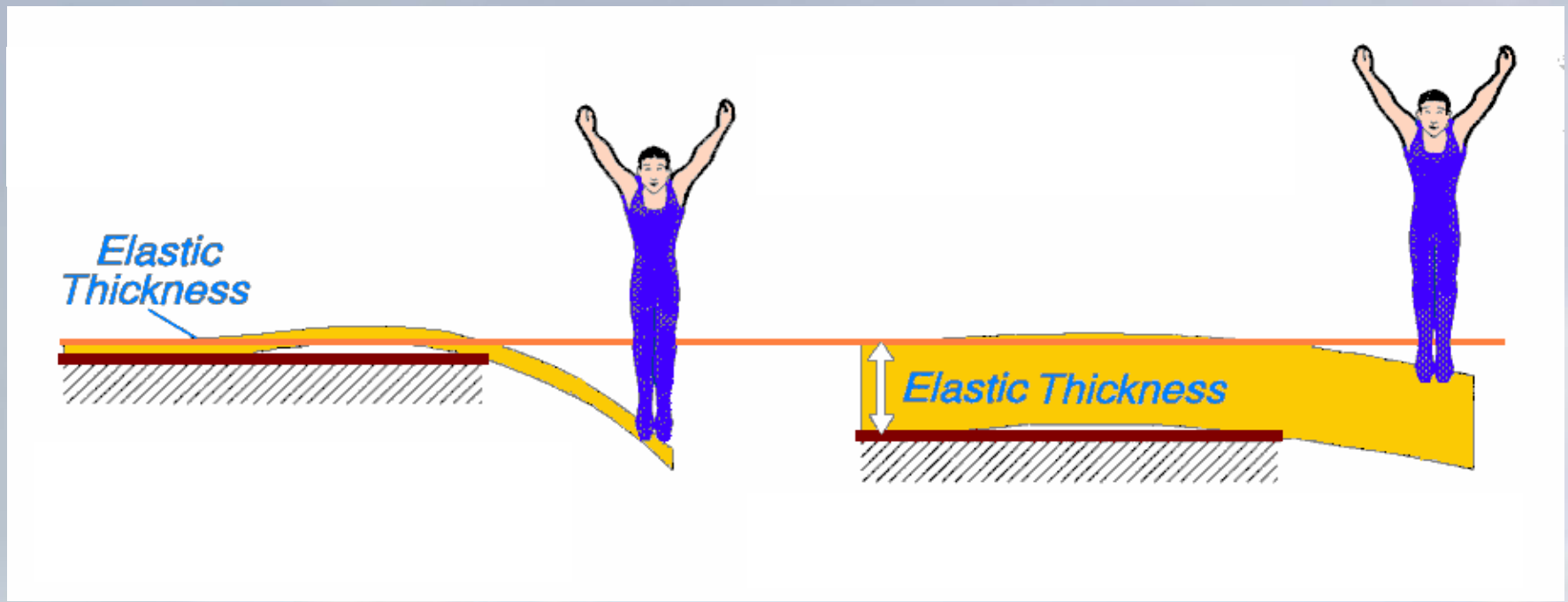
Newton: Actio = Reactio

w = deflection , q_a = load, ρ_c / ρ_m = density of crust / mantle

D synonym used to Te

$$\Delta\left[D\Delta w(\vec{r})\right] + g(\rho_m - \rho_c)w(\vec{r}) = g\rho_c h(\vec{r})$$

Wienecke 2006, Wienecke et al. 2007



The thicker the plate, the higher the elastic thickness

The higher the elastic thickness (cubic!), the higher the flexural rigidity:

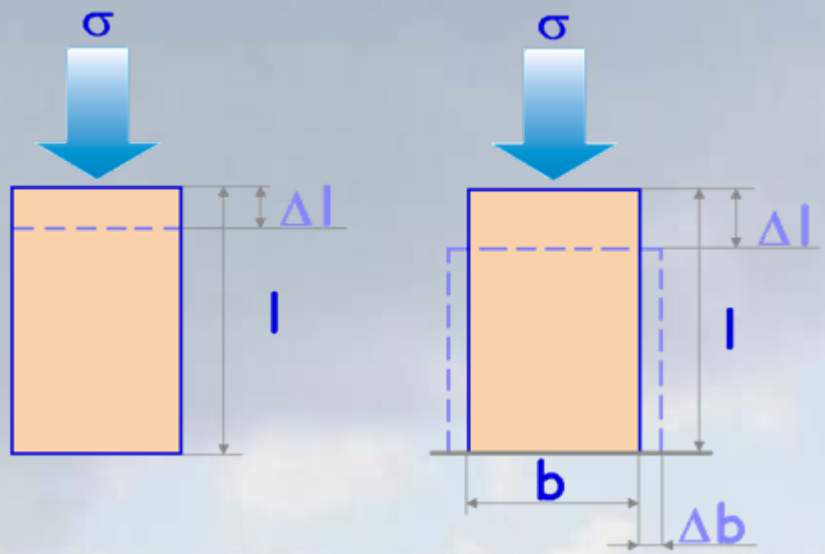
Flexural rigidity = D

Elastic Thickness = T_e

$$D \propto T_e^3$$

$D = ? \cdot T_e^3$

Flex. rigidity & elast. thickness



$$D = ? \cdot T_e^3$$

E = Young's Modulus

ν = Poisson's Ratio

$$\frac{\Delta l}{l} = \frac{1}{E} \cdot \sigma \qquad \frac{\Delta b}{b} = -\nu \cdot \frac{\Delta l}{l}$$

$$D = \frac{E}{12(1-\nu^2)} \cdot T_e^3$$

Since E /ν taken as constant, D is used synonymously to Te

Convolution radius

$$R = 4\sqrt[4]{\frac{ET_e^3}{12(1-\nu^2)} \cdot \frac{1}{(\rho_m - \rho_c)g}}$$

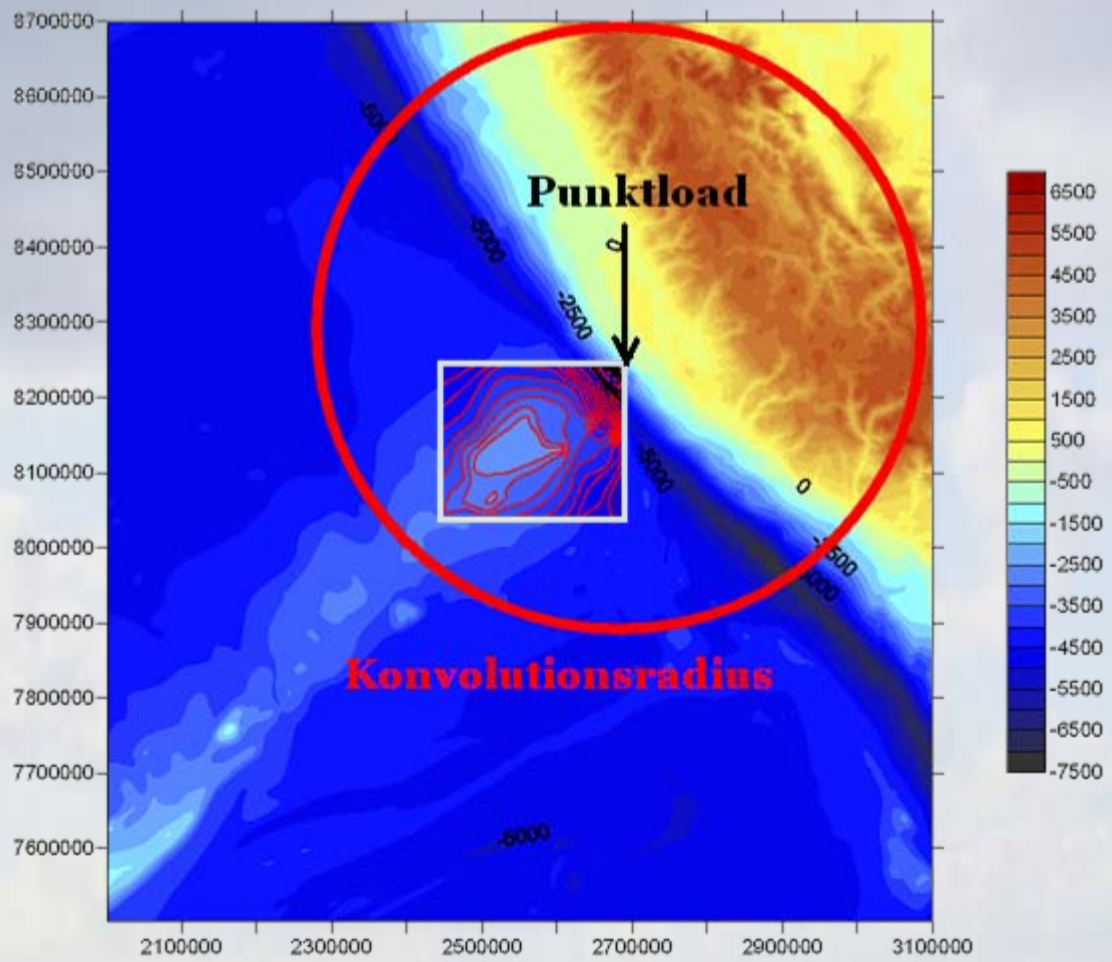
for T_e = 40km

radius is ca. 350 km

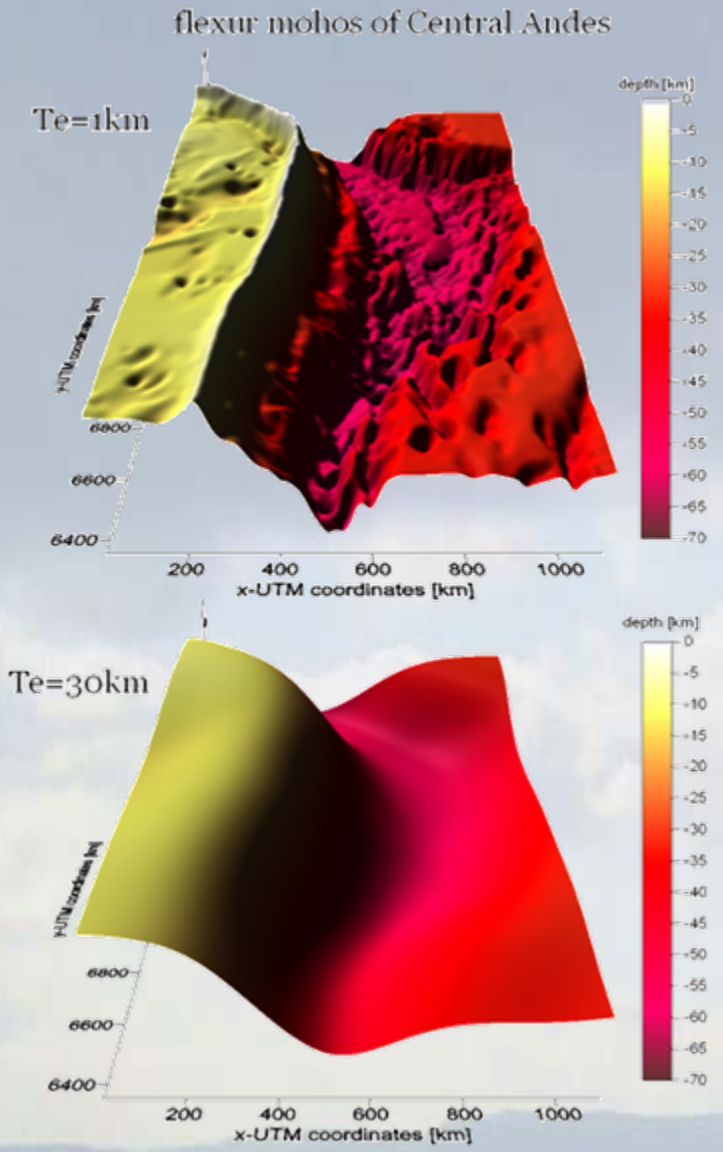
(depend on density contrast)

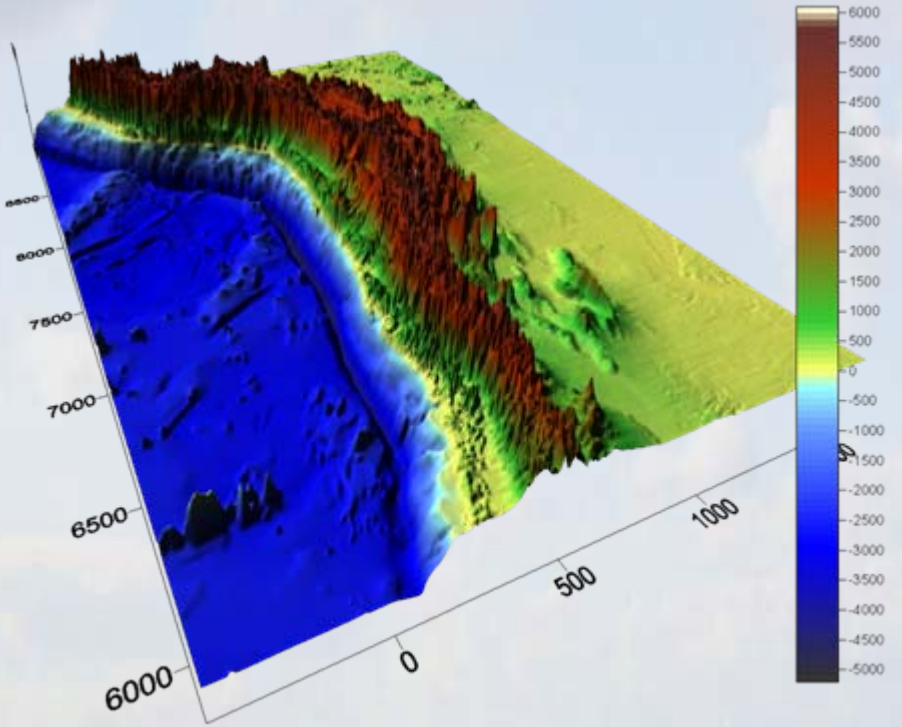
⇒ Area of topography should be greater

⇒ Cut off to avoid edge effects



Central Andes

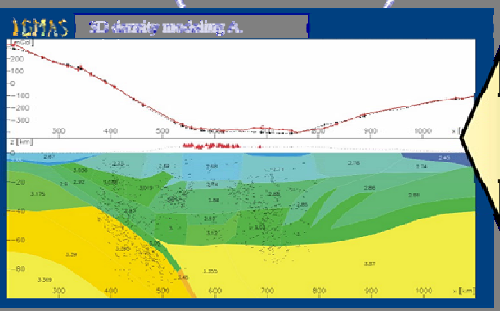




observed gravity

(Götze & Schmidt 1998)

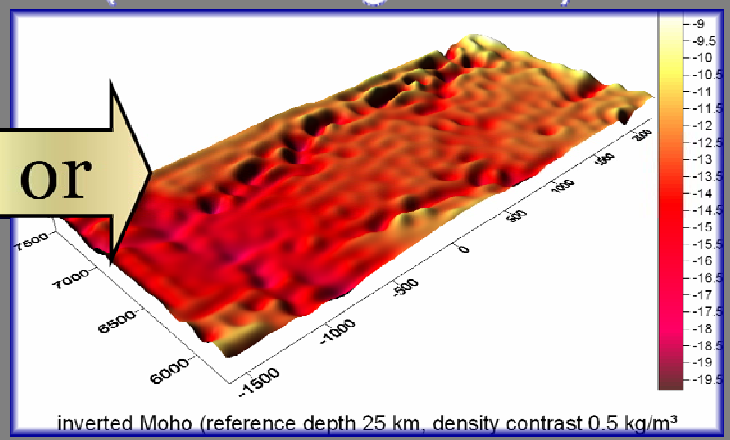
3D density modeling (IGMAS)



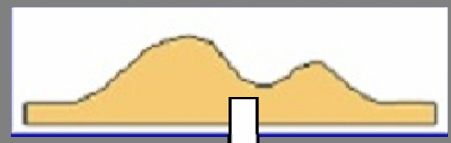
or

(Parker 1972)

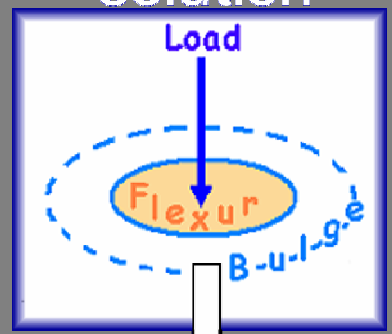
gravity inversion (Parker algorithm)



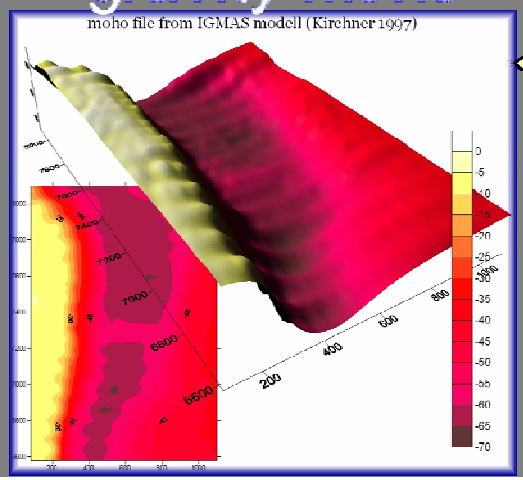
topography (DEM)



calculation analytical solution



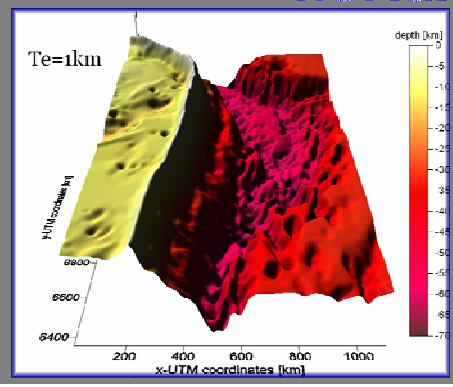
gravity moho

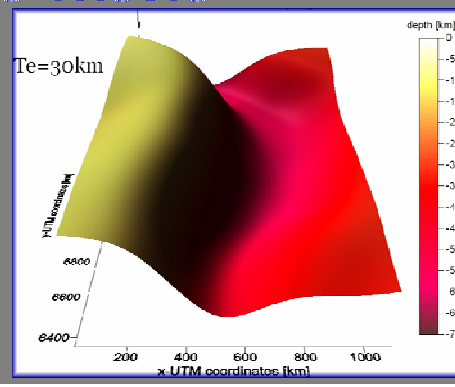


comparision

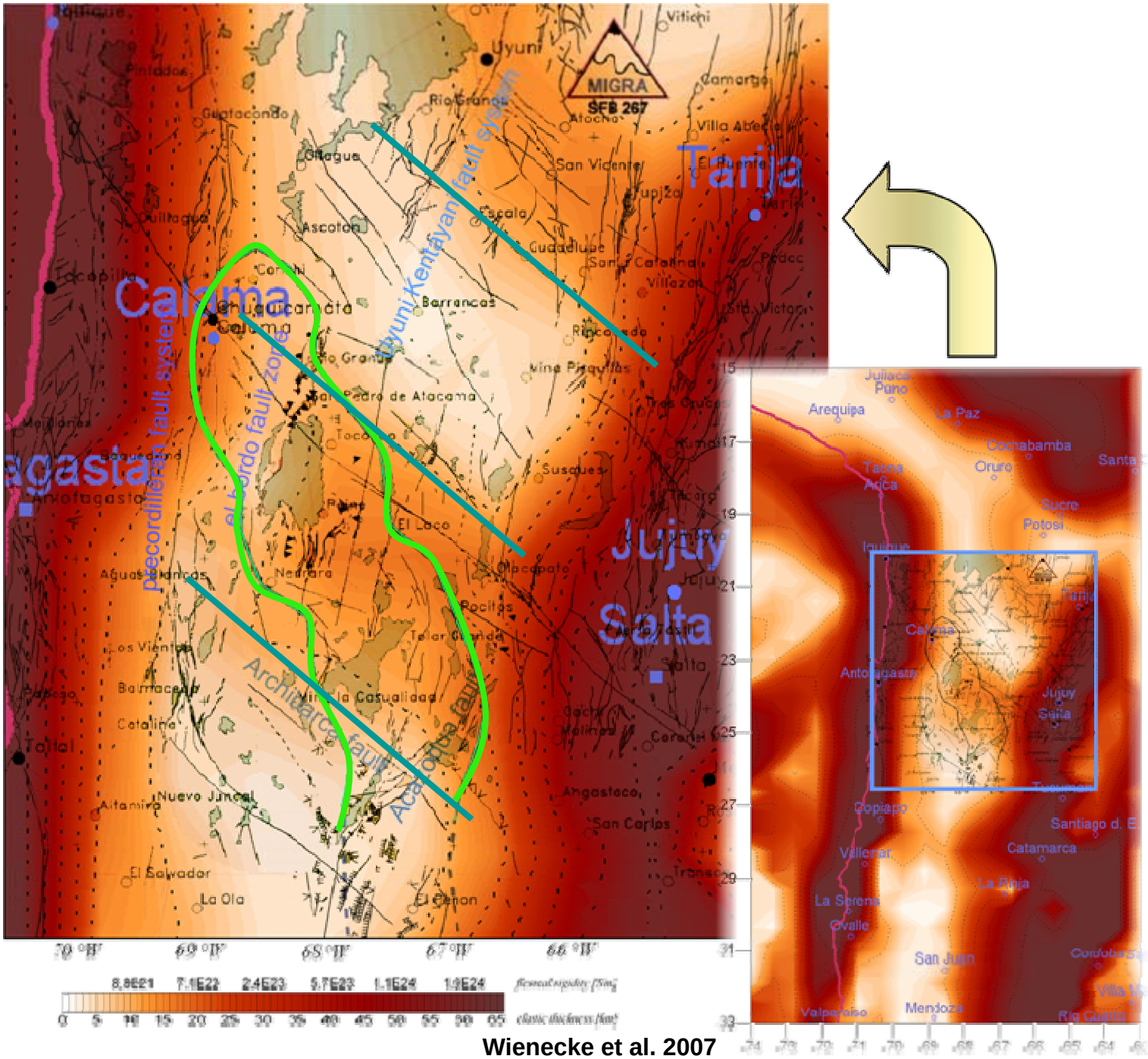
D

for each D corresponding flexure moho





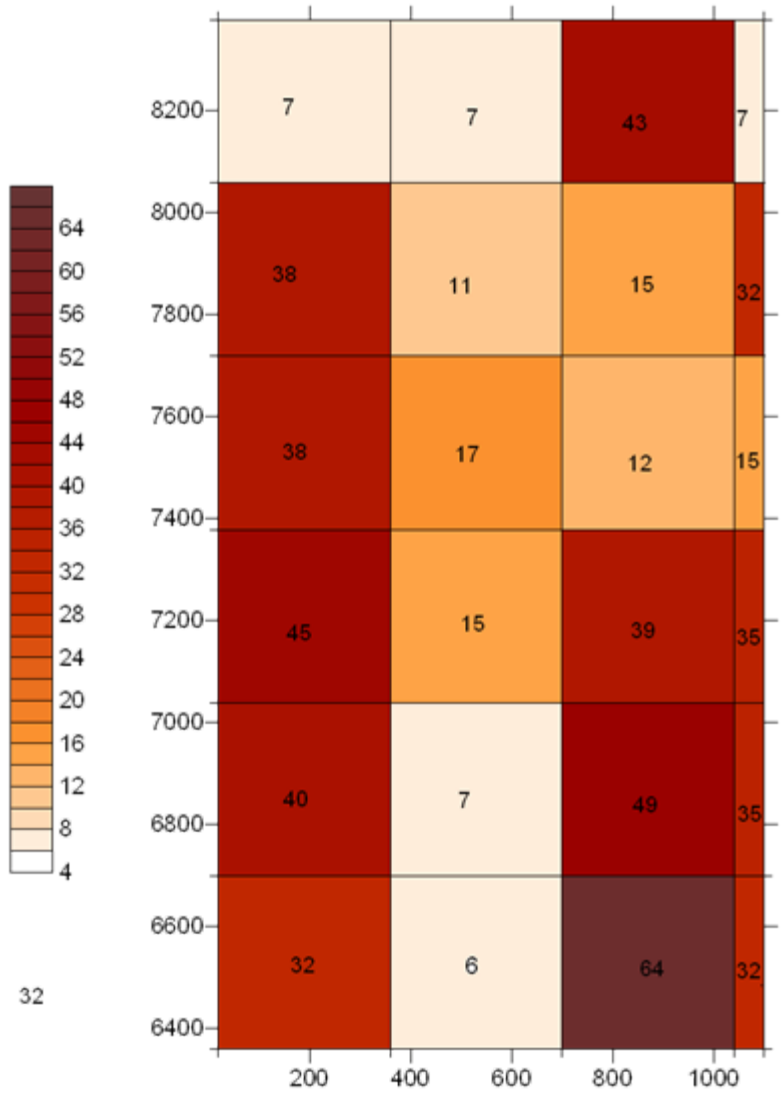
Convolution method = Braitenberg et al. 2006

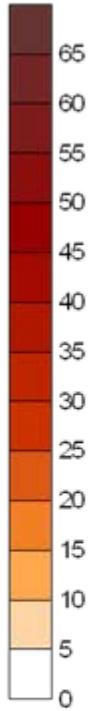


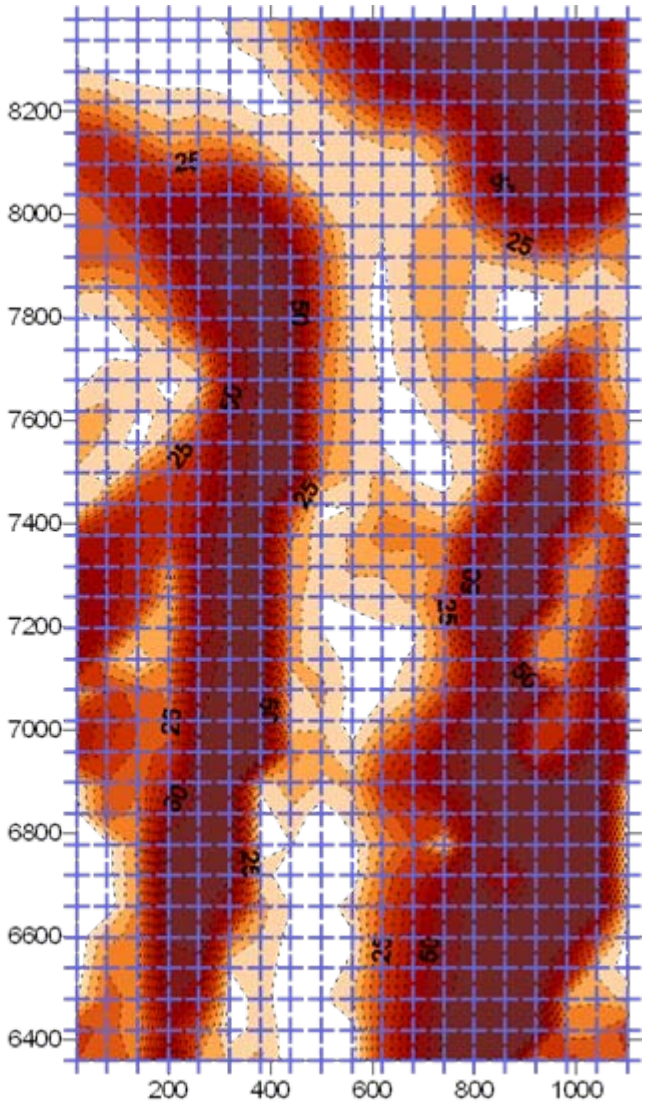
weak parts of crust→ white, light brown colors **rigid** → dark brown colors

Overlay of faults and tectonic elements: SFB267 community, e.g. Götze & Krause 2002

Advantage: with old method, a correlation with fault structures would be not visible at all !







Isostasy and flexural rigidity, for what is it good for?

Benefit => Deliveries

⇒Validate different geological concepts

⇒Derive first order information about tectonic structures

Thanx for your attention