Vertical Movements

Geology 1

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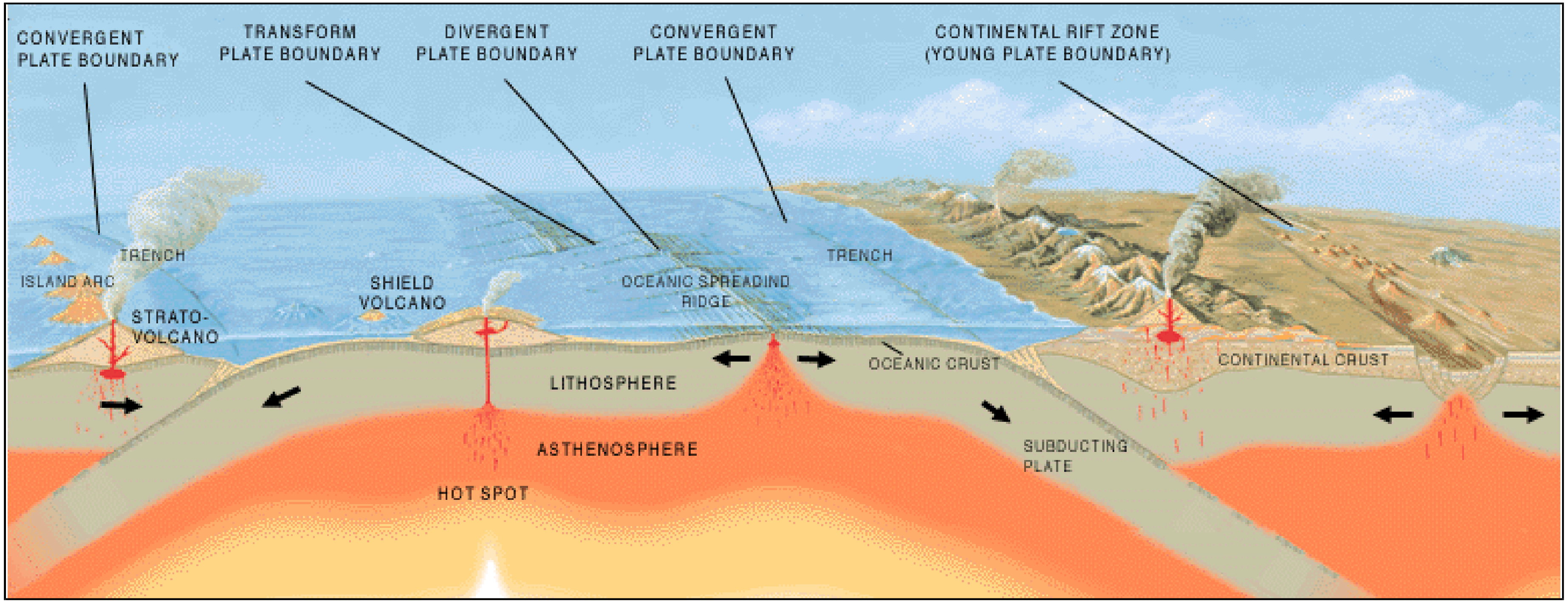
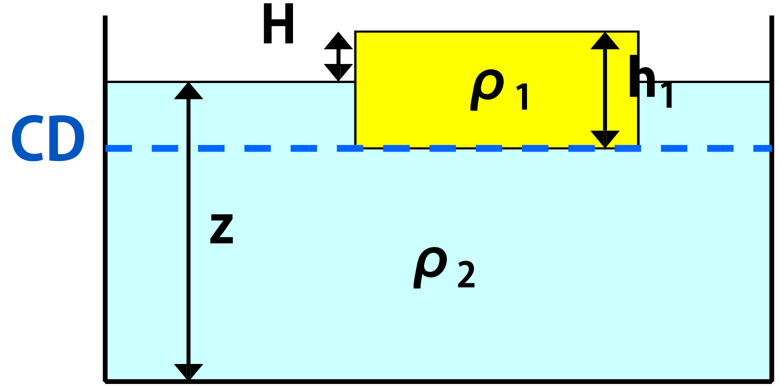
Lateral deformations can change the thickness of the lithospheric column.
This has major implications vertical movements (subsidence and uplift) of the Earth's surface leading to sedimentary basins and mountains



Isostasy:

linking weight to topography

Linking weight changes to vertical movements



Isostasy is Archimedes' law:
The weight of the floating body must be equal to that of the displaced body

$$\rho_1 g h_1 = \rho_2 g (h_1 - H)$$

$$H = h_1 - \frac{\rho_1 h_1}{\rho_2}$$

An equivalent expression: the weight of the column above a compensation depth must be the same CD=the depth under which ..nothing happens

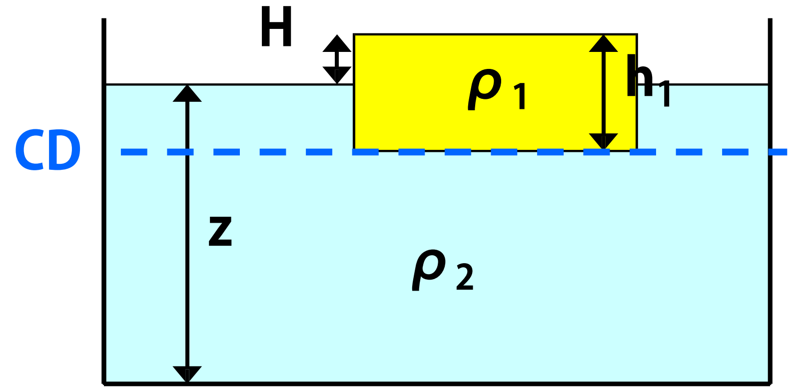
$$(h_1 - H)\rho_2 = \rho_1 h_1$$

$$H = \frac{h_1(\rho_2 - \rho_1)}{\rho_2}$$

H is the topography, the number we are interested in

Lateral changes in topography

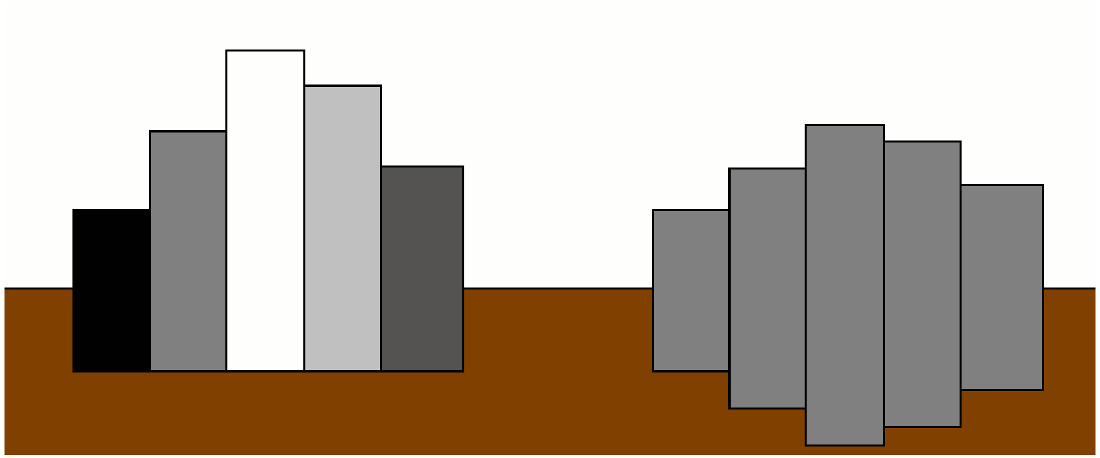
controlled by changes in the weight of the column overlying the CD



$$H = \frac{h_1(\rho_2 - \rho_1)}{\rho_2}$$

The lower the density of the column, the higher the mountains

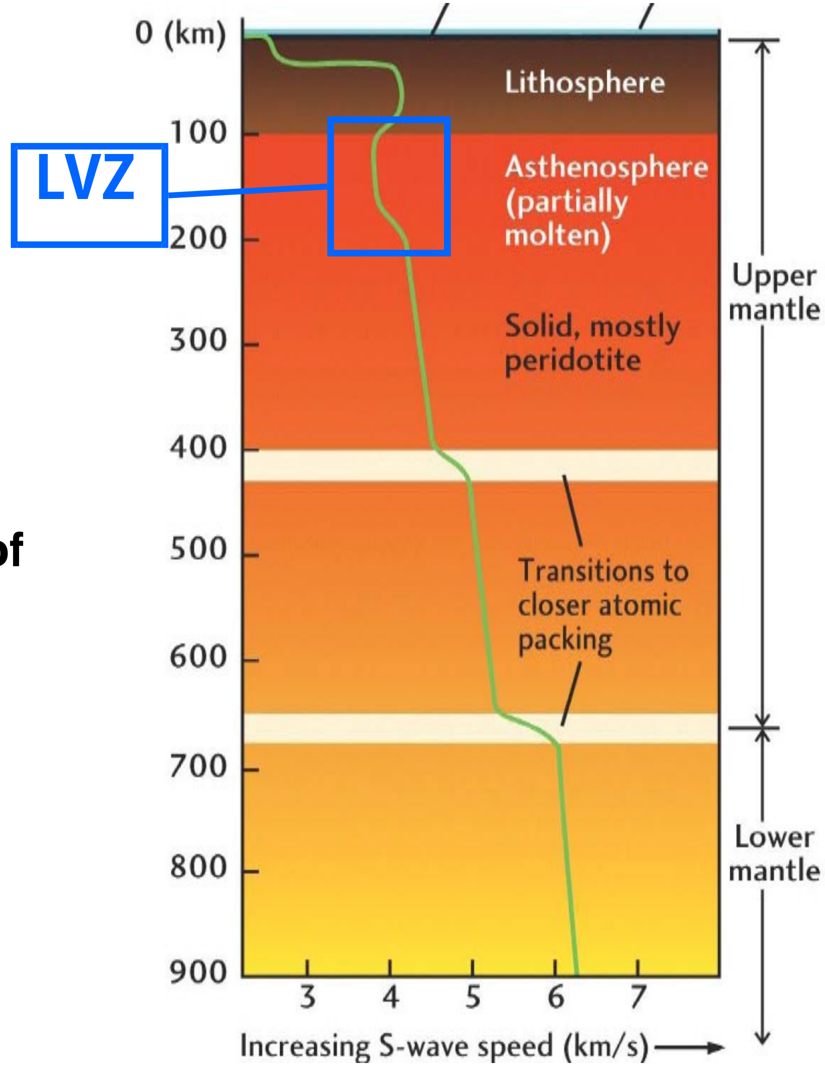
The higher the thickness of the column, the higher will be the topography



One can change densities (left), thicknesses (right) or both

http://www.geo.cornell.edu/hawaii/220/PRI/isostasy.html

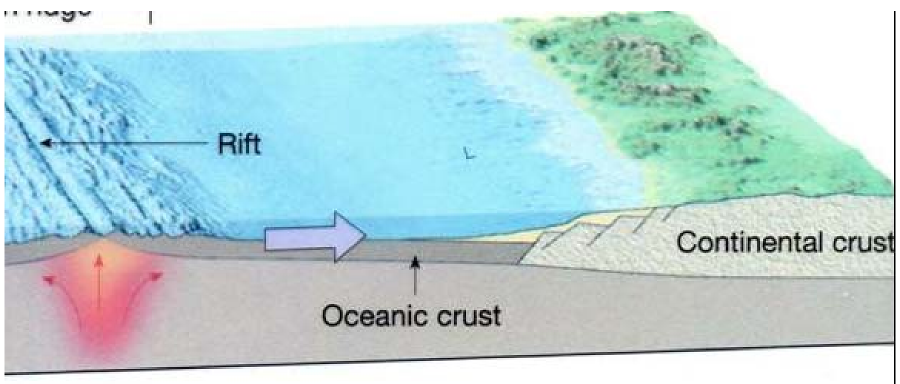
What about the Earth:
Where is the compensation level?
which is the floating block?



The best candidate for the compensation level is the LVZ with the lithosphere as floating block

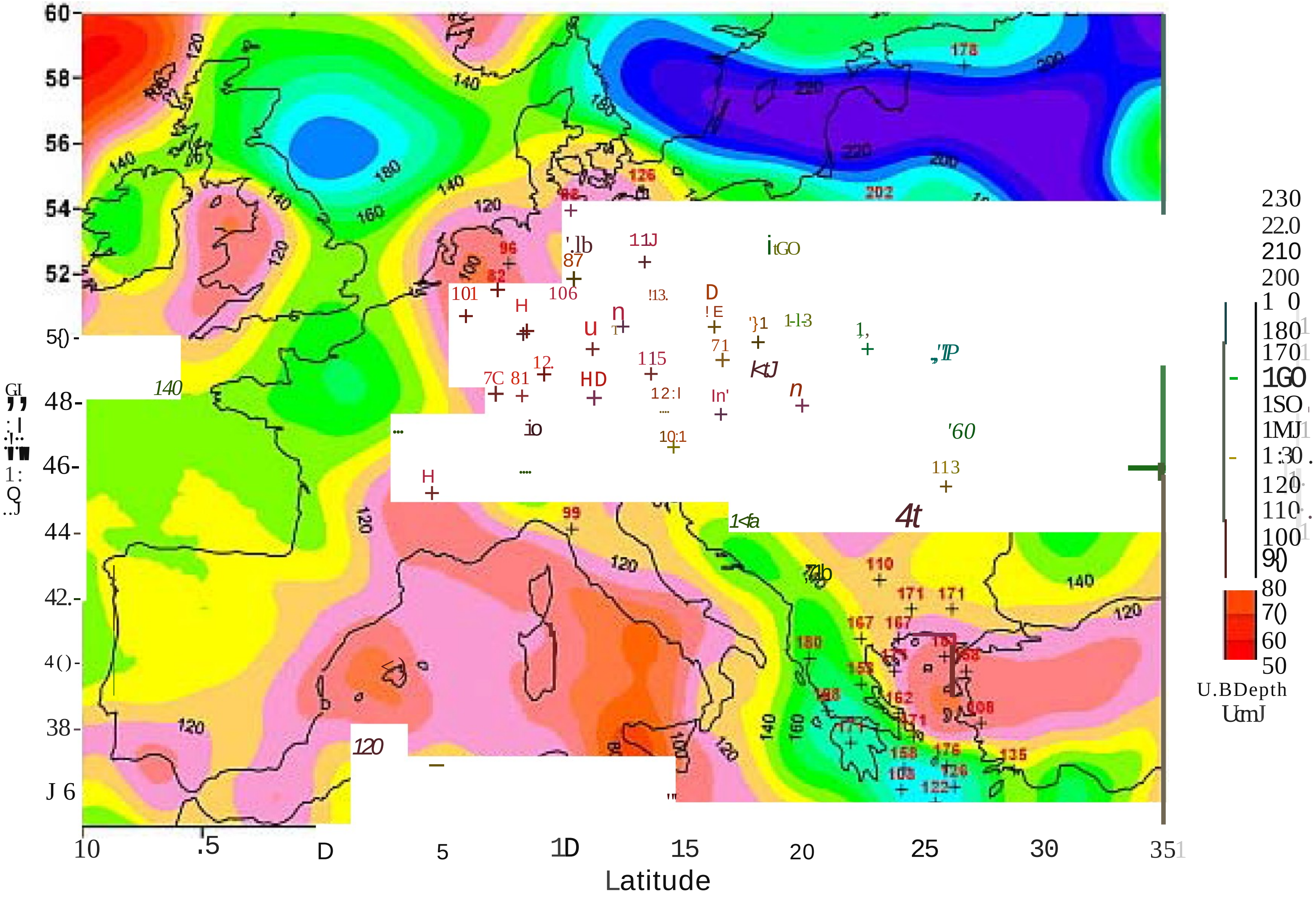
If (and this seems to be true) it floats, the density of the lithosphere must be less than that of the asthenosphere

$$\rho_{lith} < \rho_{asth.}$$

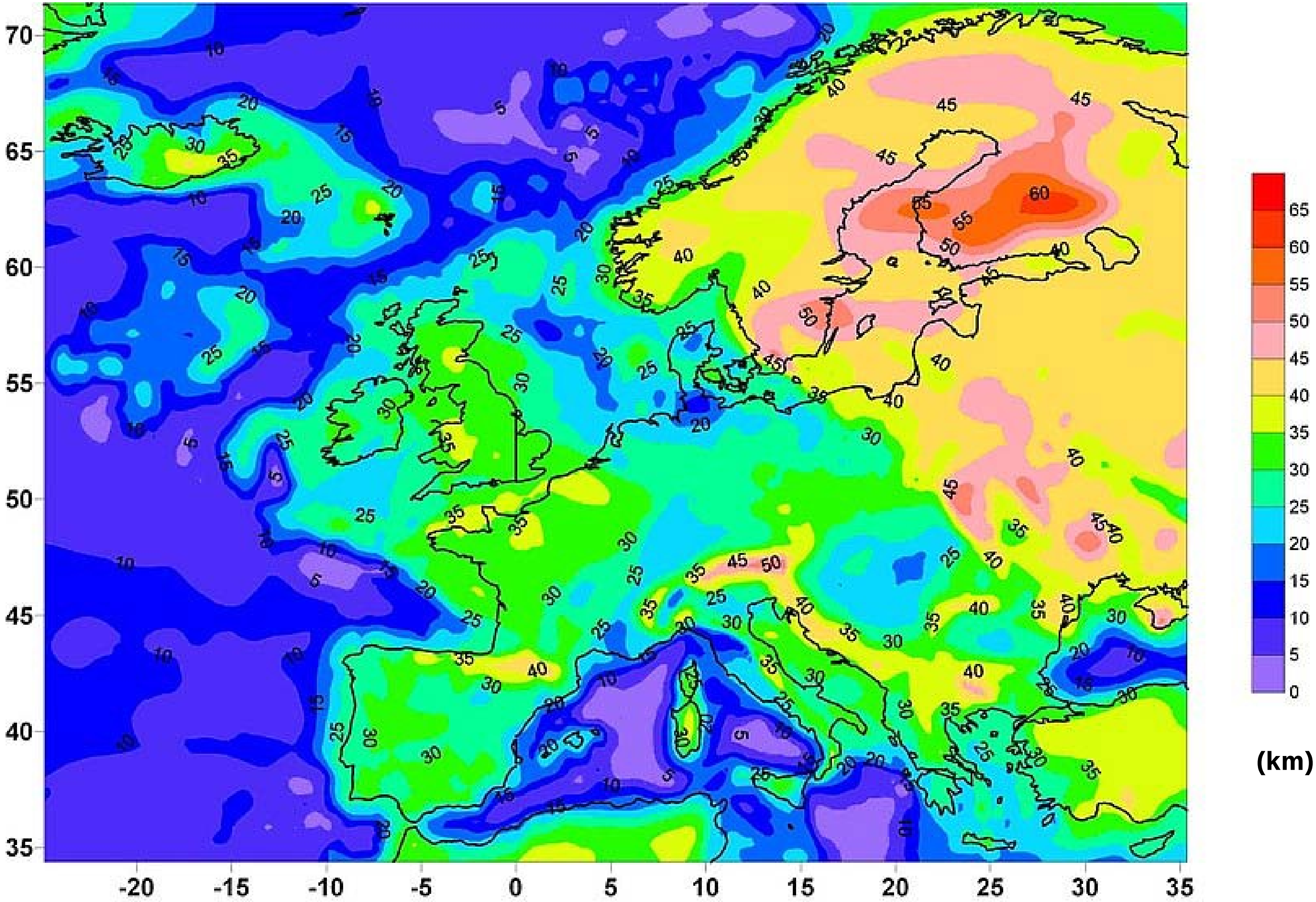


Remember that the lithosphere is a two components system, lith. mantle and (oceanic-continental) crust

Depth of the LAB (here defined as the 1200°C isotherm) in Europe



The Moho map of Europe

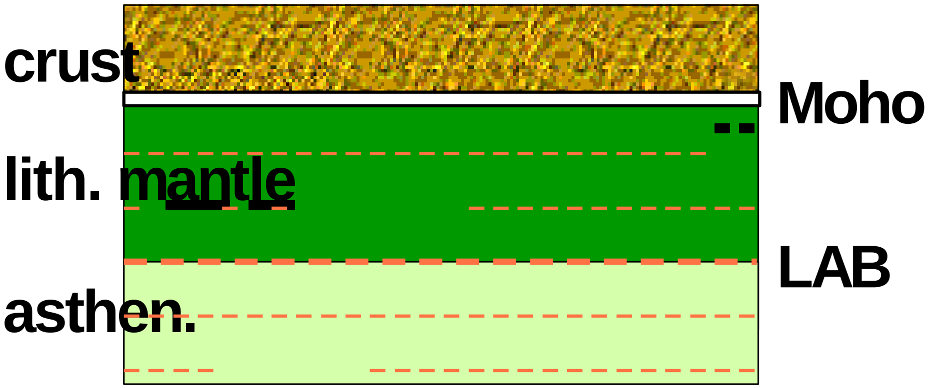


Changing weights (= vertical movements) in the Earth

$\square_{lith} < \square_{asth.}$

This is what we had. Life seems easy
If the lithosphere becomes lighter topography increases
If lithosphere becomes heavier topography decreases

Geologically not really useful, the lithosphere is a complicated "block"



ρ crust = 2.6 g*cm^{-3}
ρ lith.mant = 3.6 g*cm^{-3}
ρ asthen = 3.0 g*cm^{-3}

$\square_{crust} < \square_{asth.} < \square_{lith\ mantle}$

It seems that crust and lithospheric mantle play a different game!

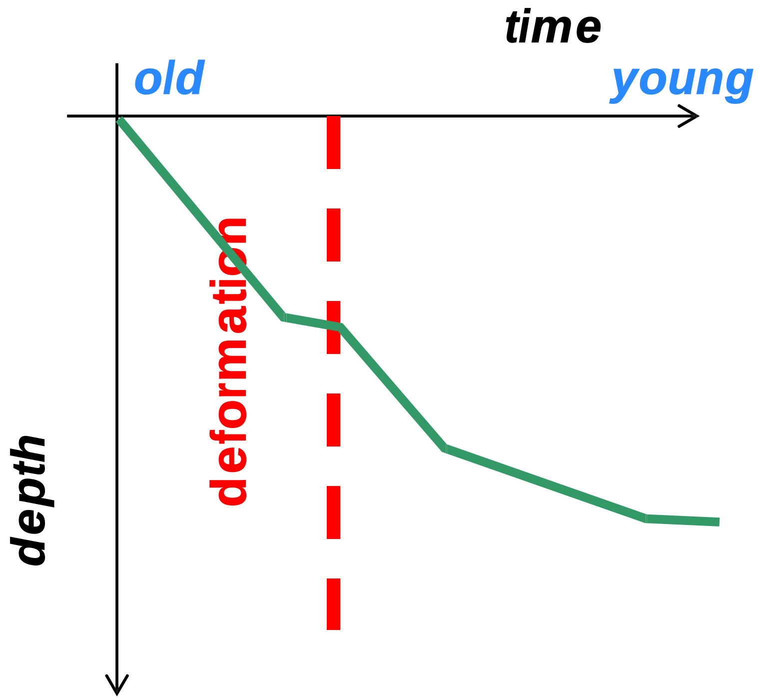
We need to look in more detail processes controlling their thickness changes and add them together (quantitative geology!)

We make a conceptual experiment
(= simpler than nature)

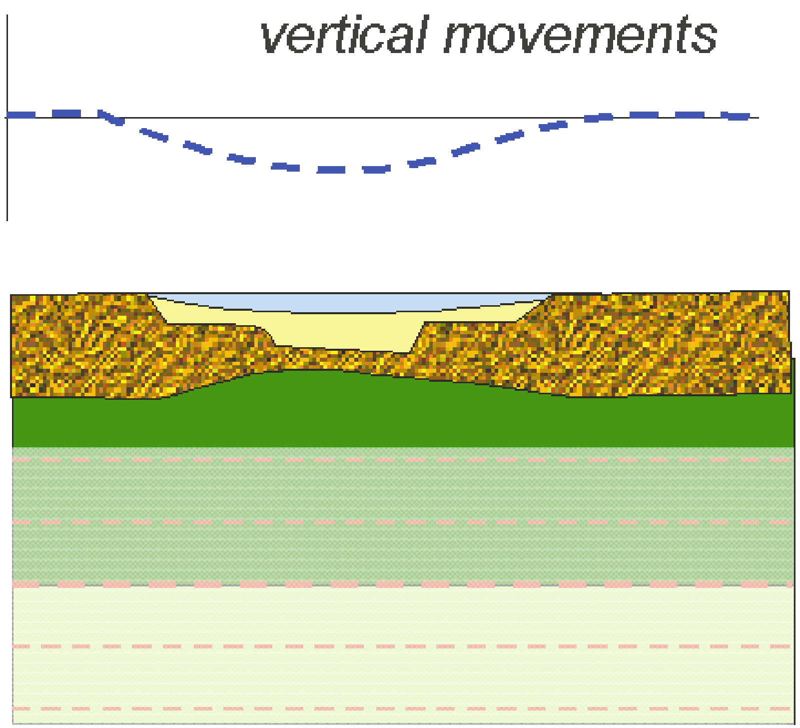
We investigate the vertical movements produced by thinning/thickening of the crust and lithospheric mantle separately

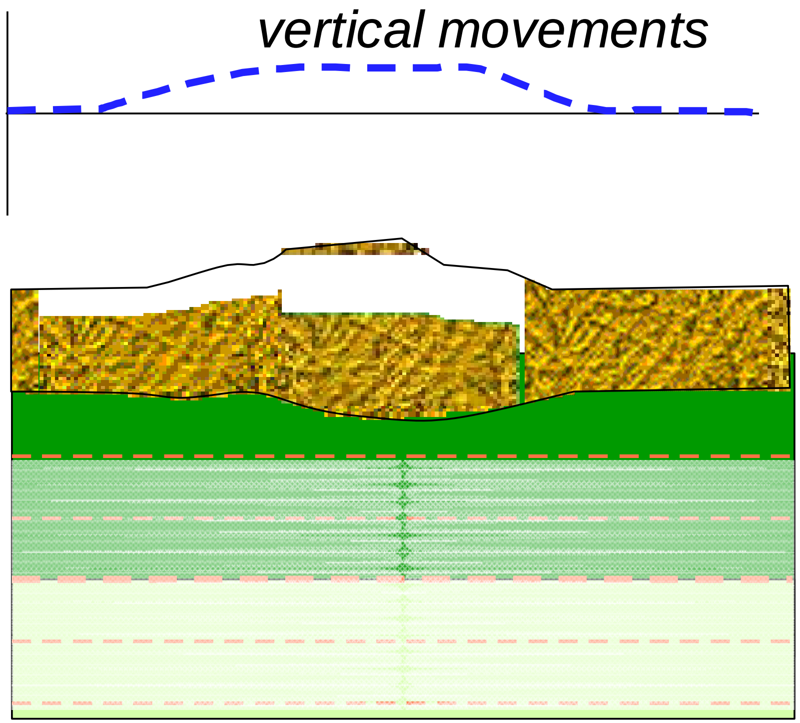
We do this by predicting vertical movements
1) during thickness changes
2) after thickness changes

A useful tool to describe vertical movements through time is a subsidence curve



Effects of changes in crustal thickness

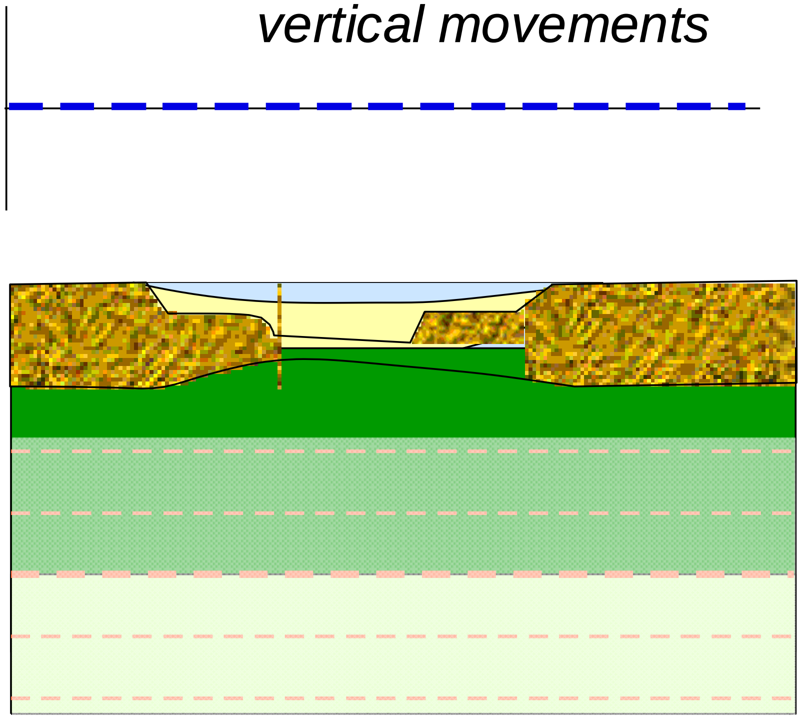


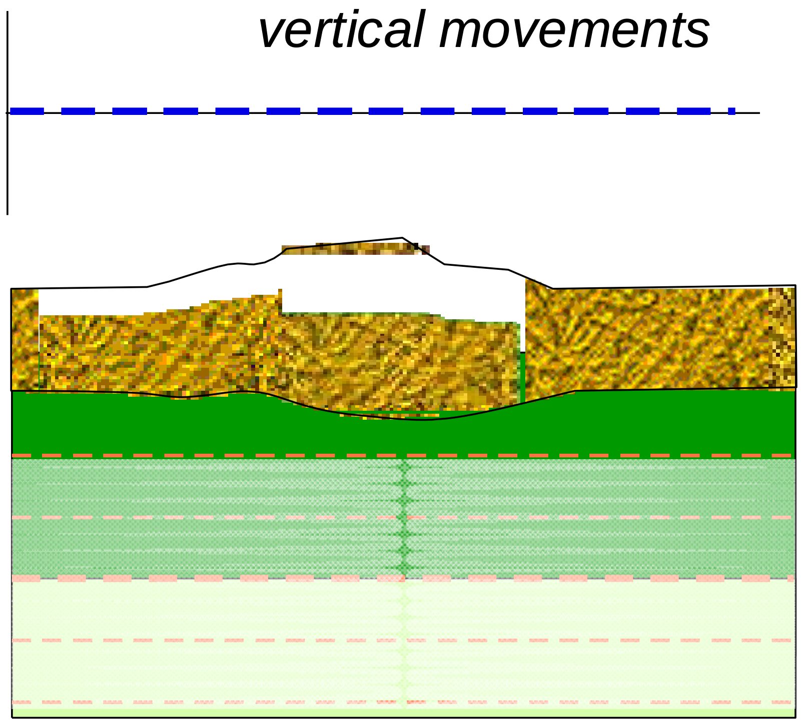


Easy:

- ***crustal thinning causes downward movement (=subsidence)***
- ***crustal thickening causes uplift***

After the end of crustal thickness changes....

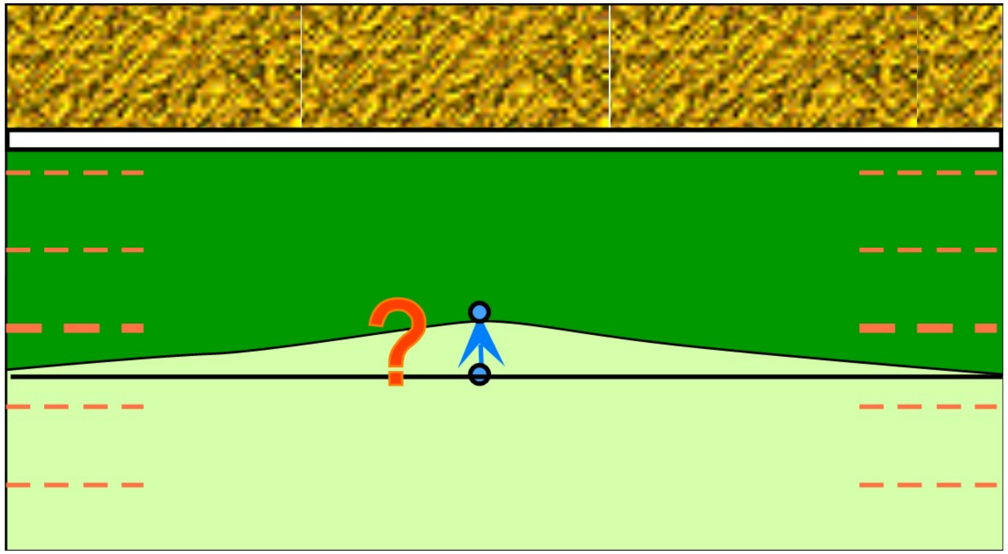




Nothing happens, no crust-driven vertical movements

The lithospheric mantle

More complicated as the base of the lithosphere is a thermal boundary



In terms of mass movements

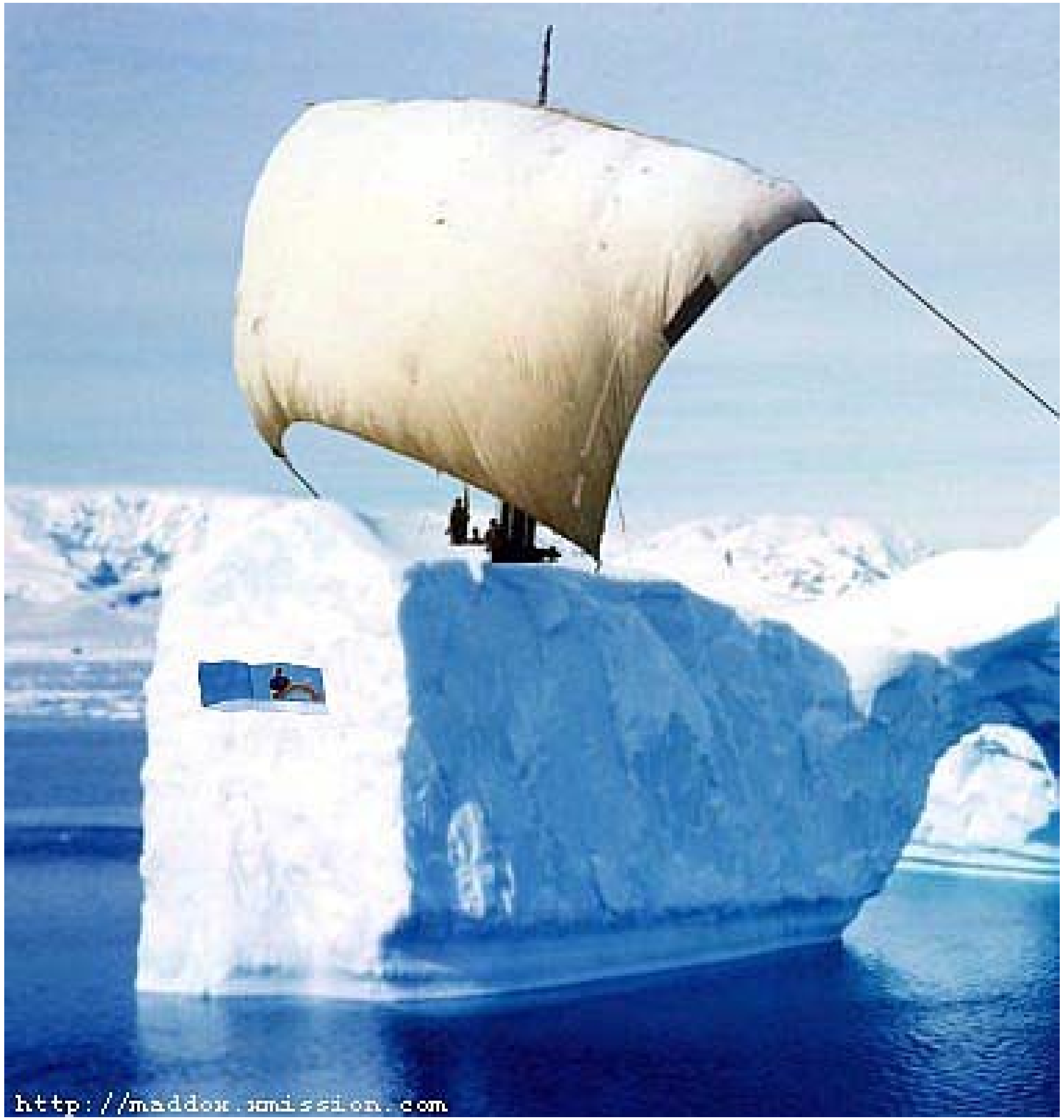
- **During "extension/thinning", mantle rocks will tend to move upward**
- **during "contraction/thickening", mantel rocks will tend to move downward**

But

If the mantle changes in thickness or not depends on the competition between advection (movement of mass) and conduction (movement of heat)

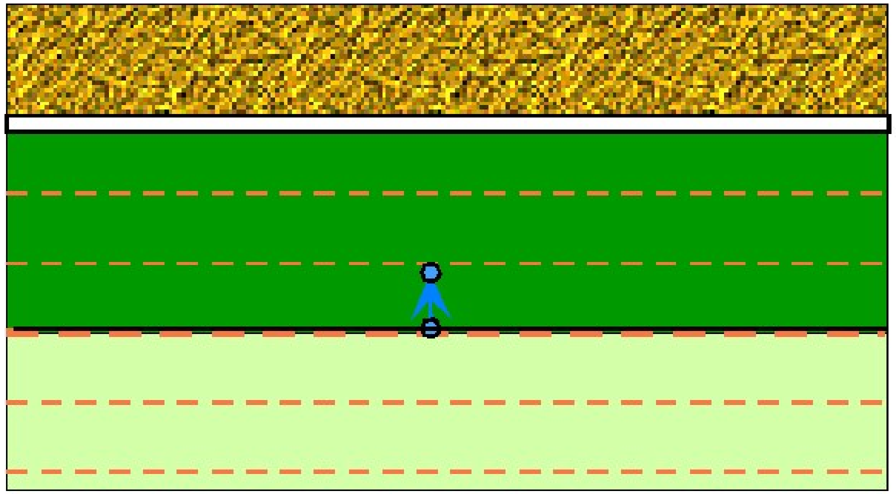
The competition between conduction and advection:

You better sail fast!

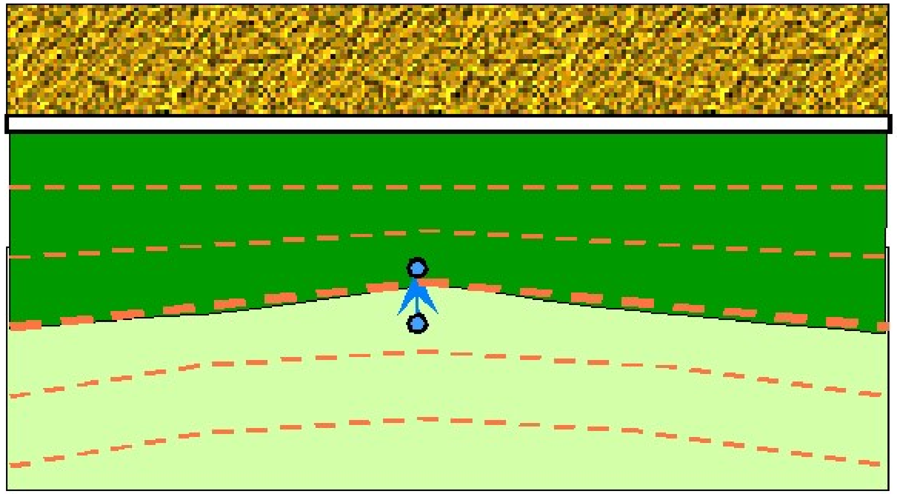


In the case of extension

If conduction prevails isotherms remain flat and the lithosphere does not thin



If advection prevails isotherms are deflected and the lithosphere becomes thinner



when thinning is slow
conduction>>advection ► little thermal anomaly ► little lithospheric thinning

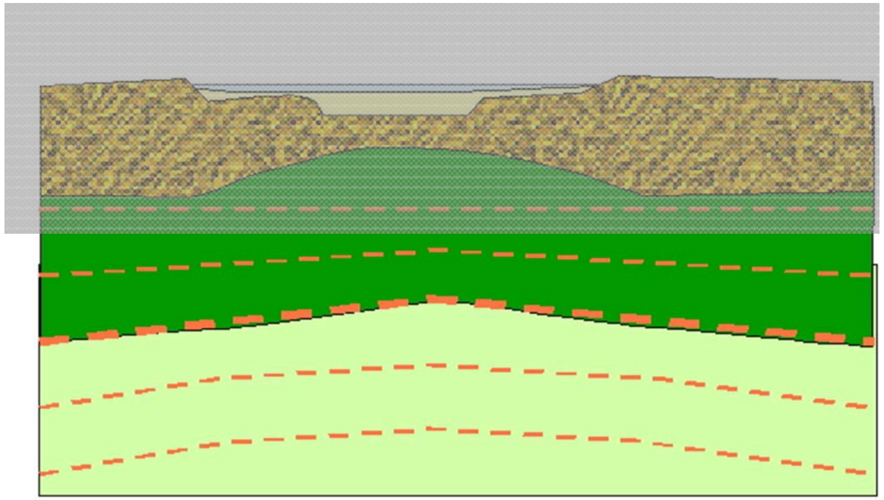
when thinning is fast
advection>> conduction ► strong thermal anomaly ► strong lithospheric thinning

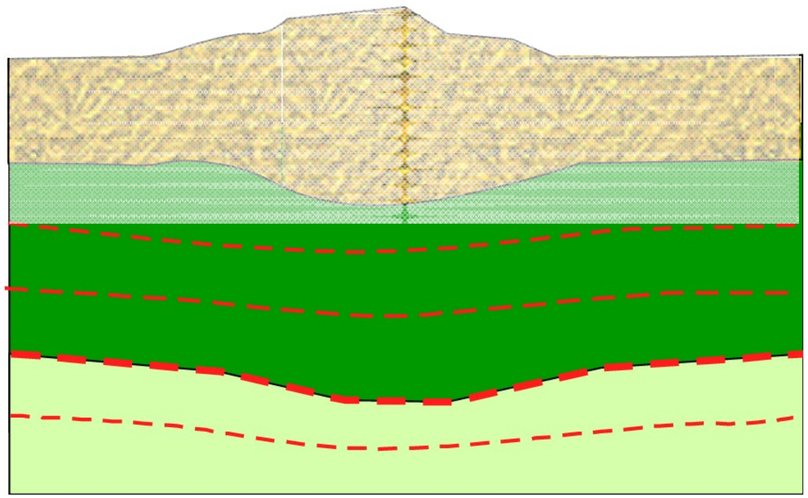
Back to our cartoons of the lithospheric mantle

Fast deformation

No thickness changes = little/no vertical movements driven by the lithospheric mantle

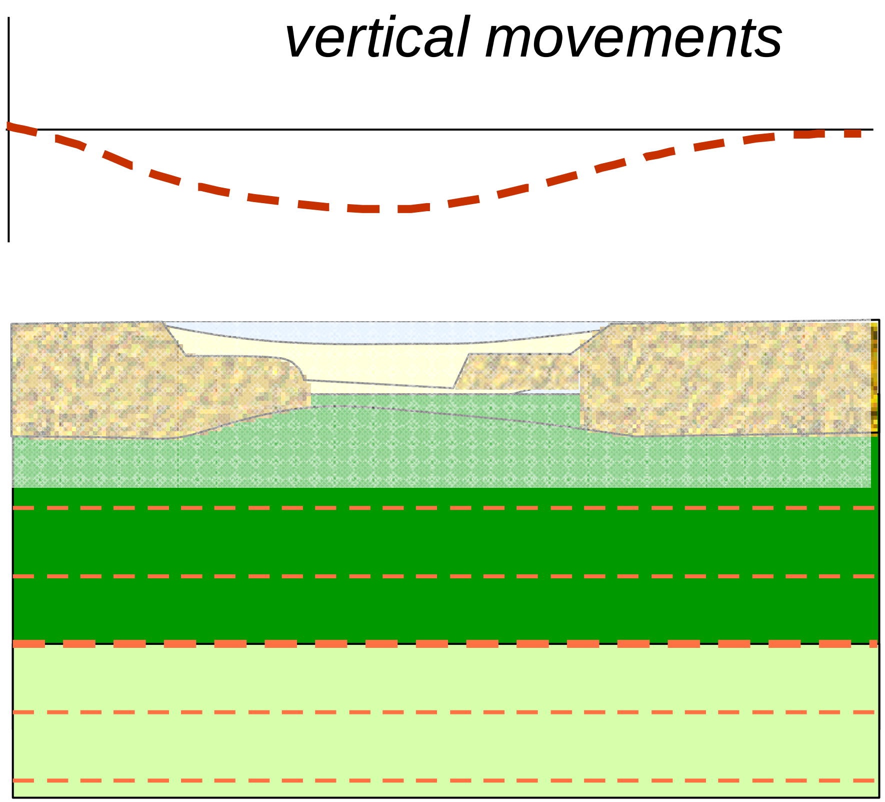
The extension case



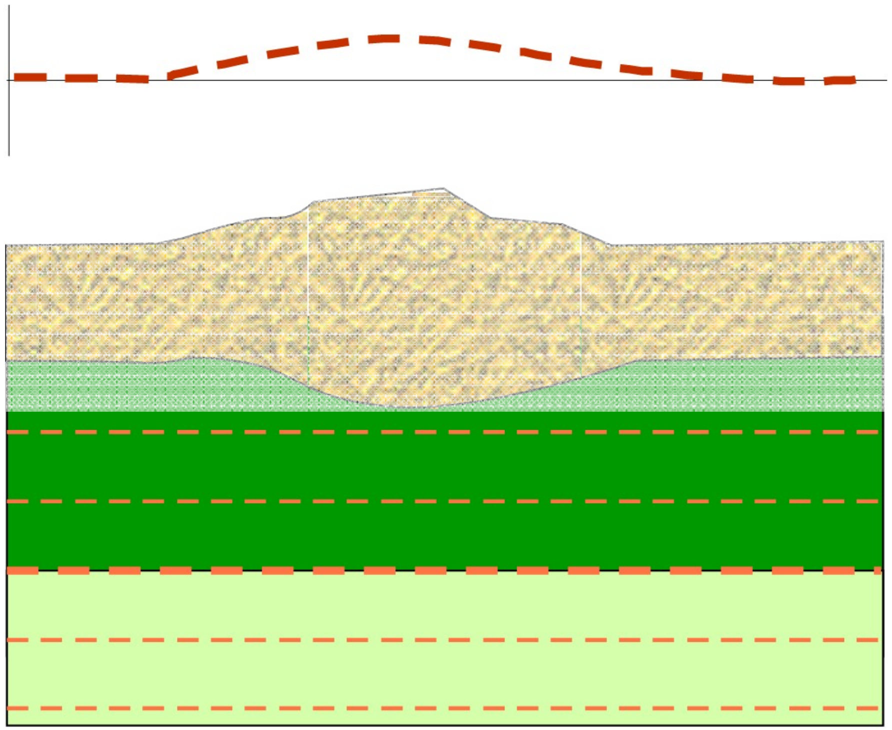


The contraction case

The lithospheric mantle during slow deformation: Important thickness changes



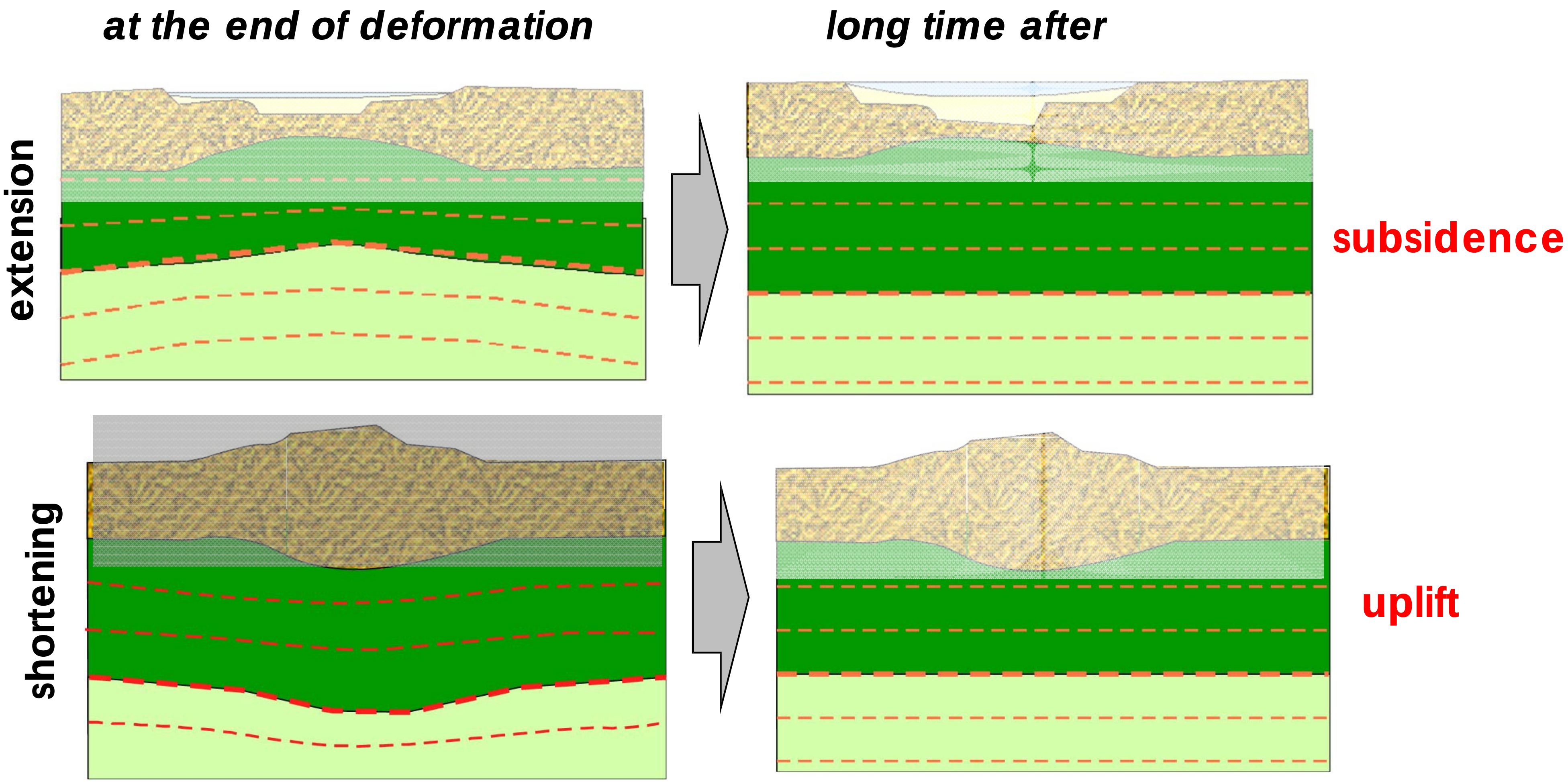
In the case of extension
the lithospheric mantle thickens!



In the case of contraction
the lithospheric mantle thins and pushed the Earth surface up!

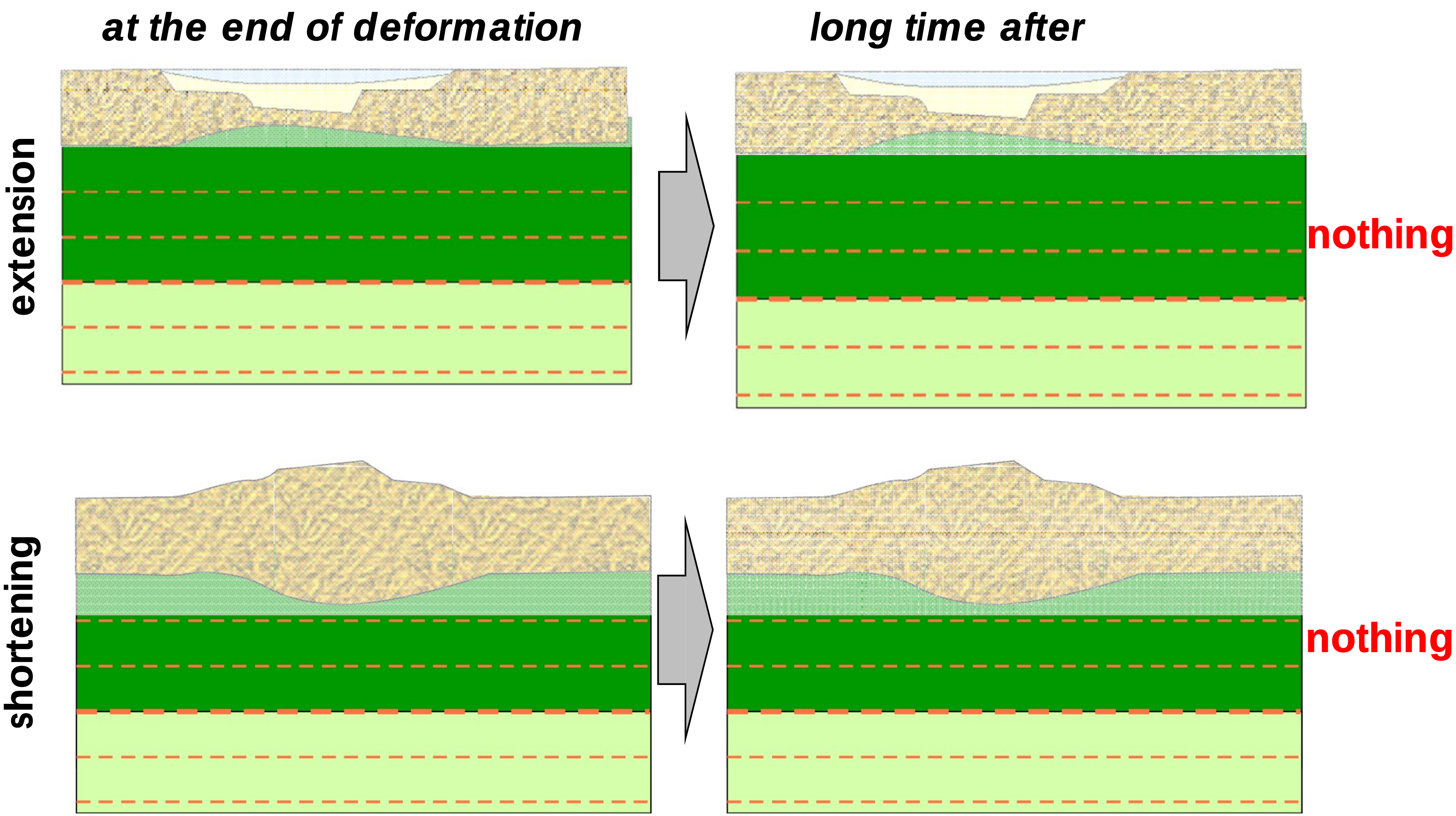
Following the end of deformation: Fast deformation

The thickness of the lithospheric mantle changes and vertical movements occur



Following the end of deformation: slow deformation

No changes in the thickness of the lithospheric mantle and no vertical movements occur



The rates of deformation controls the magnitude of the thermal anomaly present at the end of deformation

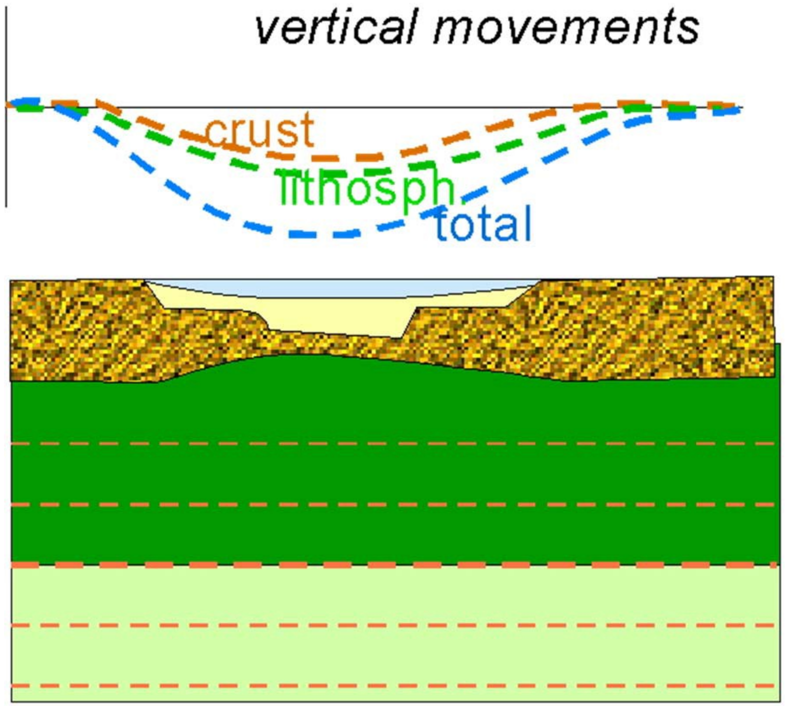
The magnitude of vertical movements depends on the amplitude of the thermal anomaly

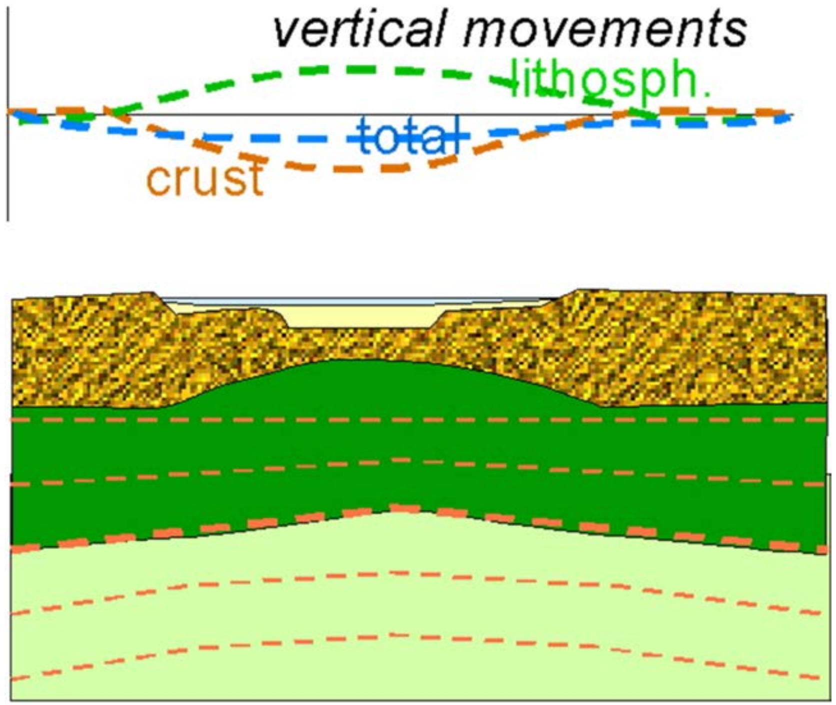
The faster extension/shortening, the stronger will be vertical movements after the end of deformation

The real world: combining crust and lithospheric mantle

slow | **fast**

during extension



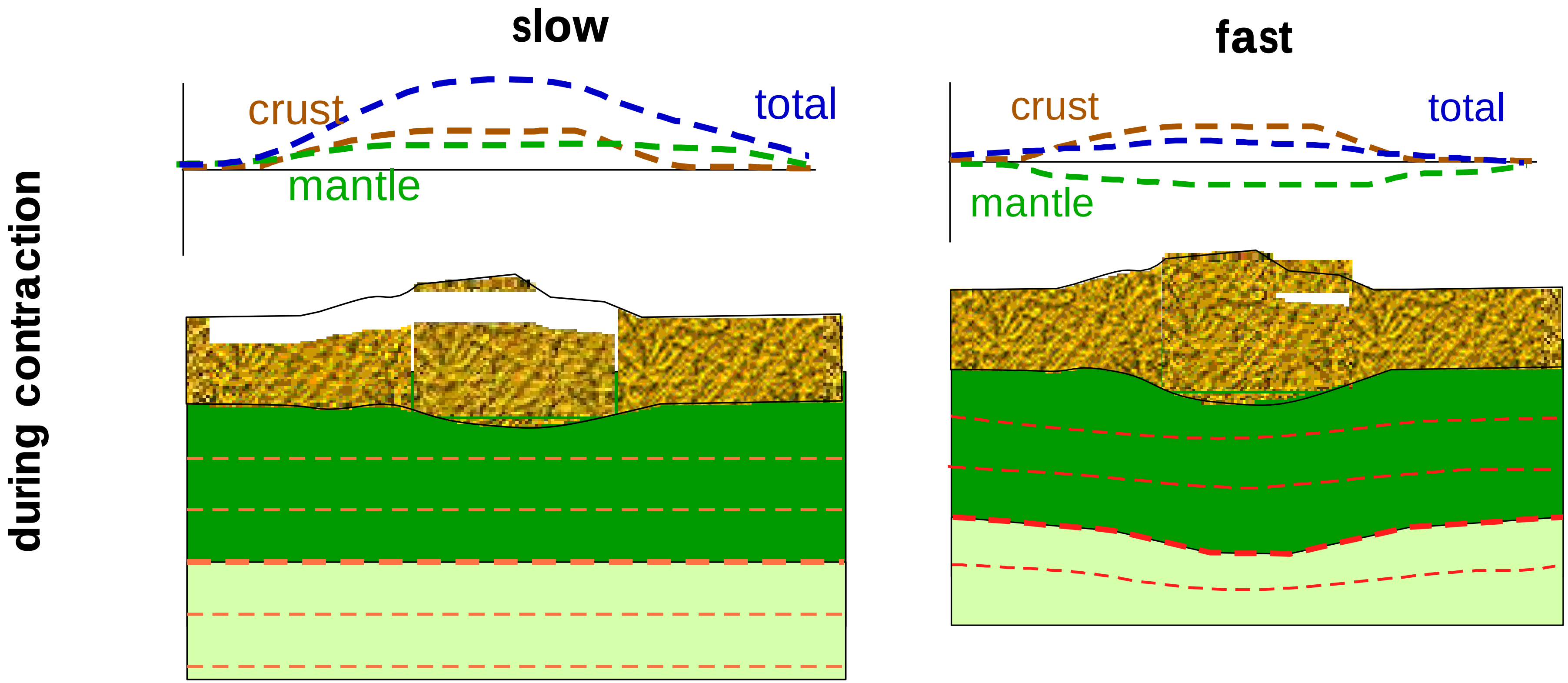


following extension

no subsidence

some subsidence

During contraction/thickening



following contraction

no uplift

some uplift

Recap:

during thickness changes:

- **the crust simply wants subsidence/uplift**
- **what the lithospheric mantle wants ... depends on the rate of thinning/thickening**

Following thickness changes:

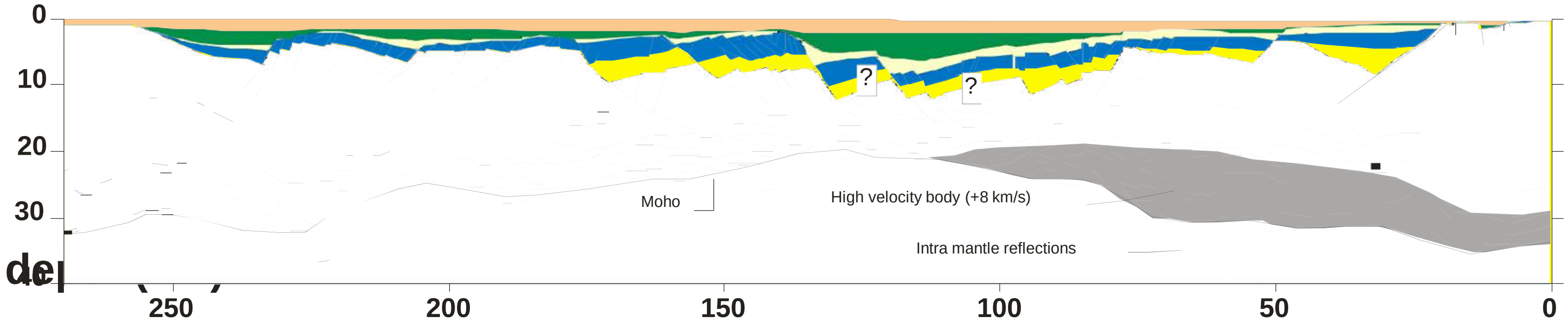
- **the crust has nothing more to say (neglecting erosion)**
- **the lithospheric mantle will impose vertical movements; their magnitude depends on the amplitude of the thermal anomaly present at the end of thinning/thickening**

What is the meaning of “slow” and “fast”?
No general answer is possible without knowledge of the geometry of the system and numerical modelling

Processes leading to load changes

Tectonics (thinning)

b)



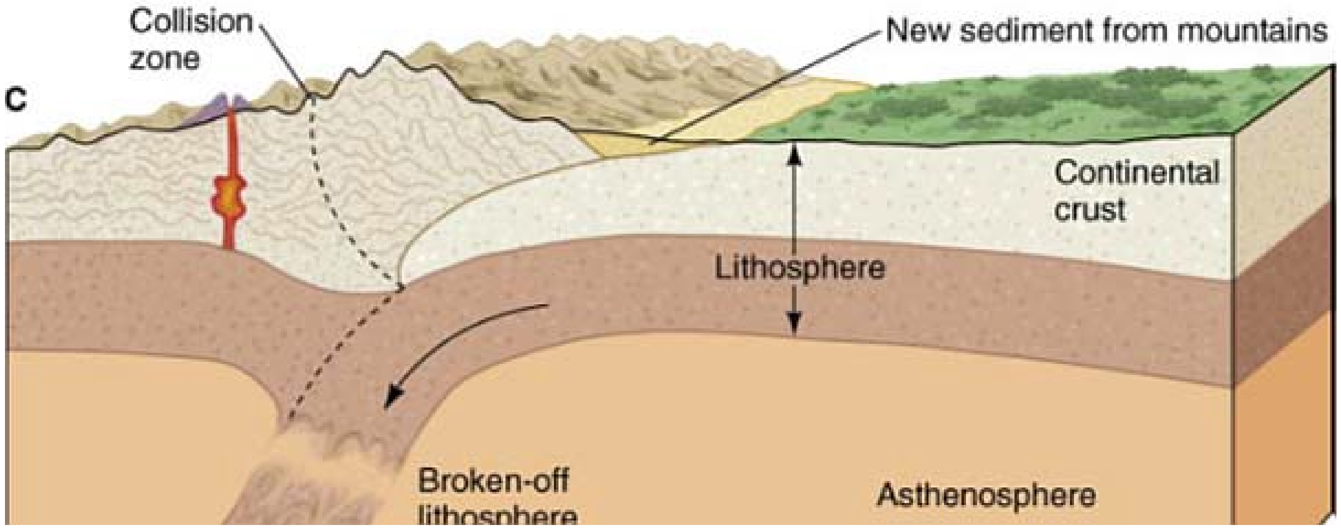
Where is the site of maximum thinning?

Where is the site of maximum subsidence?

Is there correspondence between the two?

Knowing that the green sediments were deposited until 70Ma, what will be the shape of the LAB?

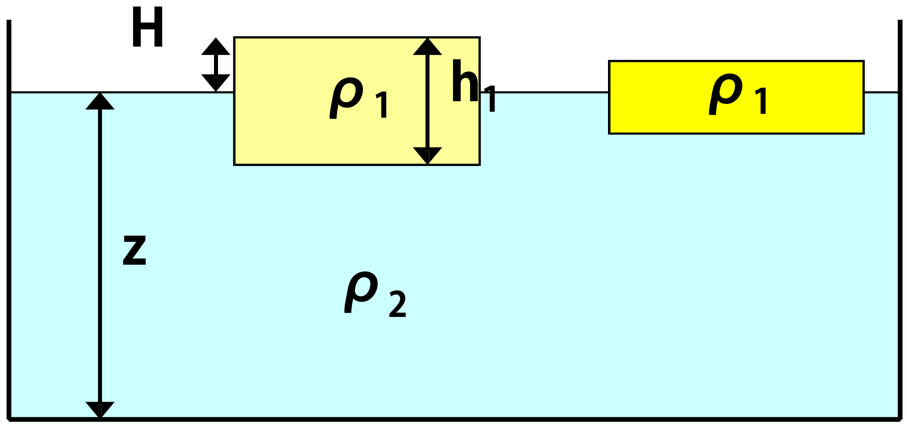
Tectonics (thickening)



other less common processes can change the density of the rocks. One of them is metamoprhism

Erosion

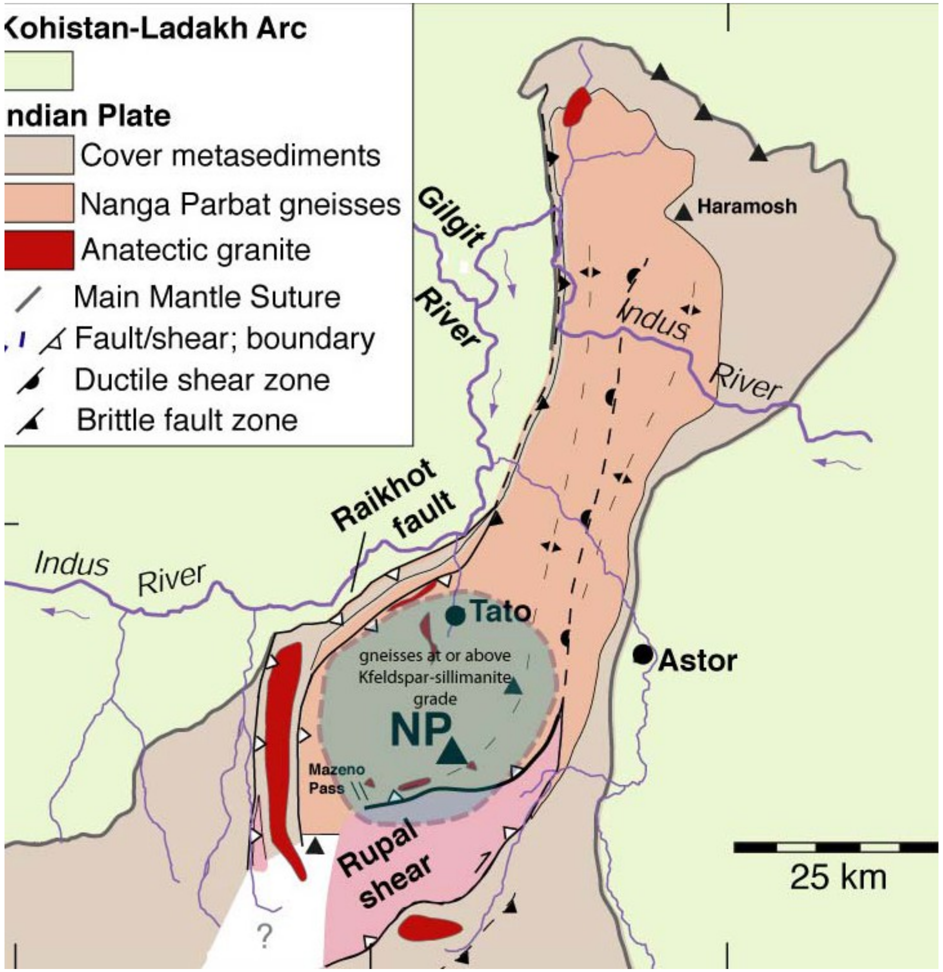
When material is eroded, the surface of the Earth goes **down** but the lower part of the block (the crust) **comes up**!

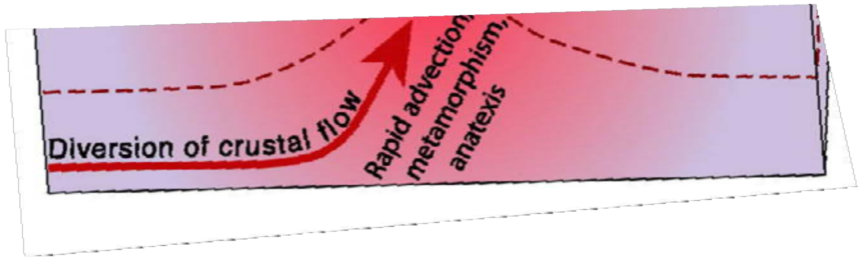


This leads to less mountain, less erosion and eventually an equilibrium profile

An extreme situation

Valleys are the places where the strongest erosion takes place





The rivers "pull up" rocks from below

The Indus river valley

Rocks are found along the river which were formed at depth of >10km and have been brought to the surface in very recent times

Sources of figures

http://tsjok45.wordpress.com/2013/06/24/geologie-trefwoord-c/

http://bc.outcrop.org/GEOL_B10/Dlecture10.html

http://dc401.4shared.com/doc/Ch0Ecp8M/preview.html

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