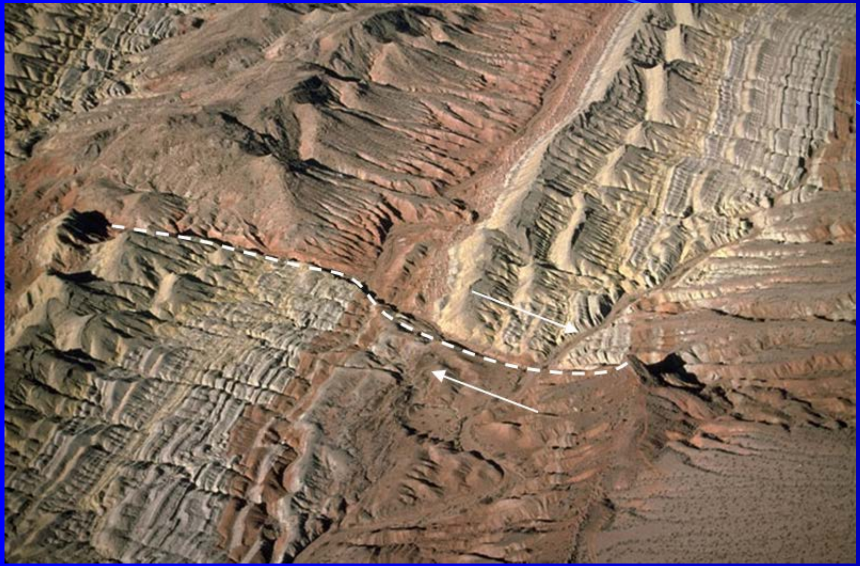
Faults

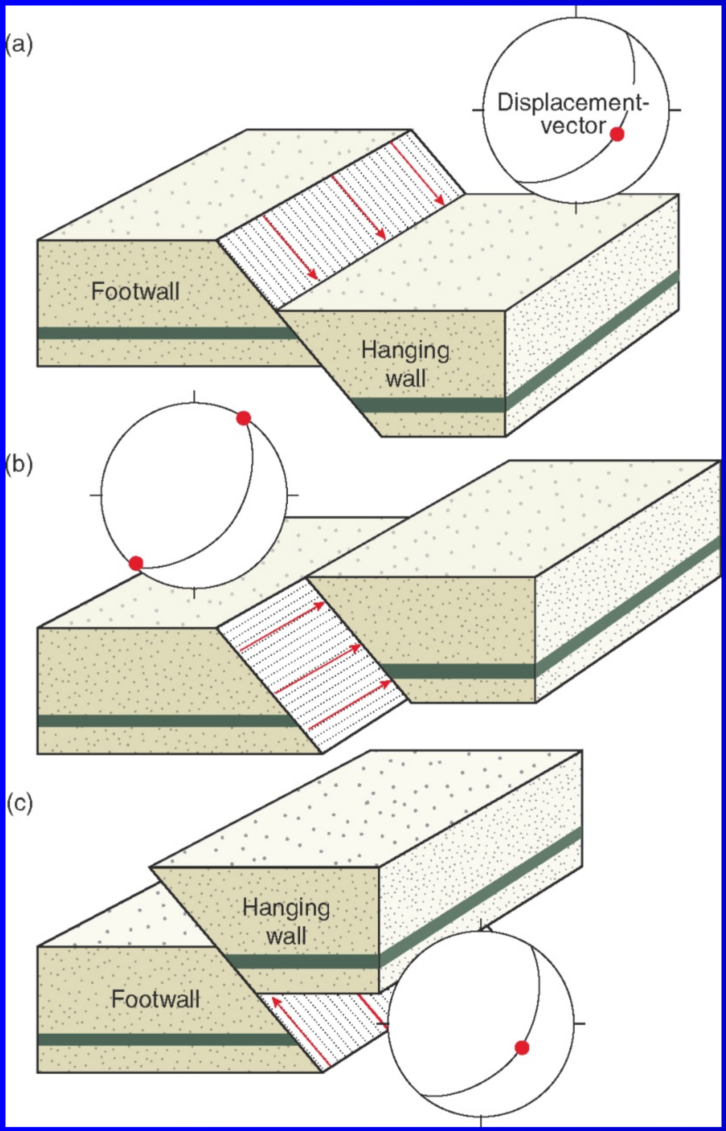


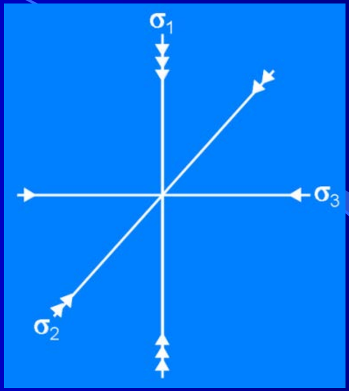
Strike-slip fault

Thrust fault

Normal fault

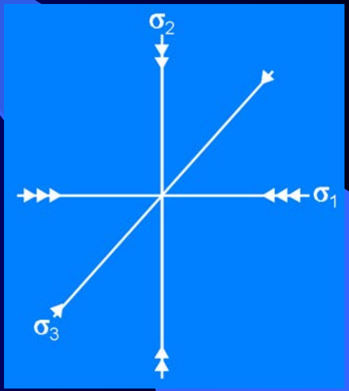
Fault – any surface or narrow zone with visible shear displacement along the zone

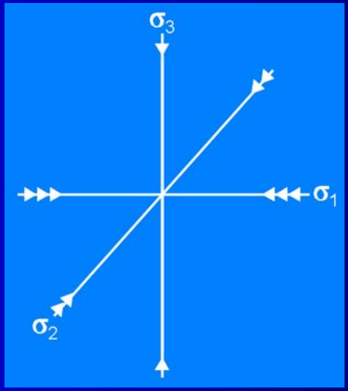




Normal fault

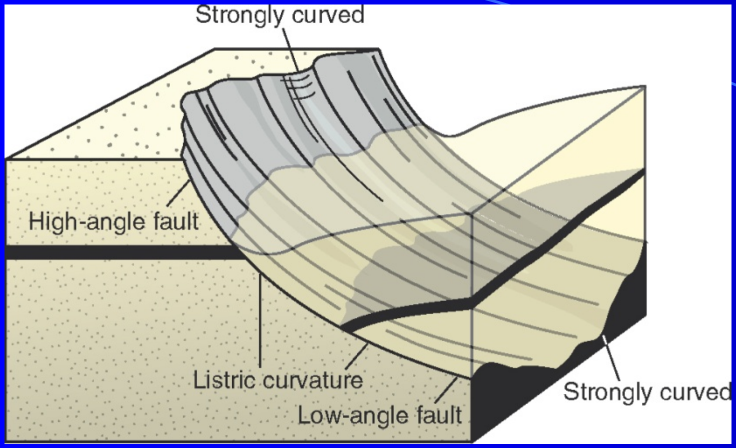
Strike-slip fault





Reverse fault

Thrust fault $<30^{o}$



Listric faults - fault plane flattens with depth

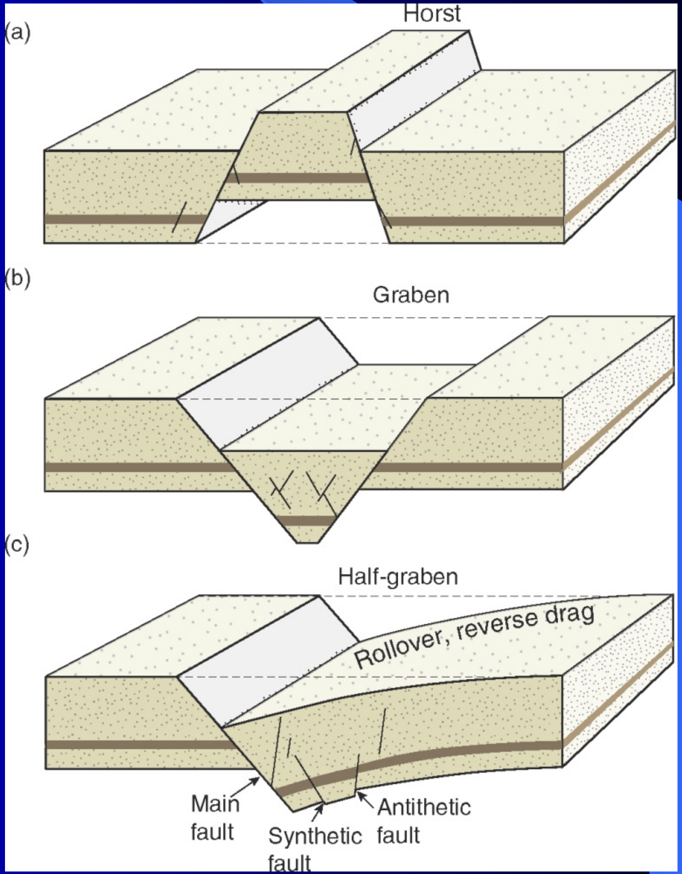
Fault combinations:

Horst - two normal faults dipping away from each other

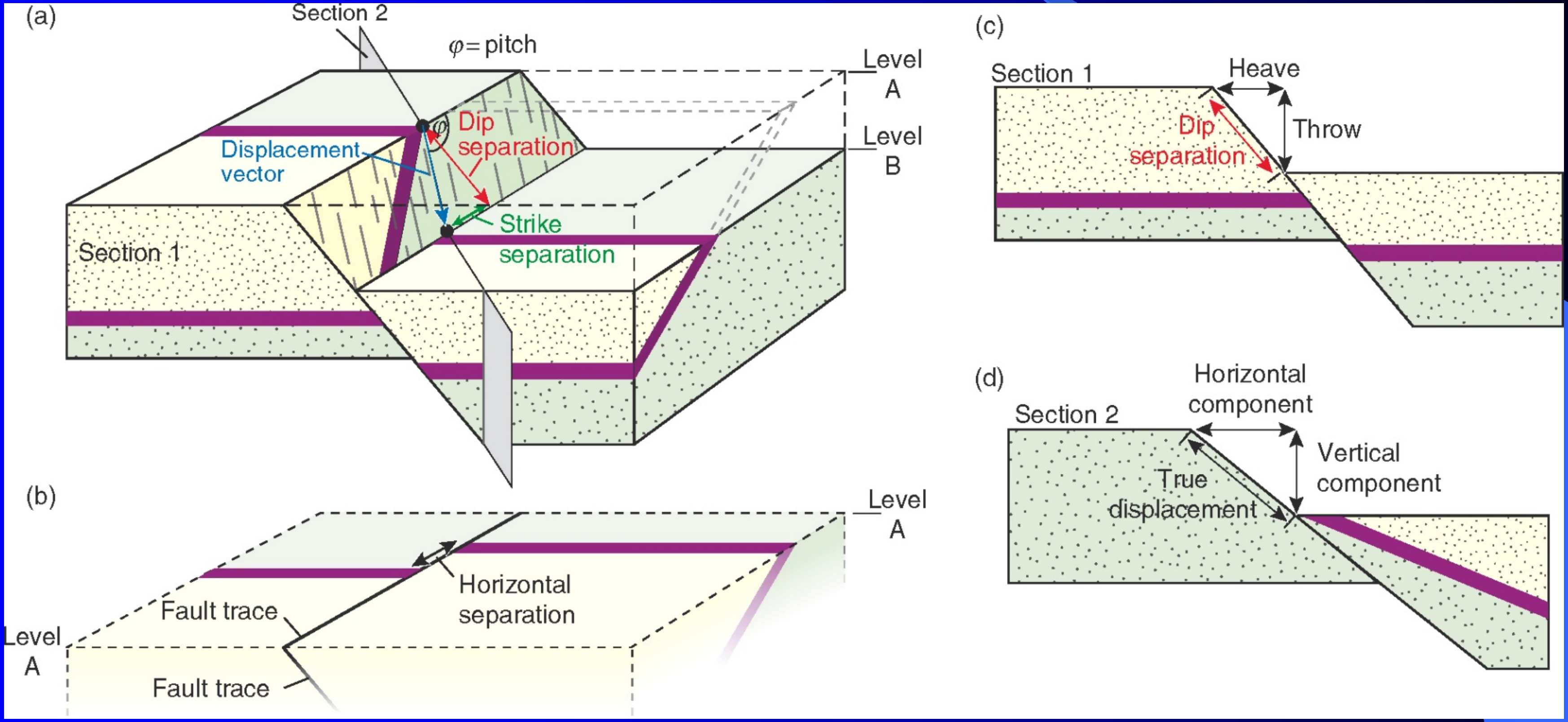
Graben - two normal faults dipping toward each other

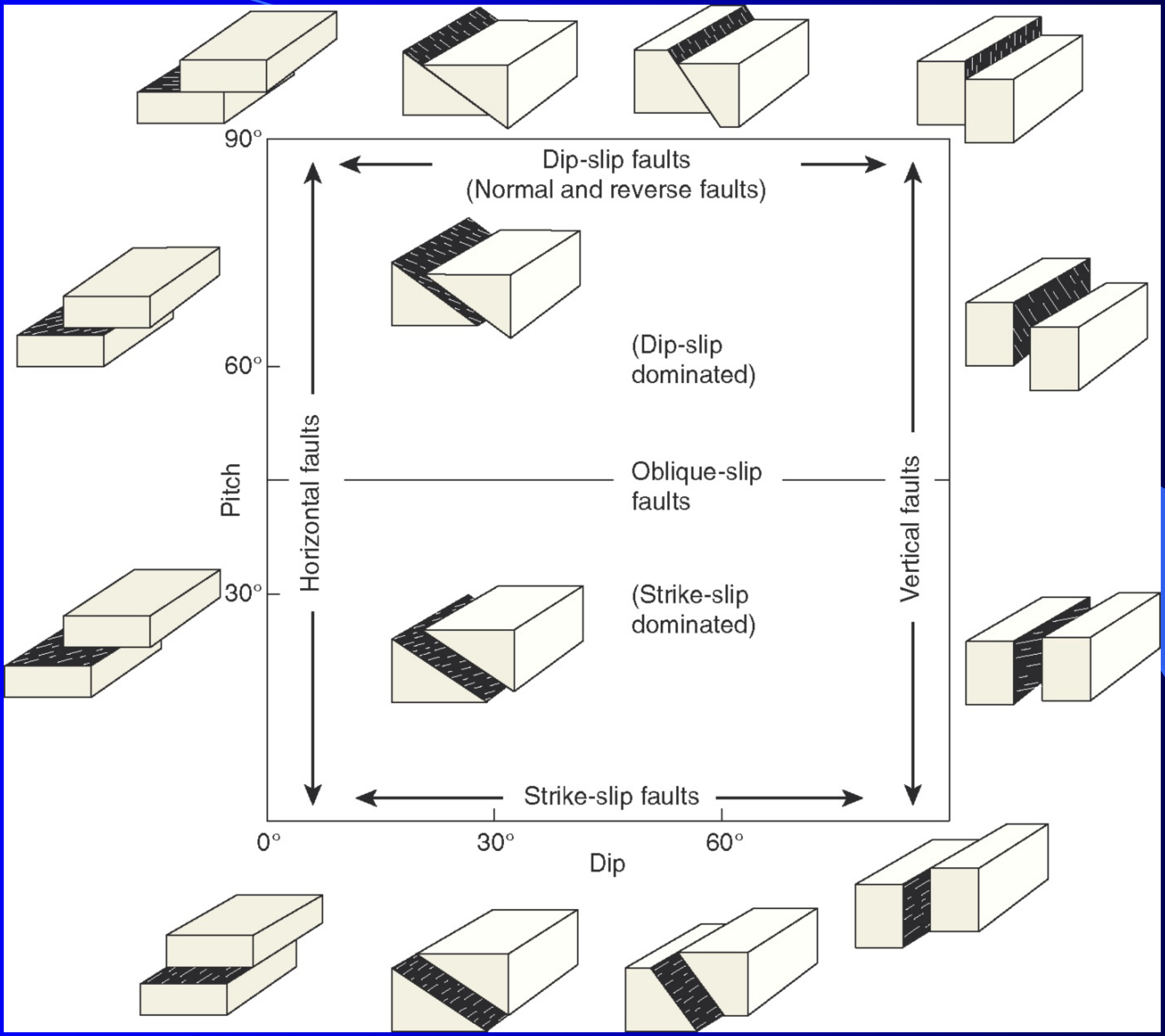
Synthetic fault – dips in same direction as the main fault

Antithetic fault - dips towards the main fault



Fault Terminology





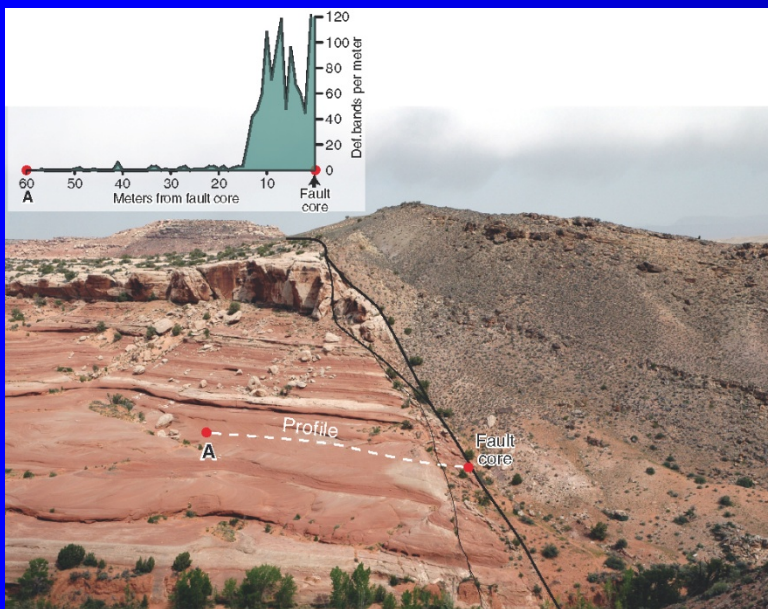
Classification of faults based on the dip of the fault plane and the pitch (angle between the slip direction and the strike)

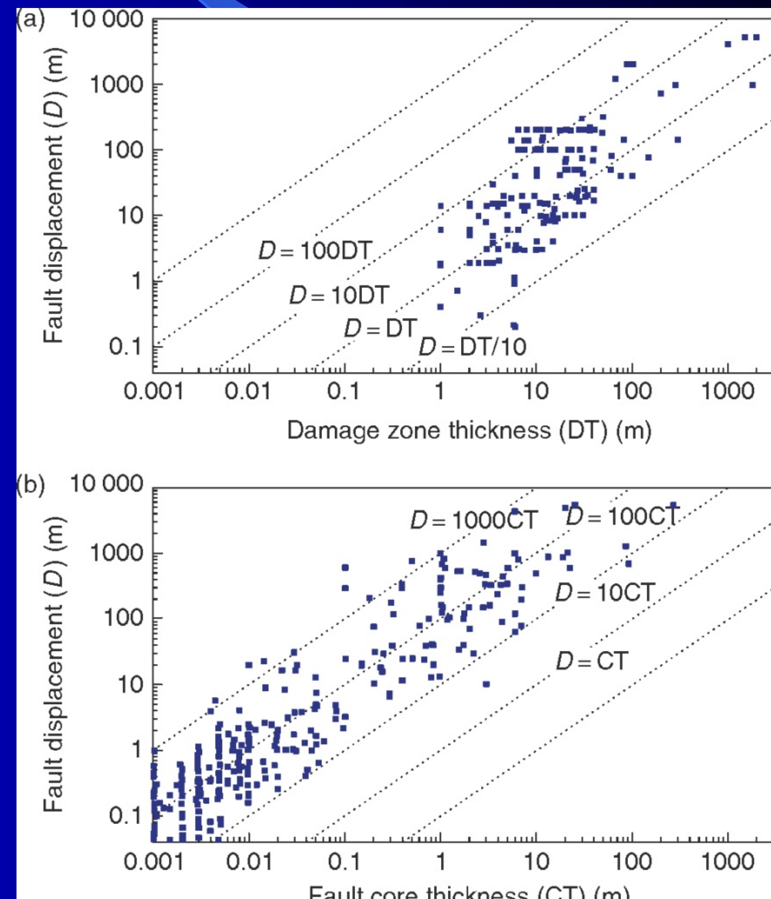
Rocks formed in fault zone

		Non-foliated		Foliated	% Matrix
Incohesive		Fault breccia (>30% visible fragments)			
Incohesive		Fault gouge (<30% visible fragments)		Foliated gouge	
Cohesive		Pseudotachylyte			
Cohesive		Crush breccia (fragments > 5 mm)			
Cohesive		Fine crush breccia (fragments 1-5 mm)			<10%
Cohesive		Crush microbreccia (fragments < 1 mm)			
Cohesive	Cataclasites — Grain size reduction by cataclastic mechanisms	Protocataclasite	Mylonite series — Grain size reduction by plastic def. mechanisms	Protomylonite	10–50%
Cohesive	Cataclasites — Grain size reduction by cataclastic mechanisms	Cataclasite	Mylonite series — Grain size reduction by plastic def. mechanisms	Mylonite	50–90%
Cohesive	Cataclasites — Grain size reduction by cataclastic mechanisms	Ultracataclasite	Mylonite series — Grain size reduction by plastic def. mechanisms	Ultramylonite	>90%
Cohesive			Mylonite series — Grain size increase by recrystalliz.	Blastomylonite	

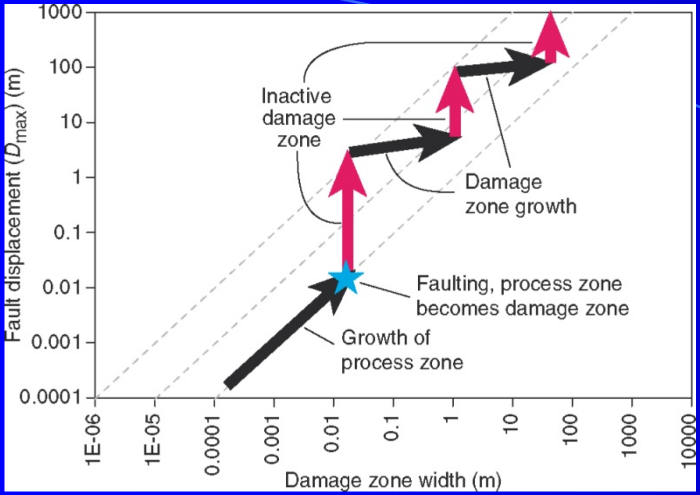
Fault core – ranges from simple slip surface up to a several meter wide intensely sheared zone.

Fault damage zone – density of brittle deformation structures that is higher than the background level. It includes the fault core.

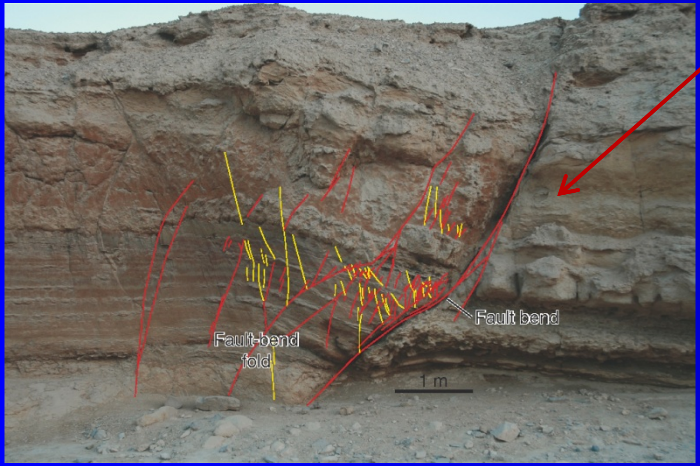




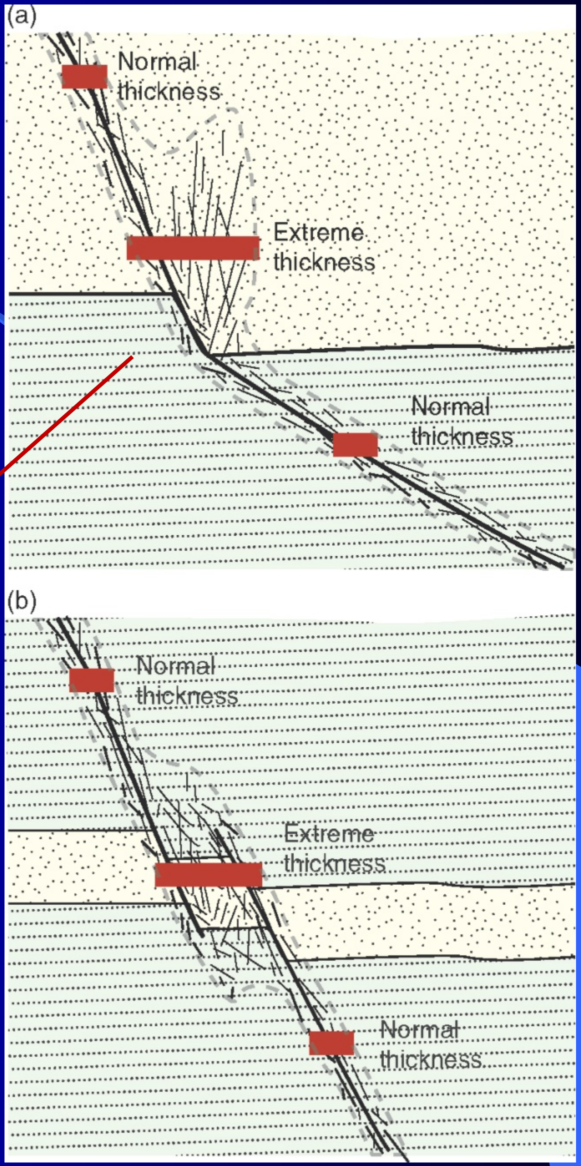
There is a positive correlation between fault displacement and the thickness of the fault core and fault damage zone.



Damage zone starts with growth of process zone. Once fault forms the process zone becomes the damage zone and slip occurs smoothly. Complications lock the fault. Renewed growth of damage zone until fault starts again.



Note width of damage zone and synthetic and antithetic shear bands.

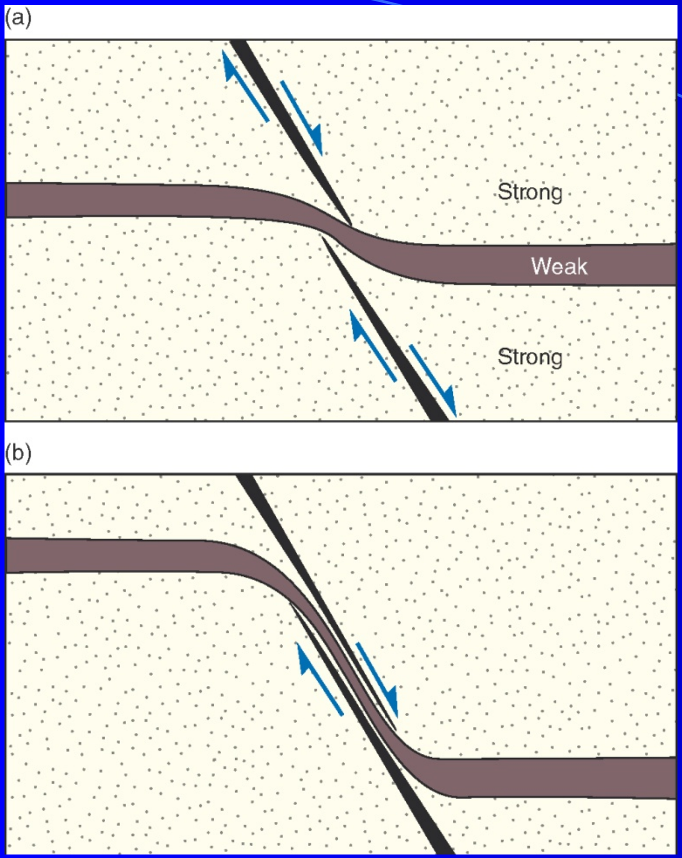


Variations in thickness of damage zones related to (a) change in dip and (b) linkage.

Drag is folding of layers around a fault by means of brittle deformation mechanisms directly related to the formation and/or growth of the fault. (This is a very confused discussion in the book. The brittle deformation is related to the fault. The layers actually deform ductilely. Drag-like structures can also be seen in the brittle-ductile transition zone where the rocks are behaving plastically.)

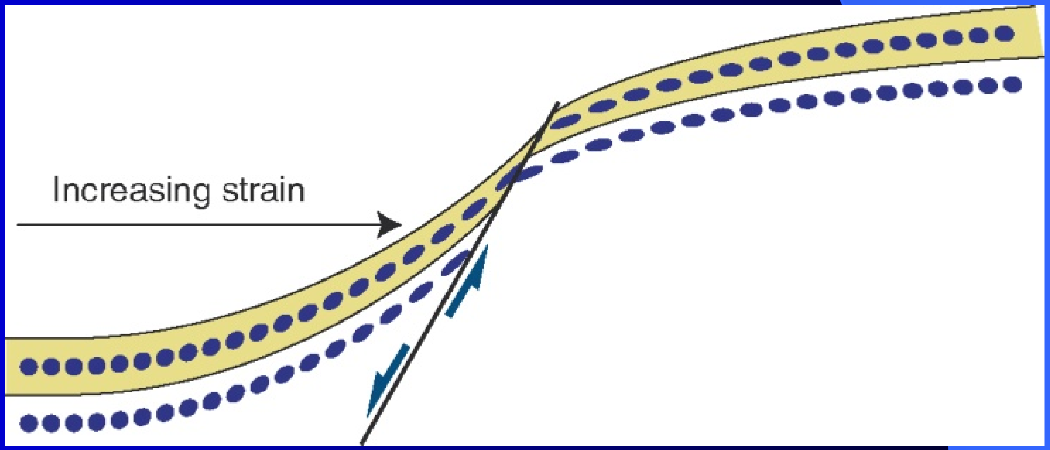
The axes of drag folds make a high angle to the displacement vector of the fault. For dip-slip faults and subhorizontal layers this means the fold axes are subhorizontal.

On the image the fault is vertical (dashed white line).

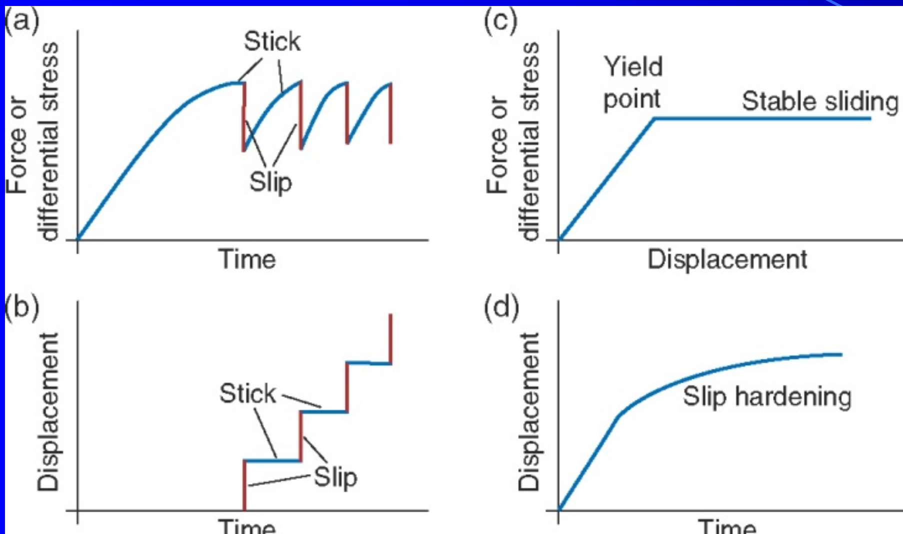


Normal dragging of mechanically weak layer (e.g. clay) between two overlapping fault segments.

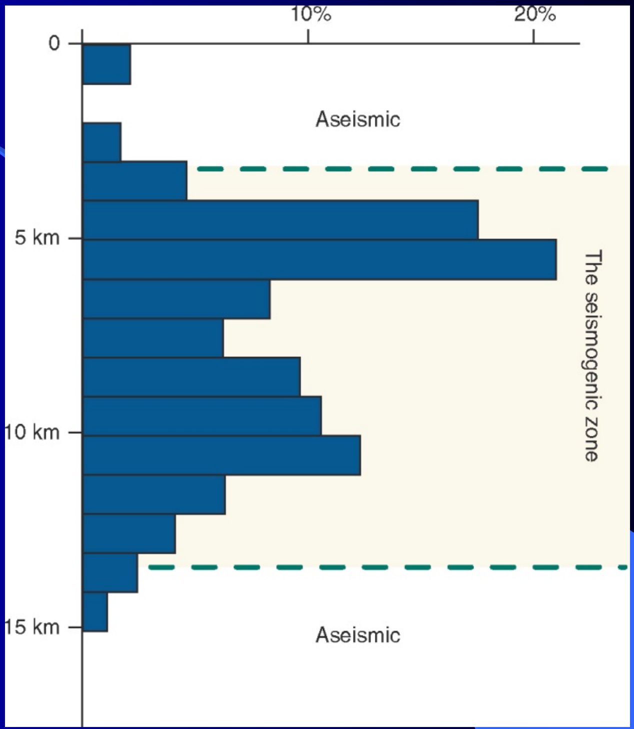
Strain ellipses showing the relation between layer orientation and strain. Note that strain increases as one approaches the fault plane.



Fault growth and seismicity



Stick-slip versus Stable sliding (with or without slip hardening).



Stable sliding is favored by:

- Small normal stress
- Low-angle faults along overpressured layers in sedimentary sequences
- Porous sediments and sedimentary rocks
- Clay-rich rocks
- Clay gouge in fault zones
- Temperatures above ~300°C (plastic regime)

The factors that favor stable sliding result in low seismic activity near the surface and at depths greater than 15 km.

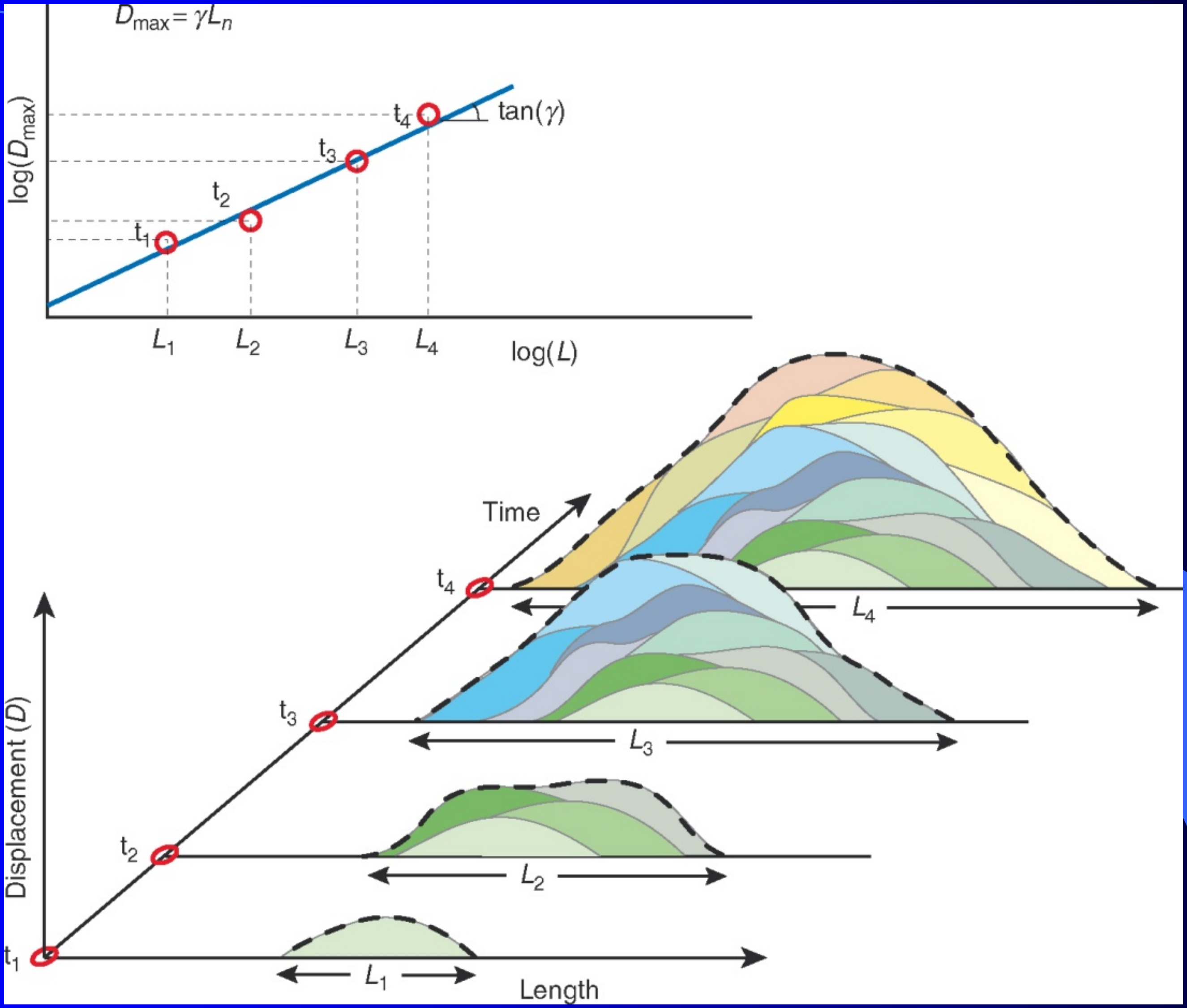
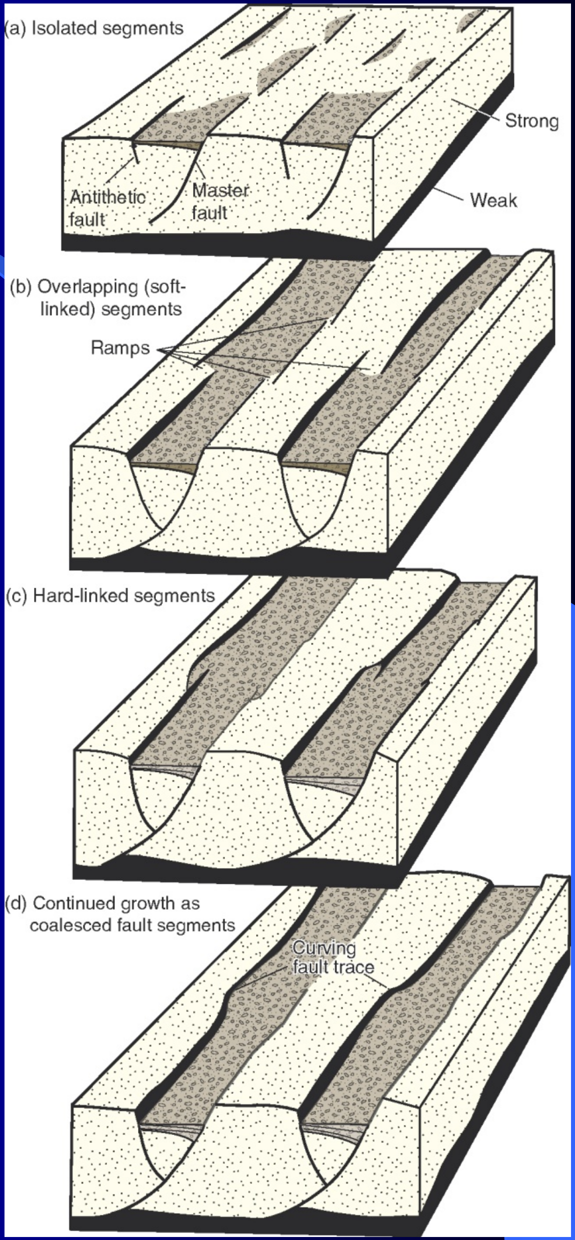


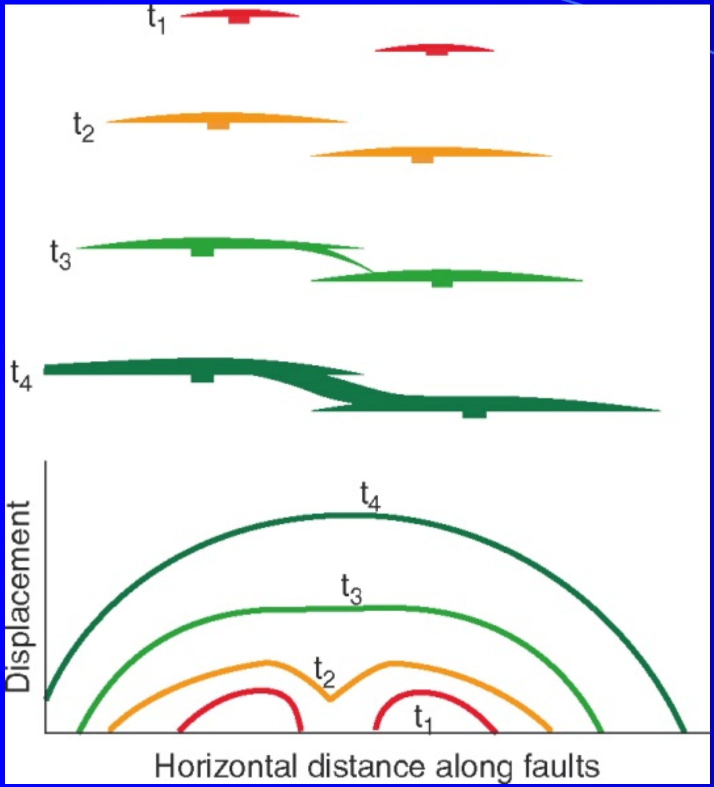
Illustration of displacement accumulation through repeated slip events. Each event results in up to a few meters of displacement. In this model a bell-shaped cumulative displacement profile emerges which resembles that of a single slip event. The result of this model is a straight line in a logarithmic length - displacement diagram.

Fault linkage

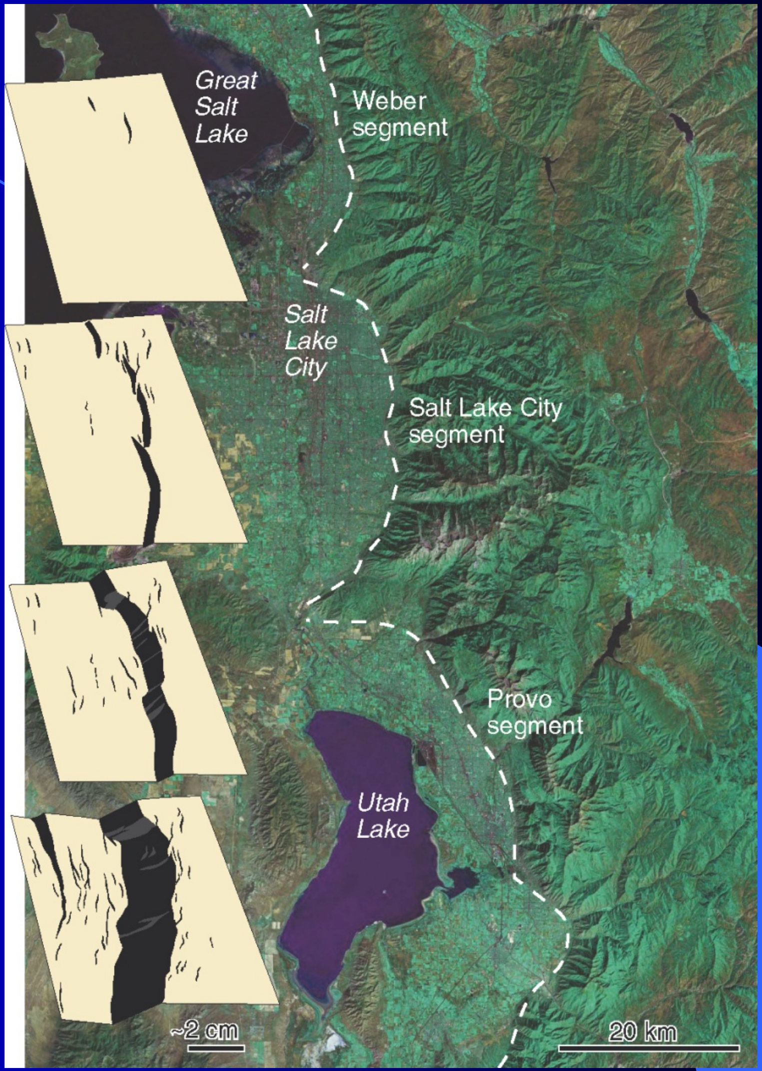
Extension fractures at the edge of a paved road. Pavement is saturated with fractures and additional strain will be accommodated by the coalescence of existing fractures.

Development of long faults from isolated fractures.



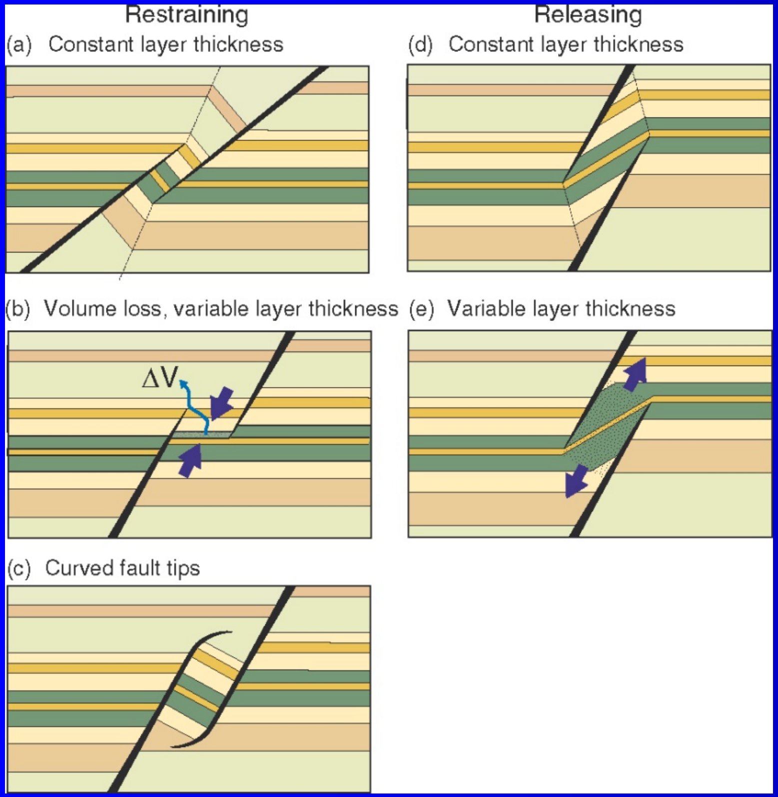


Change in displacement along two faults that overlap and coalesce. The upper part shows the two segments in map view. The lower part shows the displacement profile.



Wasatch fault zone near Salt Lake City indicated by white dashed line. The curved fault geometry indicates a history of segment linkage.

Fault linkage in the slip direction

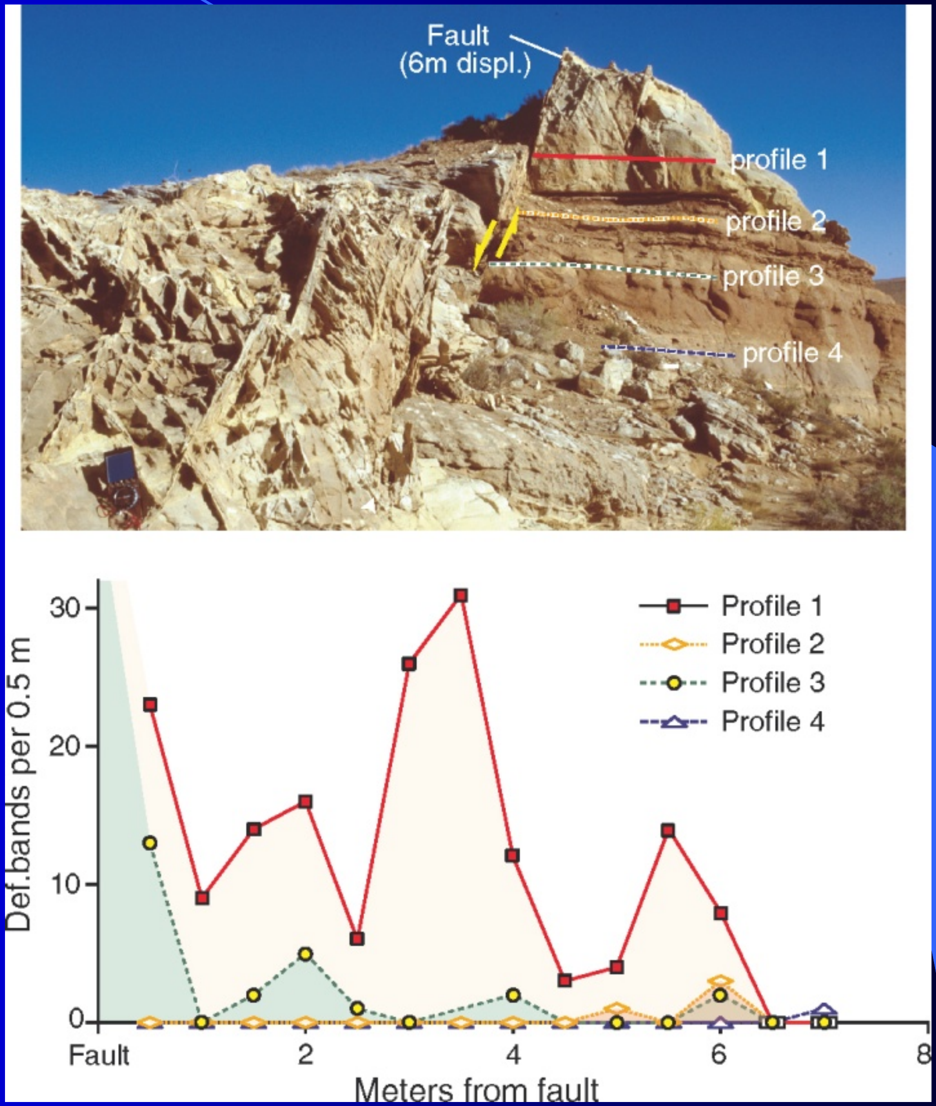


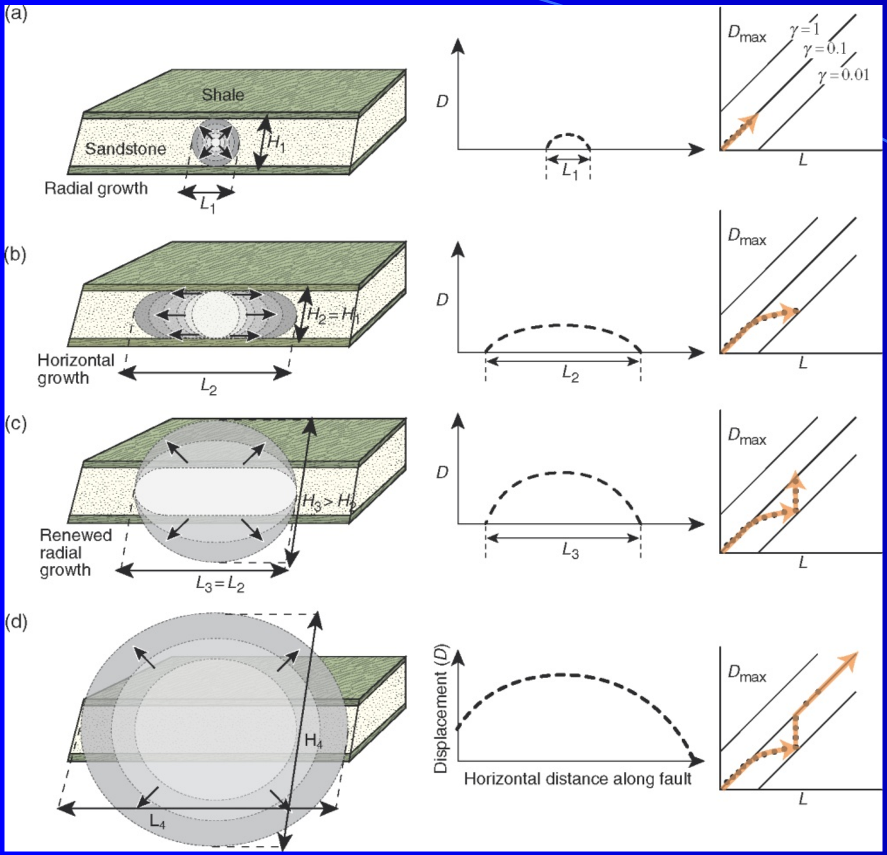
Restraining overlap zones show shortening in the displacement direction. Releasing overlap zones where the fault arrangement and sense of displacement cause stretching within the overlap zone.

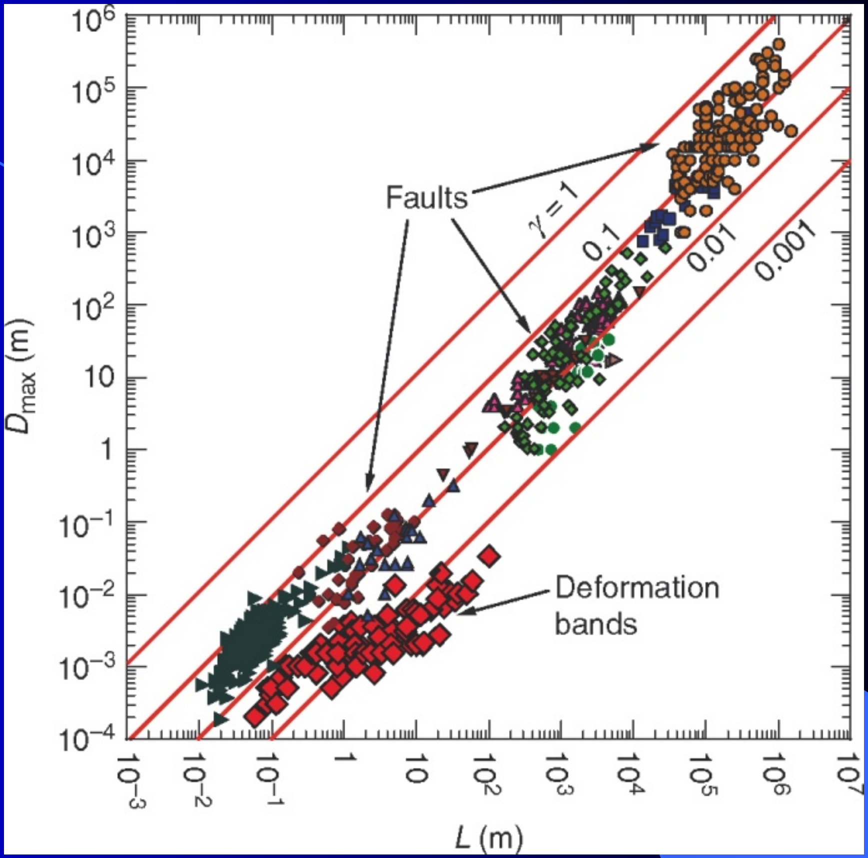
Overlapping faults where a shale layer is caught and smeared in the overlap zone.

Mechanical stratigraphy, i.e. physical properties of various rock layers, affect fault growth. For example, sandstones may fracture while at the same stress shales behave ductilely. Other examples involve ordinary fracture versus formation of deformation bands.

Distribution of deformation bands in the footwall of a fault with a 6 m displacement. The frequency is considerably higher in the clean, highly porous sandstone (Profile 1) than in the more fine-grained layers (Profiles 2 and 3). It is also lower in the thin sandstone layer (Profile 4).







Left: Growth of a fault in a layered sequence. The fault nucleates in the sandstone layer (a) with a normal displacement profile and expands horizontally when hitting the upper and lower boundaries (b). A relatively long plateau shaped displacement profile develops. At some point the fault breaks through the under/overlying layers (c) and starts growing again in the vertical direction. The displacement profile regains a normal shape.

Right: Displacement-length diagram for faults and cataclastic deformation bands. Deformations bands are longer than predicted from their displacement.

Faults tend to increase permeability in non-porous rocks while they commonly reduce permeability in porous rocks.

Fault transmissibility or transmissivity (ability to affect fluid flow):

- **Juxtaposition of impermeable and permeable rocks across a fault plane.**
- **Cataclasis in fault core reduces grain size and therefore reduces porosity and permeability.**
- **Diagenetic effects. For example dissolution quartz and re-precipitation of quartz in the fault core.**
- **Clay and shale smears. Clay or shale layers become incorporated into the fault during movement on the fault.**