Indian Institute of Technology, Kanpur
Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

# Lecture 20. Break or Flow.. how does a rock deform?

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IITK Experimental Rock Deformation Laboratory

## Aims of this lecture

- Brittle, Ductile and Brittle-Ductile deformation
- Rheology – Elastic, Viscous and Plastic
- A couple of examples

## Brittle; Ductile and Brittle-Ductile

- Cohesion *ability (stress) to hold particles together in static condition*
- Friction *resistive force develops between two adjacent particles/surfaces due to stress*

**Brittle:** The rocks must have lost its cohesion to produce joints, cracks, fractures faults (low PT phenomenon)

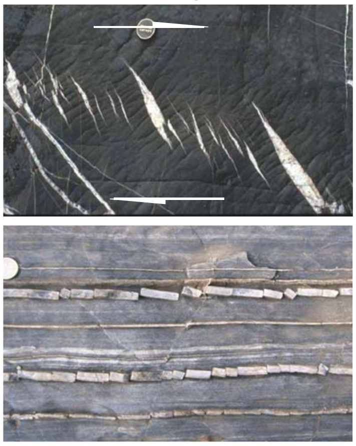
**Ductile:** The rocks do not loose cohesion but flow (high PT phenomenon)

**Brittle-Ductile:** Show both brittle and ductile deformation (intermediate PT phenomenon)

These are observation based and essentially scale dependent

## Brittle; Ductile and Brittle-Ductile

*Brittle* regime

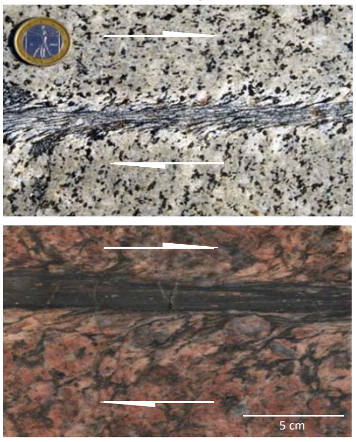


...high concentration of shear fractures, cracks representing localized *brittle* deformation

*Brittle-ductile* regime

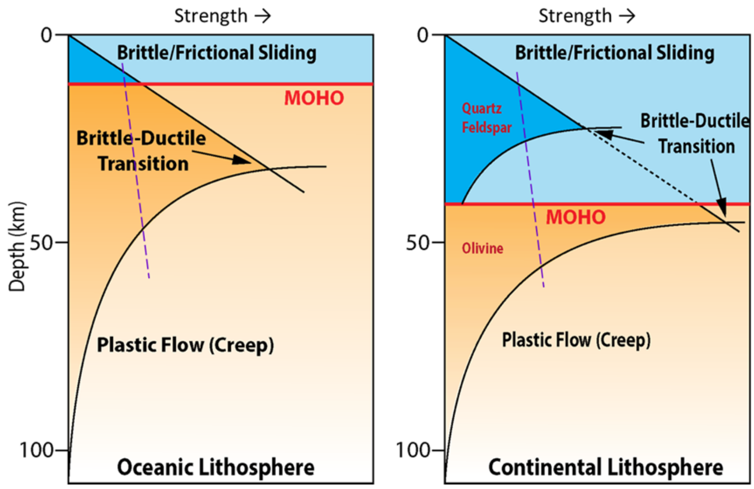
...both ductile and brittle features; developed either simultaneously or sequentially

*Ductile* regime




...structural fabrics, (*e.g.* schistosity) contrasting to the surroundings, indicating localization of intense penetrative *ductile* strain

## Brittle; Ductile and Brittle-Ductile




## Basics and Definitions

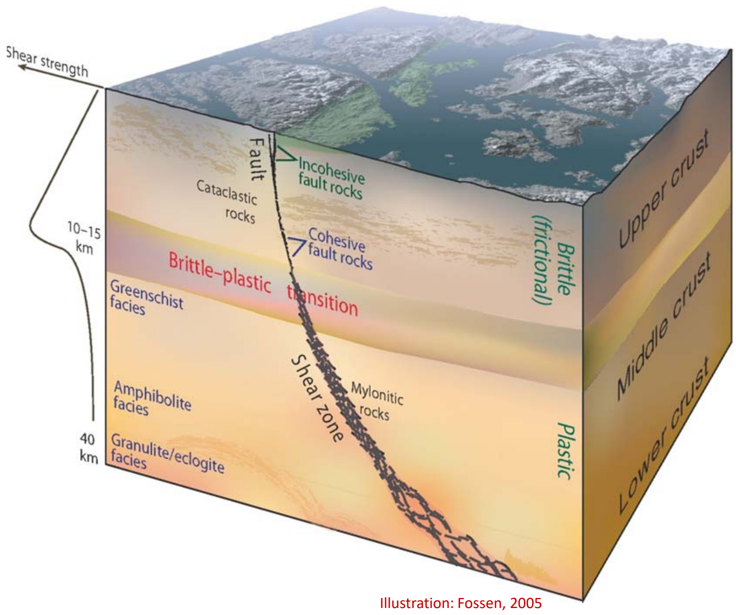



Illustration: Fossen, 2005

Simplified model of the connection between faults, which normally form in the upper crust, and classic ductile shear zones. The transition is gradual and known as the brittle–ductile transition.

The depth depends on the temperature gradient and the mineralogy of the crust. For granitic rocks it normally occurs in the range of 10–15 km.

## Rheology

We have learnt "Strain" and "Stress". It is high time now to ask the question, are they related to each other? If yes, how and what is/are the controlling parameter(s) in this relationship?
--- The answer is given in the subject, called **RHEOLOGY**.

The study of the behaviour (flow) of materials under deformation. Rheology ~ $\rho\varepsilon\iota$ – ***flow*** *in Greek*.

The different deformational responses to applied stress depend on the physical properties of the material under consideration and on external parameters (pressure, temperature and time).

## Speaking about "FLOW"

- ***Solid*** and ***Fluid***, in Rheology do not correspond to the definitions based on atomic structures of the materials.
- A material is fluid, independently on its atomic structure, when it flows under constant stress (and under certain conditions).

Think how all the materials, we are all familiar with, will flow along a uniformly polished inclined plane in room condition, only under the effect of gravity….

| | |
|---|---|
| Water | Syrup |
| Cooking oil | Honey |
| Raw Glycerine | Tar oil |
| Wall-paint | Asphalt |
| Tomato Ketchup | Glass |

## Rheology - classification

- Like all other materials, studied under continuum mechanics, can be described to respond to stress by three fundamentally different end members -

| | |
|---|---|
| **Elastic Rheology** | Recoverable |
| **Viscous Rheology**<br>**Plastic Rheology** | Non-recoverable |

**Note:** The rheology is a large topic and almost all subjects deal with this topic. You will get only a glimpse here. For advanced learning, contact me separately.

## Elastic Rheology

- Stress is linearly proportional to strain and the later is fully recoverable (*Hooke's Law*)

This linear relationship is expressed as: $\sigma = E\varepsilon$

***E*** is known as **Young's modulus** or the **Elastic modulus** (also denoted Y) or the stiffness of a material, defined as the slope of the stress-strain curve. Hooke's law is a constitutive equation for elastic materials. Physically, ***E*** quantified, how hard a rock is to deform elastically.

## Viscous Rheology

- Fluids, in general, has a resistance to flow under stress. The quantification of the resistance of a fluid to flow is knows as **VISCOSITY** (*$\eta$*) [or, coefficient of viscosity]. Greater the viscosity value, higher is the resistance to flow.

- A perfectly (ideal) viscous material flows like a fluid when influenced by an external force. This means that there is no elastic deformation involved.

- This deformation behaviour at constant volume (*Newtonian Fluid*) is idealised by a **linear viscous constitutive** equation.

## Plastic Rheology

- Under some natural conditions the strain-response of rocks cannot be explained neither by elastic nor by viscous rheology.

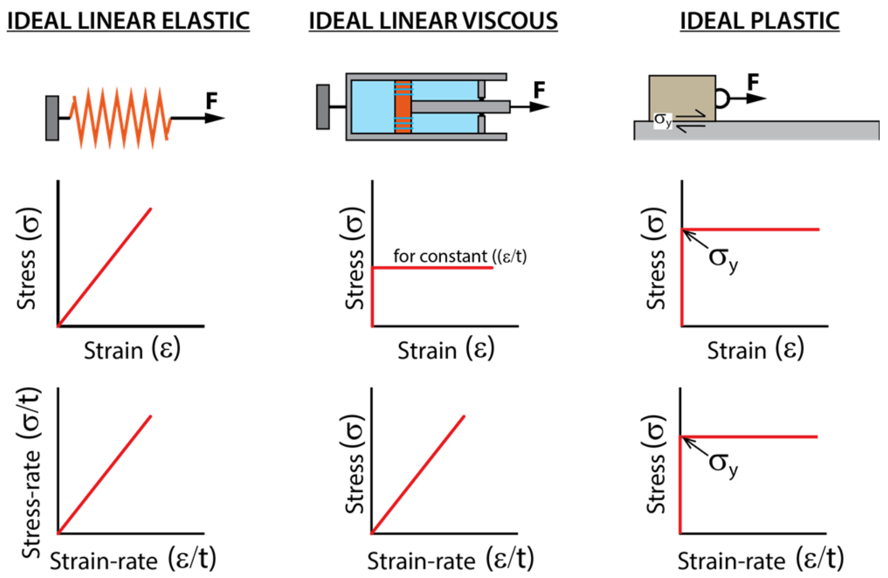
- These materials, during deformation, initially display an elastic behaviour; however, they flow readily at or little above the Yield Stress.

- This typical behaviour of materials under stress is best described the **PLASTIC** Rheology.

- Plastic Rheology is a description of a material behavior under stress to undergo irreversible (permanent) deformation after yield strength (elastic limit) of the material.

- During the the post yield deformation, the rocks must maintain its continuity (cohesion) and should not produce fracture at the scale of observation.

## Summary of Rheology Basics




## Review of the terminologies

- Brittle
- Ductile
- Brittle - Ductile

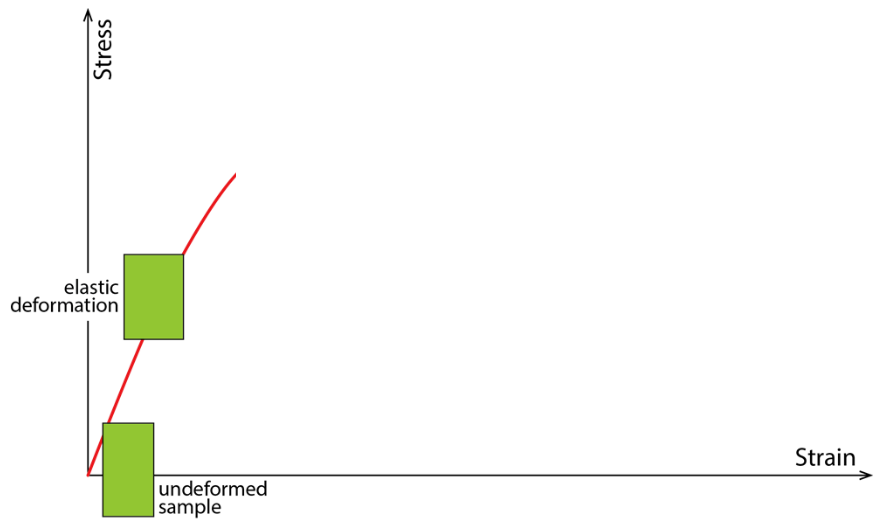
TYPES OF DEFORMATION

- Elastic
- Viscous
- Plastic

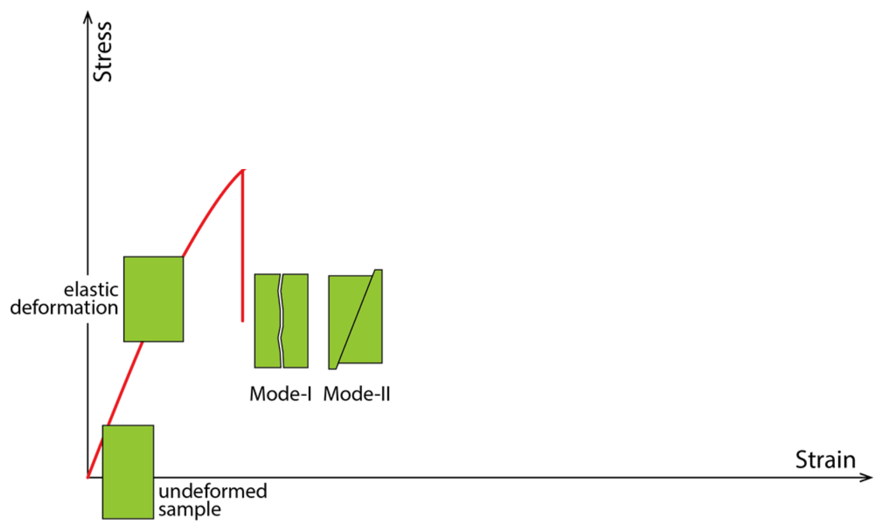
FLOW / MECHANISMS OF DEFORMATION (RHEOLOGY)

**Brittle** deformation is always **Plastic,** whereas, **Ductile** deformation includes everything which are *not* **Elastic** and **Brittle.**

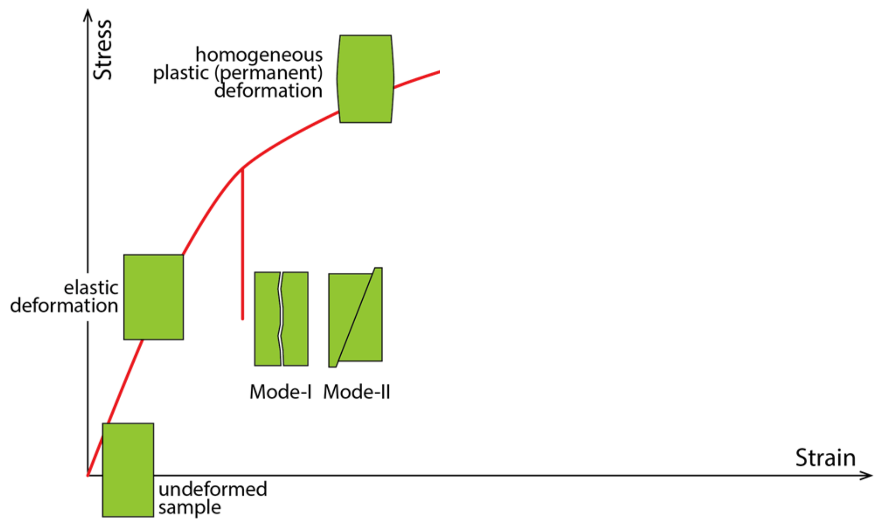
## Brittle; Ductile and Brittle-Ductile



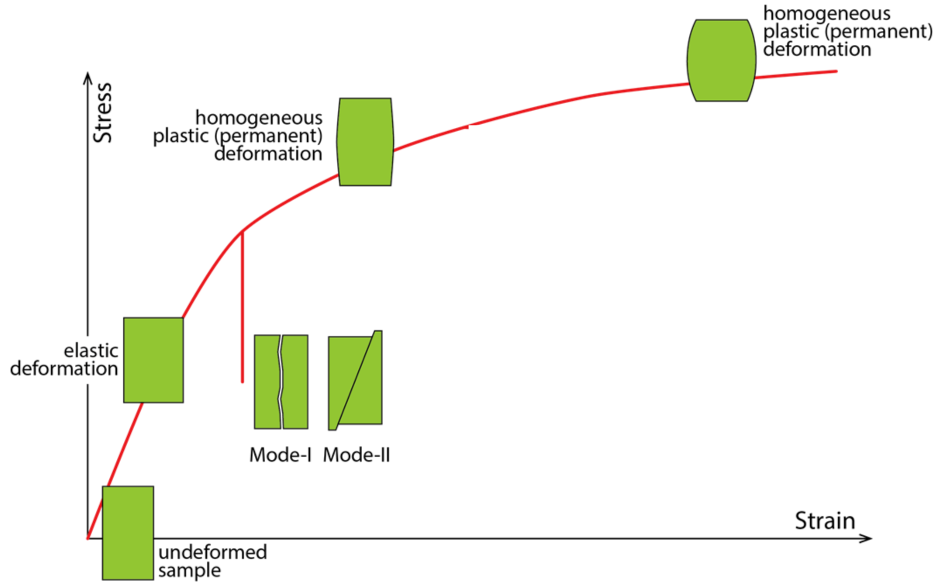

## Concept of Localized deformation



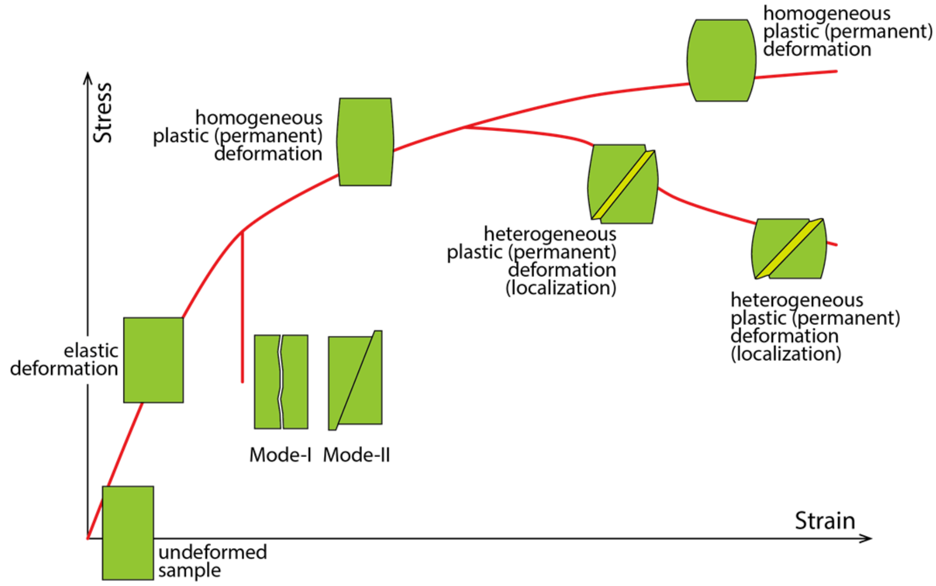
## Concept of Localized deformation




## Concept of Localized deformation

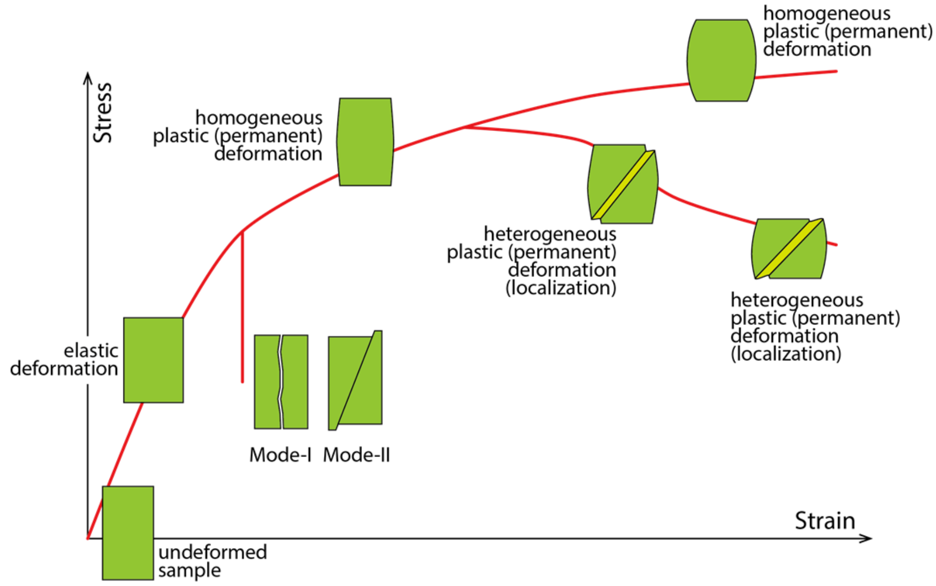


# Concept of Localized deformation

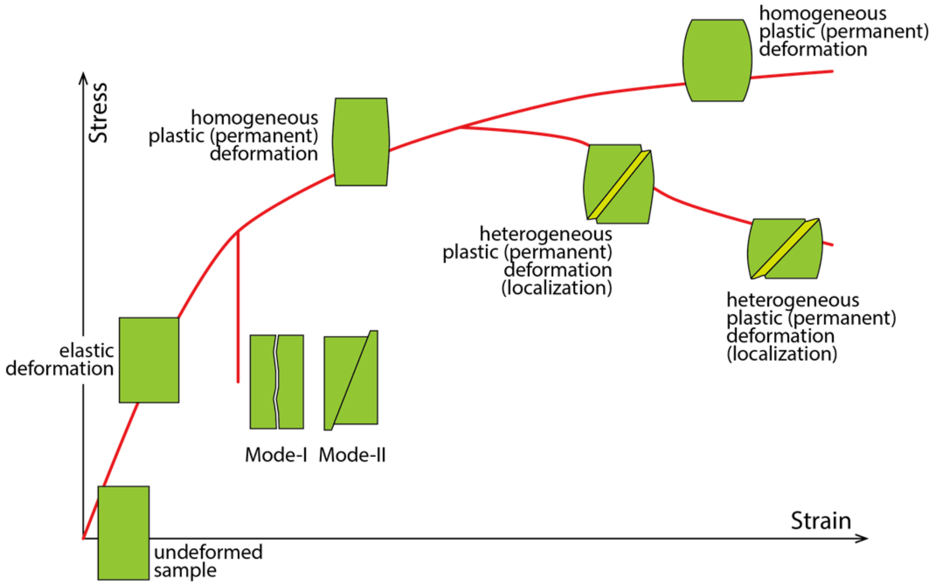




# Concept of Localized deformation



## Concept of Localized deformation



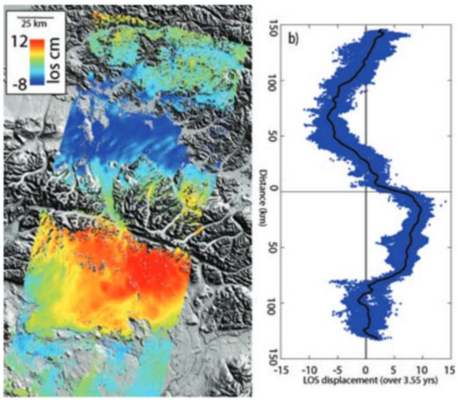

## Combined rheology

Rheology of rocks as combined viscous and elastic (visco-elastic).

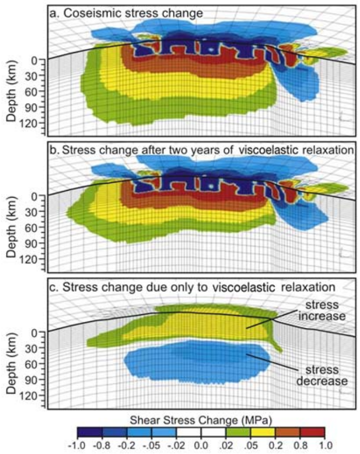
Rheology of rocks as combined elastic and plastic (elasto-plastic).

Rheology of rocks as viscous and plastic (visco-plastic).

## Example I: 2002 Denali Earthquake (M 7.9)



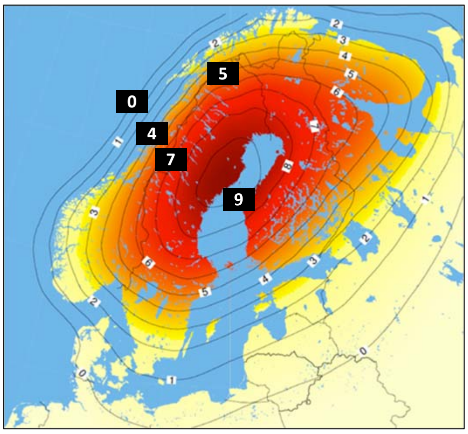

The Denali Fault and the peak displacements [*Briggs et al., 2009, GJI*]



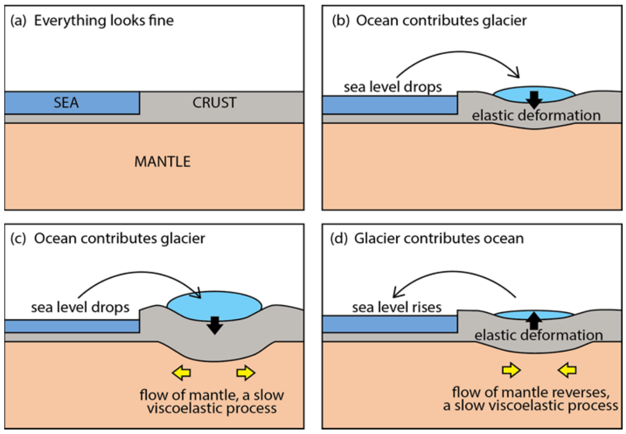

Calculated (a) coseismic, (b) postseismic,and (c) the difference (postseismic minus coseismic)shear stresses (planes parallel to fault surface [*Freed et al., 2006, JGR Solid Earth*]

## Example II: Rebound due to deglaciation

**A part of Scandinavia is not afraid of Sea-Level Rise !!** The observations suggest the sea level here is rising like all other places; the land is rising faster.




land uplift (mm/yr) relative to the centre of the Earth

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## Next Lecture

Basic Structures and related terminologies
(Fault, Fold and Shear Zones)