Definitions and Terminology

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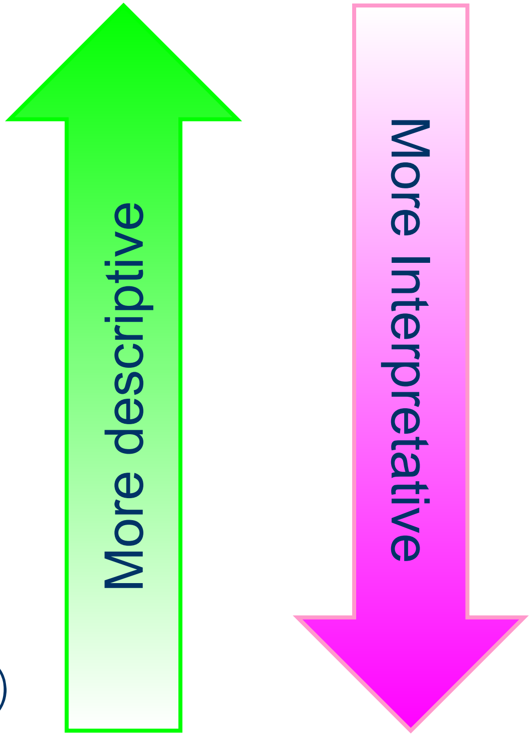
This Lecture

- **Purpose**: Introduce the crucial basic terminology of Structural Geology
- **Outline:**
  - Orientation of planes and lines
  - Faults
  - Folds
  - Faults/Fold relationships
  - Fractures
  - Typical Features for shortening/extention environments

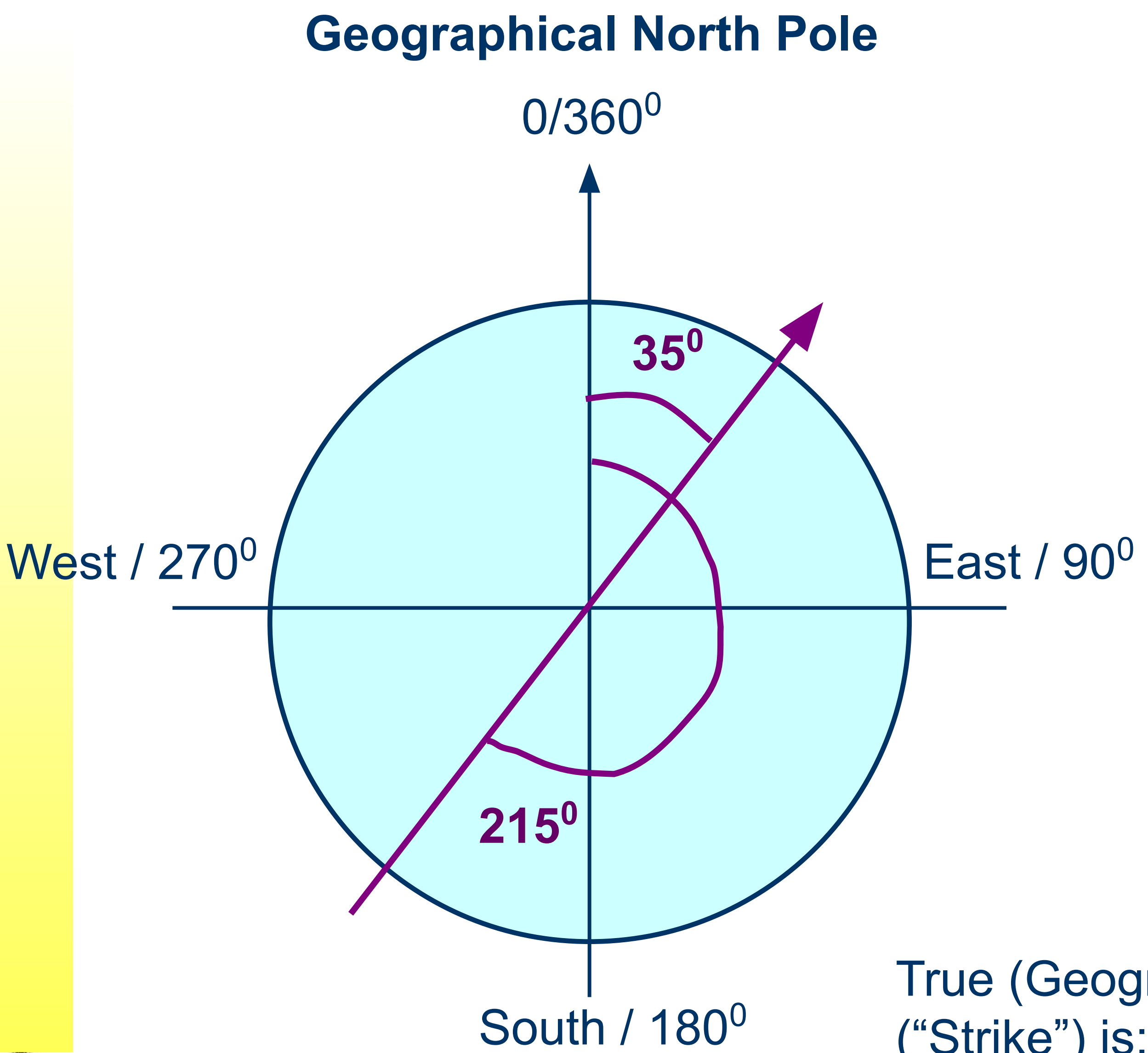
Analysis Levels

- **Geometrical**
  - shape and body's relations
- **Kinematical**
  - motions
- **Geomechanical**
  - stress/strain relations (incl. ductile/brittle type of deformation)



Increasing level of complexity

Strike



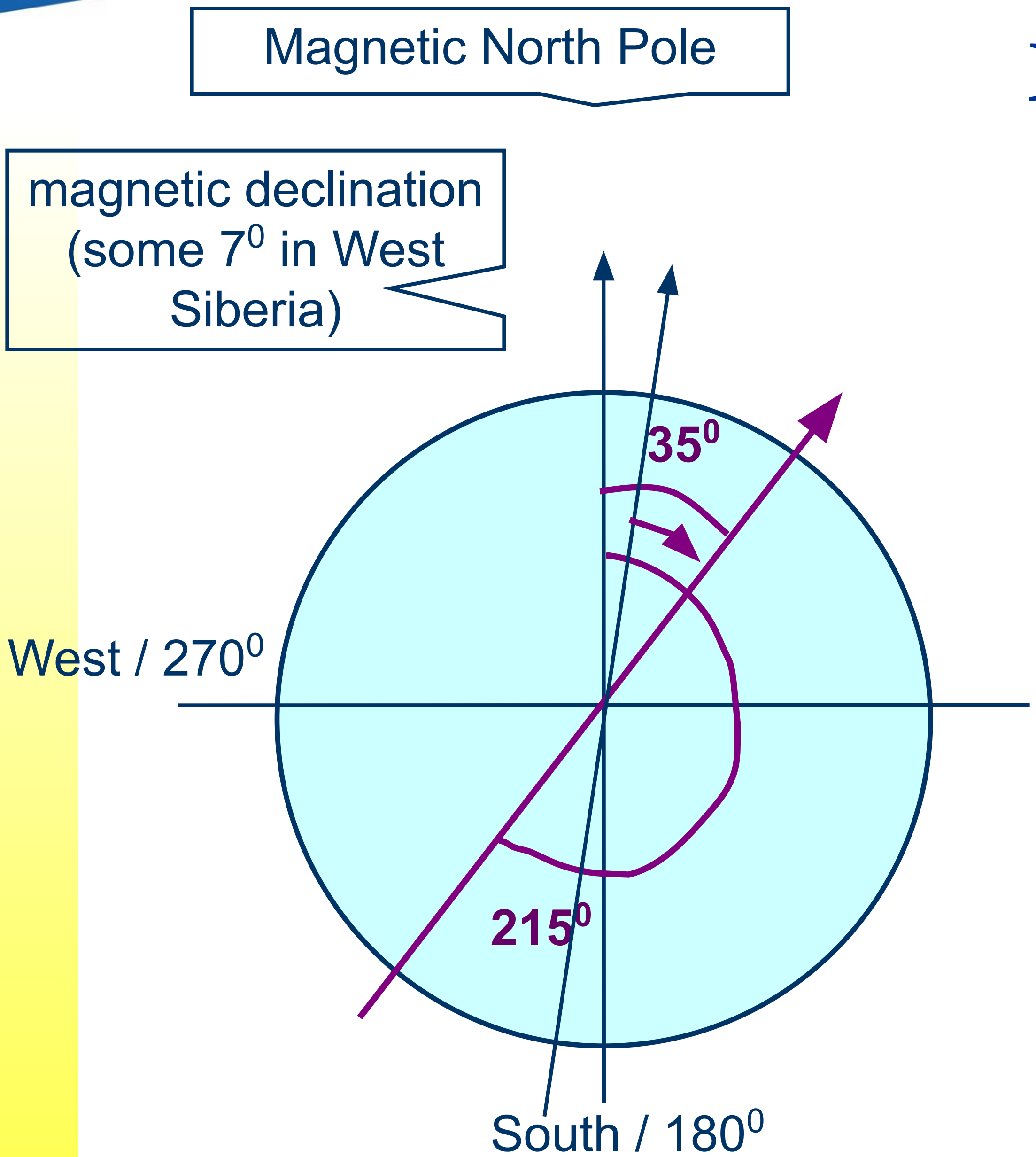
Rules:

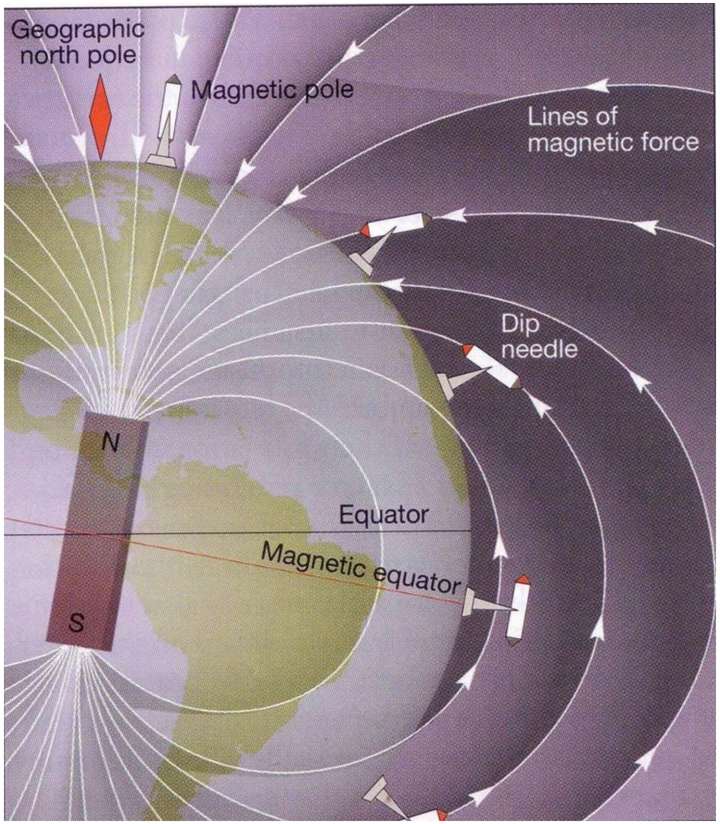
- **always** measure clockwise,
- may be measured with two results with 180^0 difference:

  35^0 or 215^0 – both are correct

True (Geographical) Strike Direction ("Strike") is: 35^0

Line Orientation

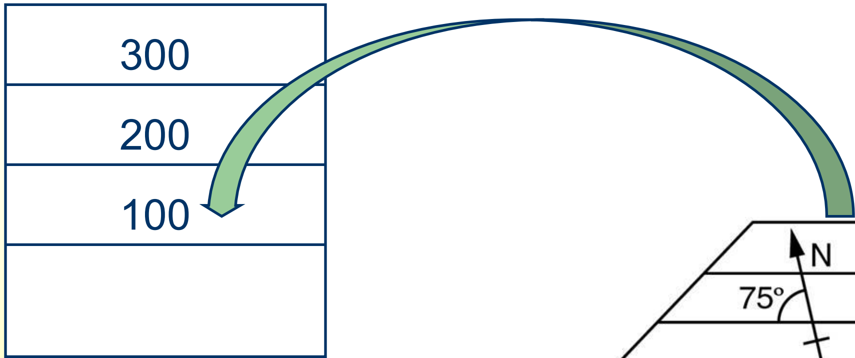




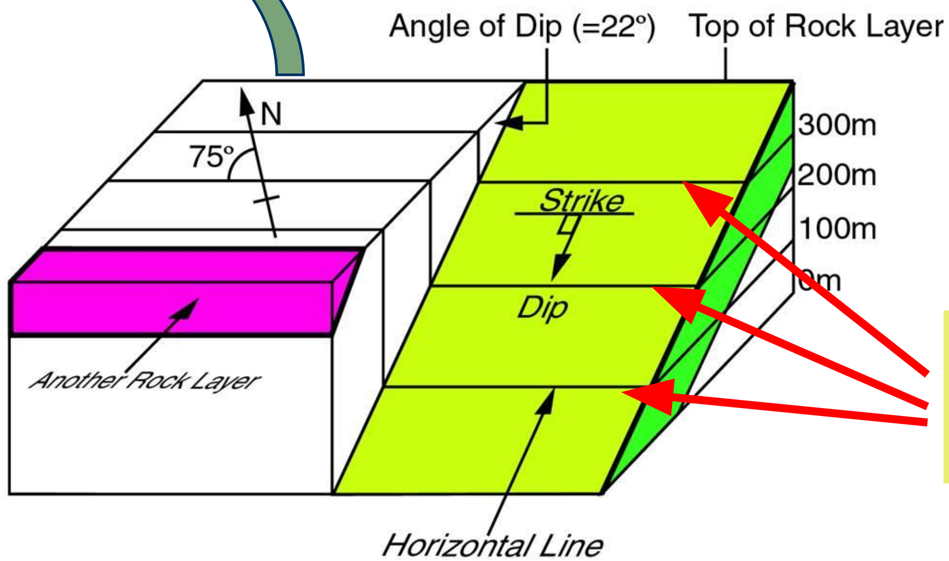
Magnetic Strike Direction is: 35^0-7^0 = 28^0, so correction +7^0 has to be made for compass

Planes Orientation

projection



Structure Contour Map

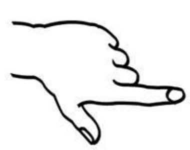


Contour Lines

True for the Left-Hand Rule.

Basically dip should be noted: 22*SW*/105.

Alternatively Dip direction (Instead of Strike) may be noted.



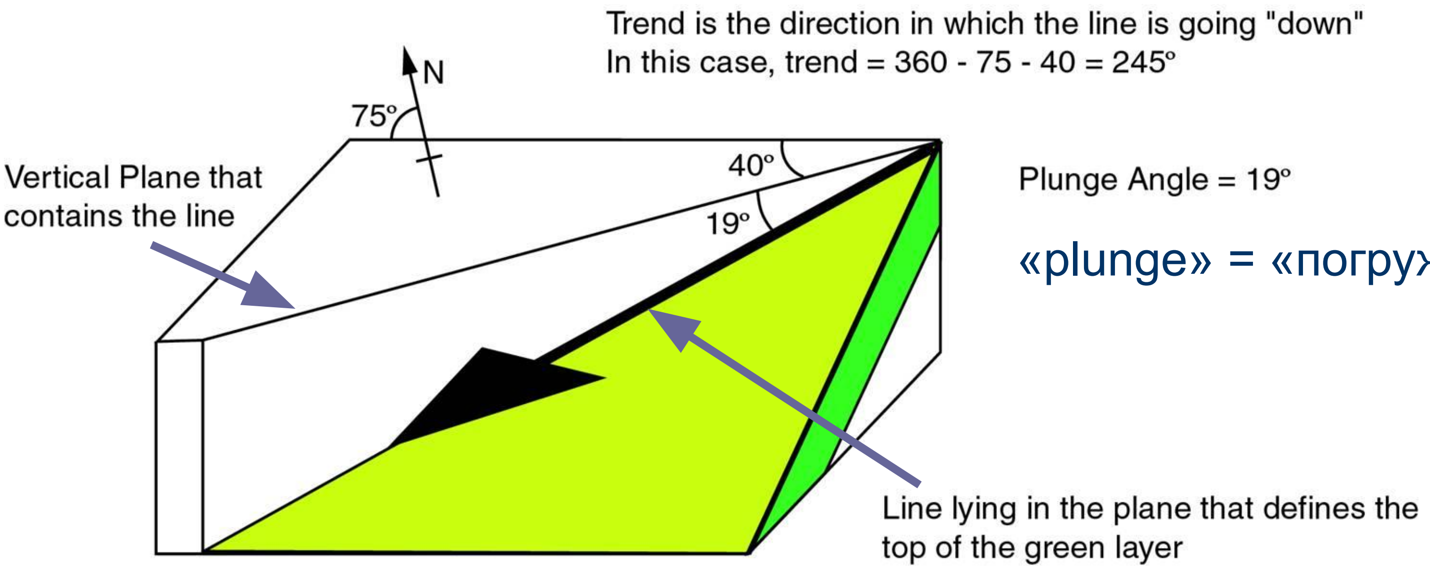
Left-Hand Rule:
If left thumb points **down** dip,
then left index finger points in **strike** direction.

In this example: dip = 22°, strike 105°

This is written as: 22/105
(other conventions exist)

Multiple "rules" exist…

Orientation of Lines



«plunge» = «погружение»

In this example: plunge = 19°, trend = 245°

This is written as: 19/245

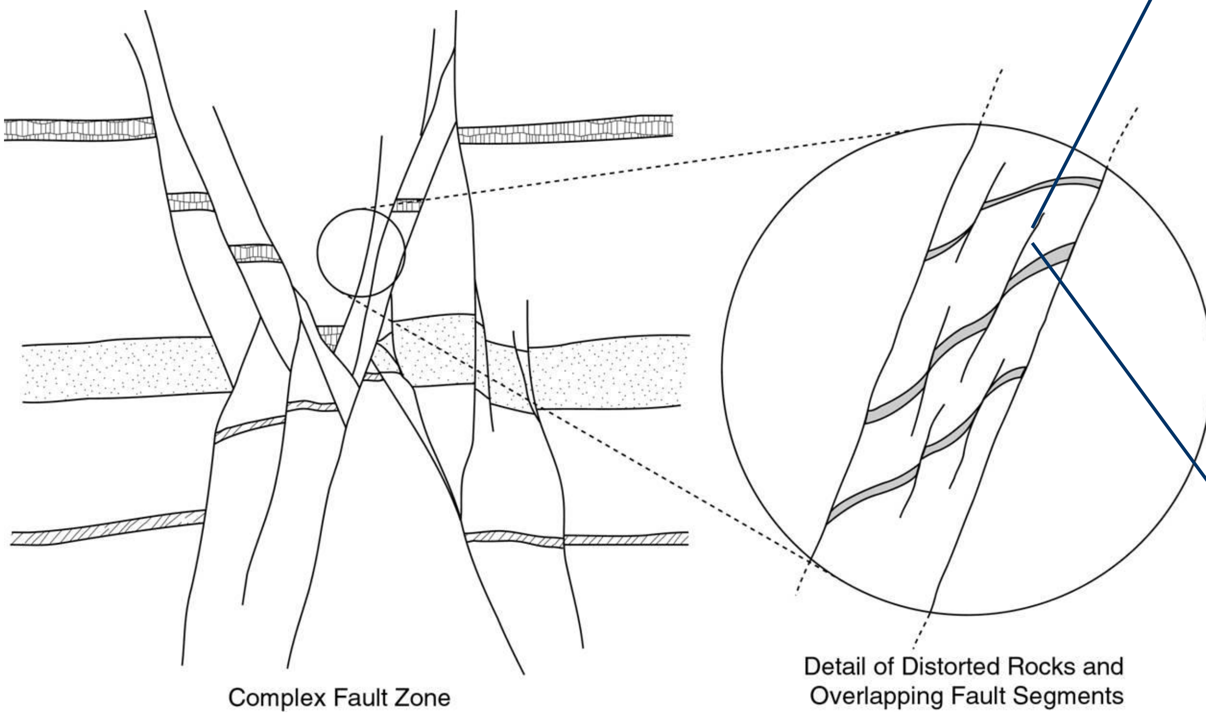
Again, multiple "rules" exist…

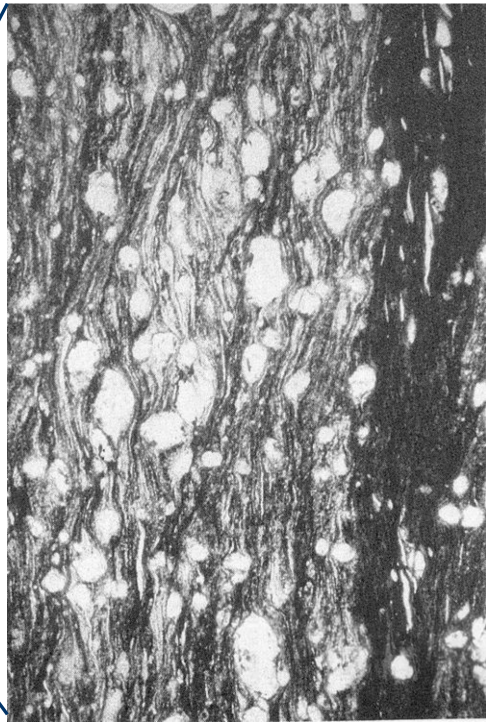
Faults

- More-or-less planar surface along which there has been relative displacement of the two sides?

OR

- Process zone (finite thickness) in which fault-rock materials are created and altered?

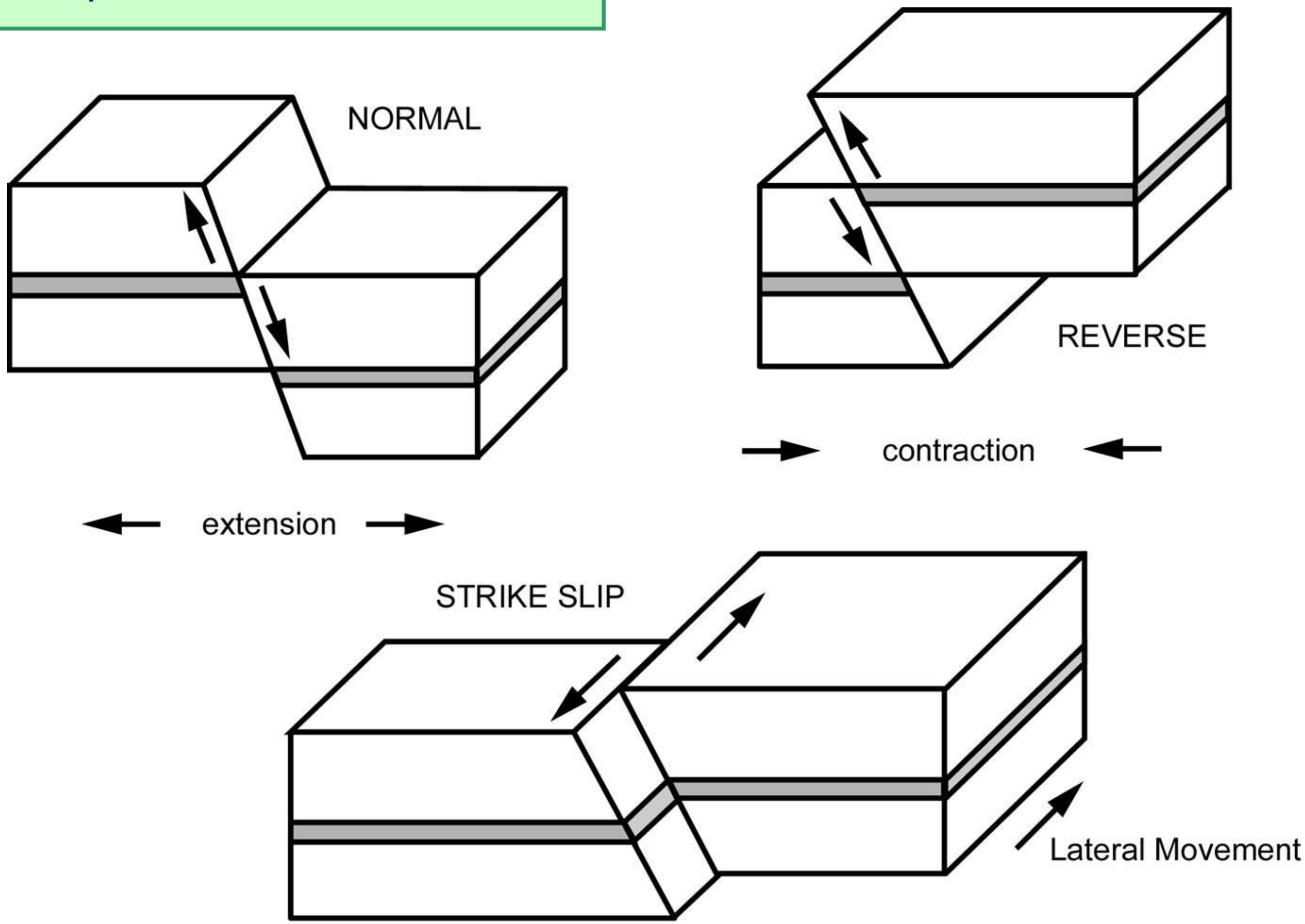




(Hooper, Hatcher, 1988)

Fault Names

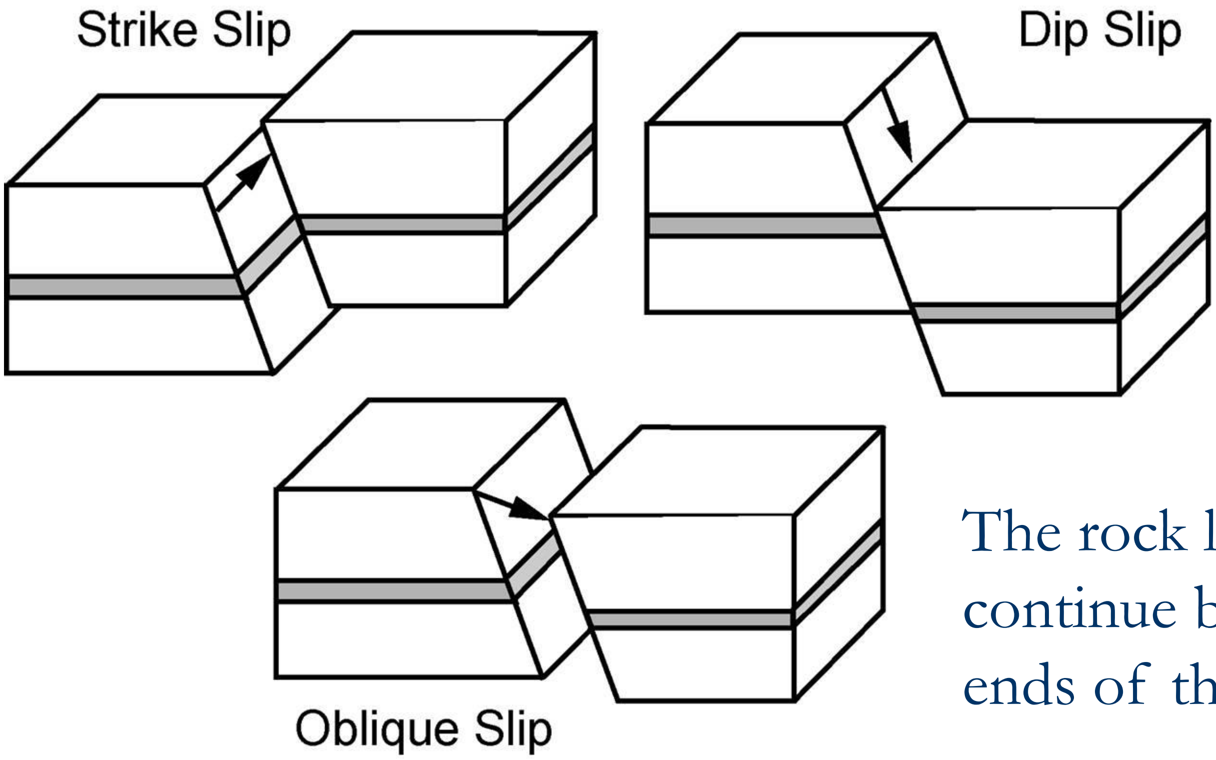
- Normal Fault = «сброс»
- Reverse Fault = «взброс»
- Strike Slip Fault = «сдвиг»



Slip Direction

Strike Slip Direction:

- opposite block moves to the left: ***Sinistral Strike Slip*** = «левосторонний сдвиг»
- opposite block moves to the right: ***Dextral Strike Slip*** = «правосторонний сдвиг»

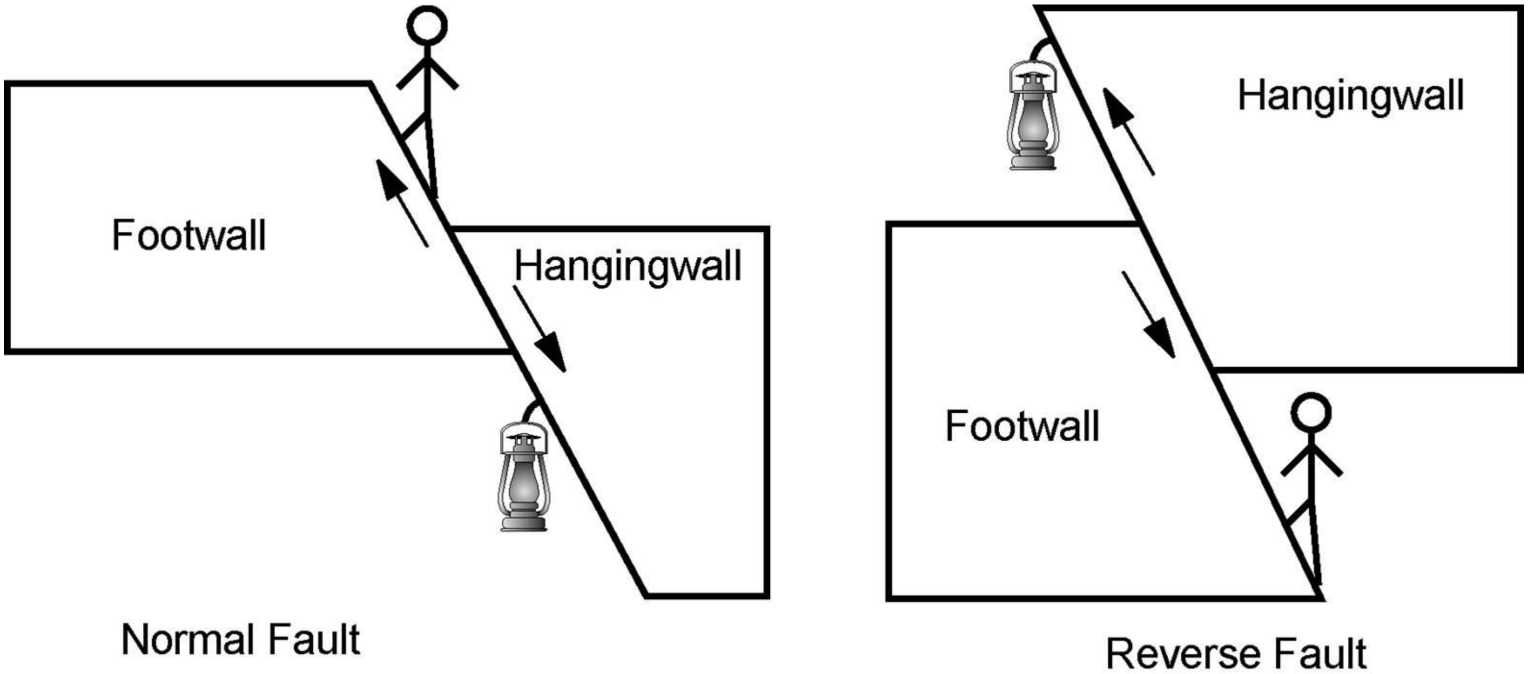


The rock layers continue beyond the ends of the drawing!

Naming the Blocks

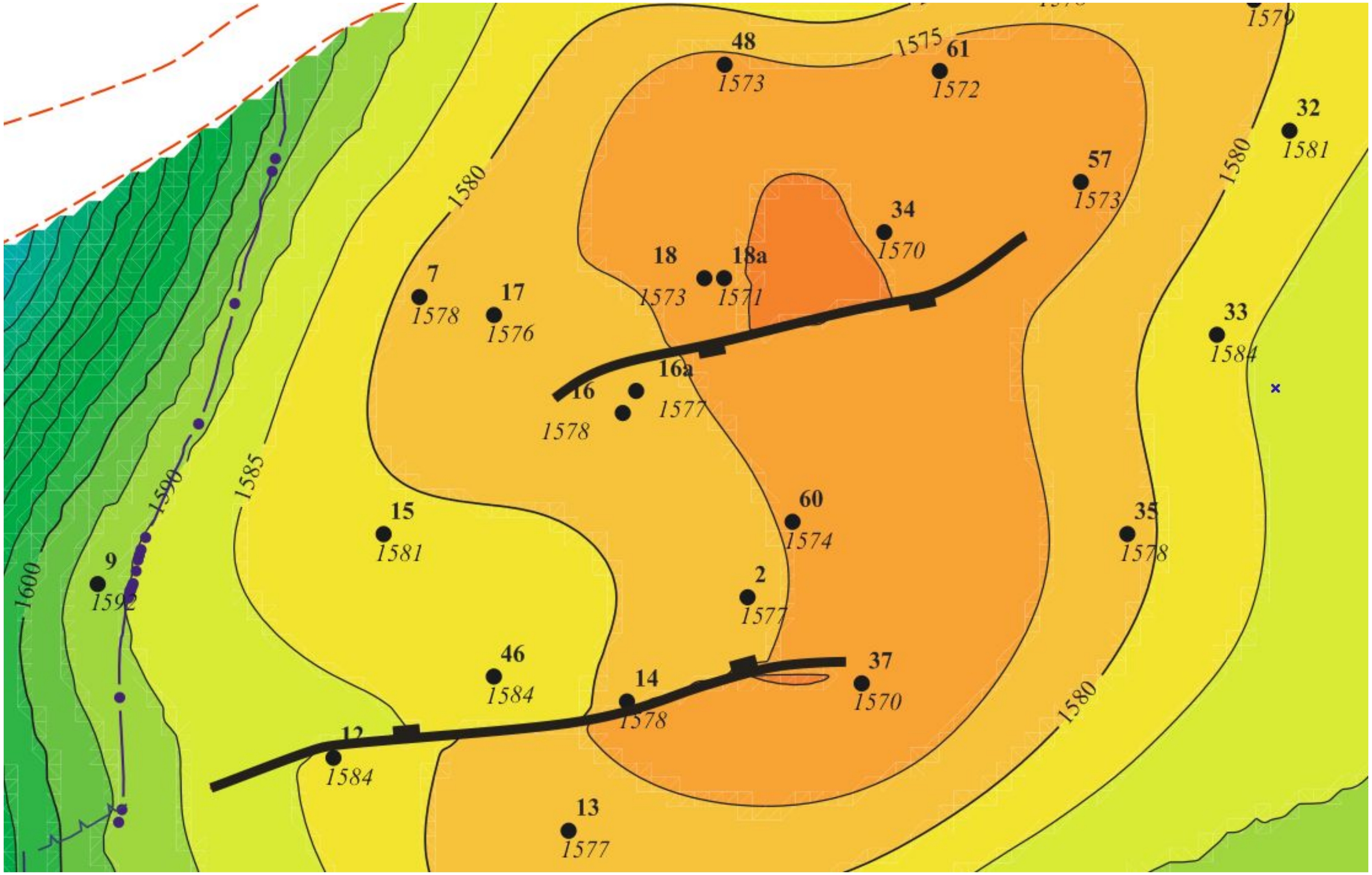
- Hangingwall = «висячее крыло»
- Footwall = «лежачее крыло»

Old mining terms



Recognizing Faults on Structural Maps

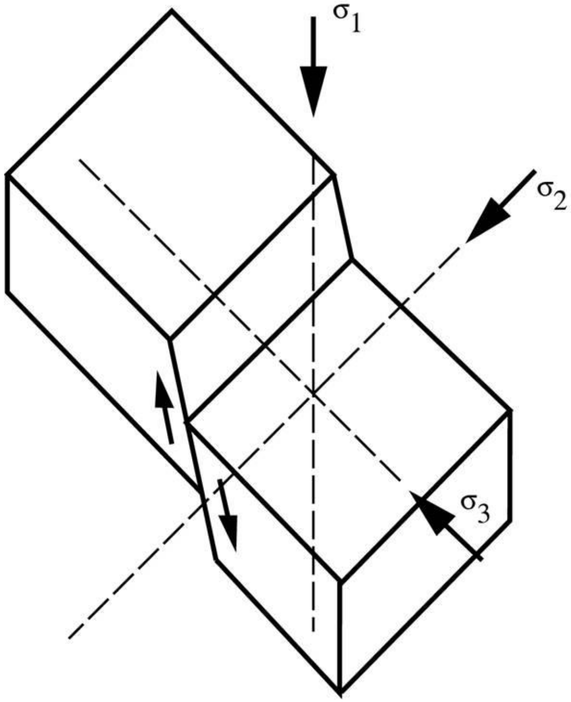
Naming the blocks and recognizing fault' types

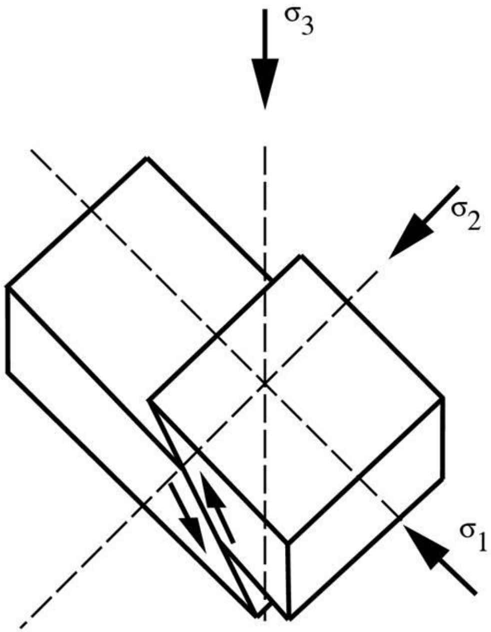


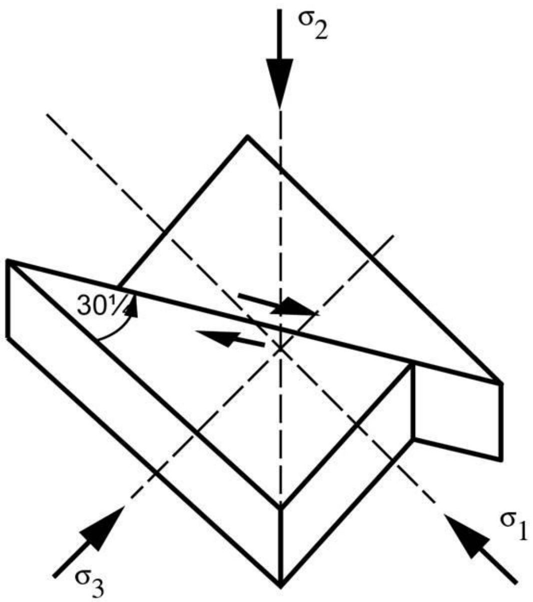
Kisimbay Oilfield, Western Kazakhstan (Bisengalieva et al., 2002)

$\sigma_1 \geq \sigma_2 \geq \sigma_3$

Anderson' Faults Concept







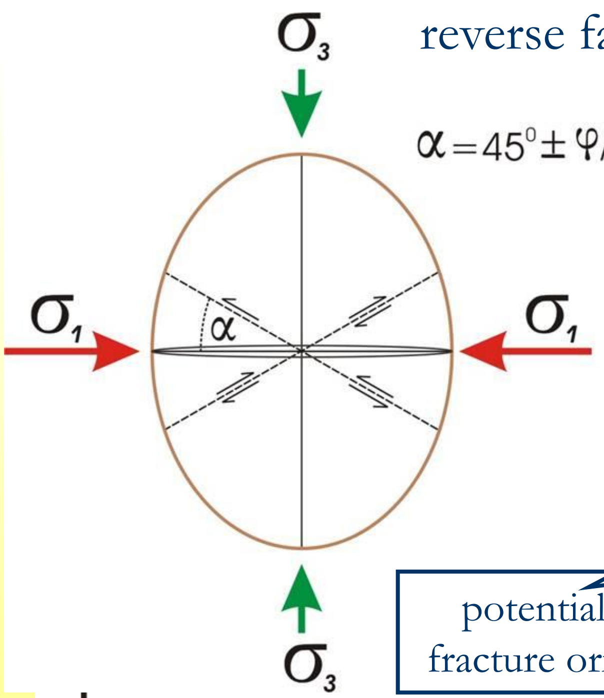
σ1 is vertical, **σ2** and **σ3** are horizontal

σ1 and **σ2** are horizontal, while **σ3** is vertical

σ1 and **σ3** are horizontal, while **σ2** is vertical

Fault's dip angle

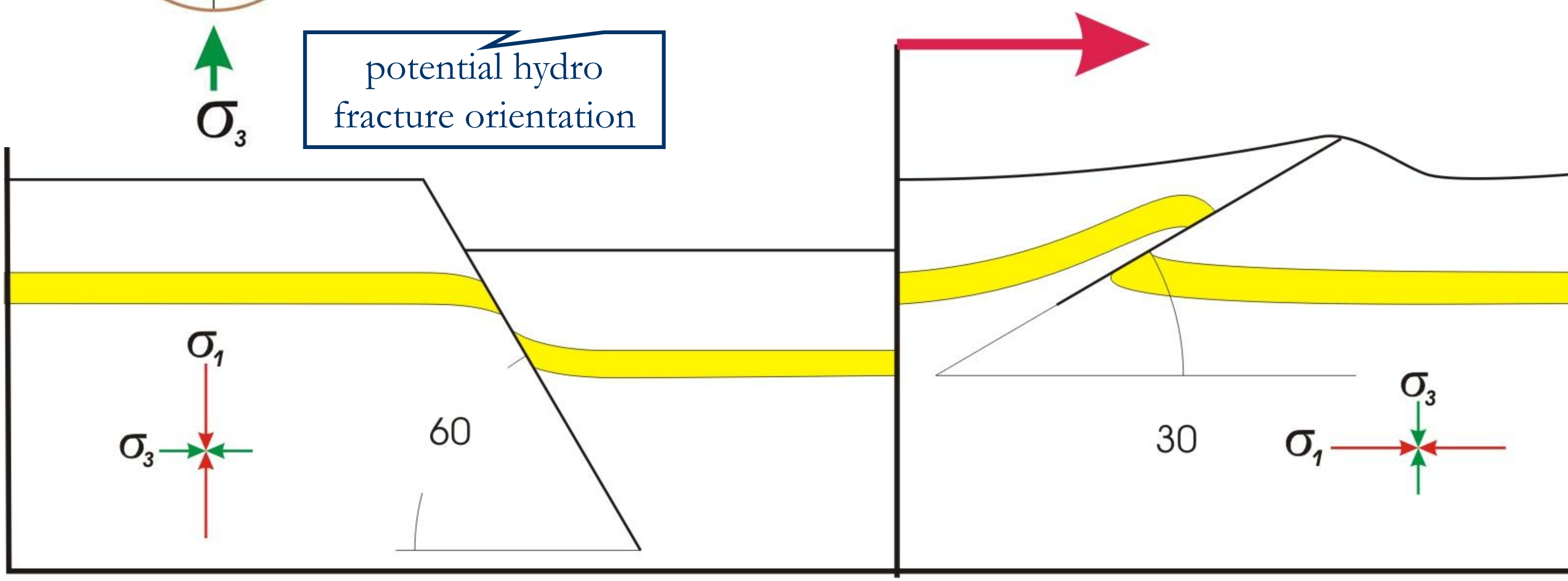
Strain ellipse (for reverse fault area)



were

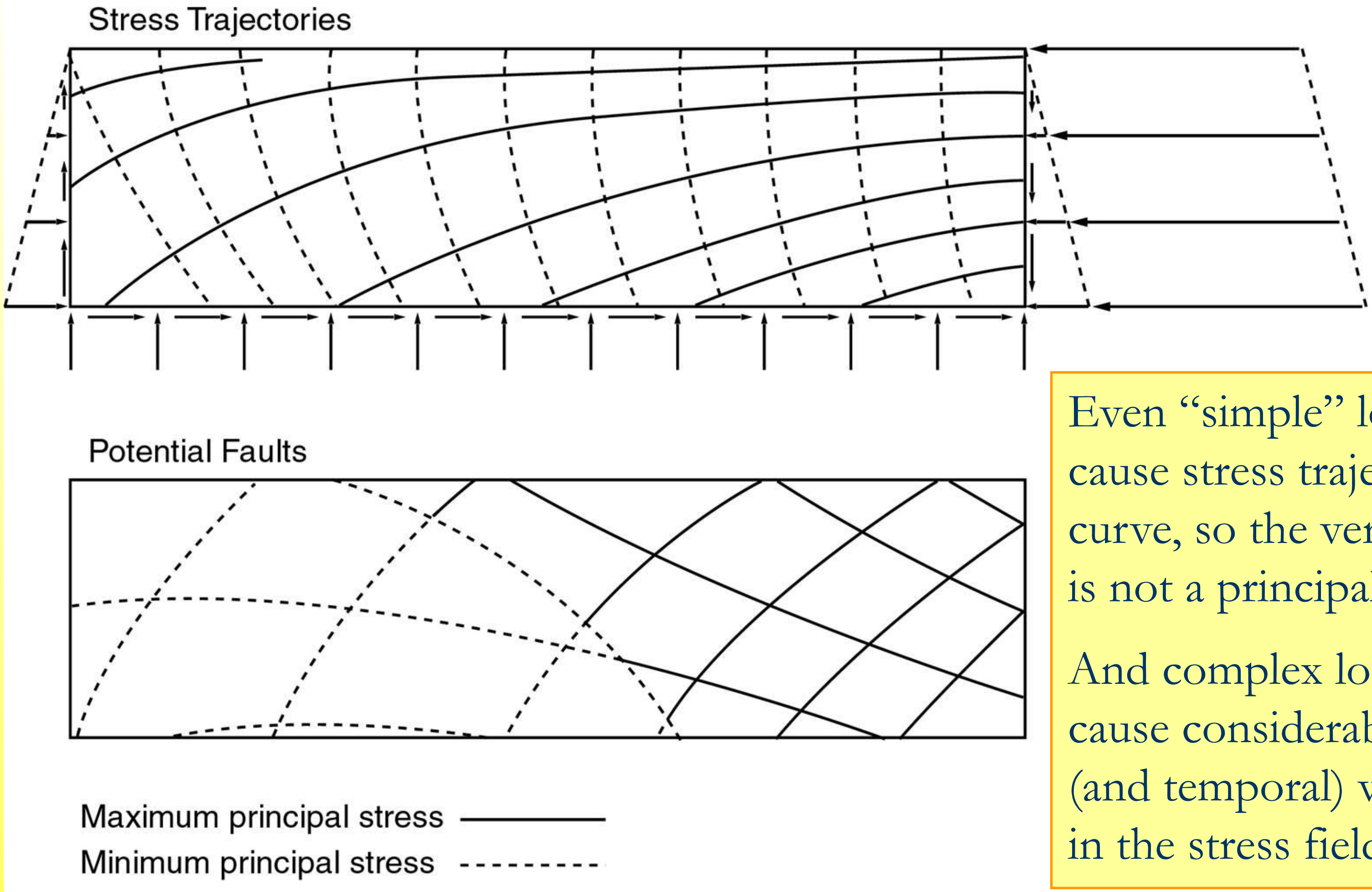
φ is a internal friction angle. For sand/sandstones within elastic behavior φ ≈ 30^{0} (and strongly depends on Poisson ratio)

potential hydro fracture orientation



Hubbert & Willis, 1957

Stress Trajectory Variations



Even "simple" loadings cause stress trajectories to curve, so the vertical stress is not a principal stress.

And complex loadings cause considerable spatial (and temporal) variations in the stress field.

Fault Sets - Extension

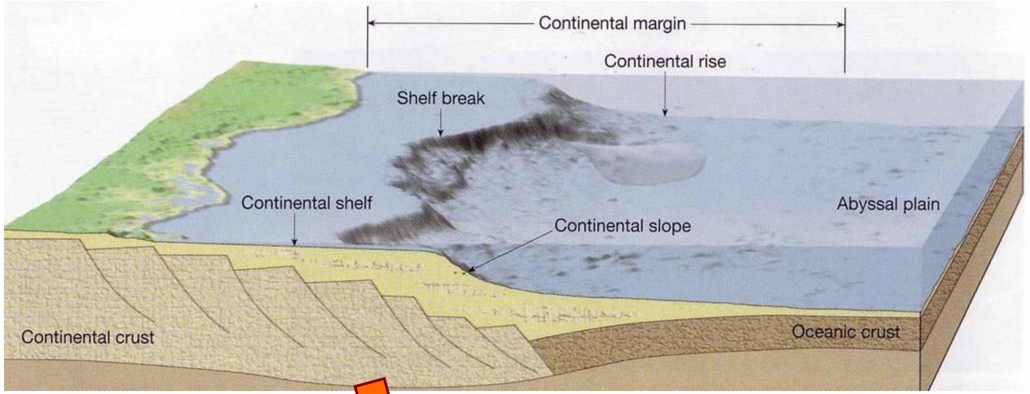
Horst = горст

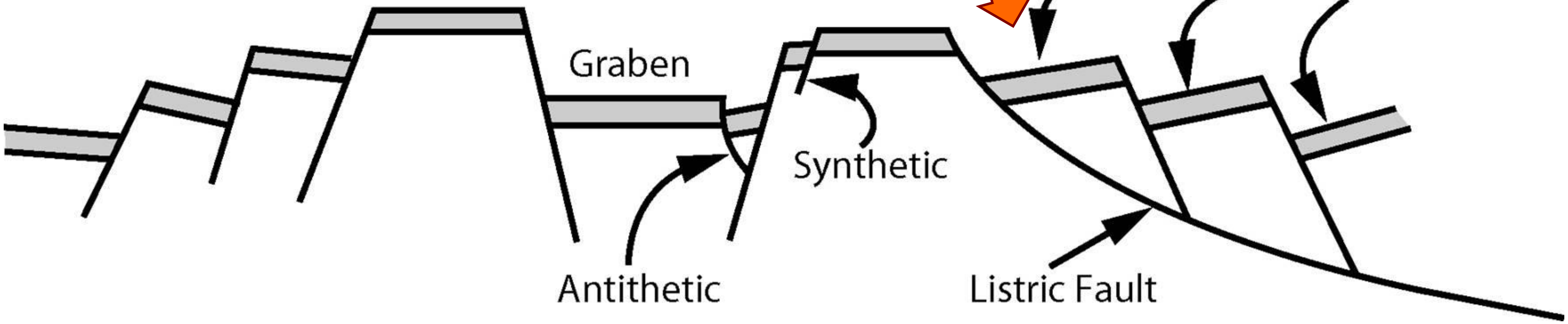
Graben = грабен

Half Graben = полуграбен

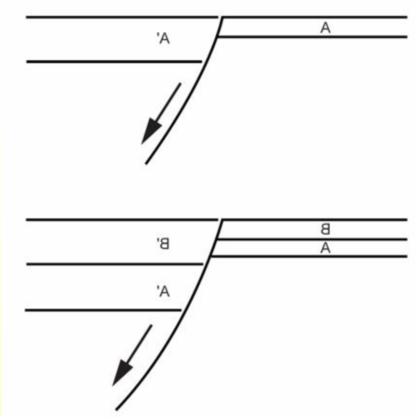
Listric Fault = листрический разлом

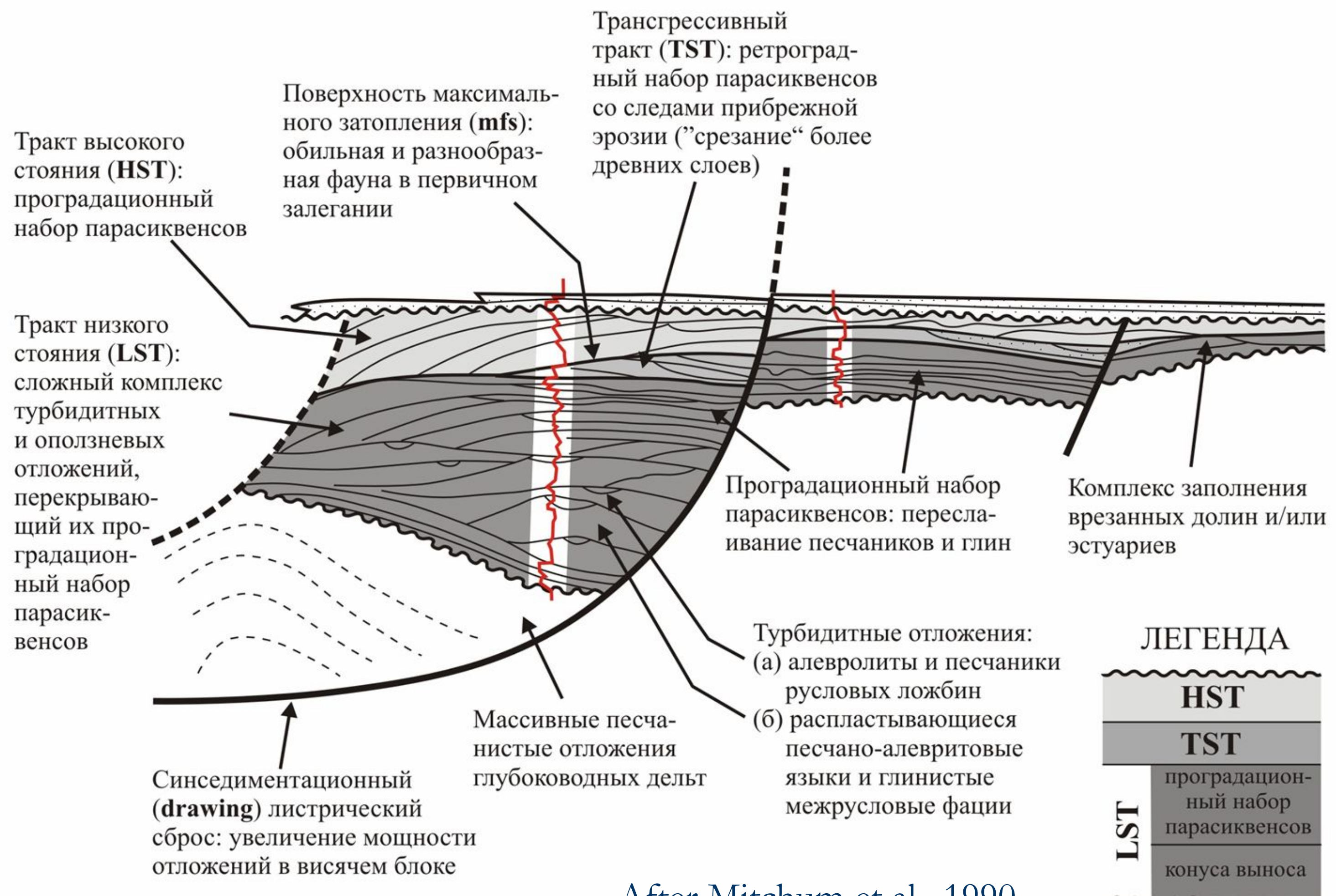
σ1 is vertical, **σ2** and **σ3** are horizontal





Fault Sets – Extension: a bit more about growing faults





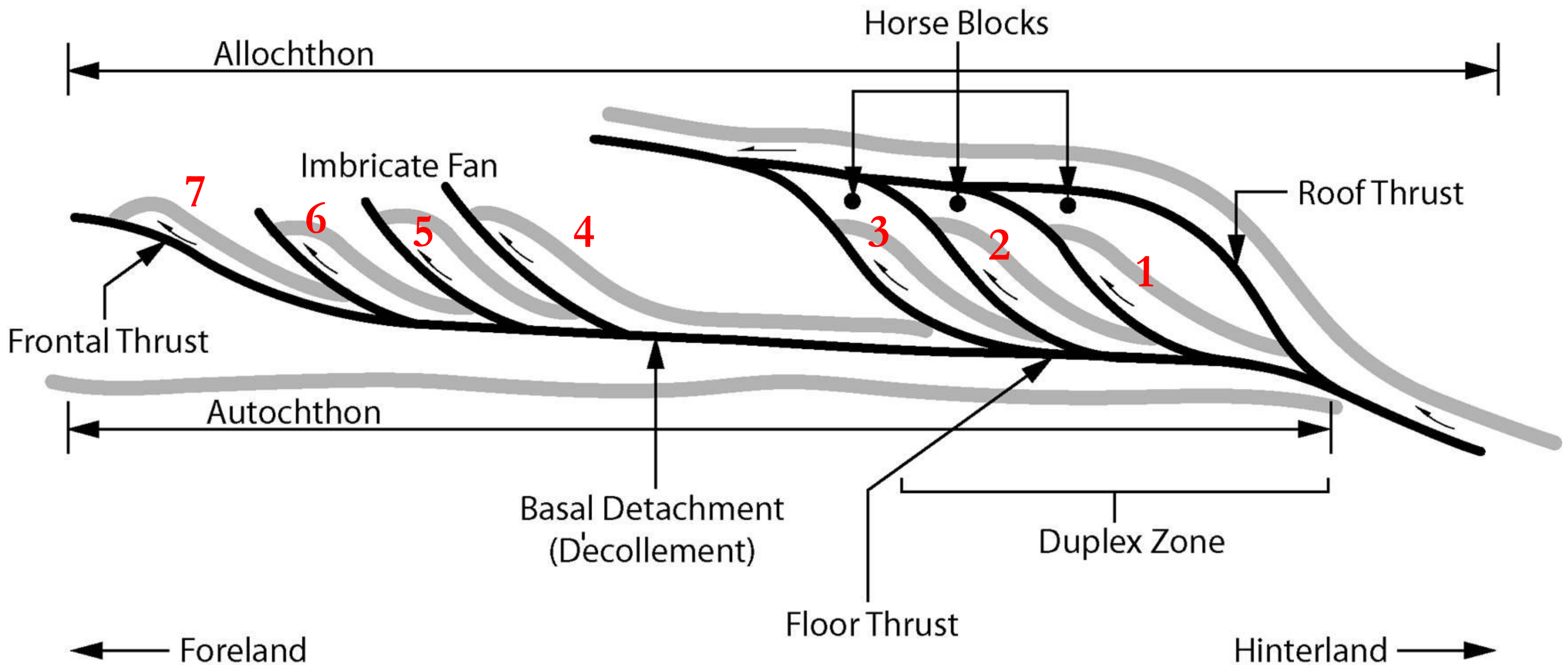
After Mitchum et al., 1990

Fault Sets - Shortening

Duplex Zone = дуплекс

Imbicate Fan = чешуйчатый надвиг

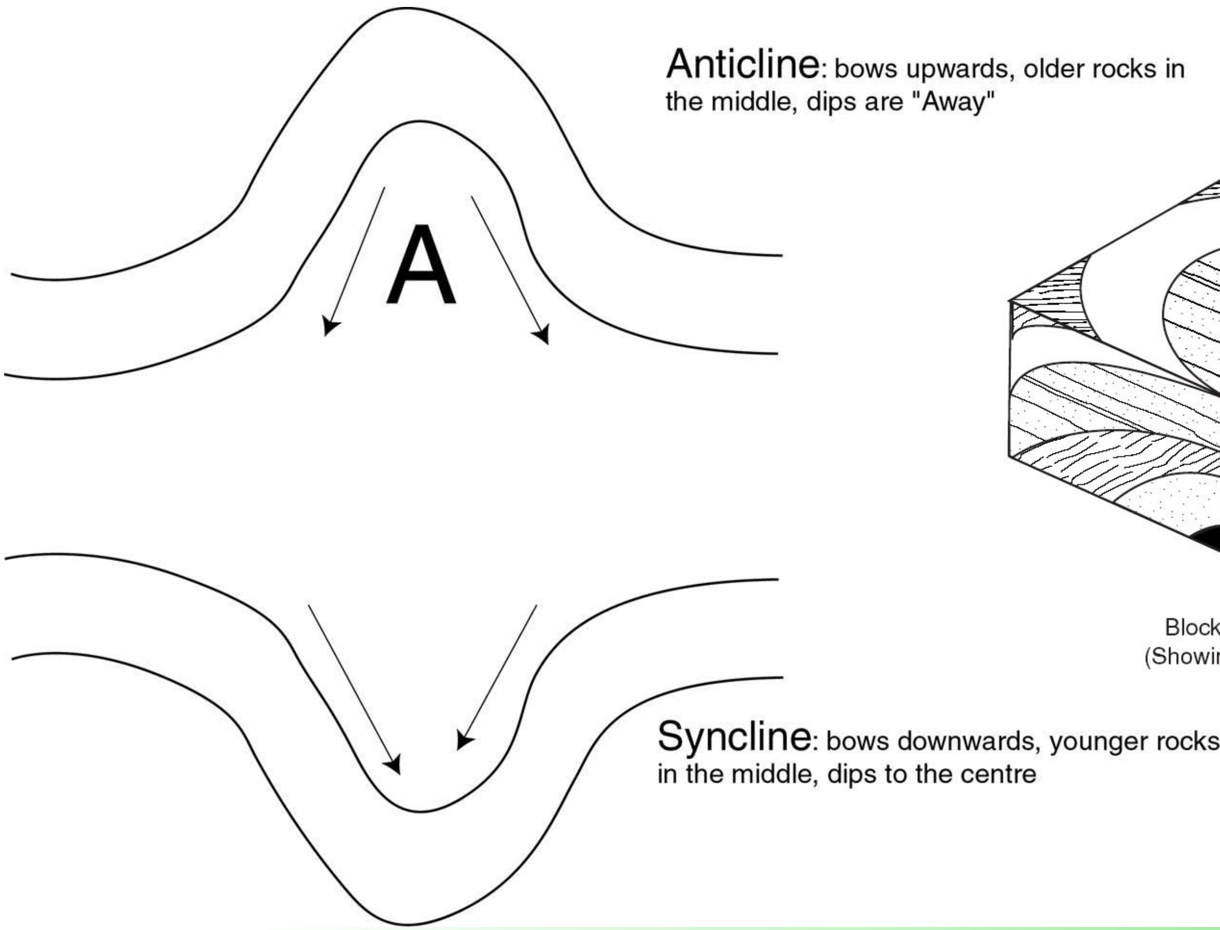
Detachment = детачмент

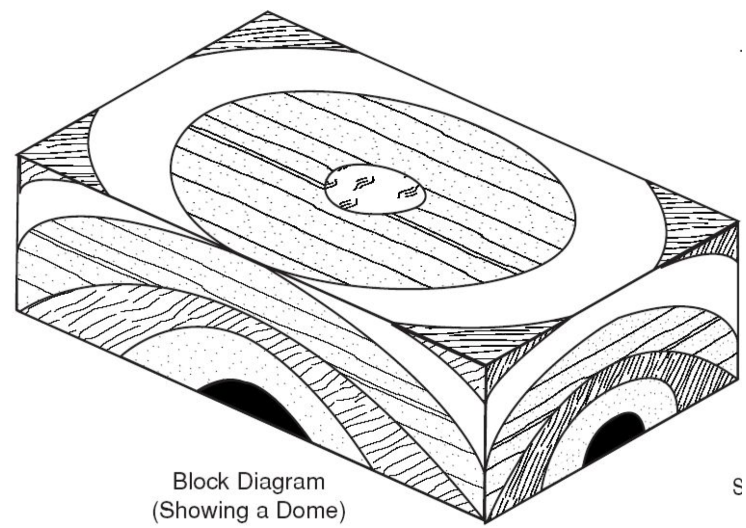


What is a fold? And Fold Names

Feature where rock layers or other markers become non-planar due to deformation

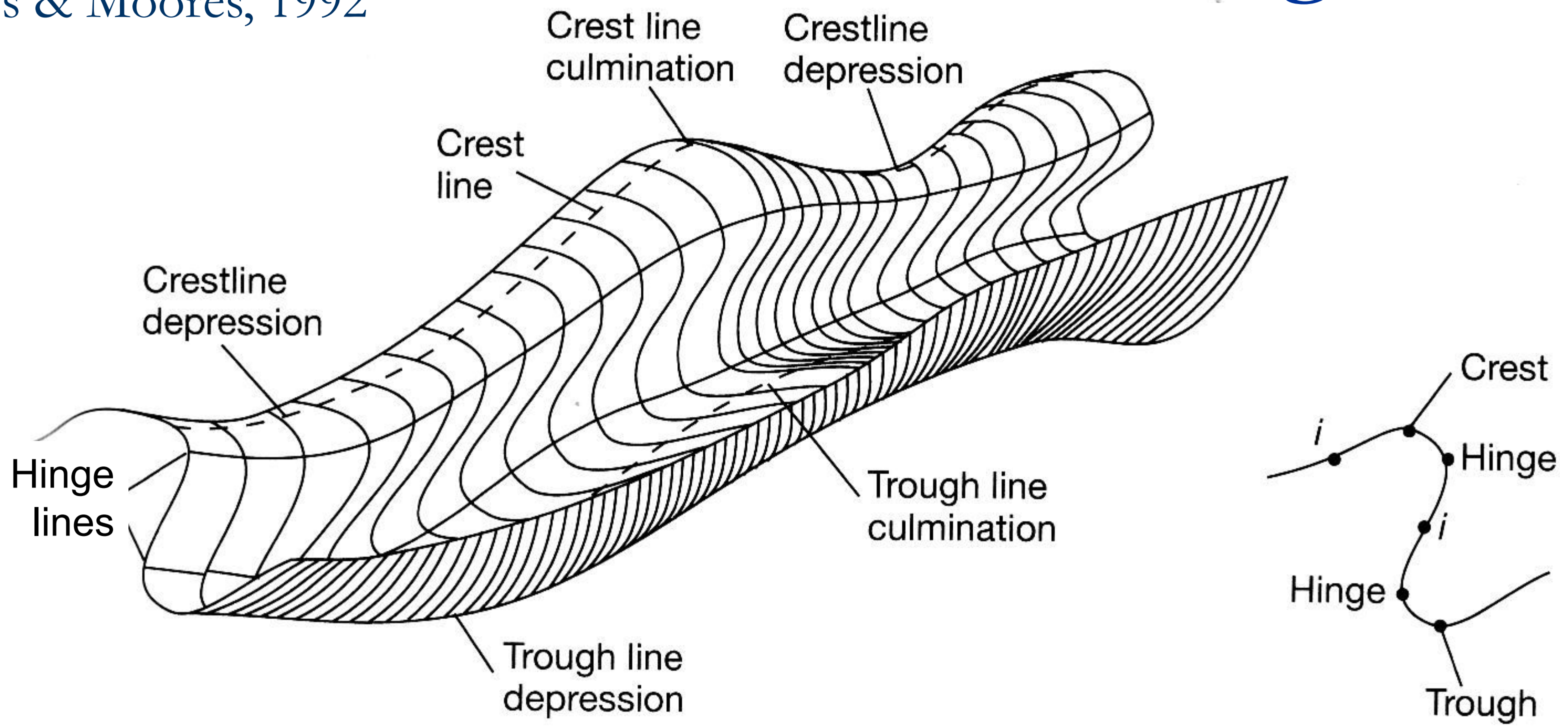
Anticlines are a major trap type





Describing Surfaces

Twiss & Moores, 1992



Crestline and Trough line are the lines of maximum and minimum elevation respectively

Hinge Line traces points with maximum curvature (doesn't necessary coincide with Crest/Trough lines)

Inflection Line (**i**) separates adjacent folds and traces area with minimal curvature (points of changing curvature sign)

Limb (or **Flank**) is low-curvature area between hinges (крыло складки)

Closure is an hight-curvature area around (or between) hinges (замок складки)

Symmetry

симметричные прямые

Symmetric folds (equal limb lengths)

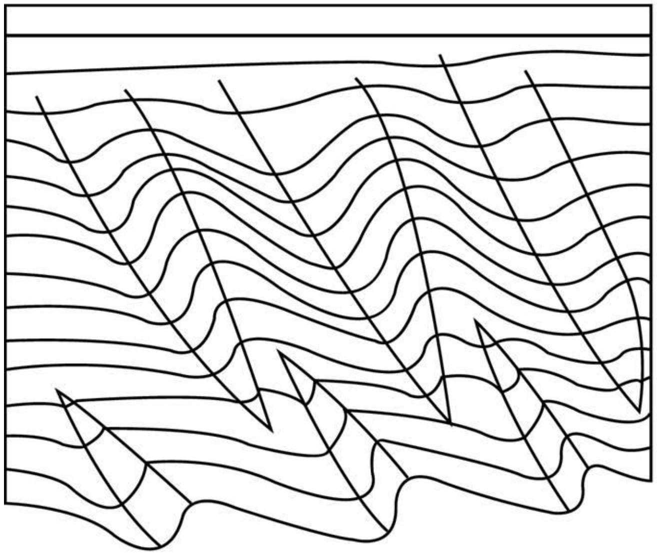
Limbs usually have same dip

Asymmetric folds (unequal limb lengths)

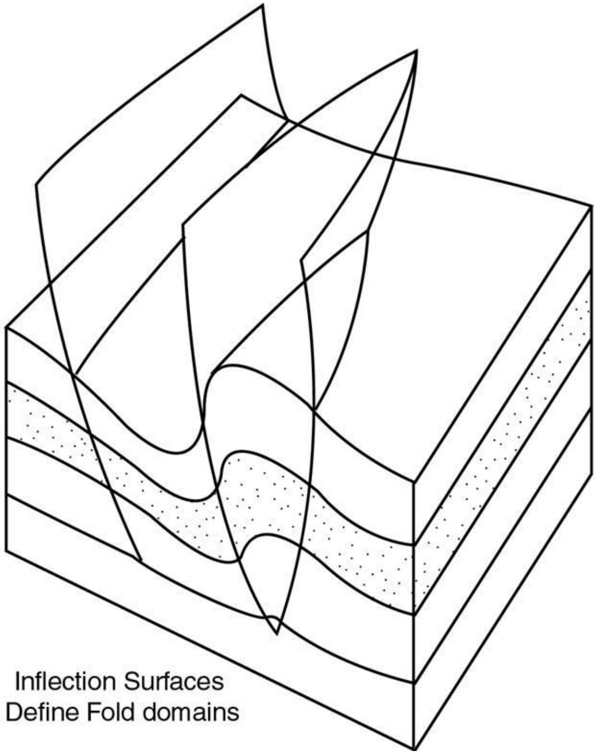
Limbs usually have different dips

наклонные (косые)

Multi-layers



Cross section of multi-layer stack showing complex array of axial surfaces

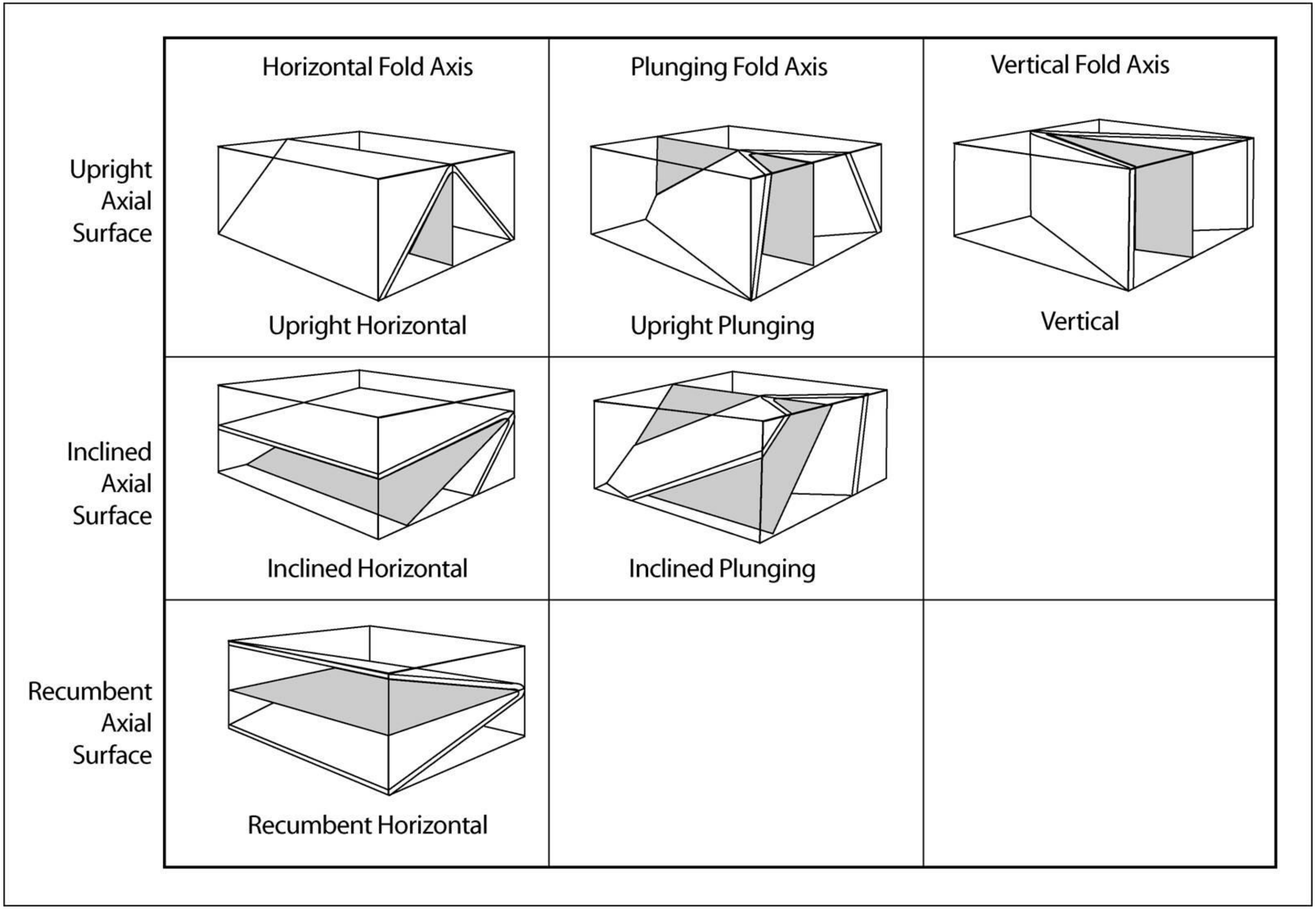


Inflection Surfaces Define Fold domains

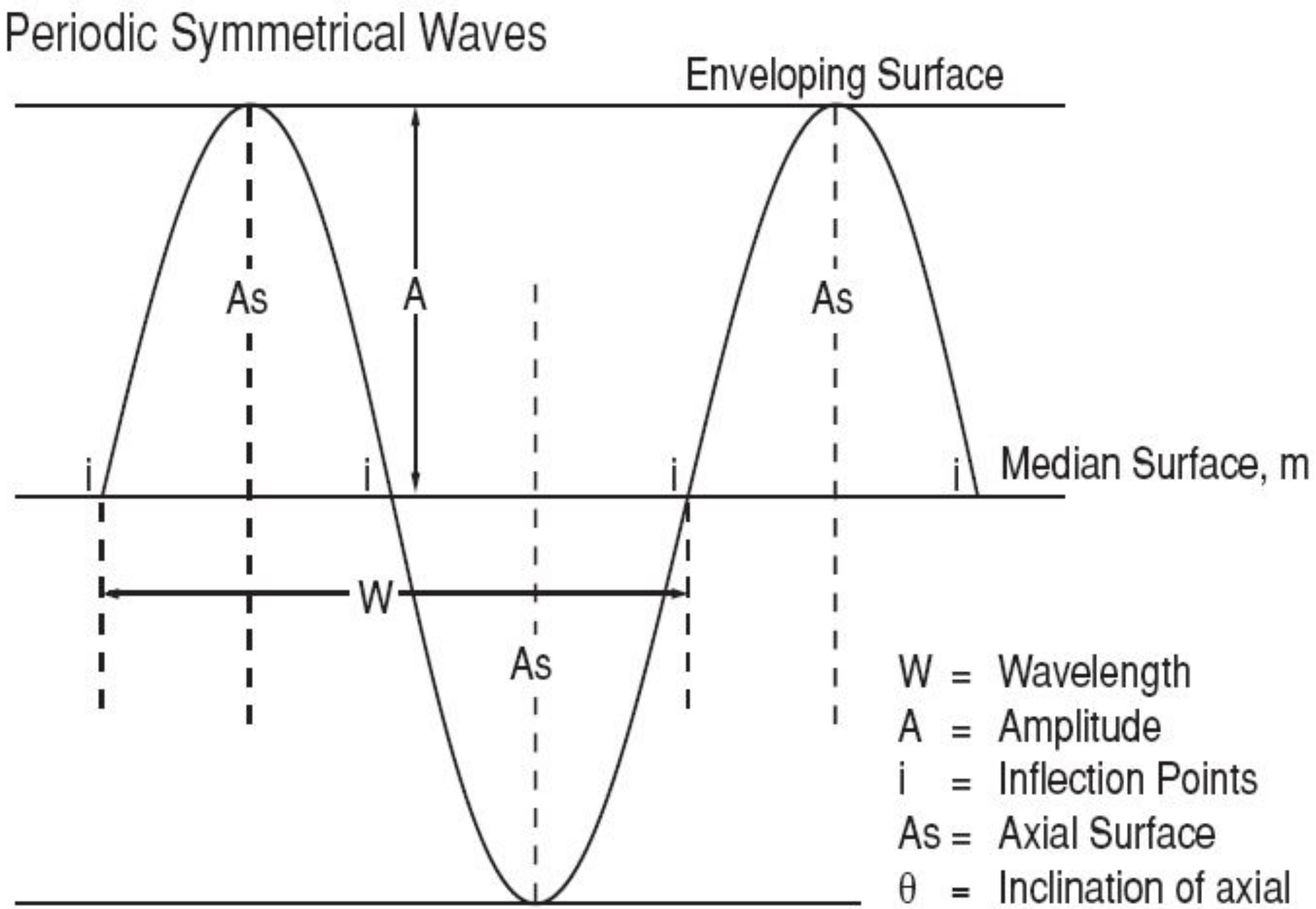
Axial surface (not always plane) connects multiple hinge lines (that is a difference with Russian terminology)

Inflection surface include inflection lines

Fold Names

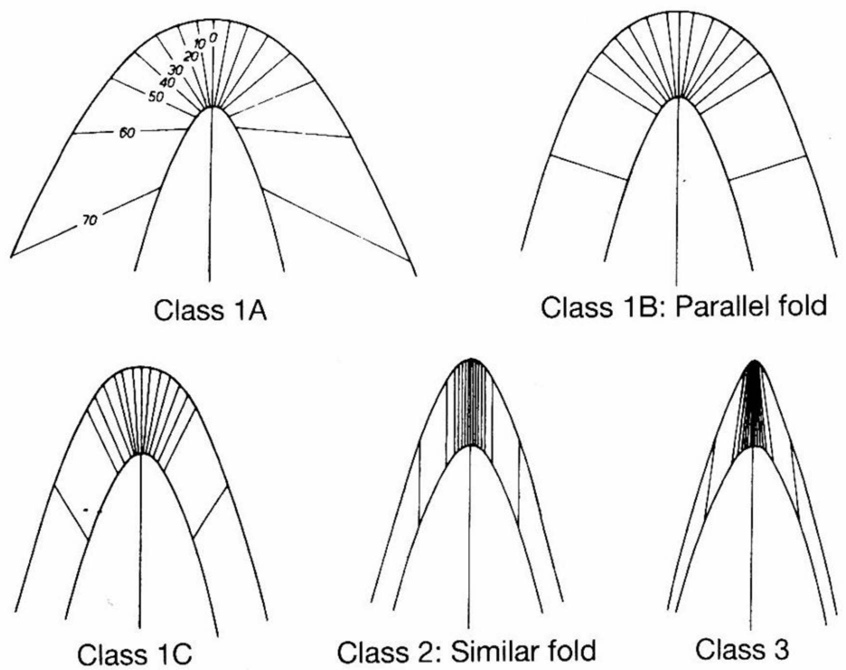

Horizontal Fold Axis
Plunging Fold Axis
Vertical Fold Axis
Upright Axial Surface
Upright Horizontal
Upright Plunging
Vertical
Inclined Axial Surface
Inclined Horizontal
Inclined Plunging
Recumbent Axial Surface
Recumbent Horizontal

Measuring Folds



W = Wavelength
A = Amplitude
i = Inflection Points
As = Axial Surface
θ = Inclination of axial surface relative to enveloping surface

Thickness changes?



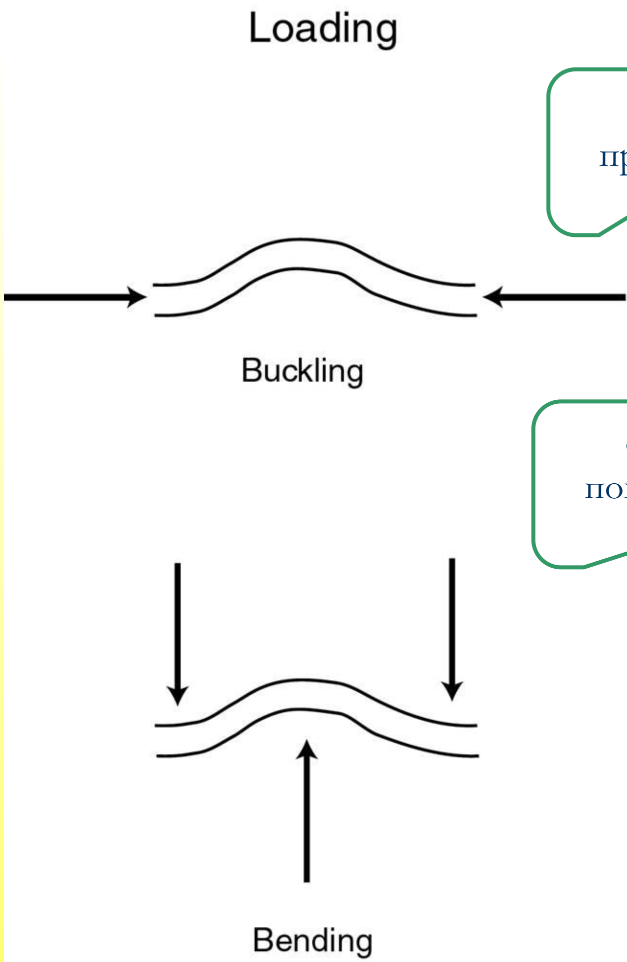
Similar Folds are more "popular" in nature: mass flow exist from high-stress areas (limbs) to low-stress (closures)

Isogone – line connected points with same dip angle

Class	Dip Isogon Geometry (from convex to concave surface)	Orthogonal Thickness (from hinge to limb)	Axial Trace Thickness (from hinge to limb)
1	Convergent		Increases
1A	Convergent	Increases	Increases
1B	Convergent	Constant	Increases
1C	Convergent	Decreases	Increases
2	Parallel	Decreases	Constant
3	Divergent	Decreases	Decreases

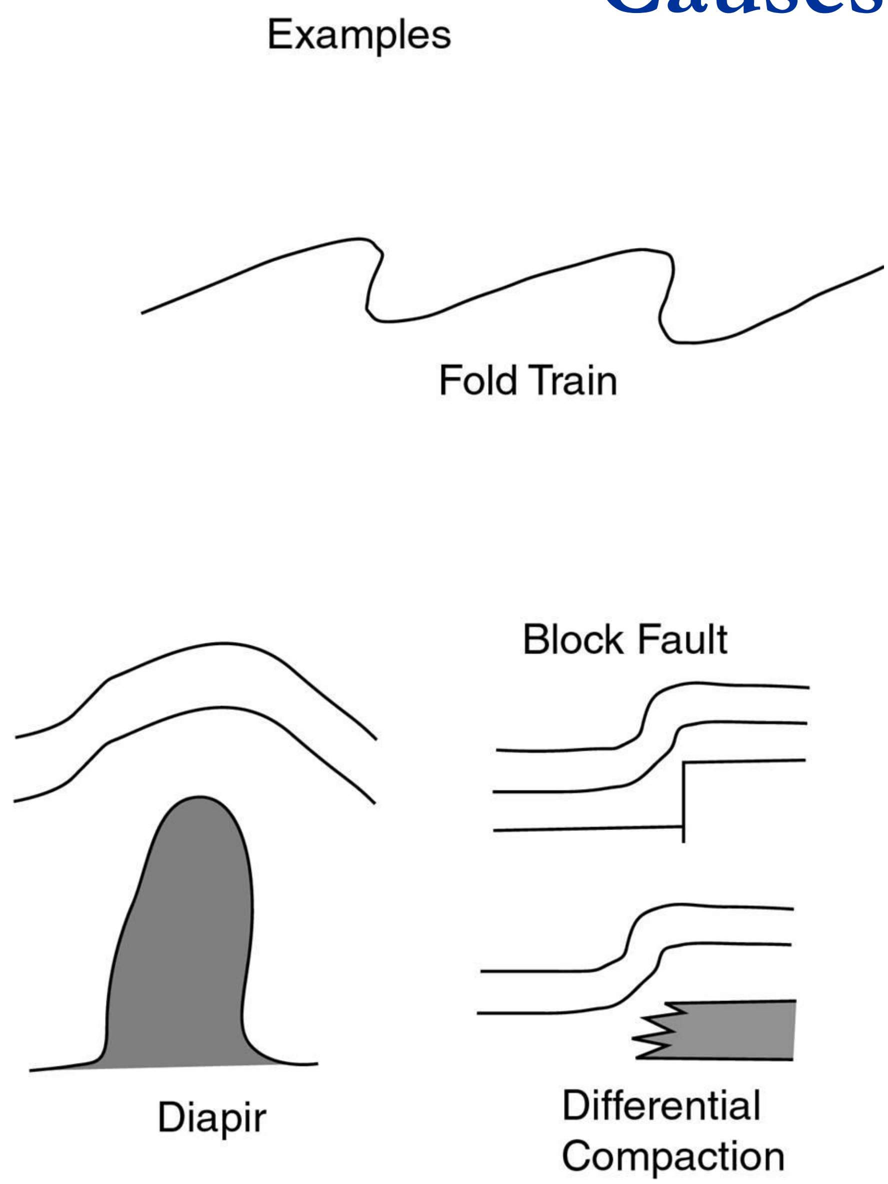
Source: After Ramsay (1967).

Causes?

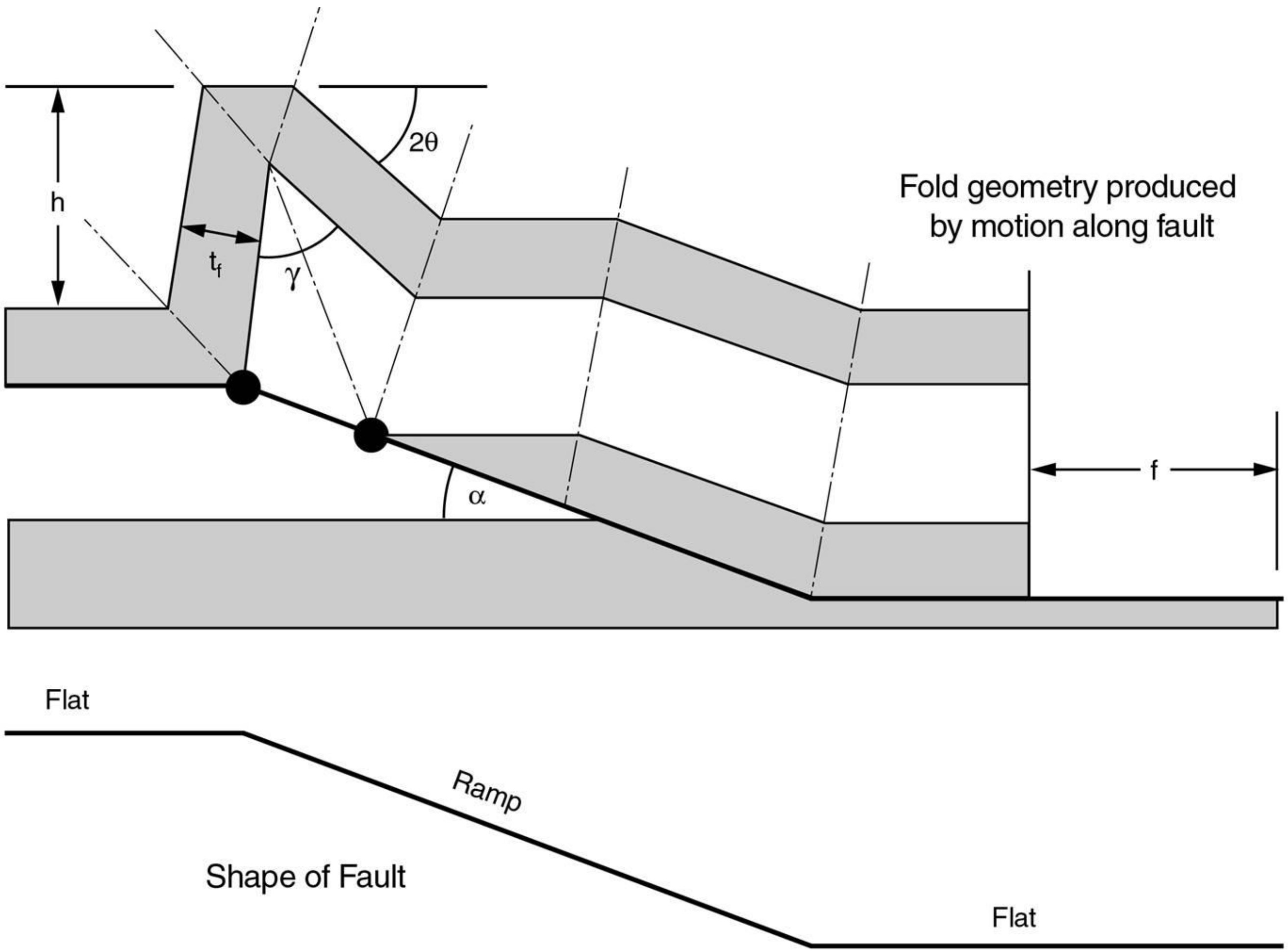


складки продольного изгиба

складки поперечного изгиба

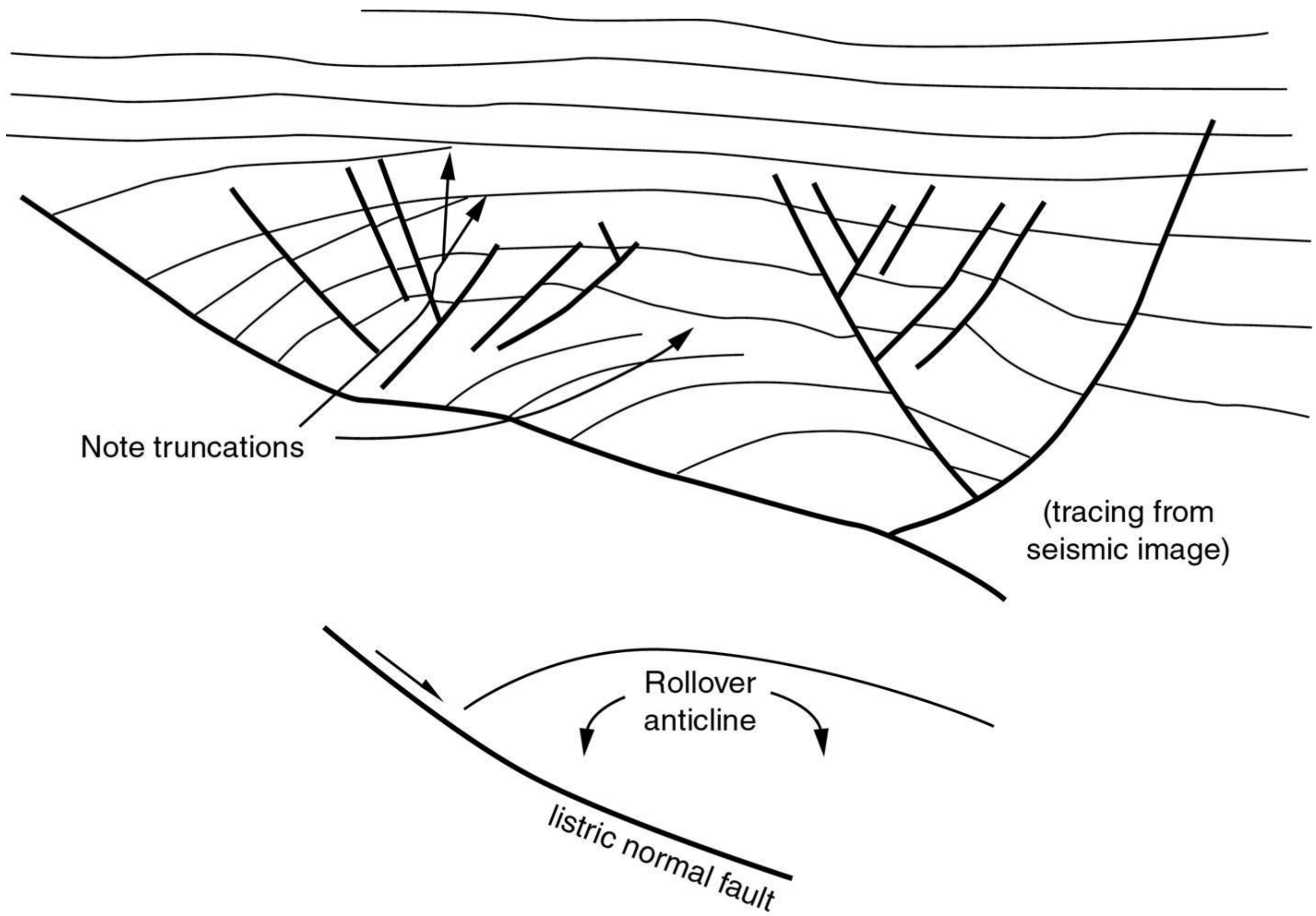


Fault-Bend Interaction: Folds

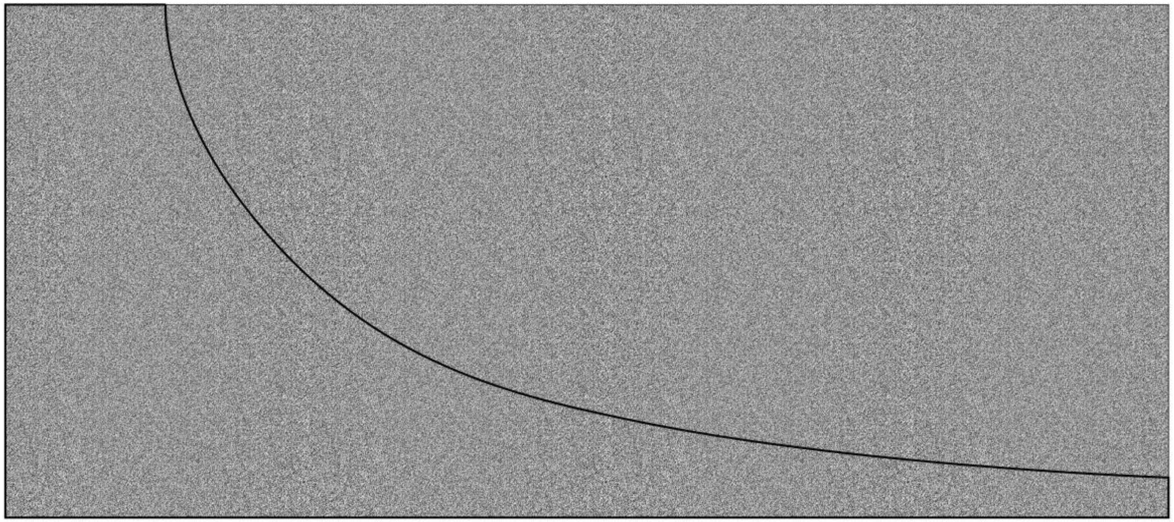


Detached Folds

Rollover Structures



Rollover Structures



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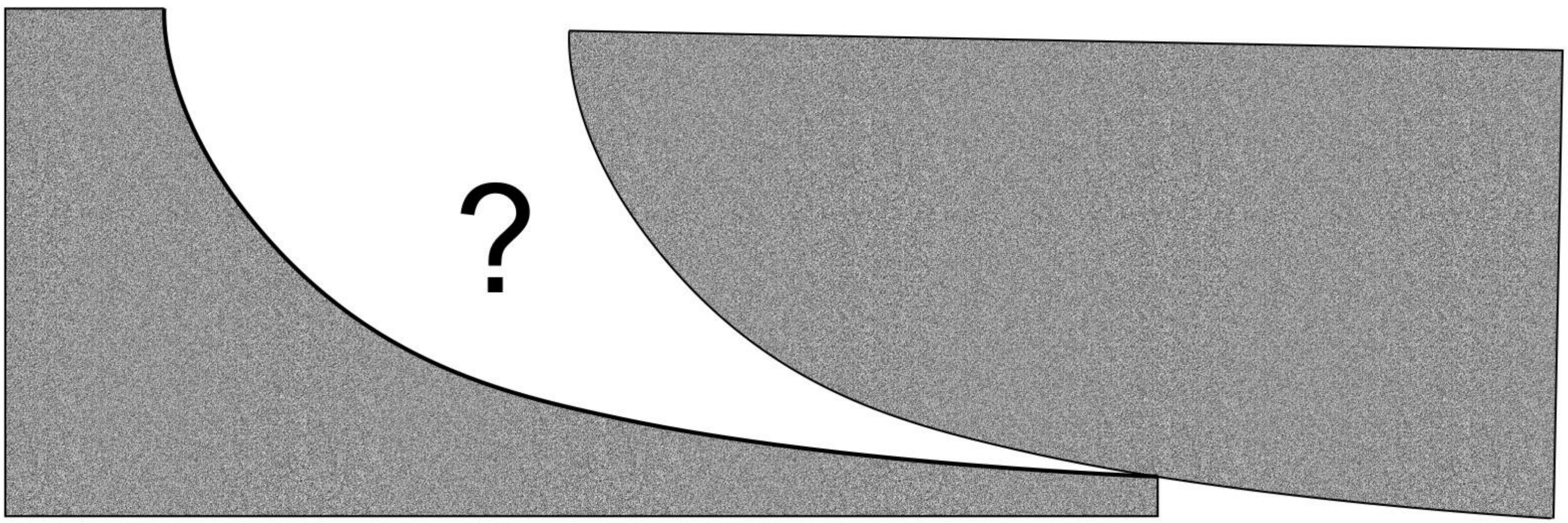
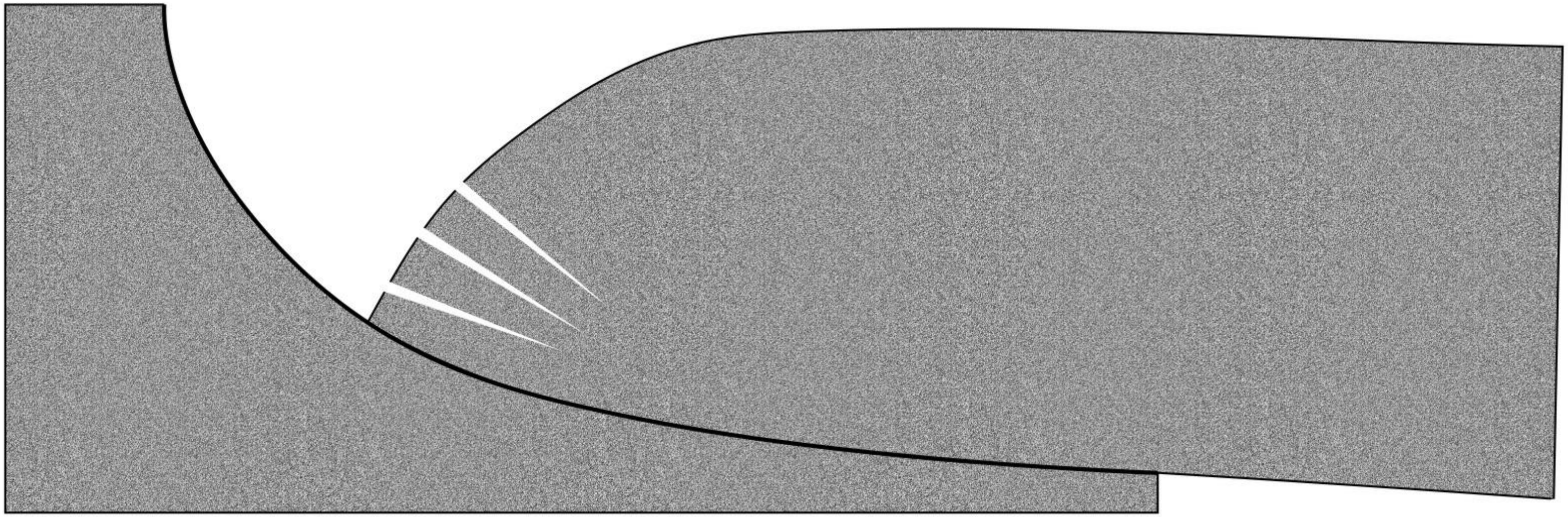


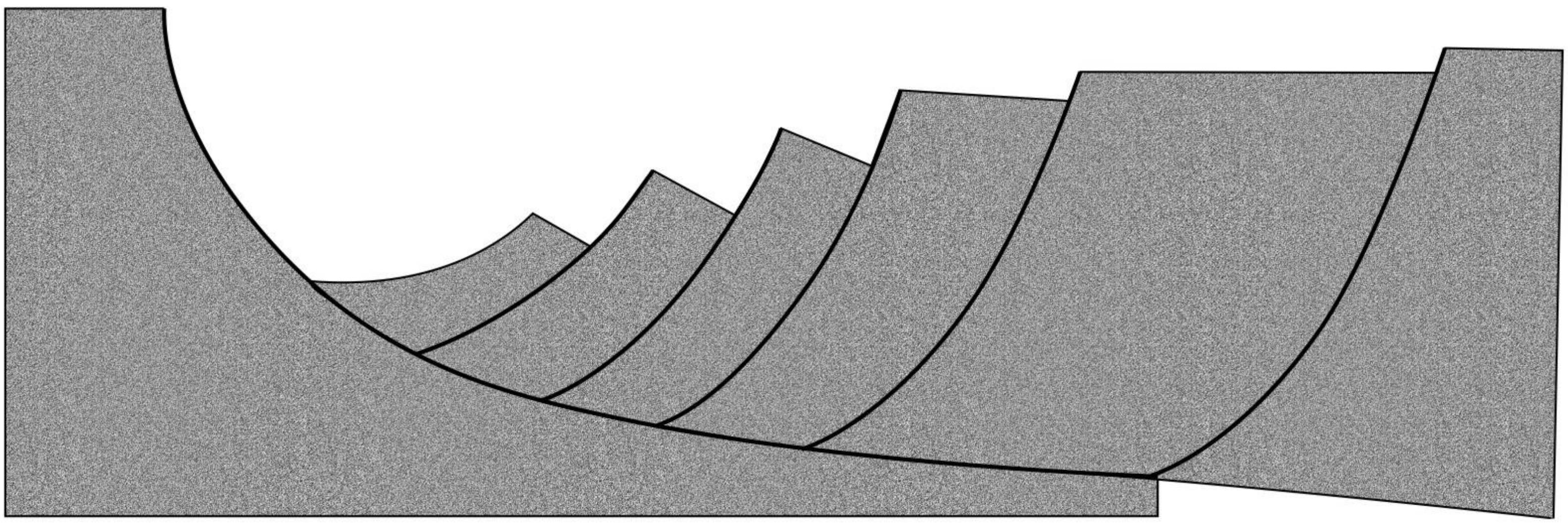
Rollover Structures

rollover anticline: ductile scenario



Rollover Structures

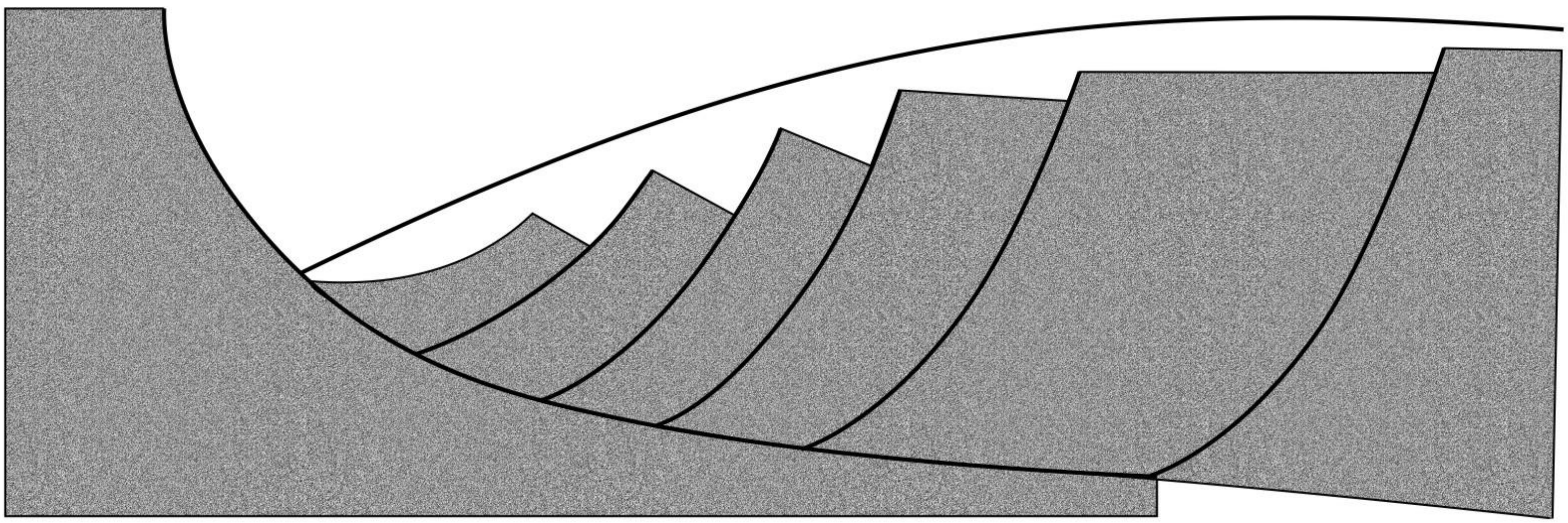
rollover anticline: brittle scenario, antithetic faults development



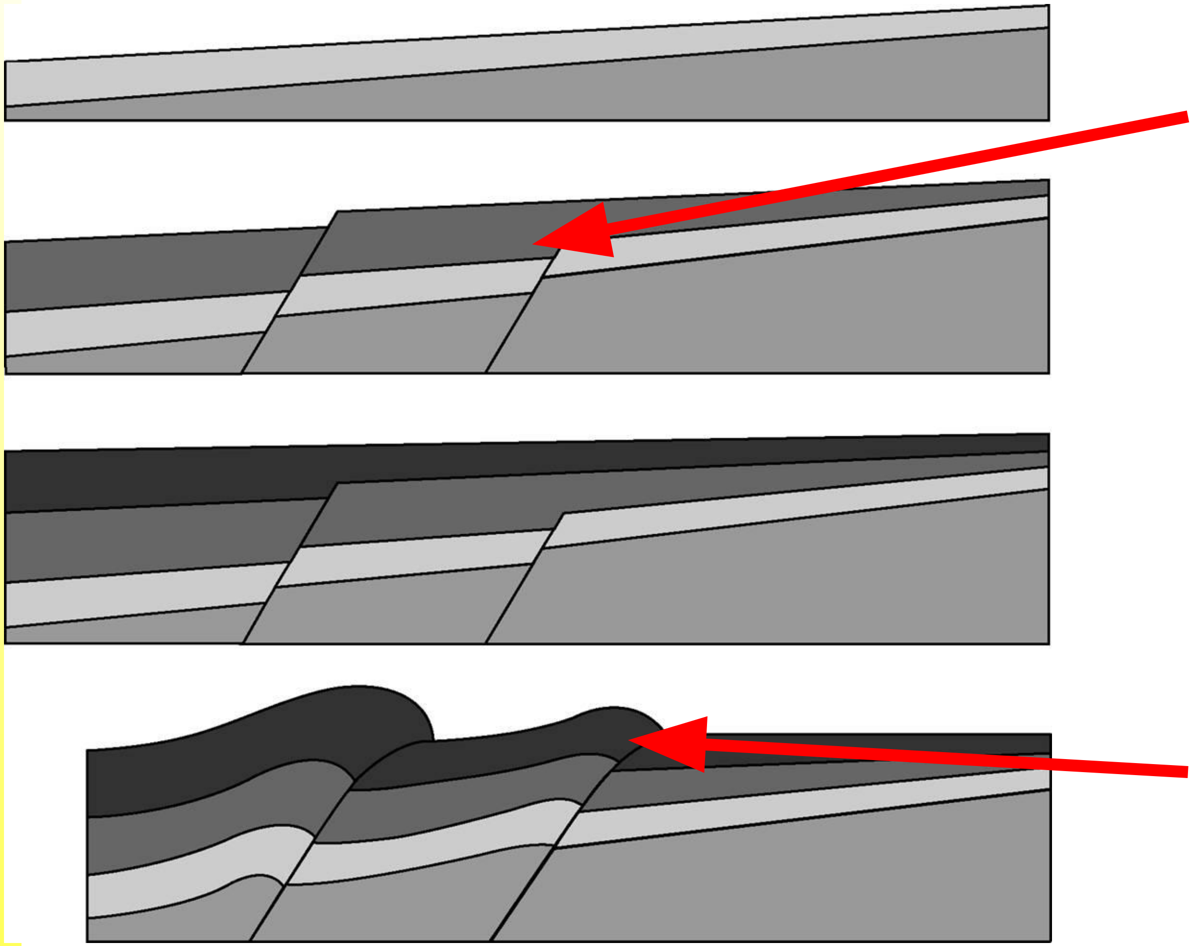
antithetic faults

Rollover Structures

rollover anticline: brittle + overlaid



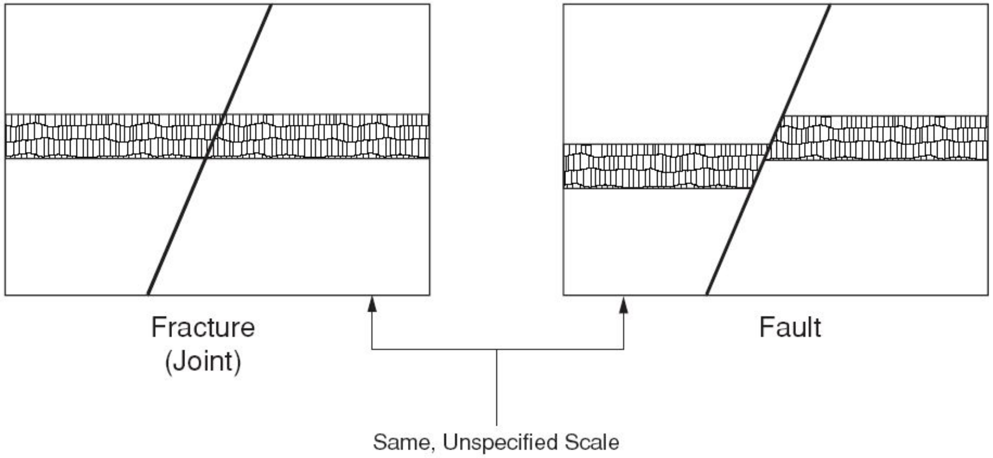
Inversion



Early: extension, with sediments thickening across faults

Later: shortening, re-use of previous faults

Fractures



Fractures vs Faults: almost invisible (not more then few mm) lateral motion along fracture surface

Fractures

$$k_f = \frac{a^3}{d} \cdot 8.35 \cdot 10^9$$

$$\varphi_f = \frac{a}{a+d} \cdot 100$$

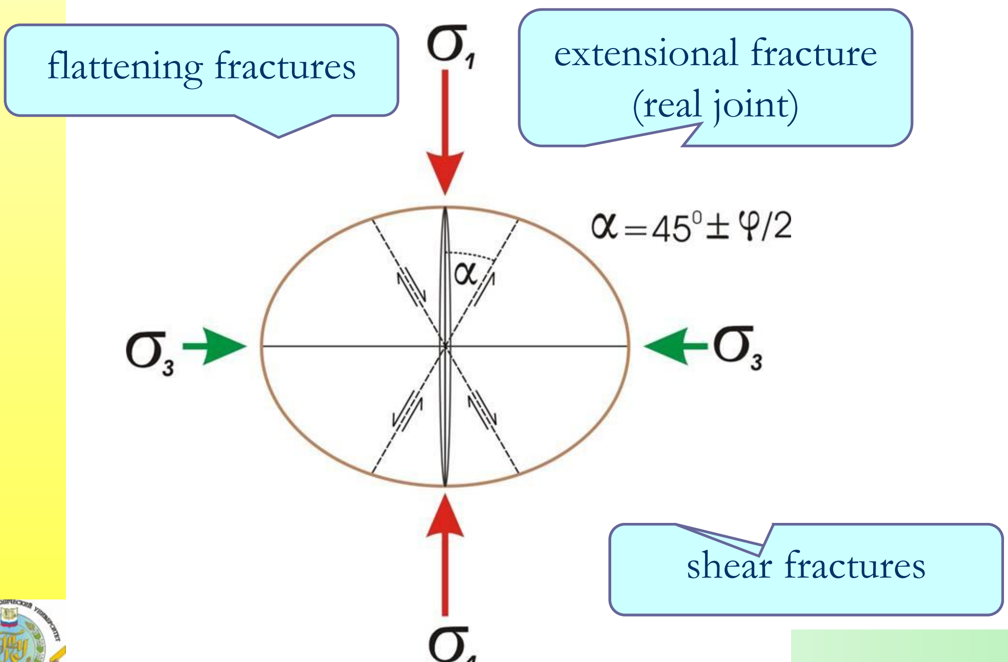
where

k_f = fracture permeability (mD)

φ_f = fracture porosity

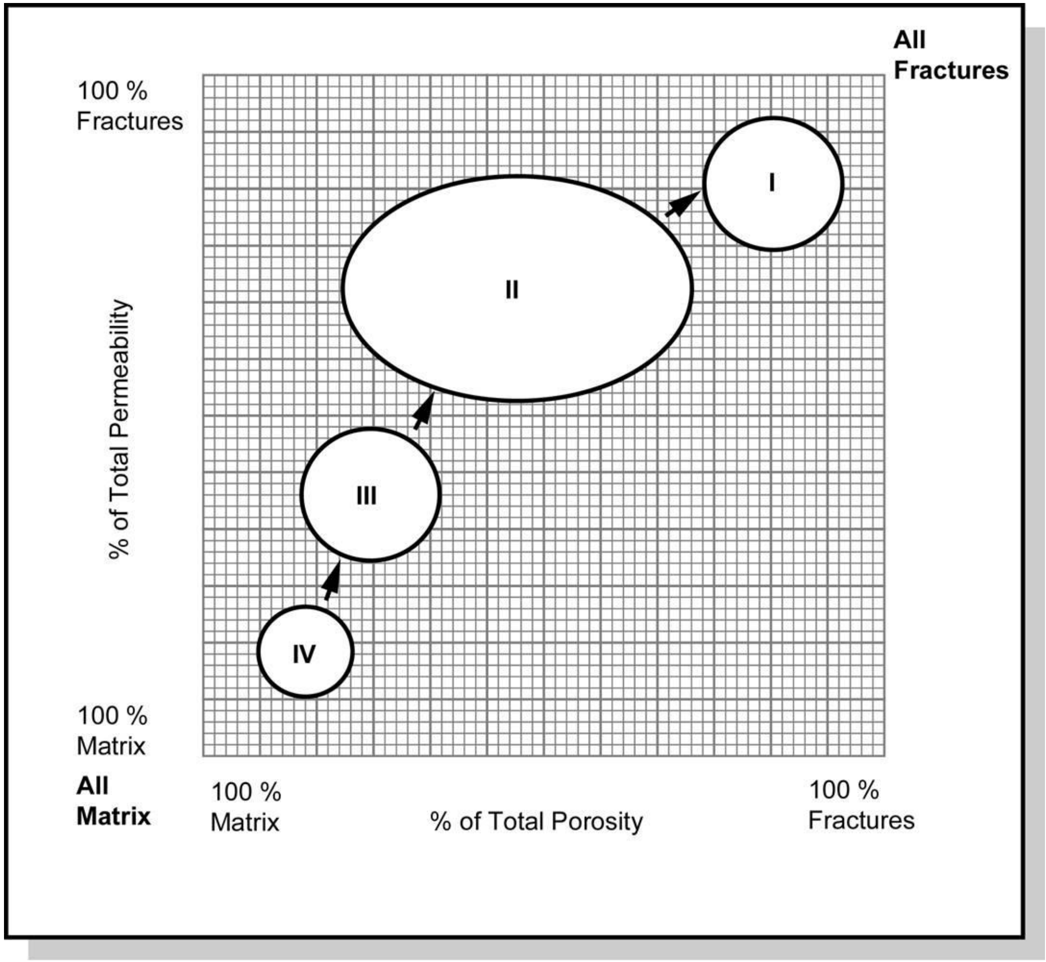
a = fracture aperture (cm)

d = fracture spacing (cm)



Some extension (if big enough difference between principle stresses) may exist producing "open" fractures with definite aperture and spacing that, being unfilled by secondary minerals, increase reservoir' permeability greatly – as cube of joint aperture

Fractured Reservoirs (joints only!)



Nelson (1992):

I – essential contribution in reservoir' porosity & permeability; deplete rapidly, basically not economic,

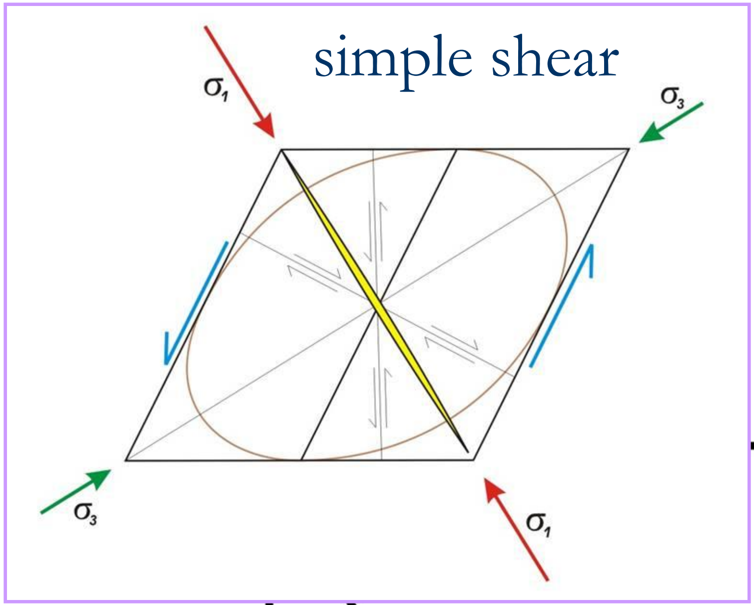
II – essential permeability; matrix porosity support fluid flow to fractures; good reserves,

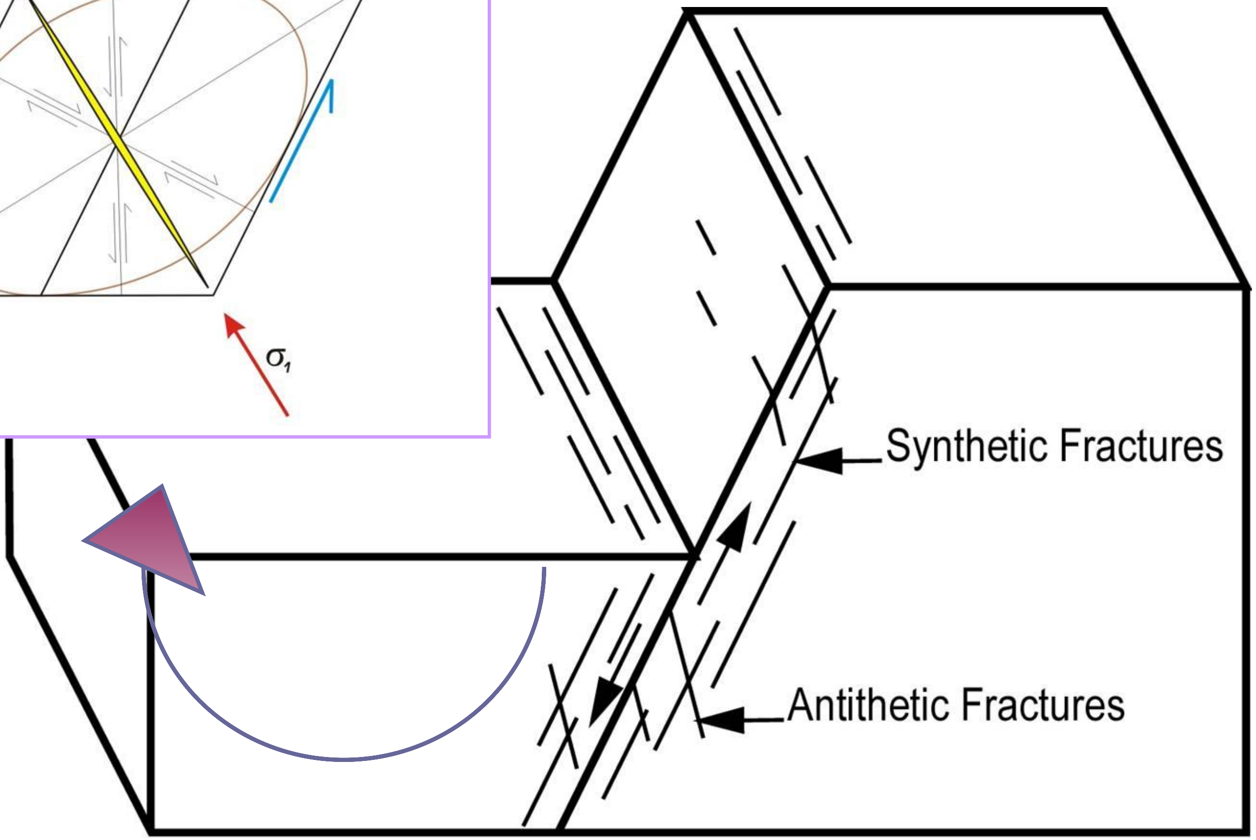
III – fractures add to reservoir' permeability, improving otherwise poor-quality reservoir,

IV – regular matrix reservoir, where fractures add permeability anysotropy/compartmentalisation.

Fault-Associated Fractures

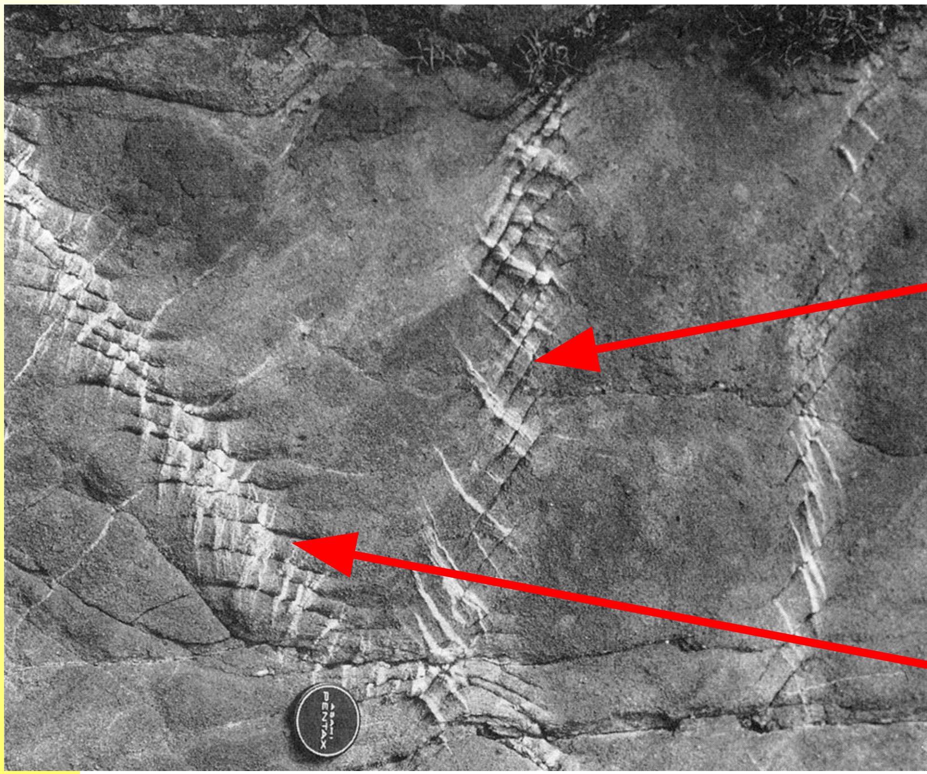
what tends to be open?

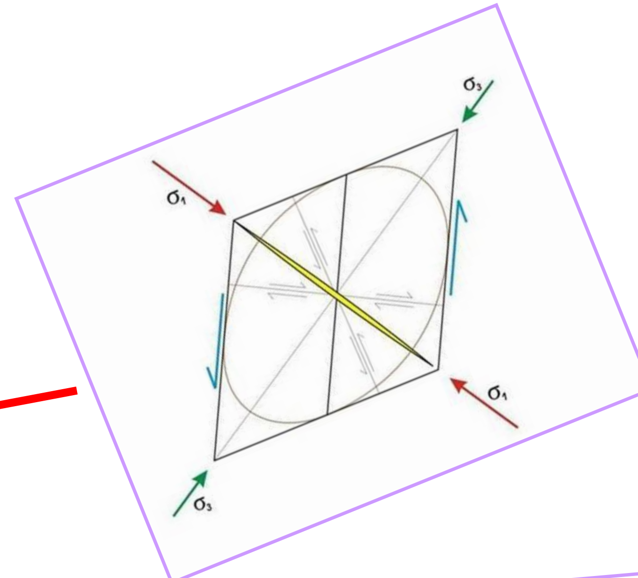


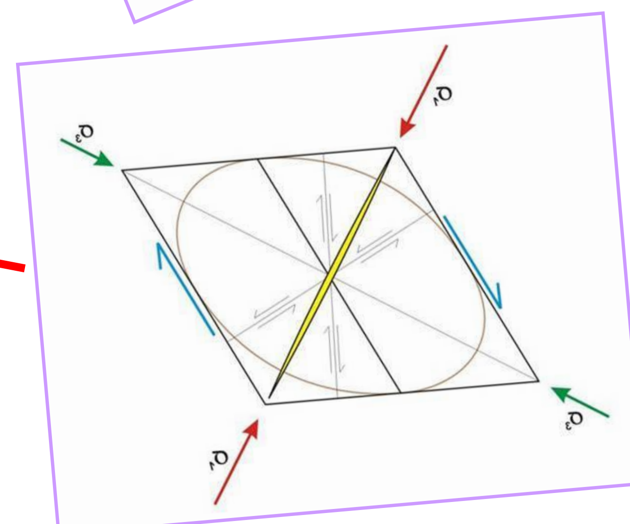


Fault-Associated Fractures

Twiss & Moores, 1992



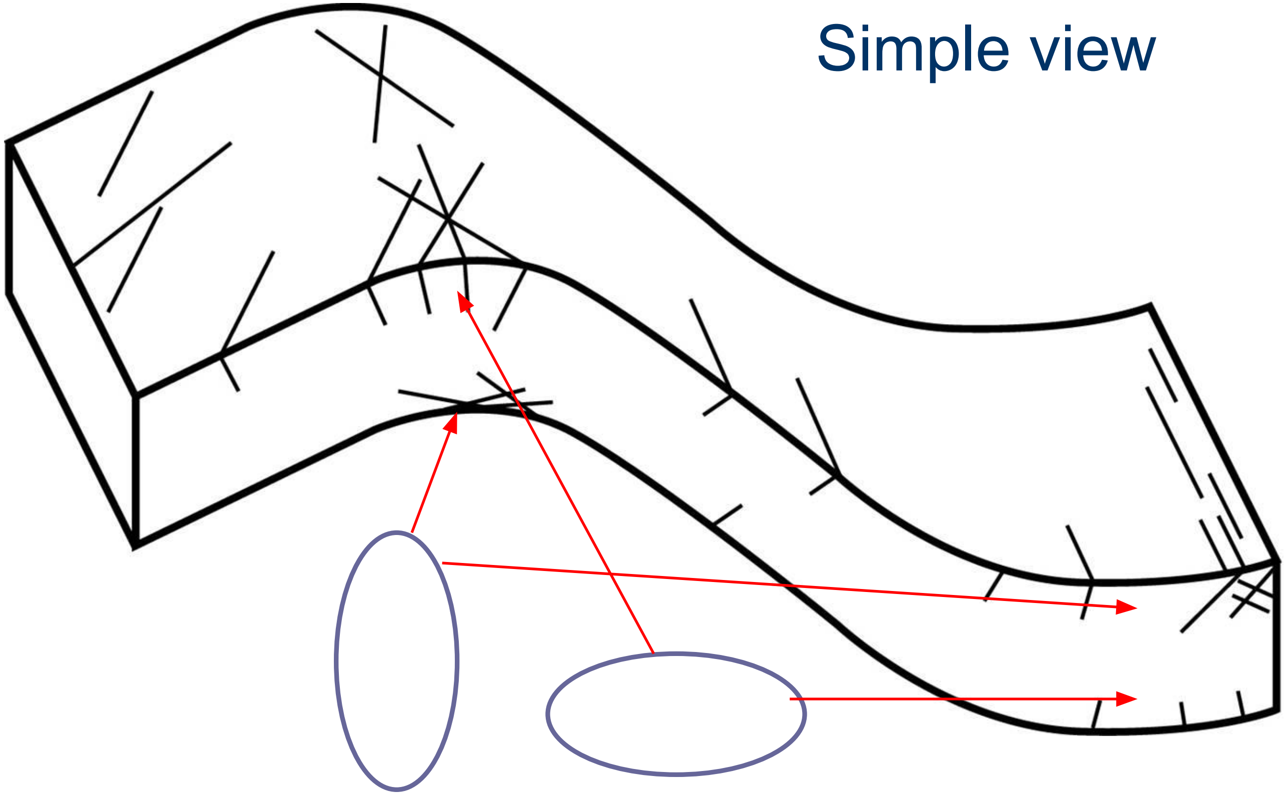




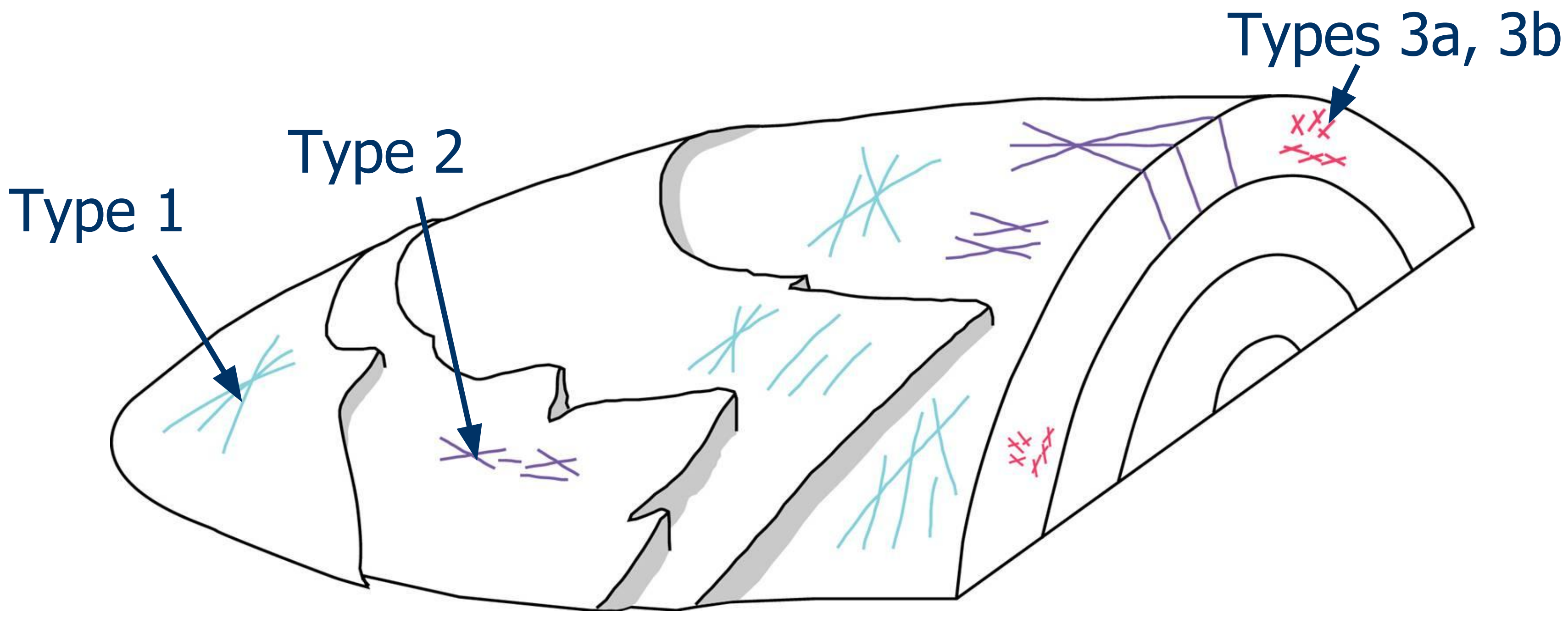
Fracturing associated with faults

Fold-Associated Fractures

Simple view



Fold-Associated Fractures

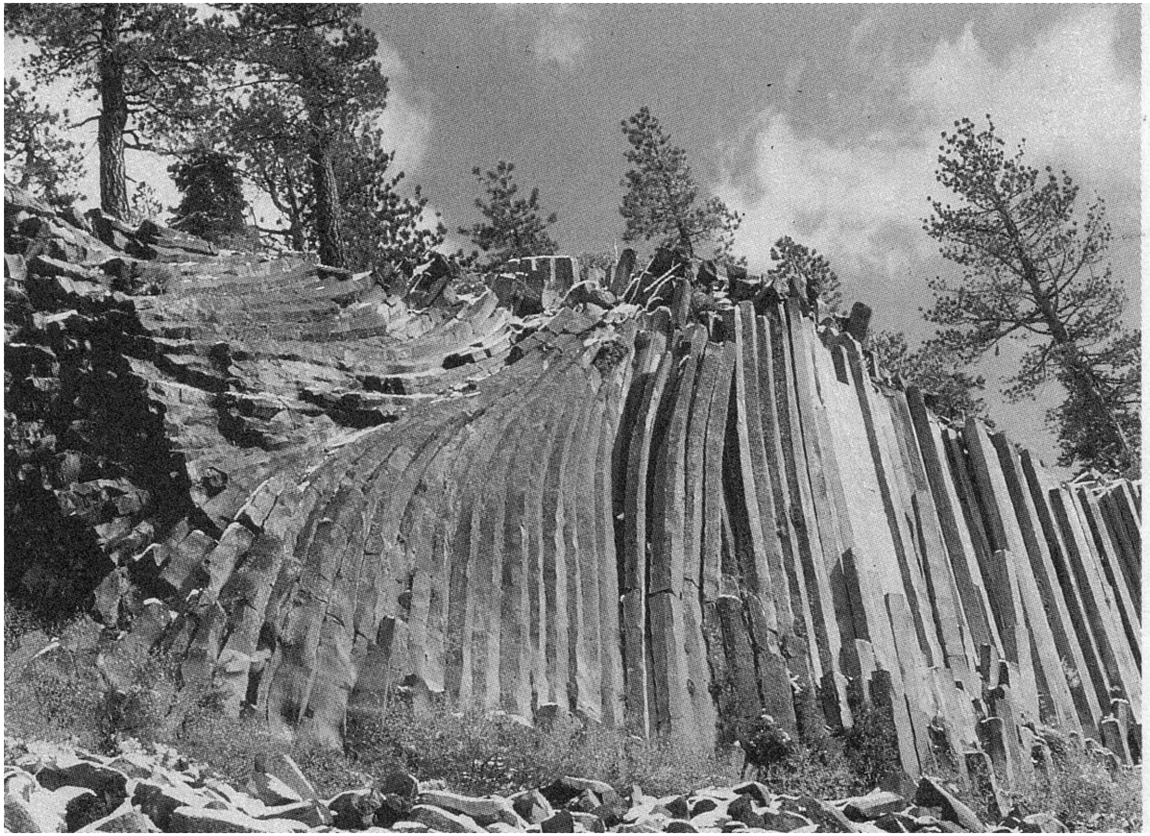


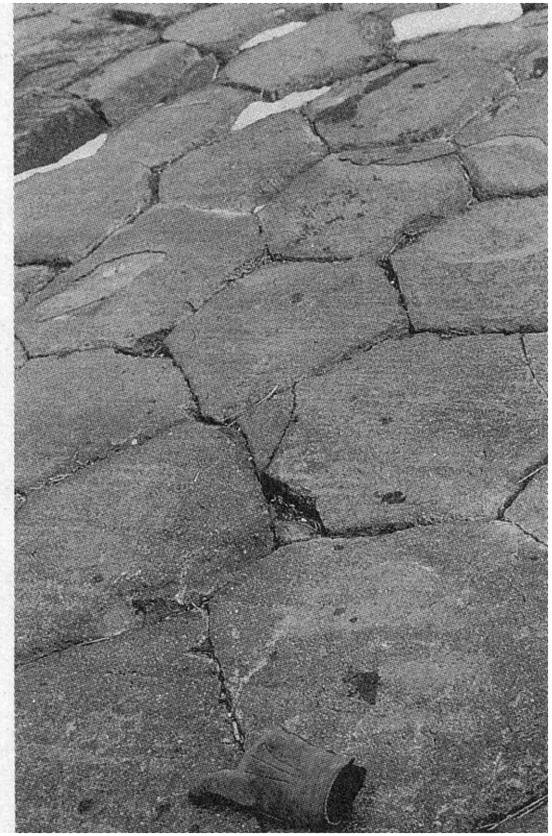
Scheme described by Stearns, 1968

Classification relates fractures and bedding orientation, plus curvature, with some aspects of a "process model"

Cooling

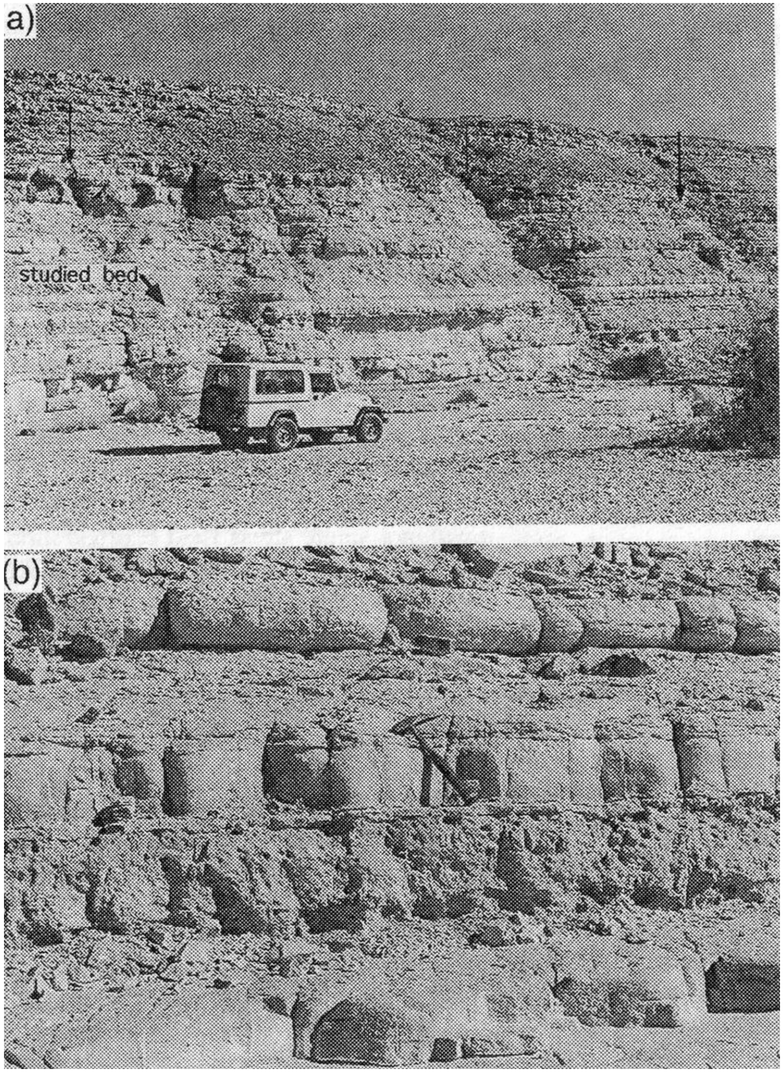
Twiss & Moores, 1992





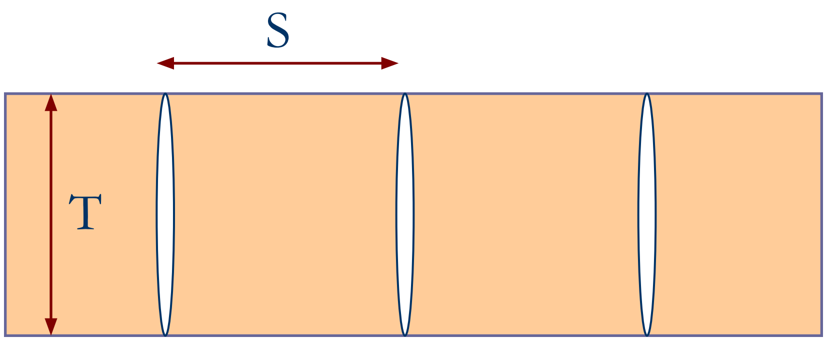
Magmatic – both plutonic and volcanic - rocks cooling (columnar basalts are good example)

High Differential Stress



Bekker & Gross, 1992

Fracturing because of general strain (big enough differential stress)



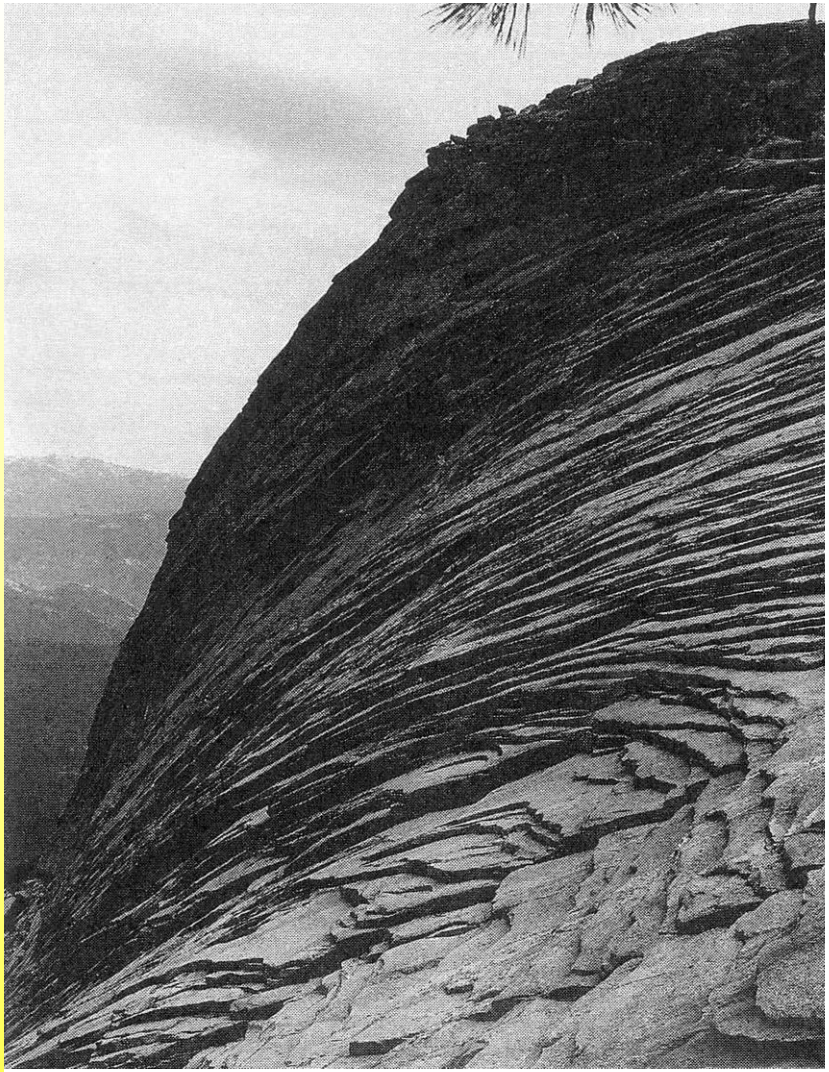
$S/T \approx 0.7 \ldots 1.2$

where:

S – fracture spacing,

T – bed thickness

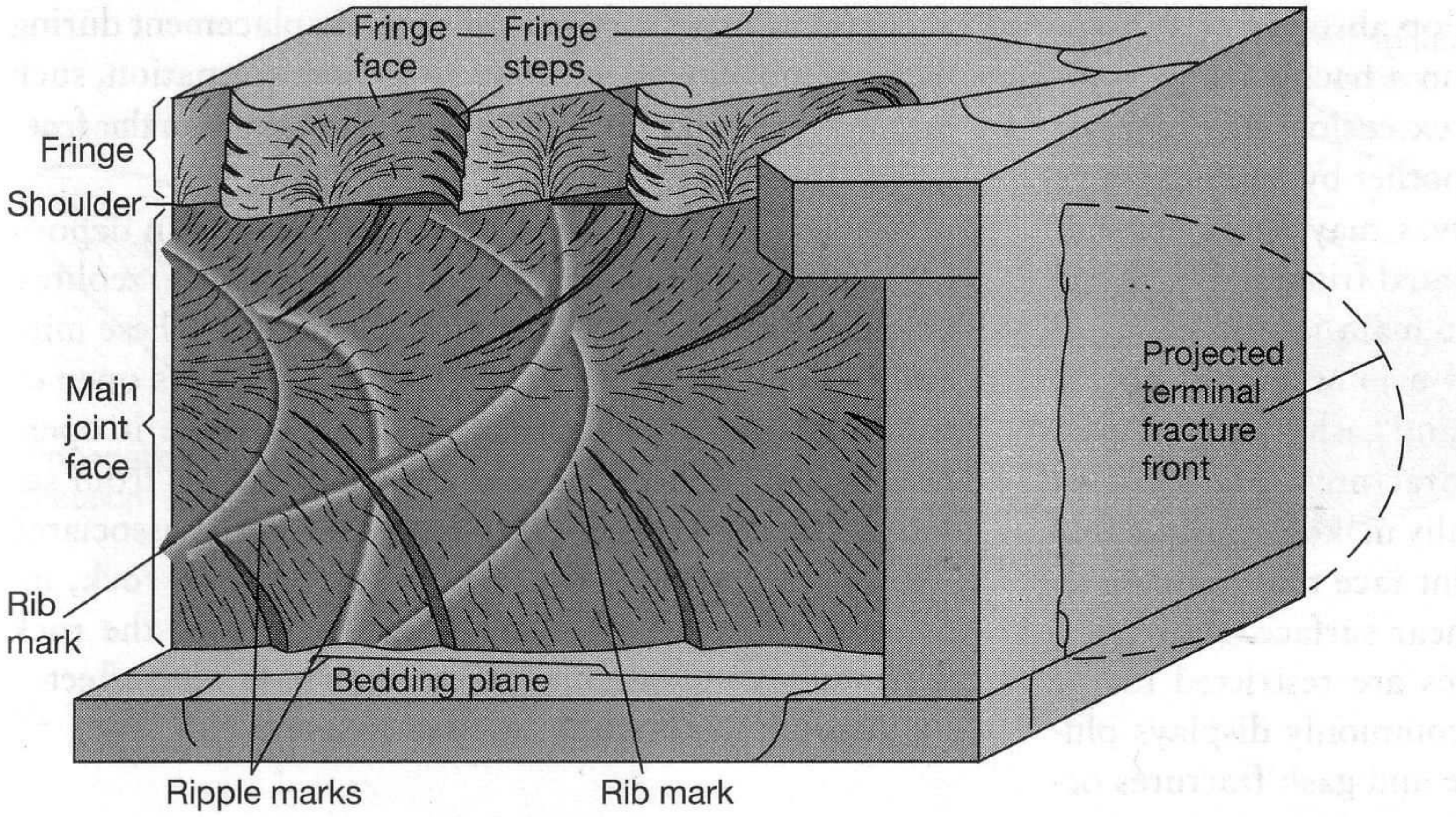
Tectonic Uplifting



Twiss & Moores, 1992

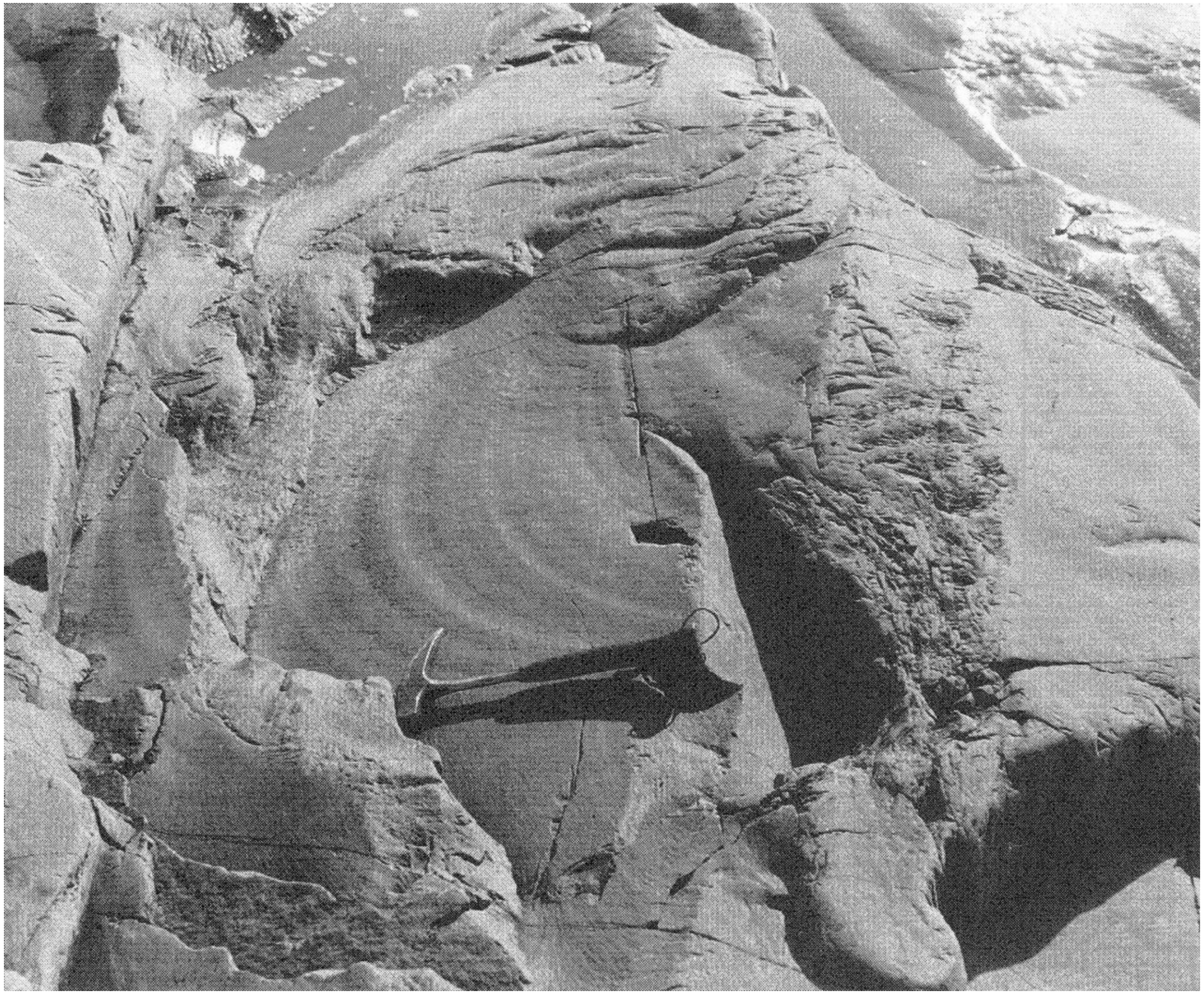
Fracturing because of tectonic uplifting – sure should be initiated by other processes (like cooling)

Natural Hydrofracturing



Twiss & Moores, 1992

Natural Hydrofracturing



Twiss & Moores, 1992