Last Time...

1) Absolute dating techniques:

** Tree Rings*
** Radiocarbon Dating*
** U-Th Series Dating*
** Amino Acid Racemization*
** Luminescence Dating*
** Fission Track Dating*
** Cosmogenic Radionuclide Dating.*

** The proper constituents necessary for each method must be present.*

2) CRN dating may directly date exposure of surfaces. Interpretation of ages remains problematic because 1) production rates change over time; and 2) Age represents convolution of prior exposure, exposure, and erosion.

**Multiple isotopes may be used to help deconvolve erosion and burial history of a sample.*

In Today's Class...

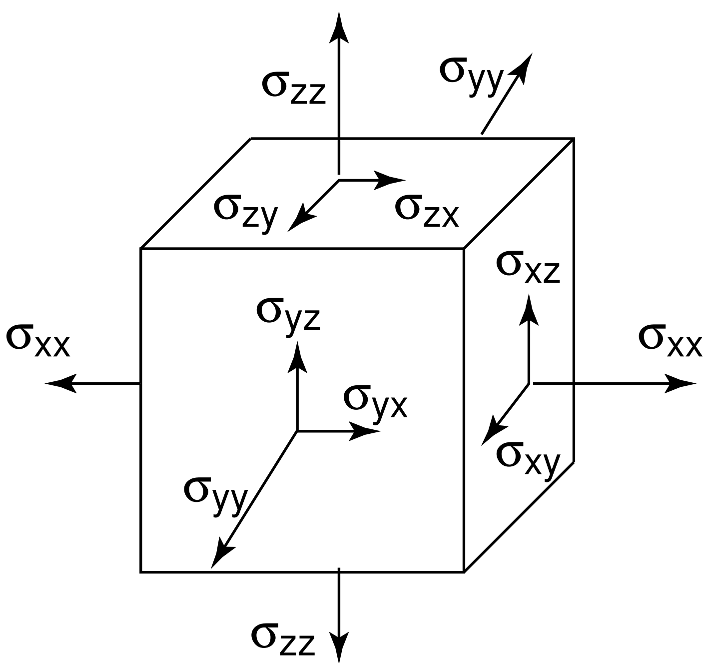
Stress, Strain, Rotation, Deformation, and Faulting

I. Stress, strain, rotation, and deformation.

II. Fault geometry, rupture models, and segmentation.

Stress

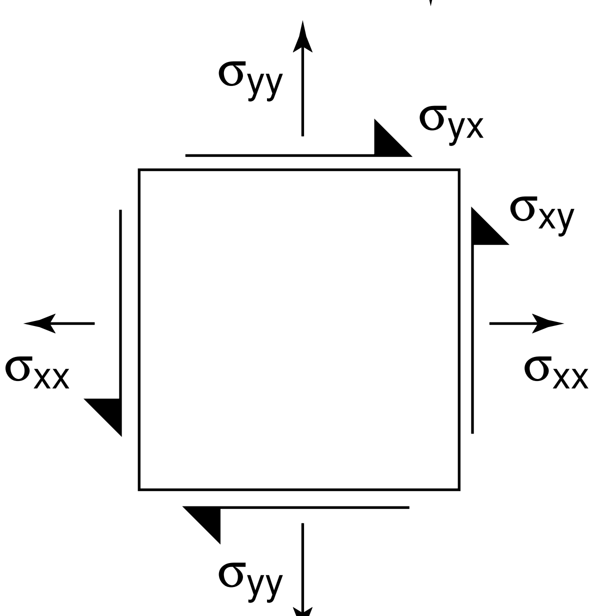
** Stress is a description of how forces are transmitted through a continuous object (solid, liquid, gas).*

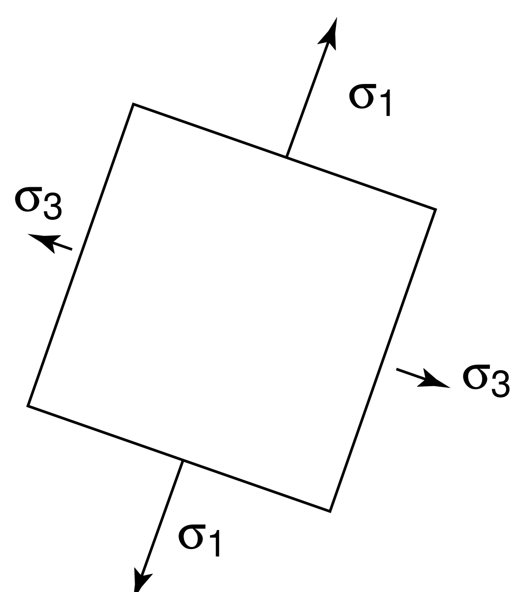


** Stresses acting normal to volume ($\sigma xx, \sigma yy, \sigma zz$).*

** Stresses acting parallel to volume (σxy, σxz, σyz).*

** When the system is in equilibrium (stresses balance), parallel stresses on opposing faces must balance ($\sigma xy = \sigma yx$, $\sigma xz = \sigma zx$, $\sigma yz = \sigma zy$).*



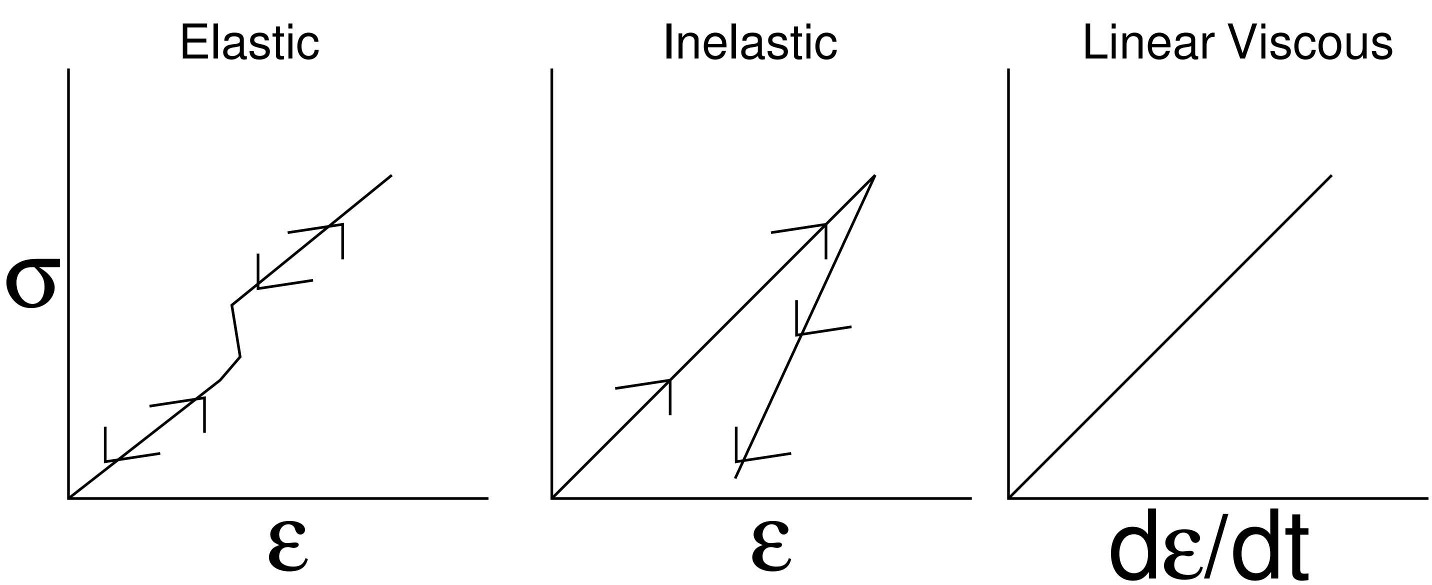


Strain

** Change in shape of an object due to imposed stresses.*

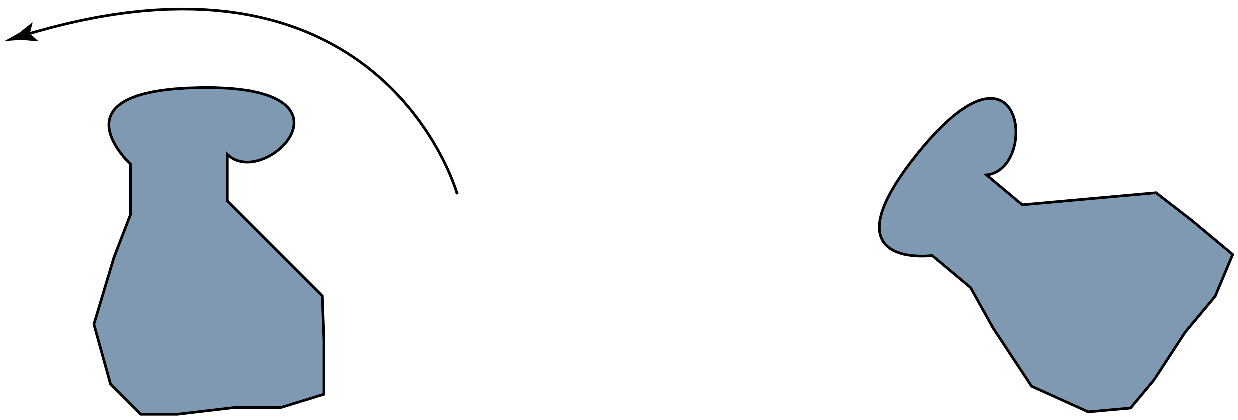
*** Strains result from stresses transmitted through crust.*

- Relations between stresses and resulting strains defined by rheology of rocks.



Rotation

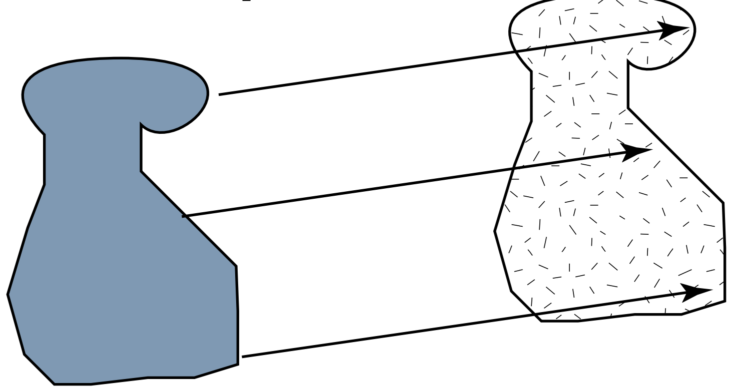
** Rigid spinning of an object about an axis:*



Initial Geometry **Final Geometry**

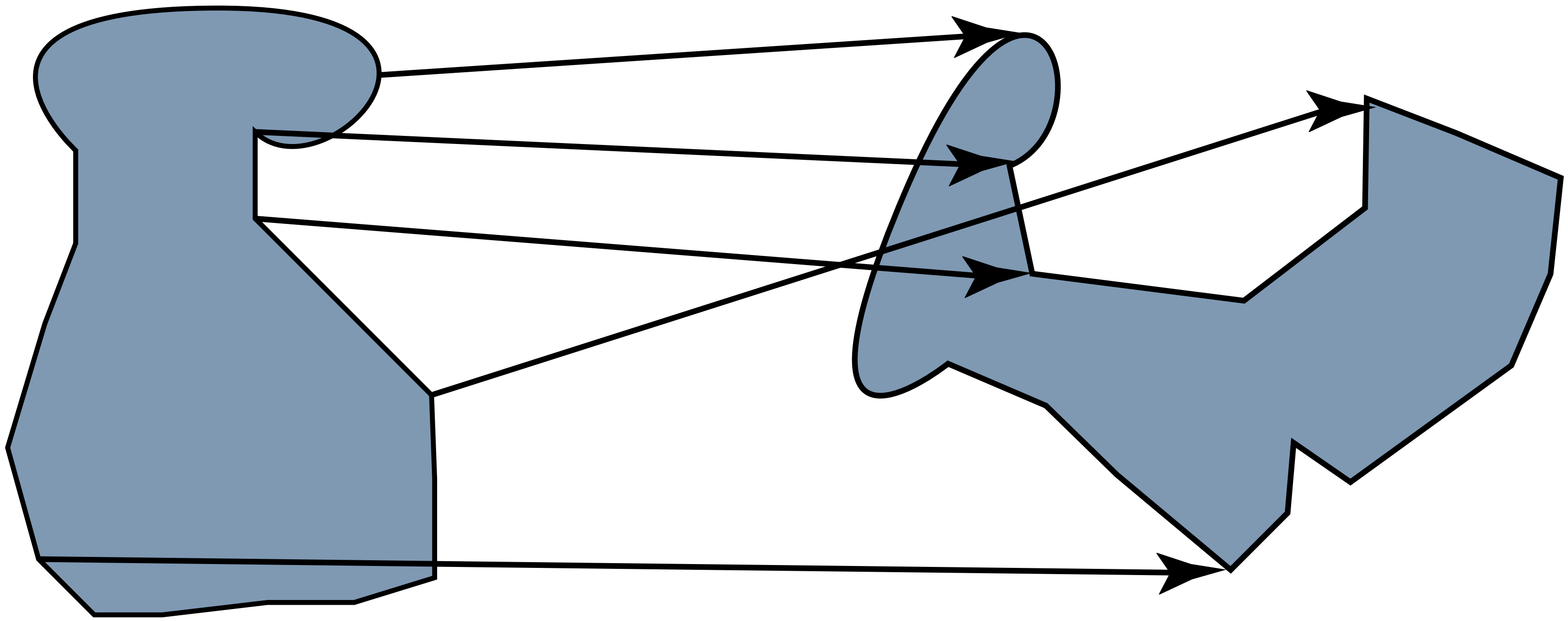
Translation

** Rigid movement of an object from one position to another:*

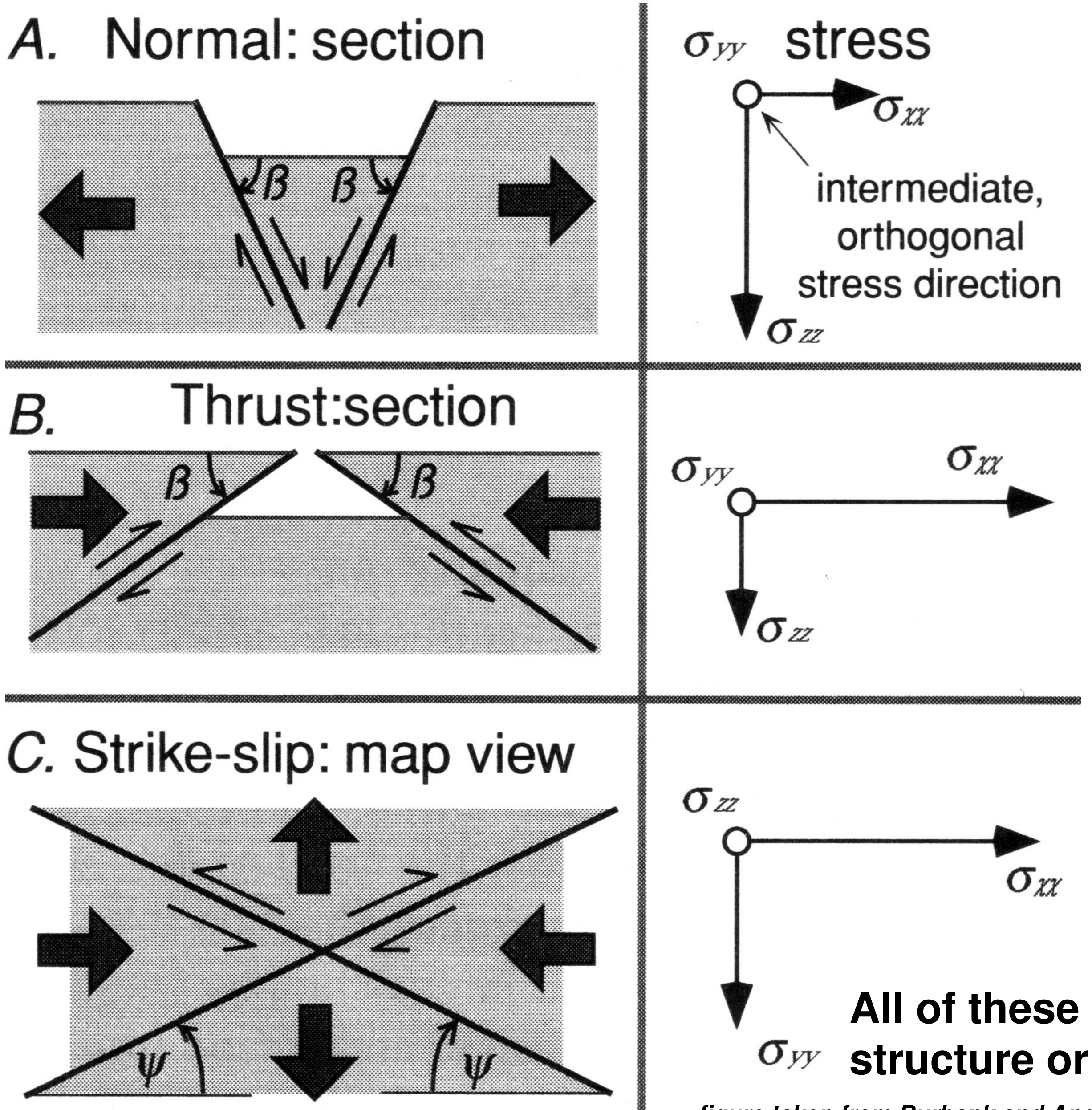


Deformation

** Combined effects of strain and rotation on an object:*



Relations between stress and fault geometries



- Normal Faults:

** Maximum compression oriented vertically.*
** Maximum tension horizontal (normal to strike of fault).*
** Fault angle 45 + ϕ/2*

- Thrust Faults:

** Maximum compression oriented horizontally.*
** Maximum tension vertical (norma to strike of fault).*
** Fault angle 45 - ϕ/2*

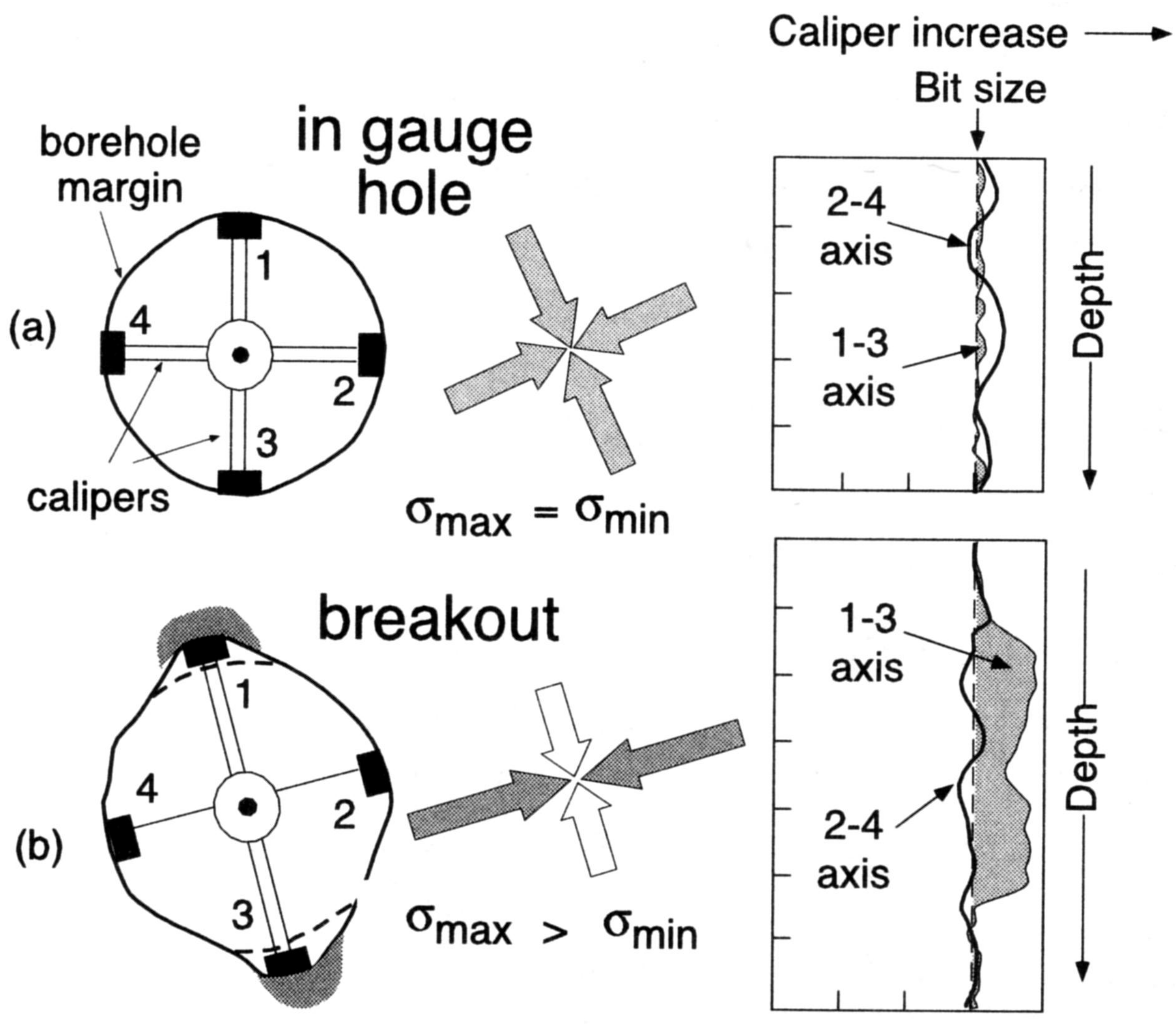
- Strike-slip Faults:

** Maximum compression and tension oriented horizontally.*
** Intermediate principal stress is vertical (normal to strike of fault).*

All of these models do not consider preexistin structure or variations in stress with depth.

figure taken from Burbank and Anderson (2001) after Turcotte and Schubert (1982)

Borehole breakouts and stress orientations



- *Borehole elongation results from differences in principal stress components perpendicular to well*

- *Large differences in horizontal principle stresses causes elongation of borehole in direction of minimum compressive stress.*

figure taken from Burbank and Anderson (2001) after Plumb and Hickman (1985)

Strain Accumulation in a Simple Earthquake Cycle

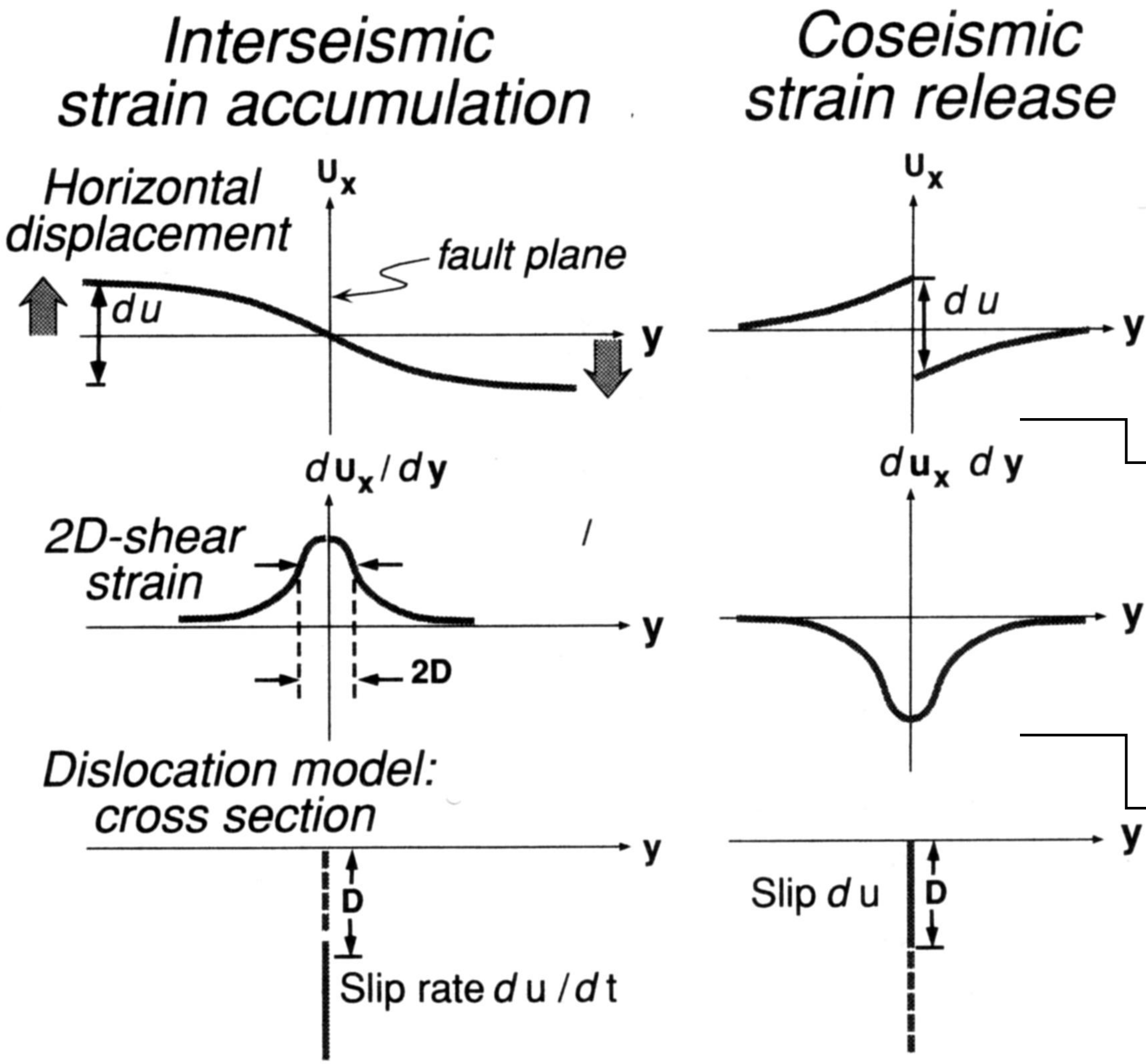


figure taken from Burbank and Anderson (2001) after Thatcher (1986)

1) Displacements: between rupture events, slip within lower layer "drags" upper crust, resulting in continuous displacements at the surface (left). Zero displacement at fault trace catches up to interseismically accumulated strain by seismic events (right).

2) Strains: Coseismic strains (right) ar exactly the inverse of the interseismically accumulated strains (left), as all interseismically accumulated strain is recovered durin earthquake.

3) Slip geometry: Between seismic events, lower extension of fault continuously slips (left). During earthquakes, upper crust ruptures (right).

Coseismic, Postseismic, and Interseismic Deformation from the Nankai trough 1946 EQ

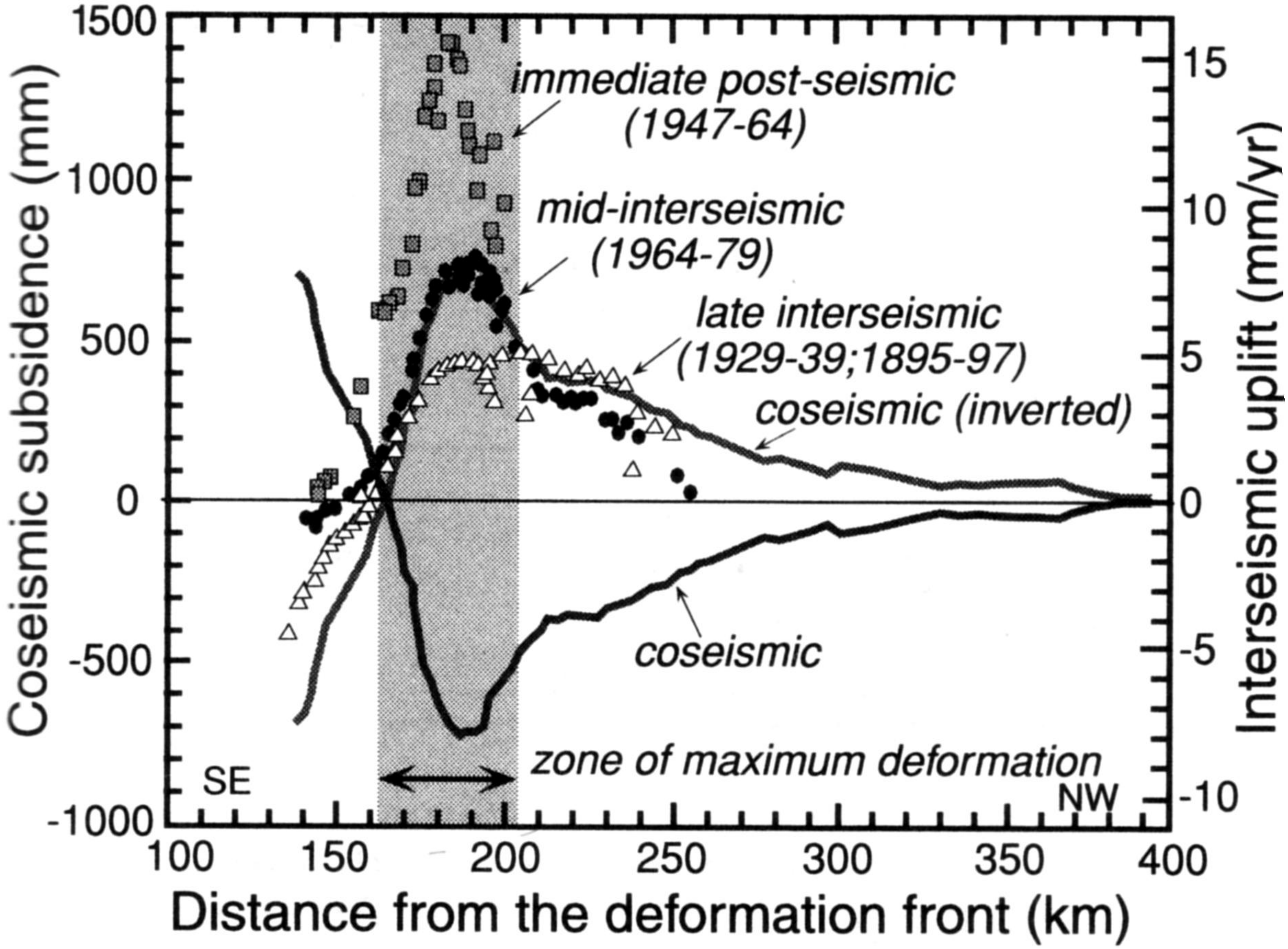


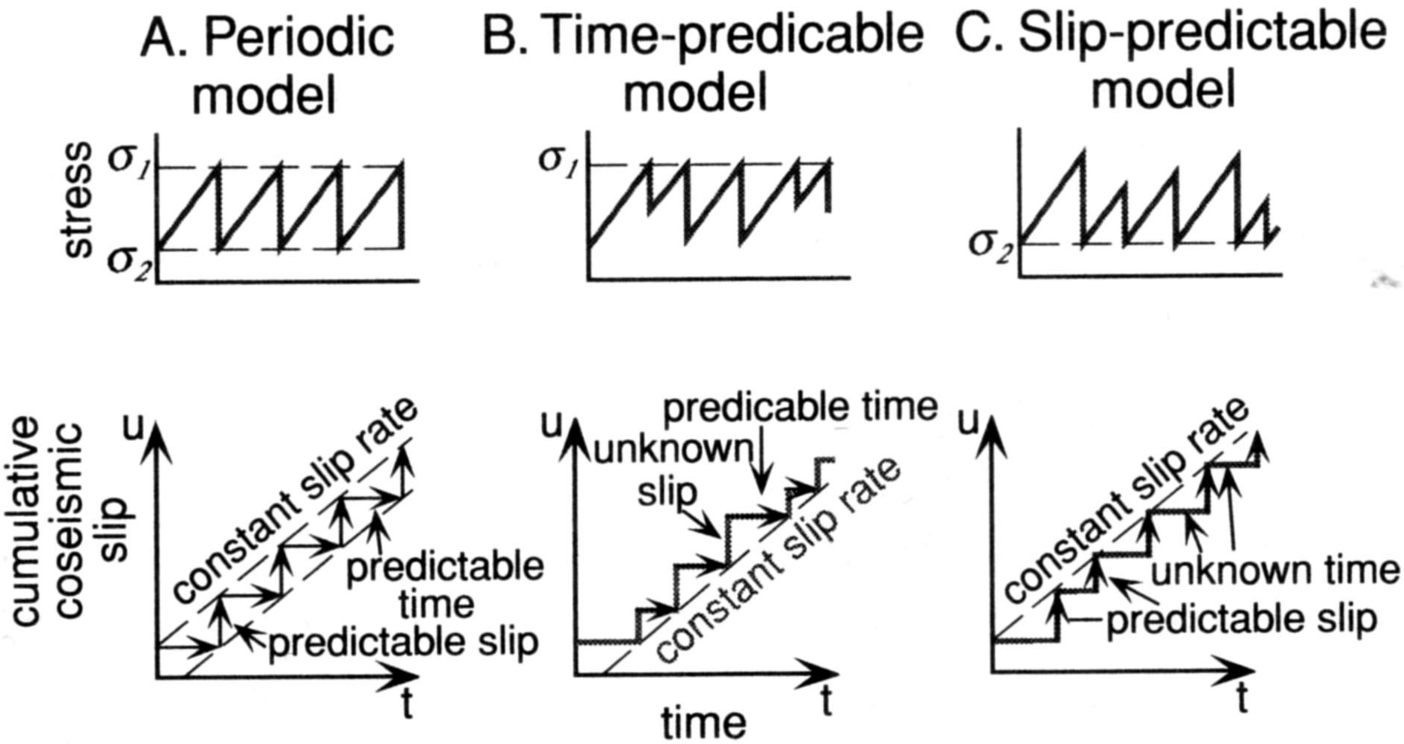
figure taken from Burbank and Anderson (2001) from Hyndman and Wang (1995)

** Mid-interseismic deformation is equal to inverted coseismic deformation, as in the simplified earthquake model.*

** Late interseismic deformation shows strain accumulation relative to mid-interseismic period.*

** Immediate post-seismic uplift over-compensates coseismic deformation.*

Models of Earthquake Recurrence



Periodic Model:

* Slip rate is constant in space and time.

* Total stress drop along fault for each event.

* Failure of fault results at a constant failure stress.

Time-predictave Model:

* Failure of fault results at a constant failure stress.

* Stress drop along fault may not be the same from event to event.

* Slip is not explicitly predicted.

Periodic Model:

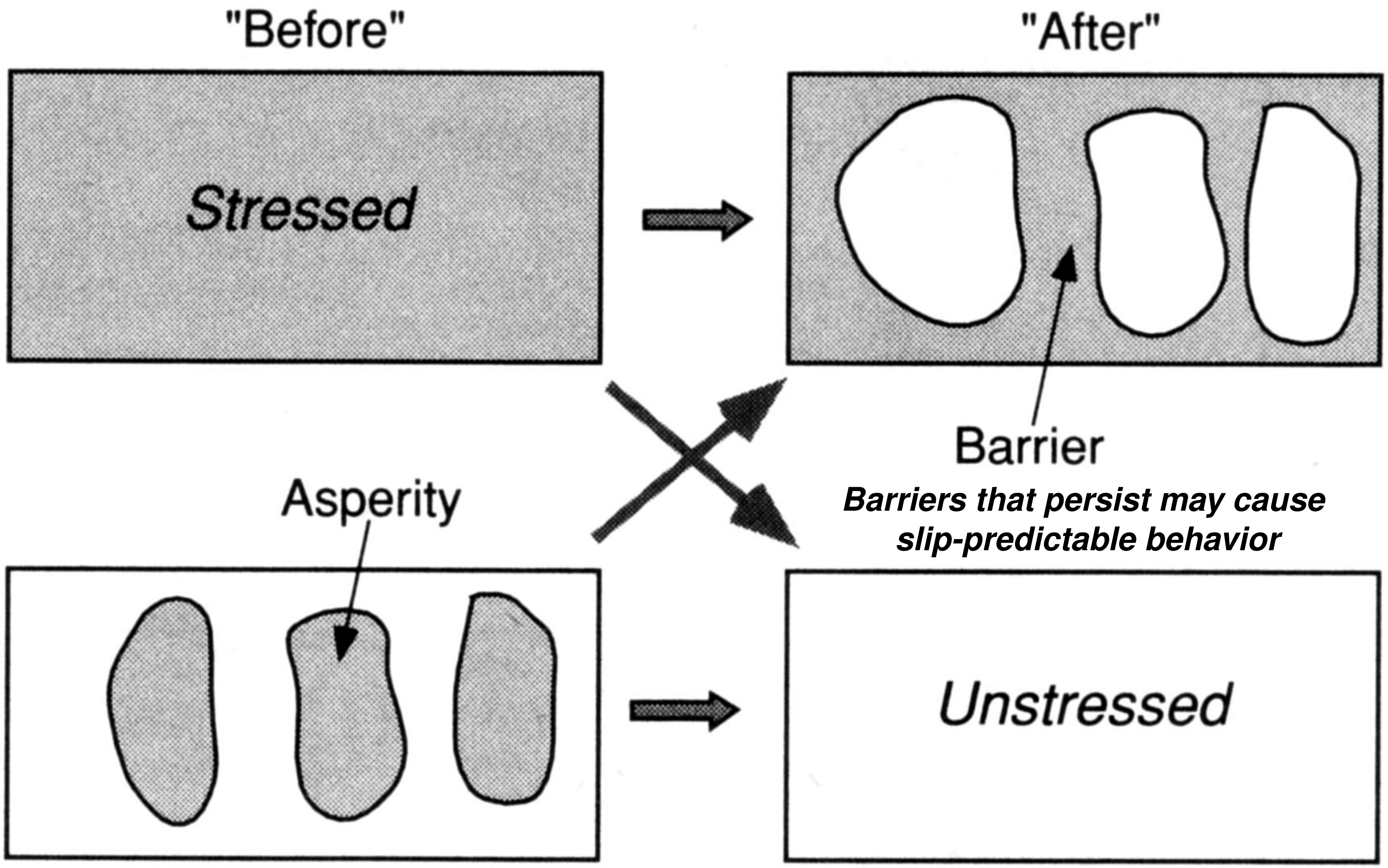
* Failure of fault results at a variable failure stress.

* Stress drop along fault always returns along-fault stress to a constant value.

* Time since last earthquake predicts slip.

figure taken from Burbank and Anderson (2001) after Shimaki and Nakata (1980)

Asperities, Barriers, and Fault Strength



Barriers that persist may cause slip-predictable behavior

Asperities that persist may cause time-predictable behavior

figure taken from Burbank and Anderson (2001) after Aki (1984)

Fault Slip Recurrence

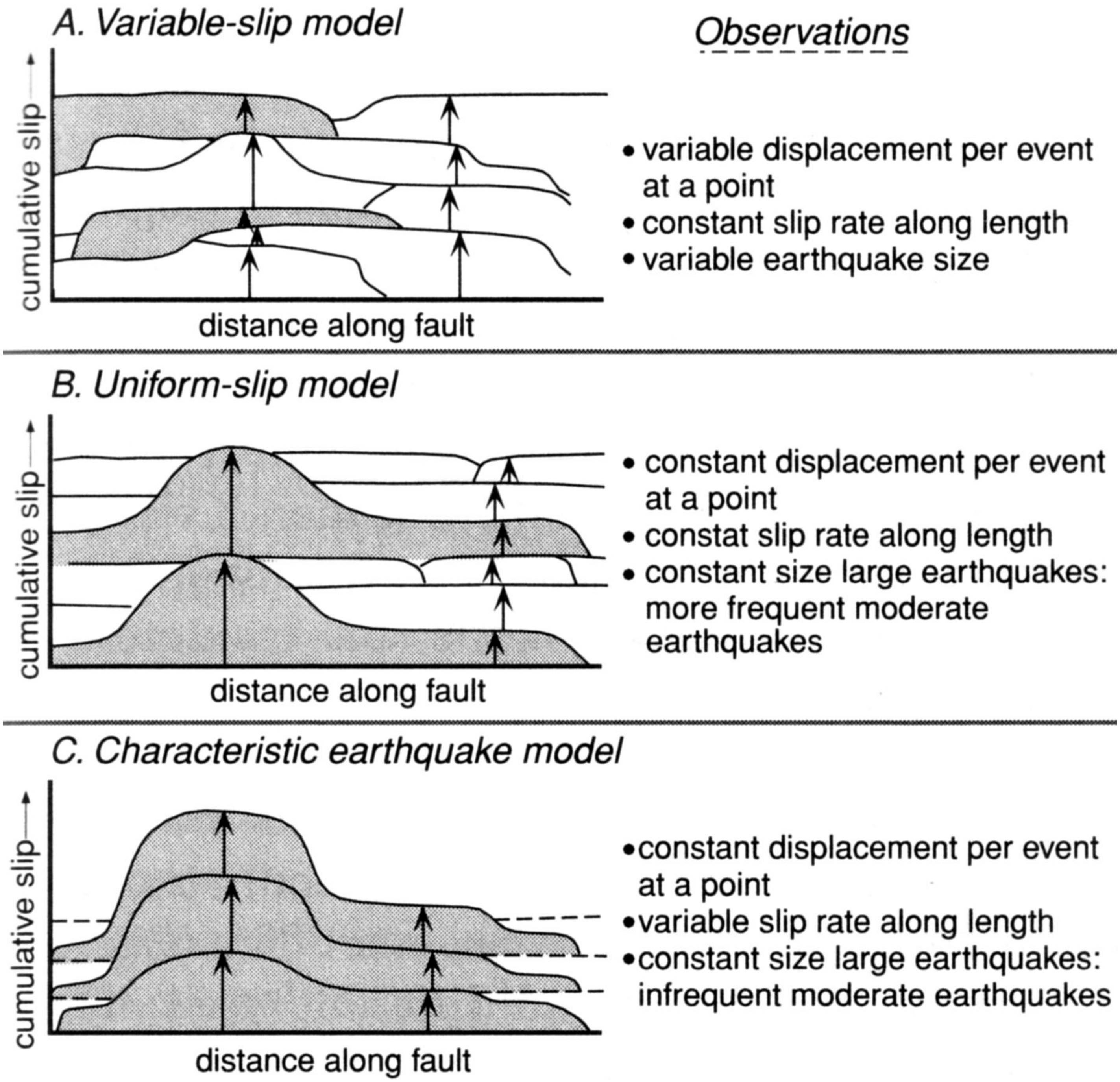
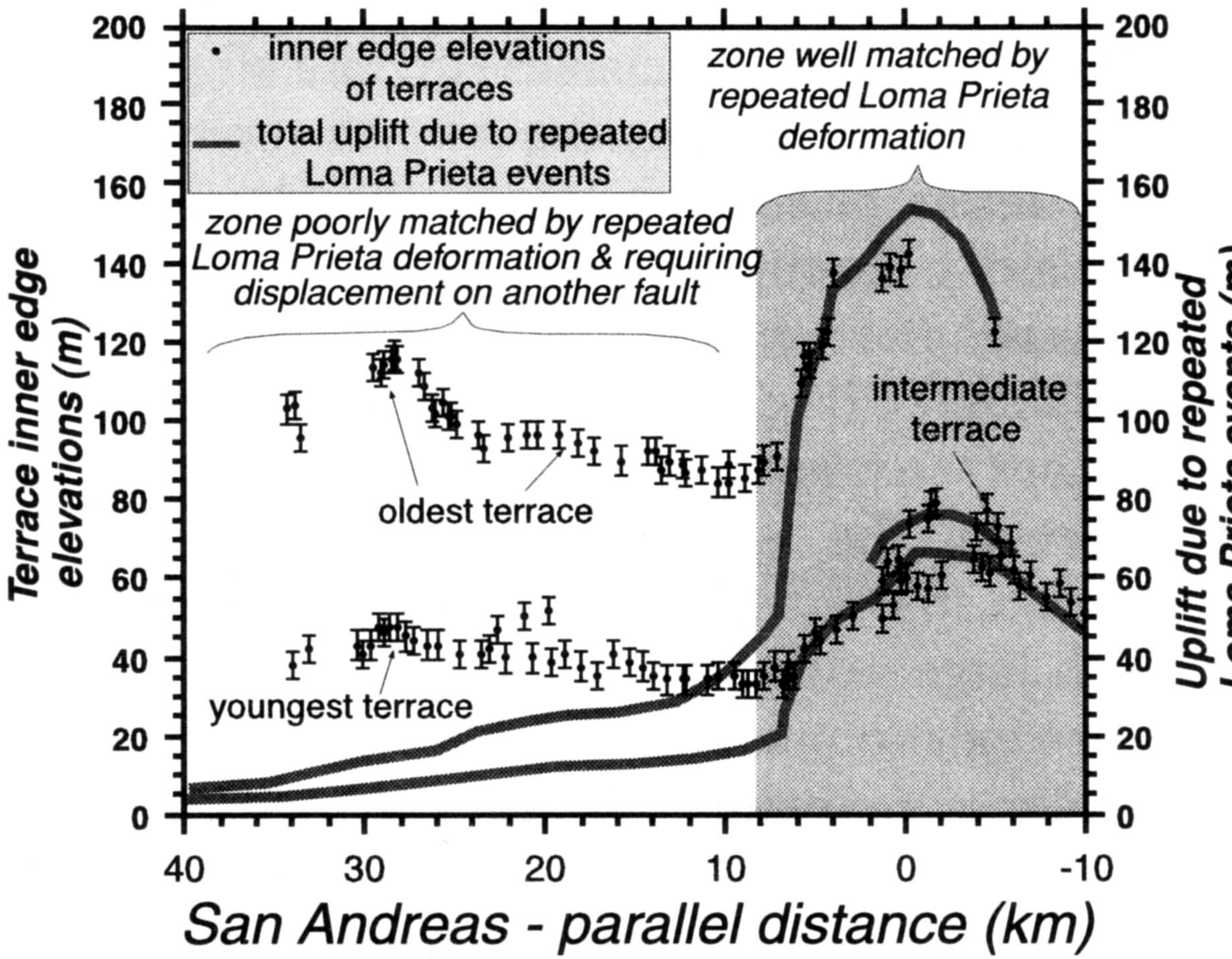


figure taken from Burbank and Anderson (2001) after Schwartz and Coppersmith (1984)

Surface Deformation Resulting from Repeated Earthquakes



** 1989 Loma Prieta Earthquake produced surface deformation throughout the Santa Cruz Mountains.*

** Marine terraces record repeated events in northeastern (shaded gray) section of profile.*

** Terraces closer to the Pacific Ocean poorly record these repeated earthquakes, requiring some other process to uplift the terraces.*

figure from Burbank and Anderson (2001) after Anderson and Menking (1994)

Length-Displacement Scaling Relations Along Faults

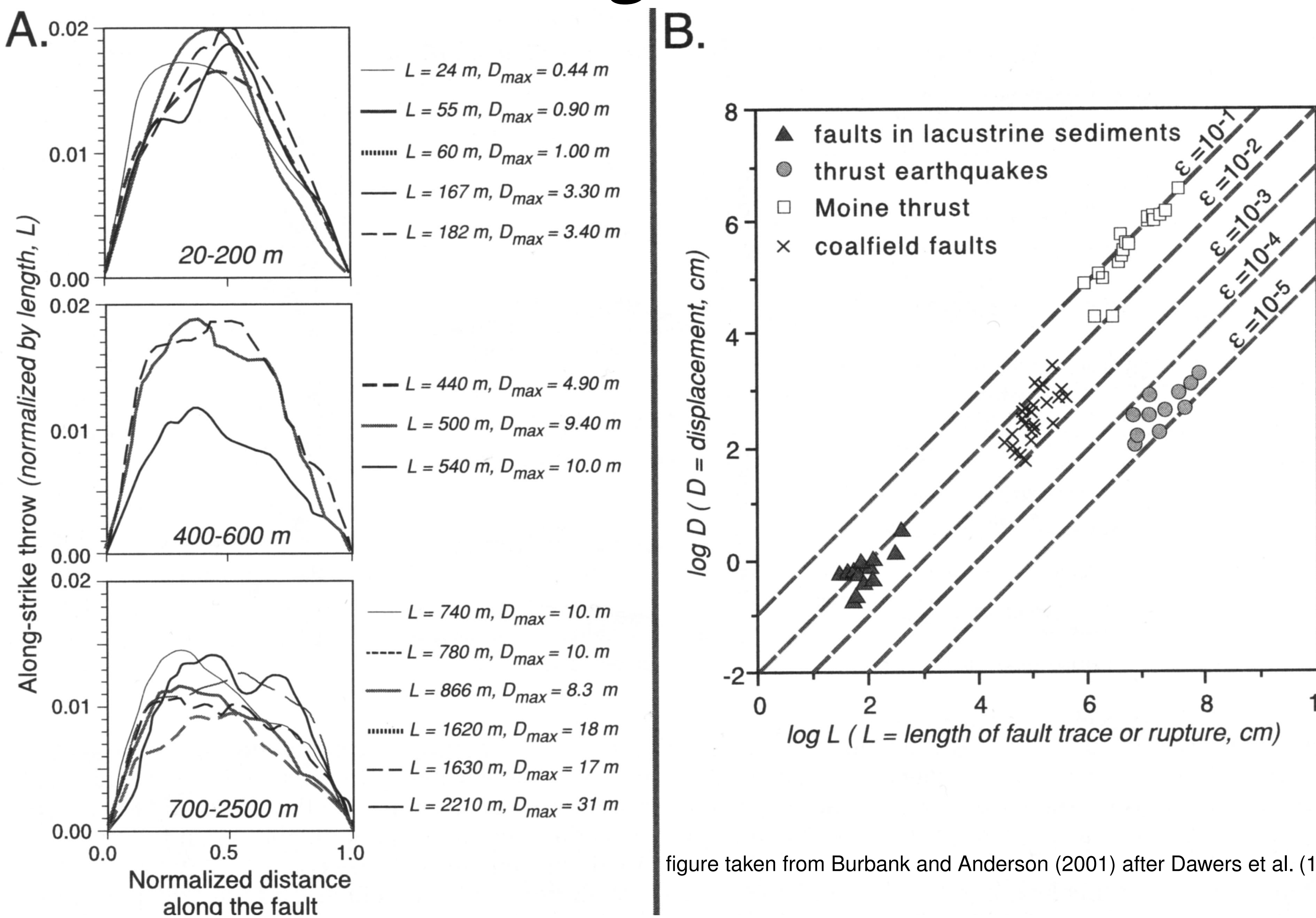


figure taken from Burbank and Anderson (2001) after Dawers et al. (1993) and Scholz (199

Fault Segmentation and Effect on Length-Displacement Scaling

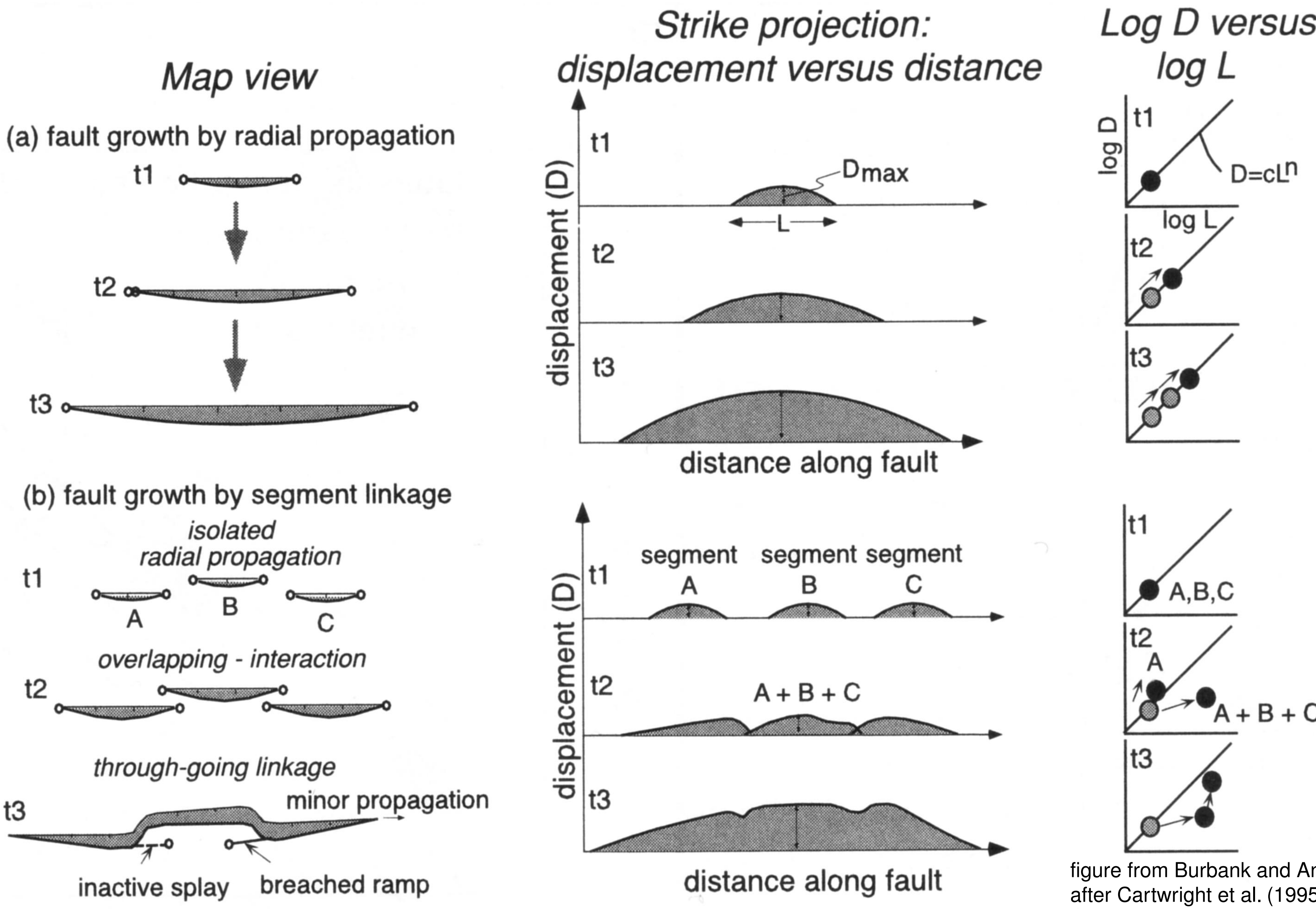


figure from Burbank and Anderson (2001) after Cartwright et al. (1995)

Important Points:

- Strain, Deformation, Rotation, and Stresses are all linked through rheology.

- Rheology describes how material deforms as the result of imposed stresses. It can result from faulting, distributed mineral grain processes, cataclastic flow, viscous flow, to name a few examples.

- We can measure orientations of stresses using borehole breakout measurements.

- Hydrofracture experiments may be used to determine magnitudes and orientations of principal stresses.

Important Points:

- Earthquake cycle in its most basic form consists of interseismic strain accumulation and coseismic strain release. In this simple model, uniform fault strength and stress release lead to periodic behavior.

- Asperities along faults may dominate maximum strength that leads to ruptures. Time-predictive model.

- Barriers that release all stress after rupture may lead to slip-predictive model.

- Faults often display systematic relations between their length and total offset.

Next Class:

Structural Relations Between Faults and Folds