Tectonic geomorphology

– studies processes and landforms controlled by tectonics

Change in landscape caused by change in landscape process

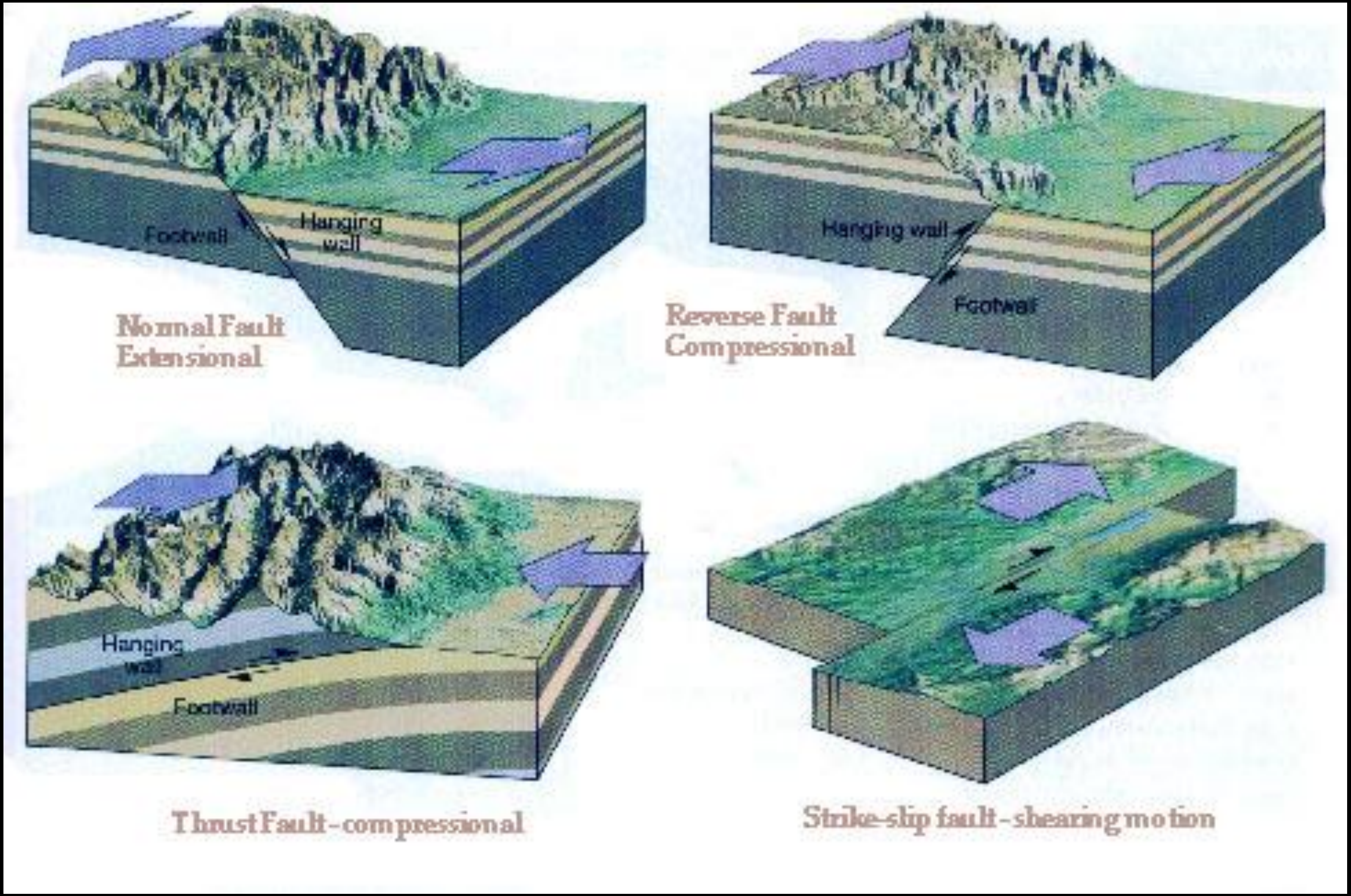
Look for **morphological anomalies** – surfaces warped, tilted, uplifted, fractured

Some features indicate the presence of a fault, but say little about activity or type of movements

Vegetation alignments, springs, fault scarps, other lineaments

Faults

3 types of faults – in various stress regime: normal faults, reverse faults, strike-slips; cumulative earthquake or creep – relief formation



video!

normal fault

strike-slip

thrust fault

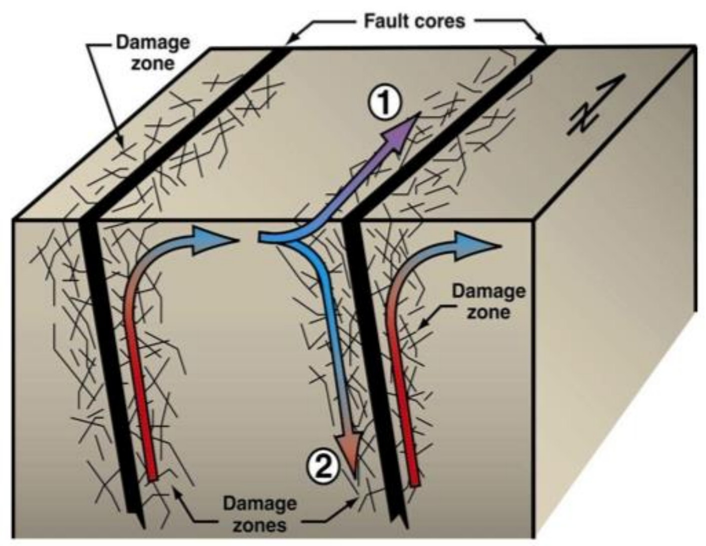
reverse fault

All Fault Types Have Potential to Disrupt Groundwater Flow/Create Scarps

- Springs – fault gouge can be an effective barrier

Forty springs - Arba Minch

Gilman Hot Springs, San Jacinto Valley



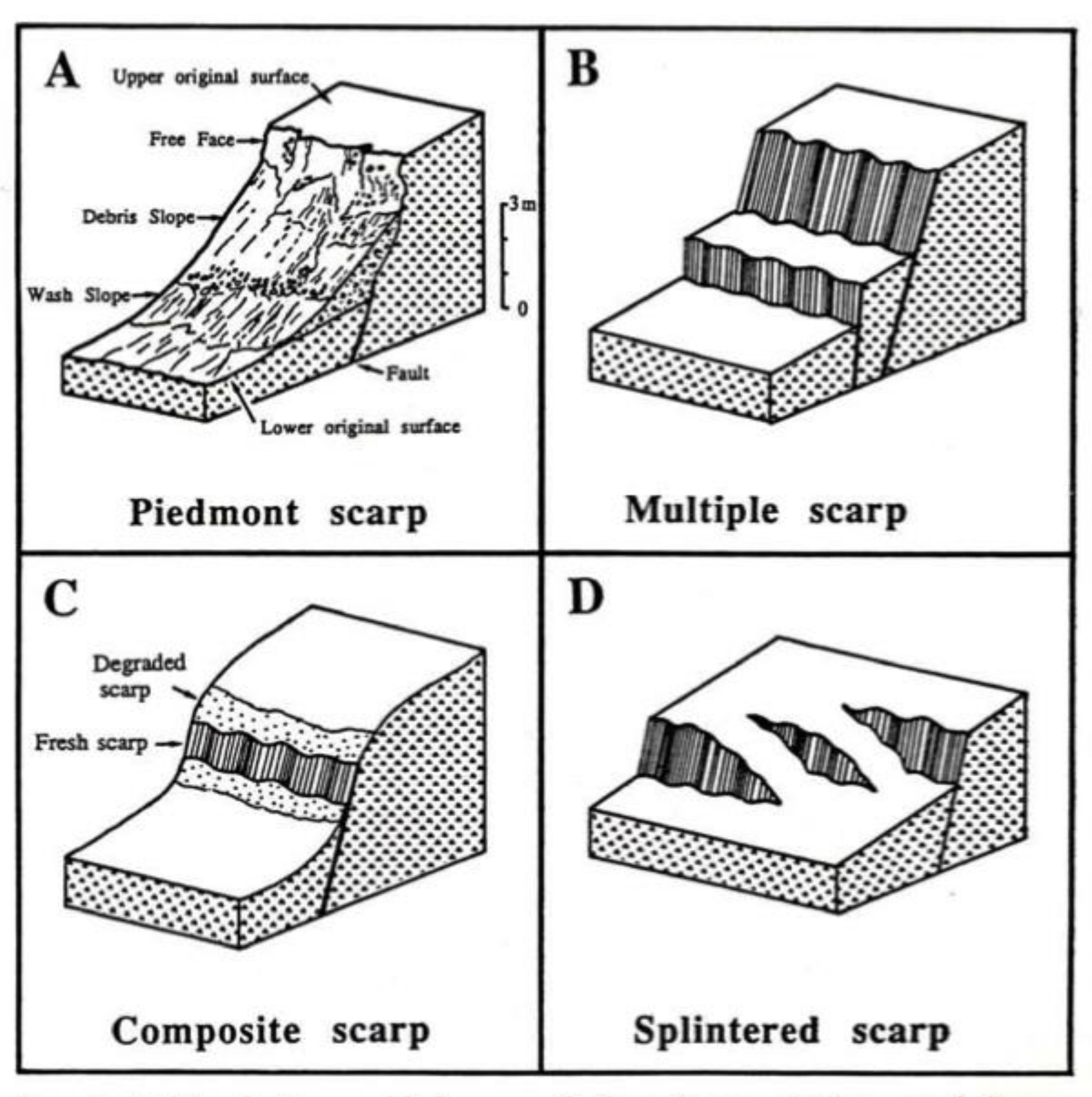
- Vegetation Lineaments (arid areas)

San Andreas Fault -
Thousand Palms Oasis,
Indio Hills, California

Scarps – all fault types, all scales

Northward across Coyote Creek Fault, San Jacinto Fault Zone

Fault scarp – tectonic landform coinciding with fault plane



Stewart, Hancock 1990

Piedmont scarp –

formed during one movement in unconsolidated sediments

Multiple scarp

- Formed on parallel faults or branches of the fault during one movement

Composite scarp (combined)

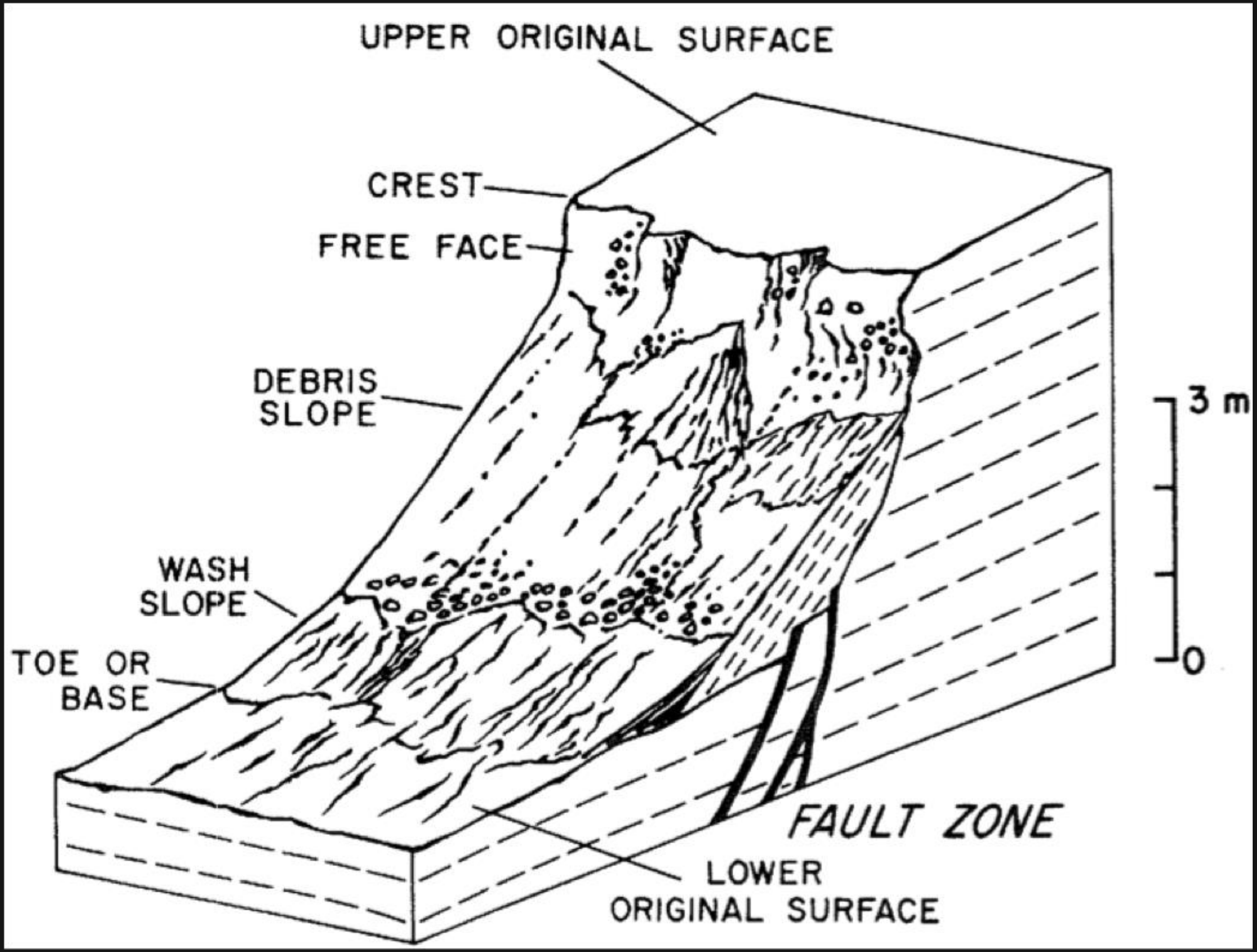
- Formed by reactivation and by degradation of the former free face

Splintered scarp –

formed -during movement distriuted on en échelon fault segments

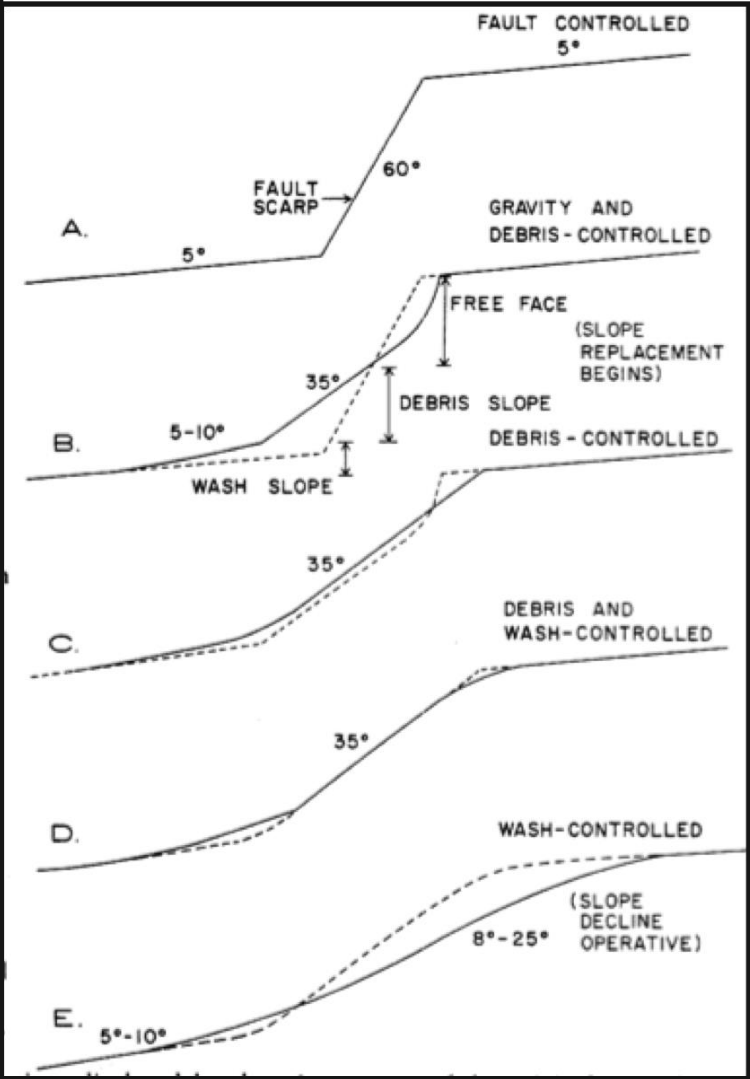
Fault scarp anatomy

- *Toe* and *crest* - upper and lower limit of fault scarp
- *Free face* - sub-vertical part, exposed alluvial fan deposits or slope deposits formed by movements – can keep the shape 10-1000 years
- *Debris slope* – scree cone accumulated bellow the free face by gravitation
- *Wash slope* – part of slope on the toe controlled by fluvial erosion or accumulation

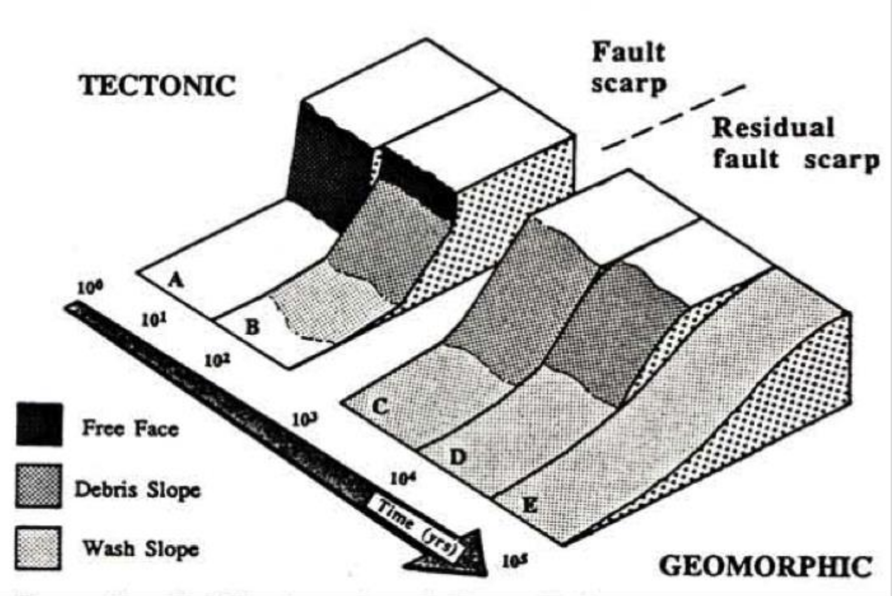


Wallace 1977

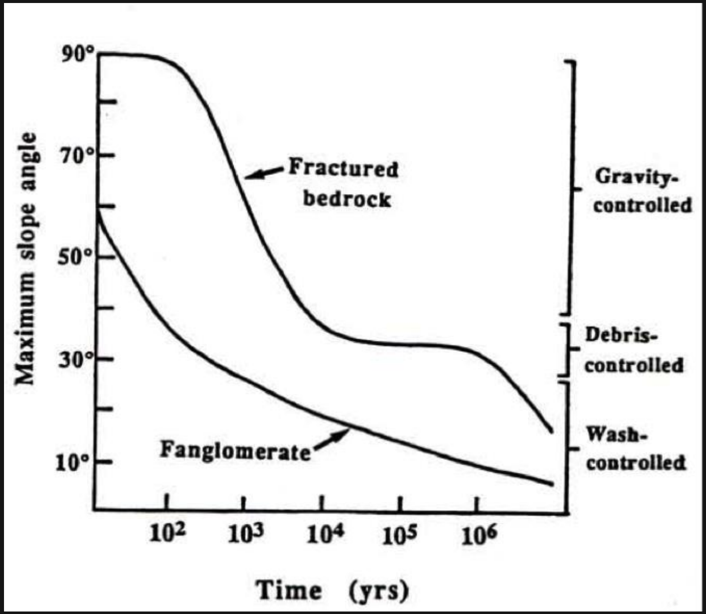
Fault scarp degradation



Wallace, 1977

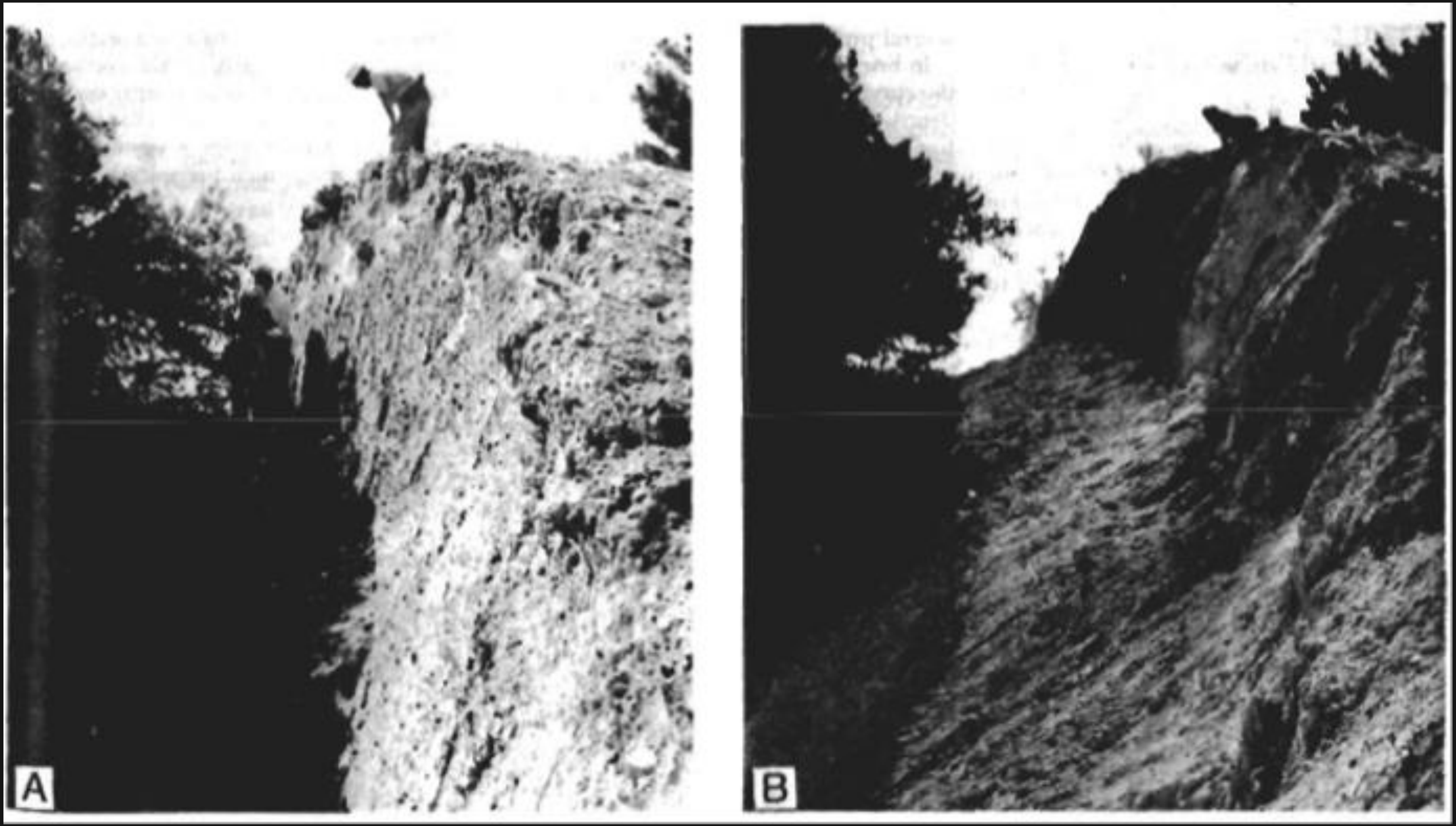


Stewart, Hancock, 1990



Wallace, 1977

Fallon-Stillwater earthquake, July 6th, 1954 M 6.6



Wallace, 1977

Pictures taken from 1954 and 1974 show several meters of retreat from the free face, forming a debris-slope.

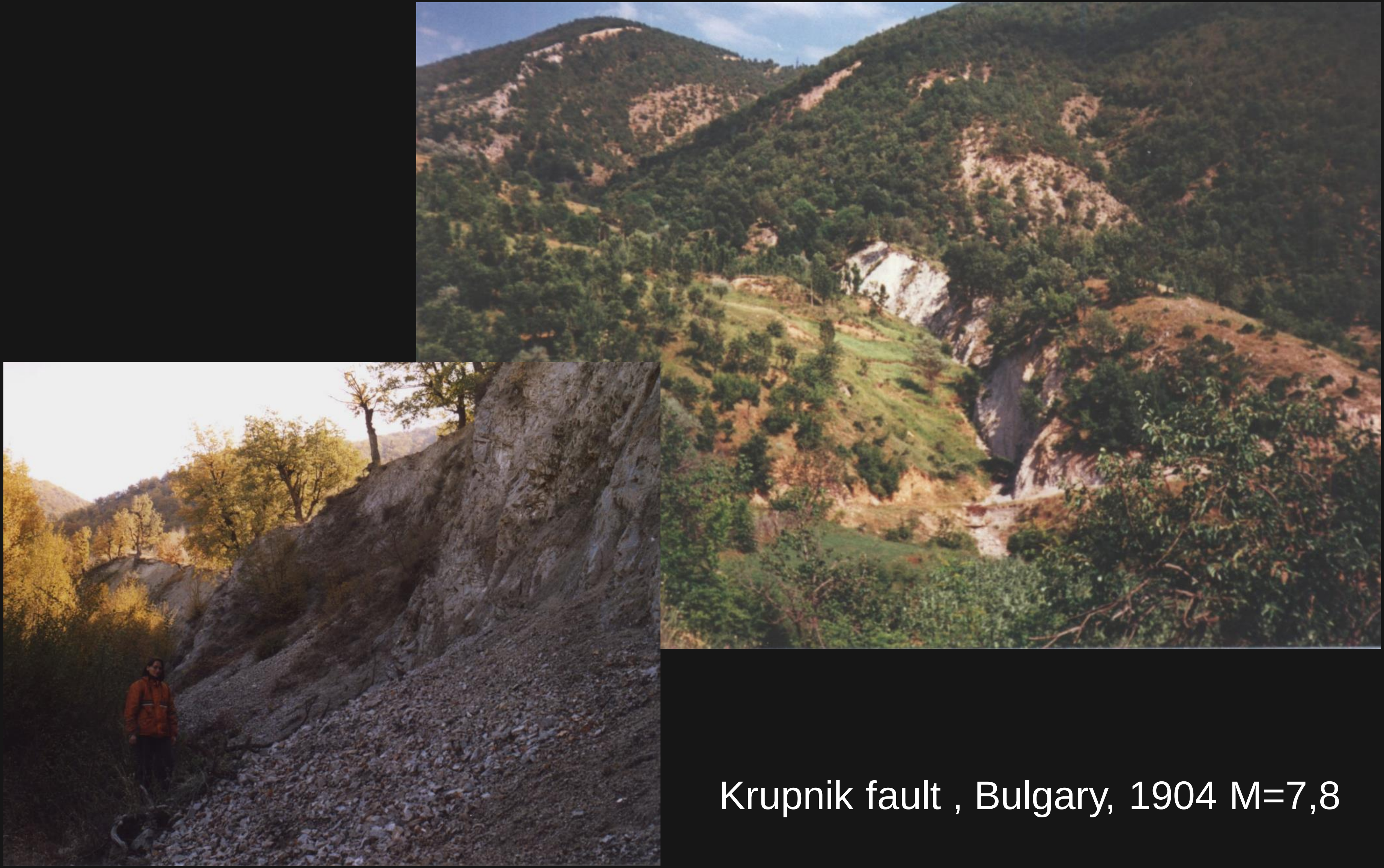
Scarp on Strike-Slip (oblique slip)

A young scarp!! TINY!

Carboneras fault, Spain

Coyote Mts, Elsinore fault, CA

Scarps on normal fault



Krupnik fault , Bulgary, 1904 M=7,8

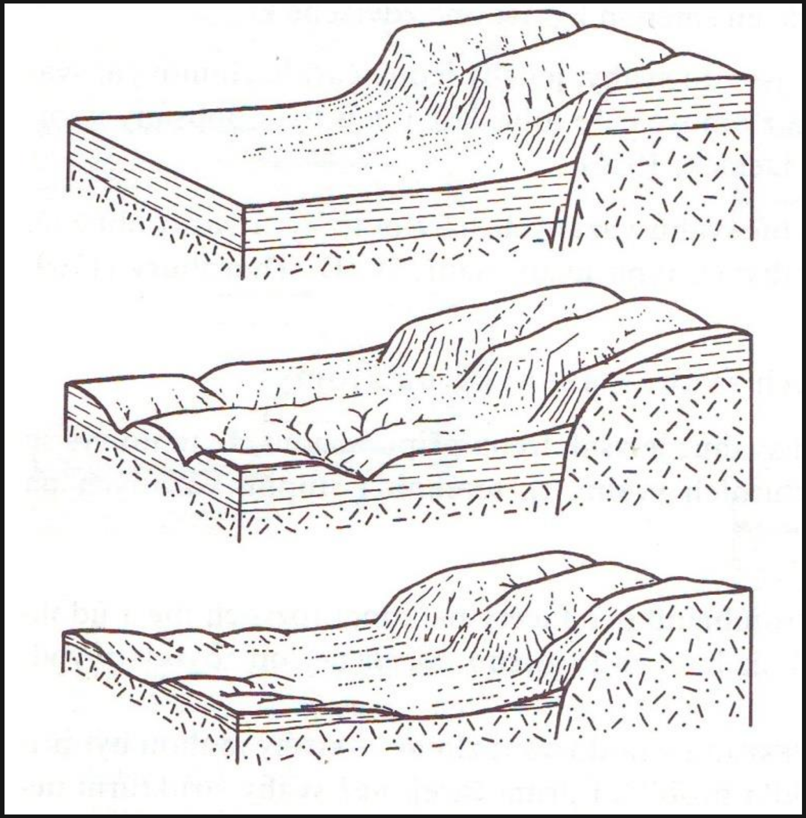
Scarps on thrust fault

Chichi earthquake 1999, Taiwan

Active or Inactive?

- Differential weathering along inactive faults can produce features that resemble features produced by active faults
  - – Vegetation lineaments,
  - – Linear valleys
  - – Scarps
    - Known as “**Fault-Line Scarps**”

Sometimes these features exist, but they are not associated with any active faulting!! (differential erosion)



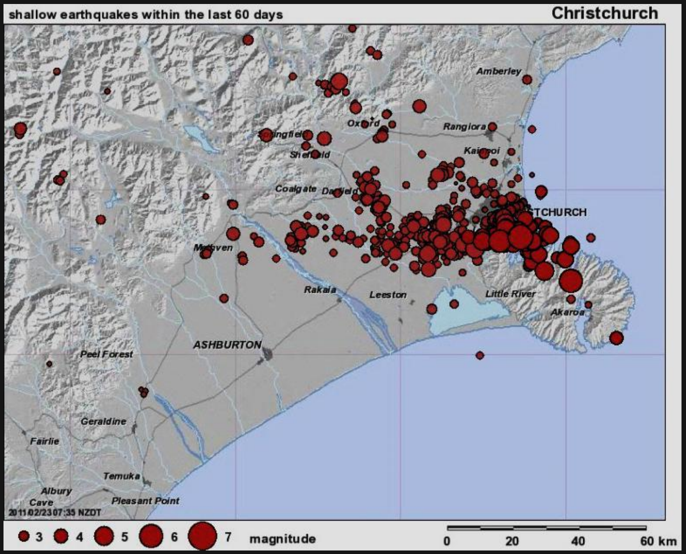
Some geomorphic features clearly indicate **young activity** (usually Holocene to late Quaternary)

- If it is expressed in the geomorphology, it is likely active (unless you can demonstrate that the features are totally erosional in nature)
  - scarps in alluvium, deflected drainages, sags, shutter ridges, side-hill benches

A general rule is that active faults produce alluvium so they bury themselves, so locally, the evidence for activity may be obscured along some portions of the fault

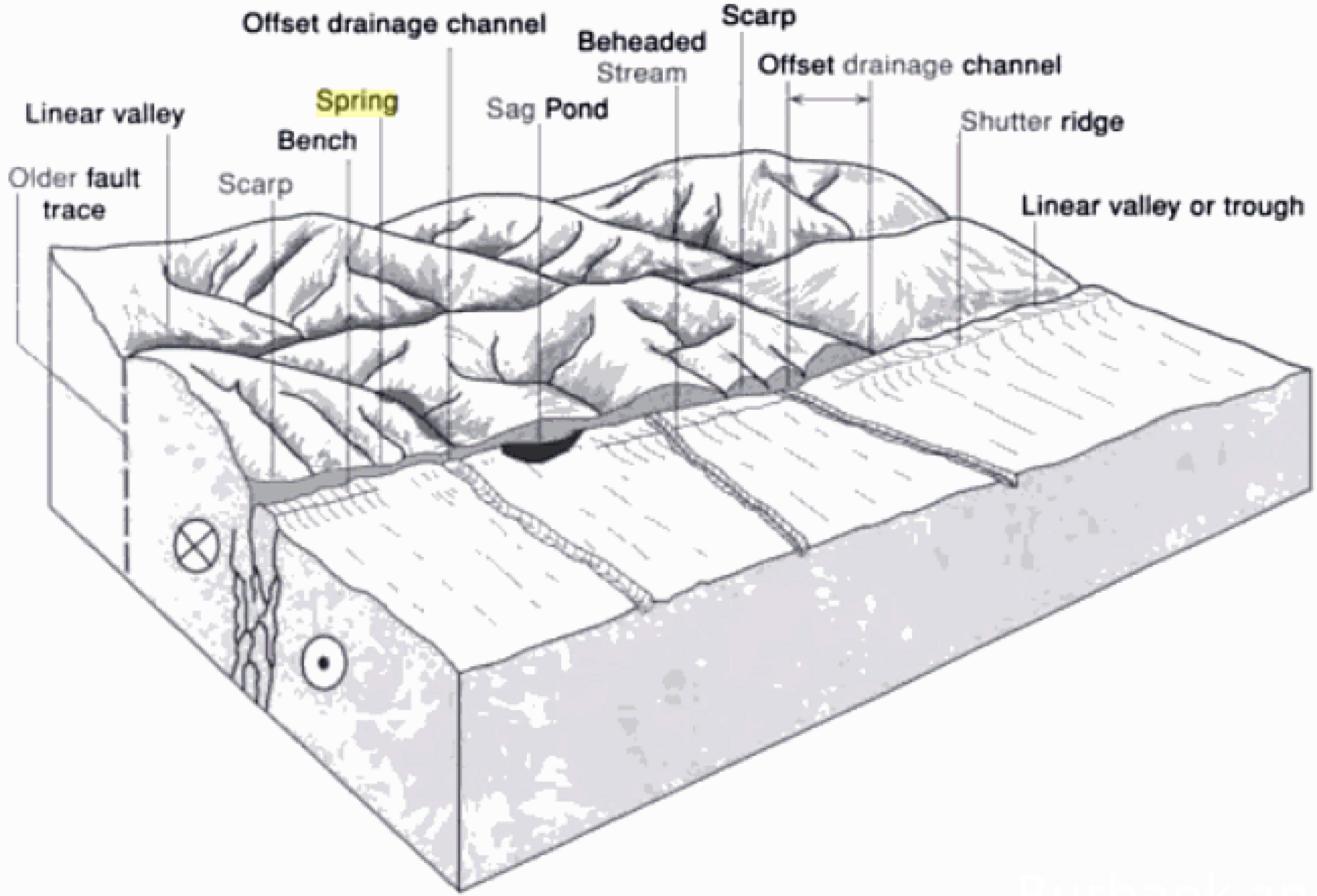
Christchurch EQ 21.2. 2011, M = 6.3, NZ

- **unknown fault,** uplift of Southern Alps – 10mm/year =high sedimentation, sediments obscure the fault trace



Active Strike-Slip Fault Geomorphology

FIGURE 4.18. Overview of strike-slip geomorphology



Burbank and Anderson, 2001

A linear trough along fault, sag ponds, shutter ridges, offset ridges and drainages, springs, scarps, and beheaded streams are typical geomorphic features indicative of strike-slip faulting. The older, abandoned fault trace displays analogous, but more erosionally degraded features. Modified after Wesson et al. (1975).

Effects on Stream Channels

Offsets

- Implies a previously straight, now-curved channel as a result of displacement
- the bend in the channel must agree with the sense of slip!

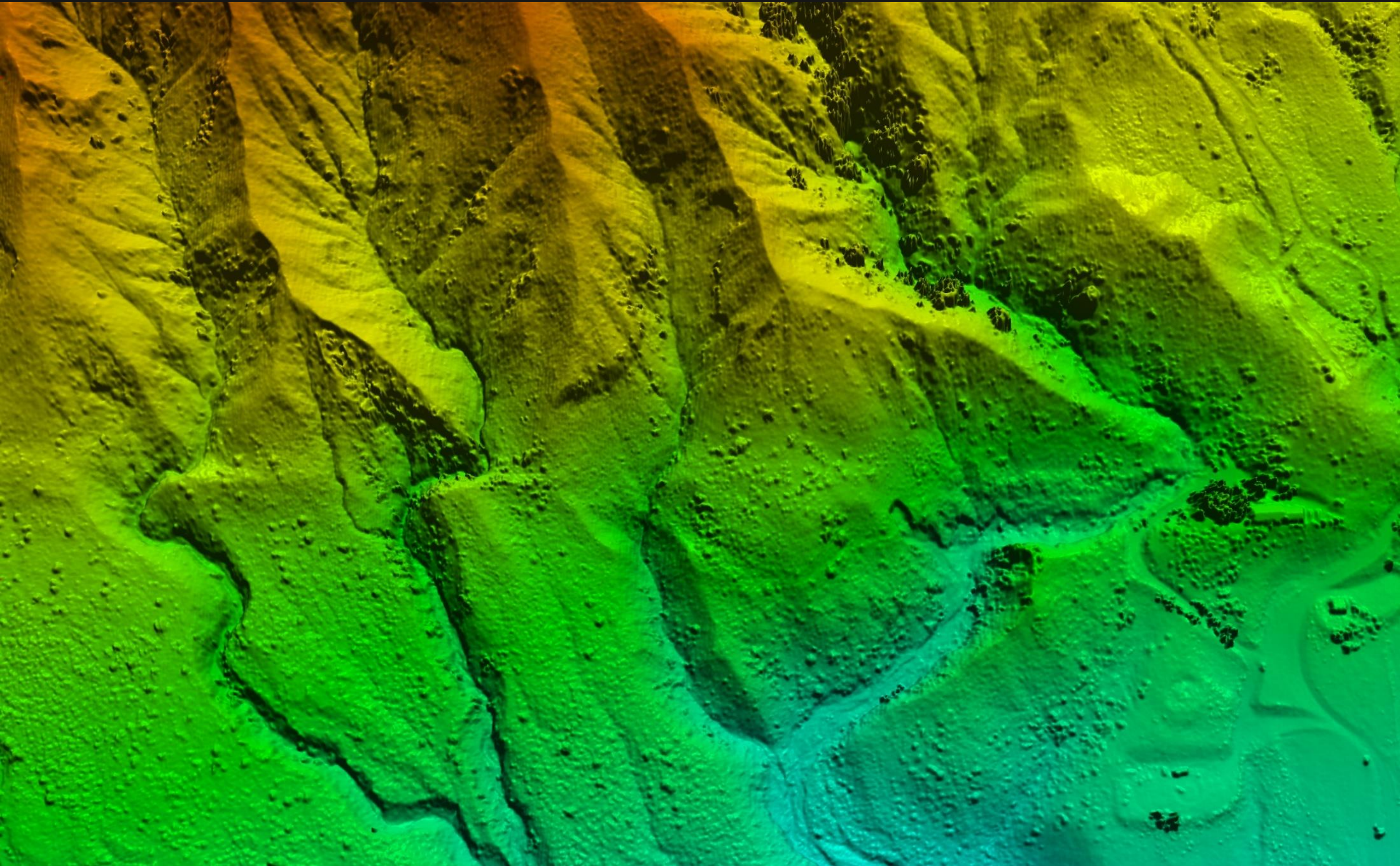
Deflections

- The curve in the channel can be with or against the sense of slip
- Result of drainage capture
  - (water will take the easiest path downhill, alluvial fans)

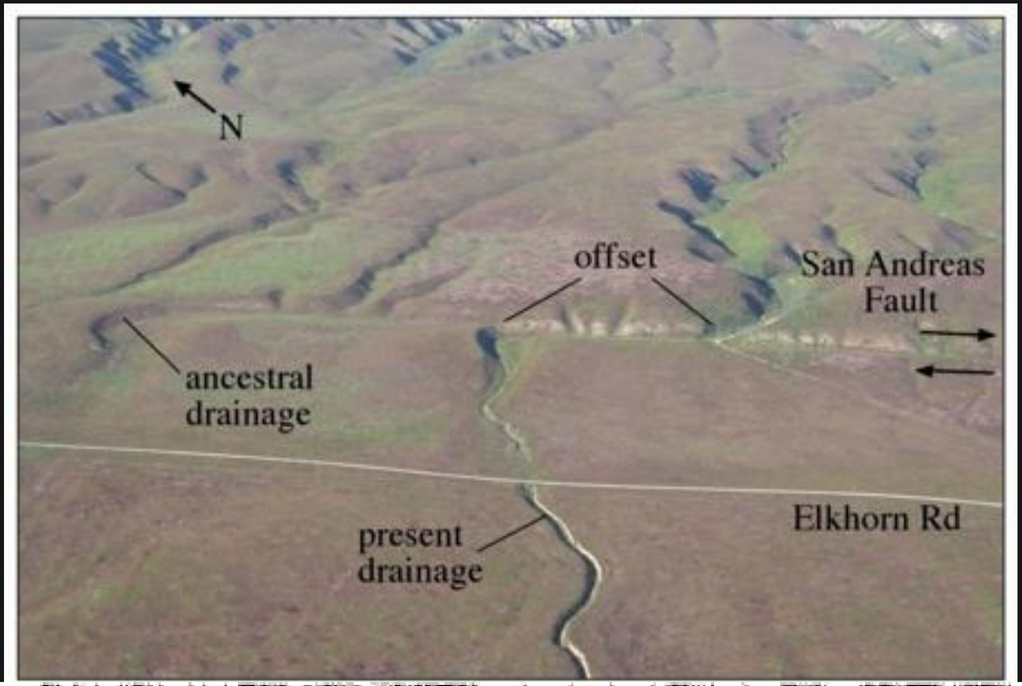
All offsets are deflections, but not all deflections are offsets!

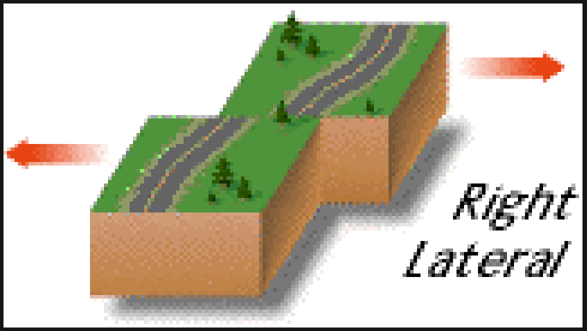
Offset channels

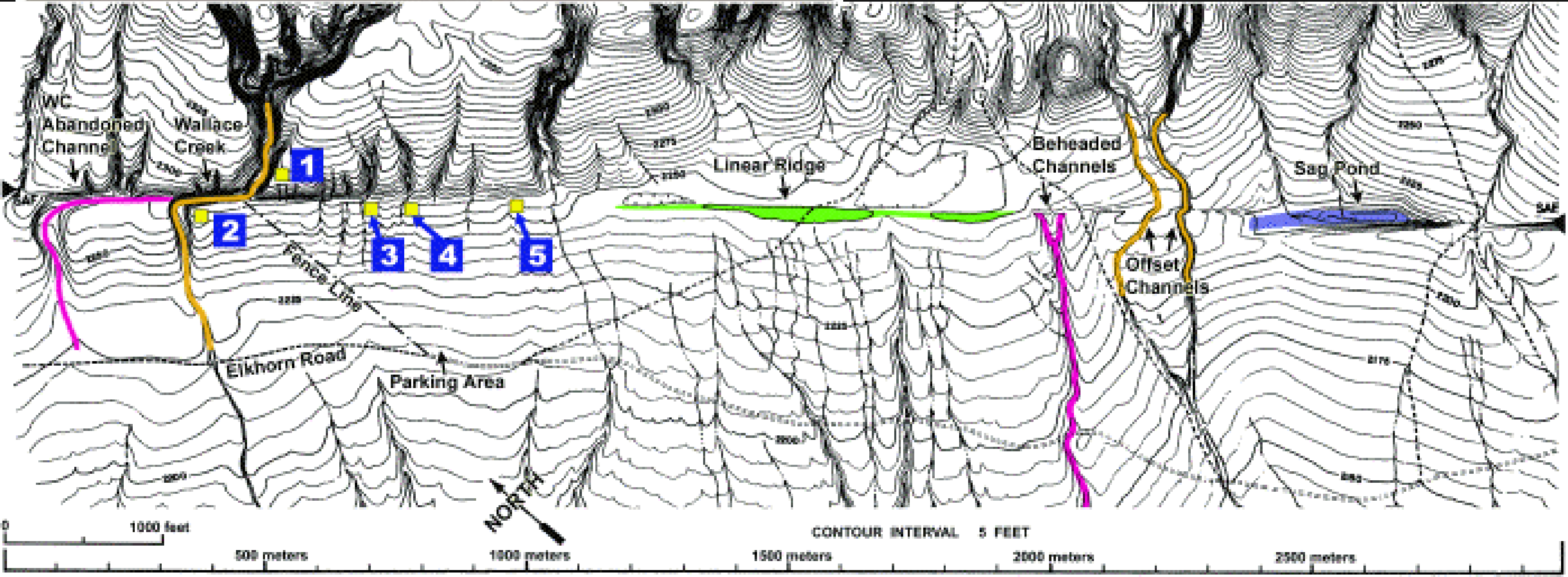
Pitman Canyon ~ 46 - meter offsets



San Andreas Fault, Carrizo plain, CA

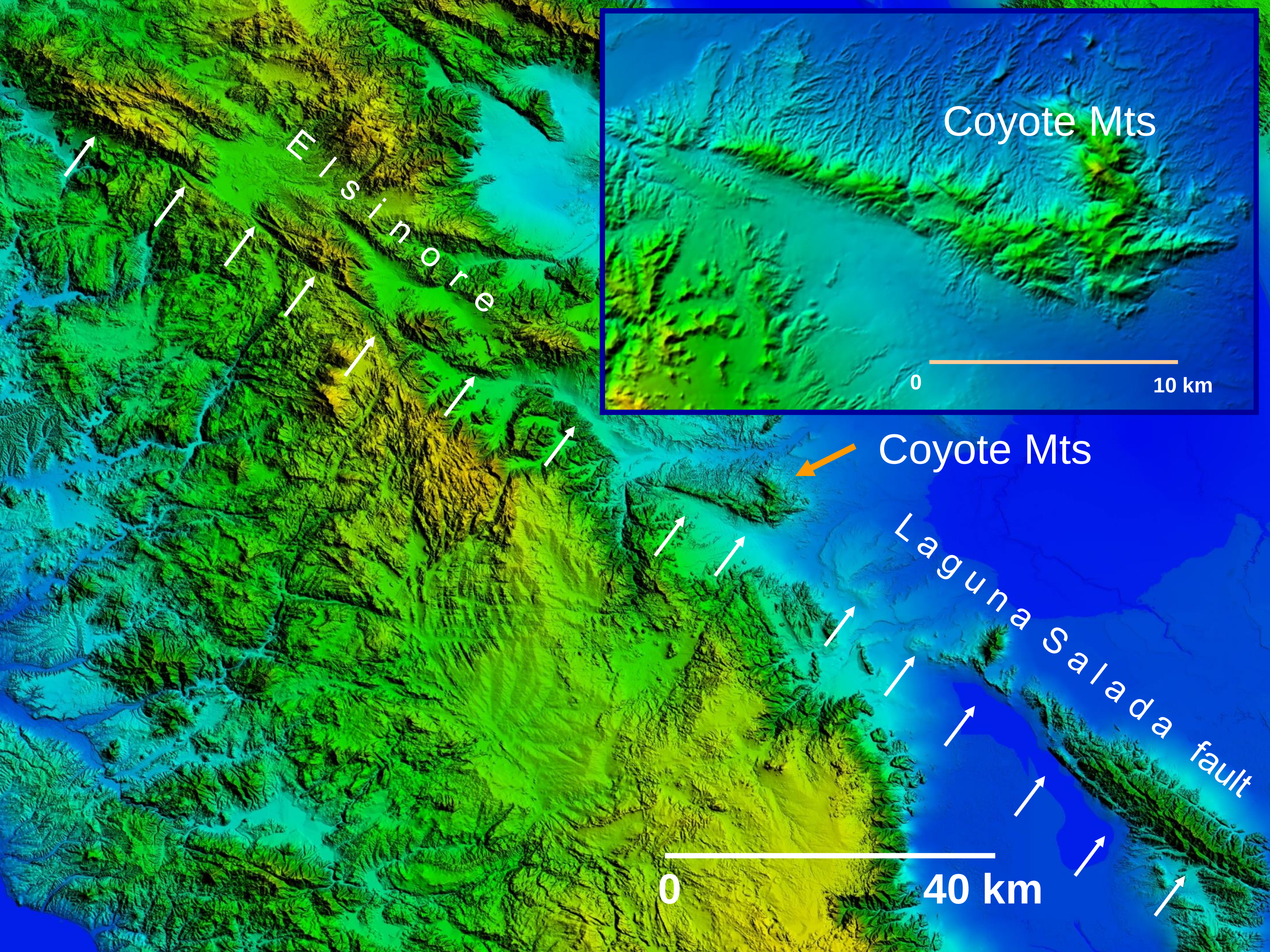


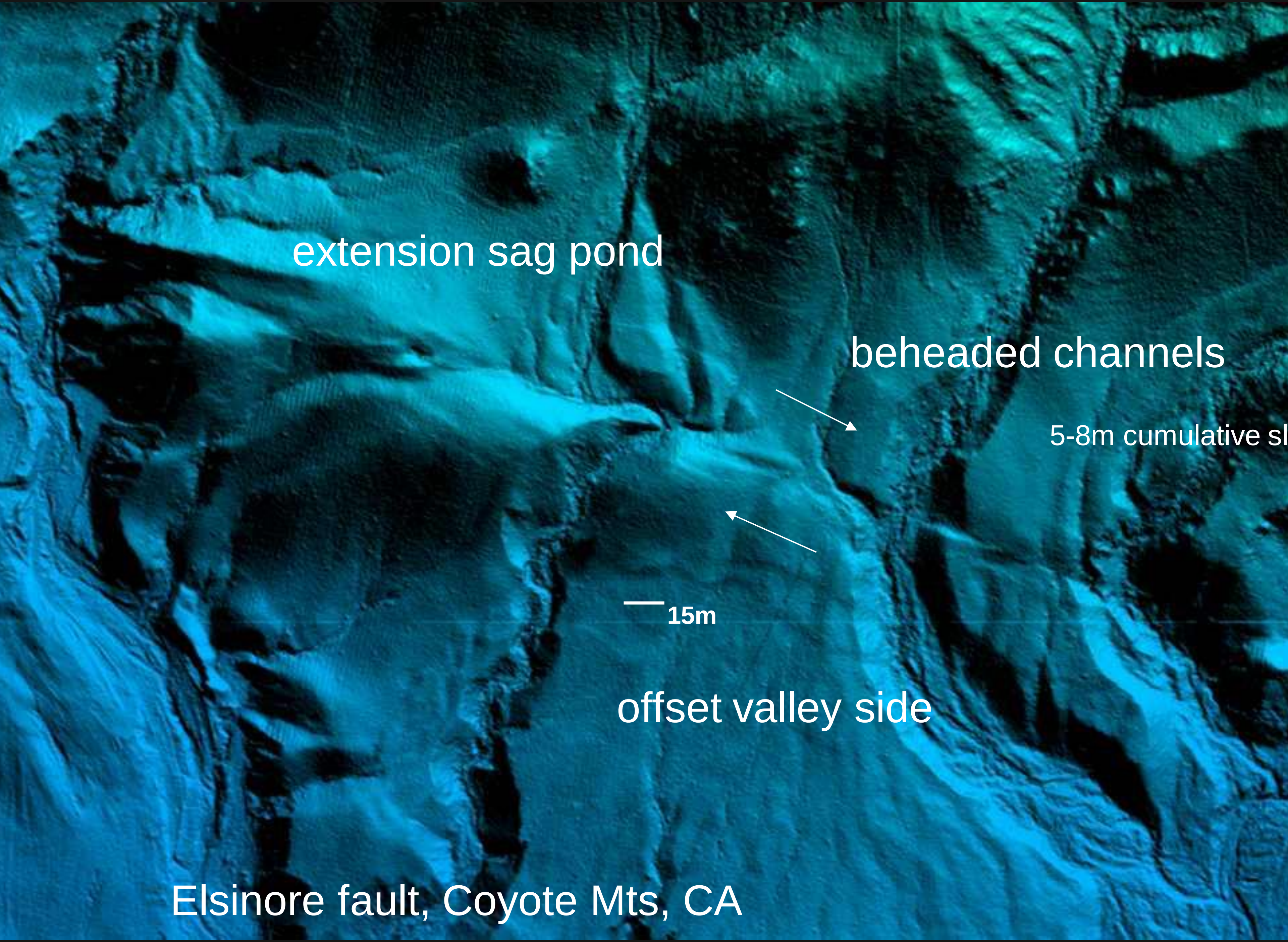




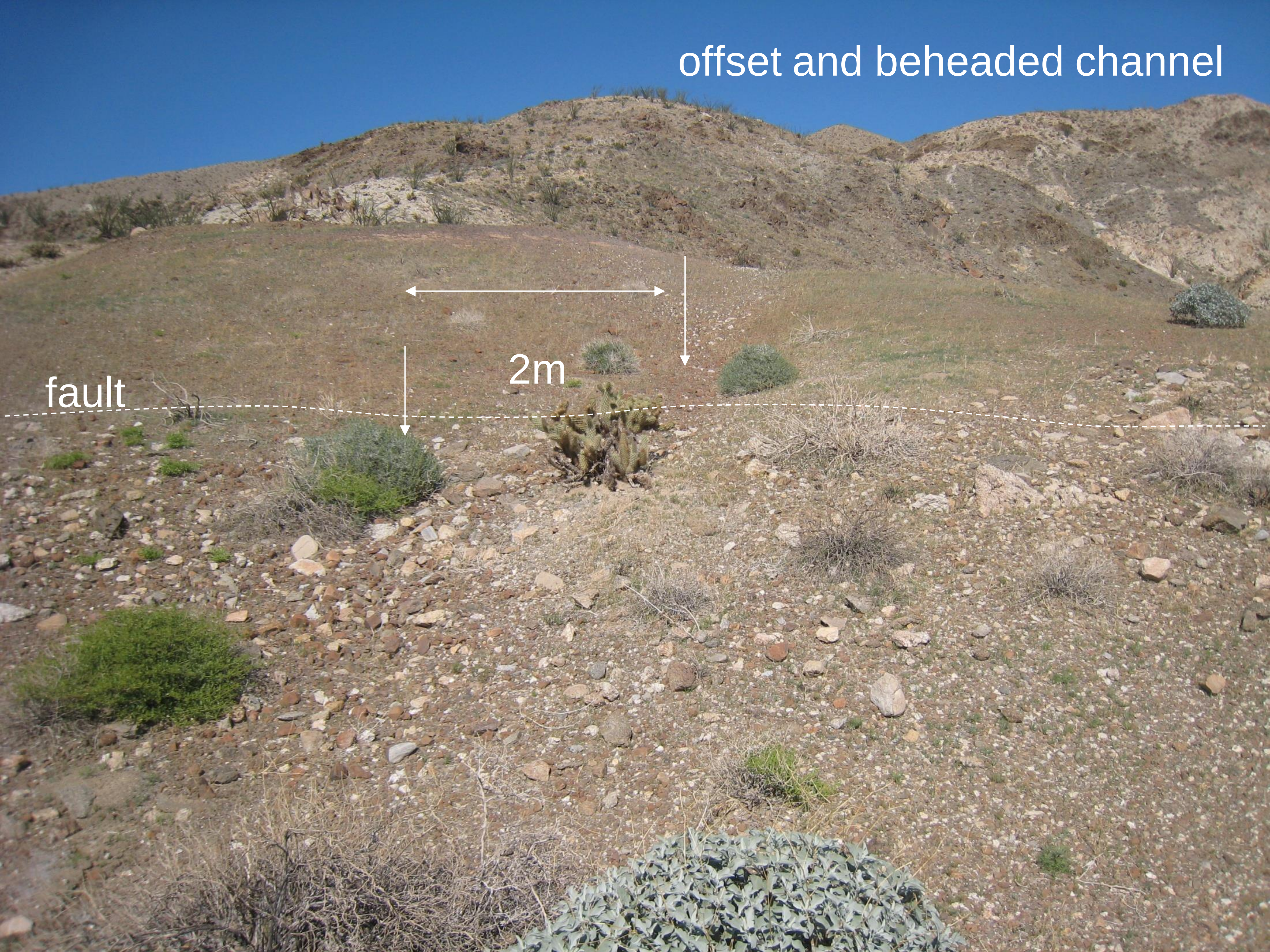
Offset channels

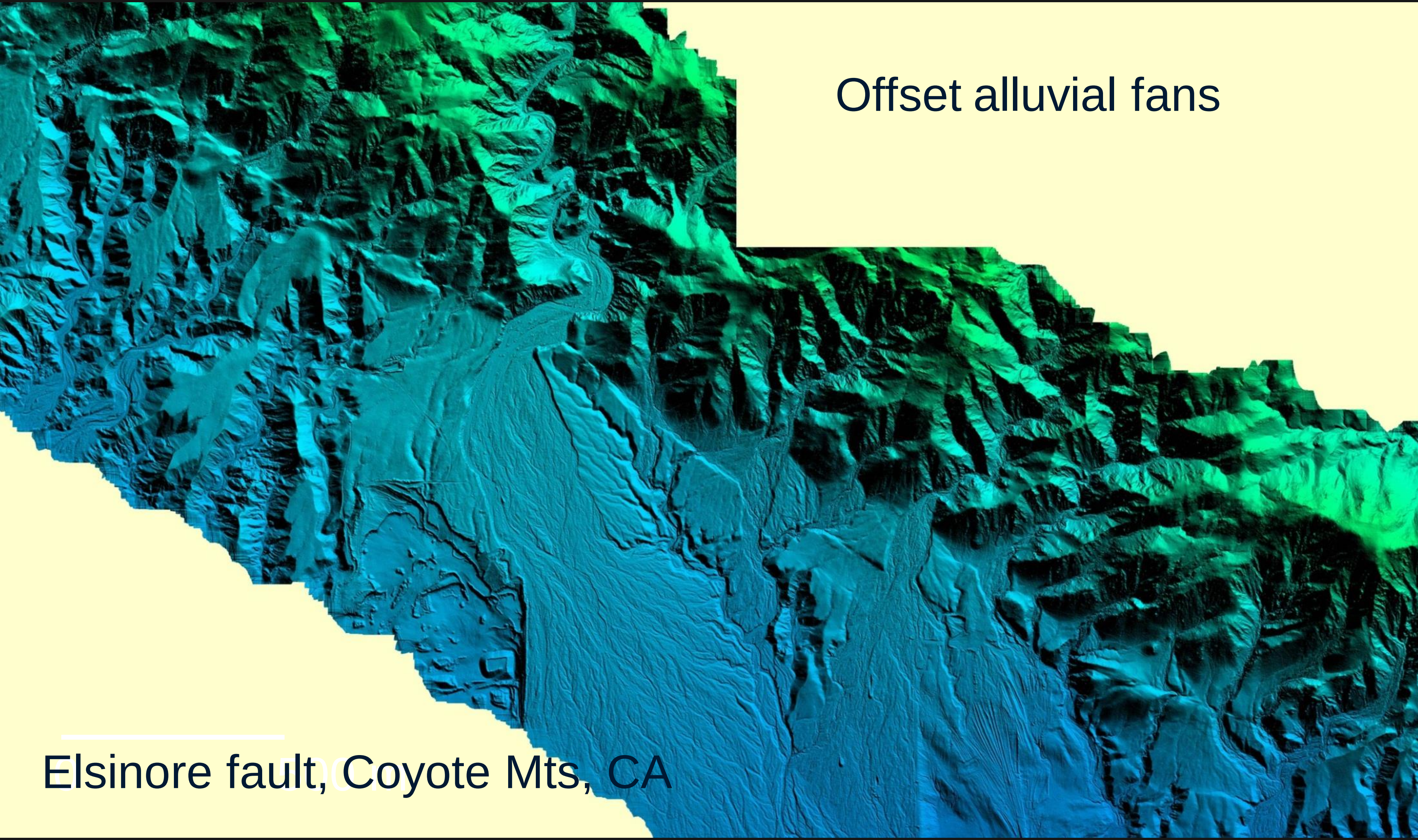
Carizzo plain


Coyote Mts
0
10 km
Elsinore
Coyote Mts
Laguna Salada fault
0
40 km



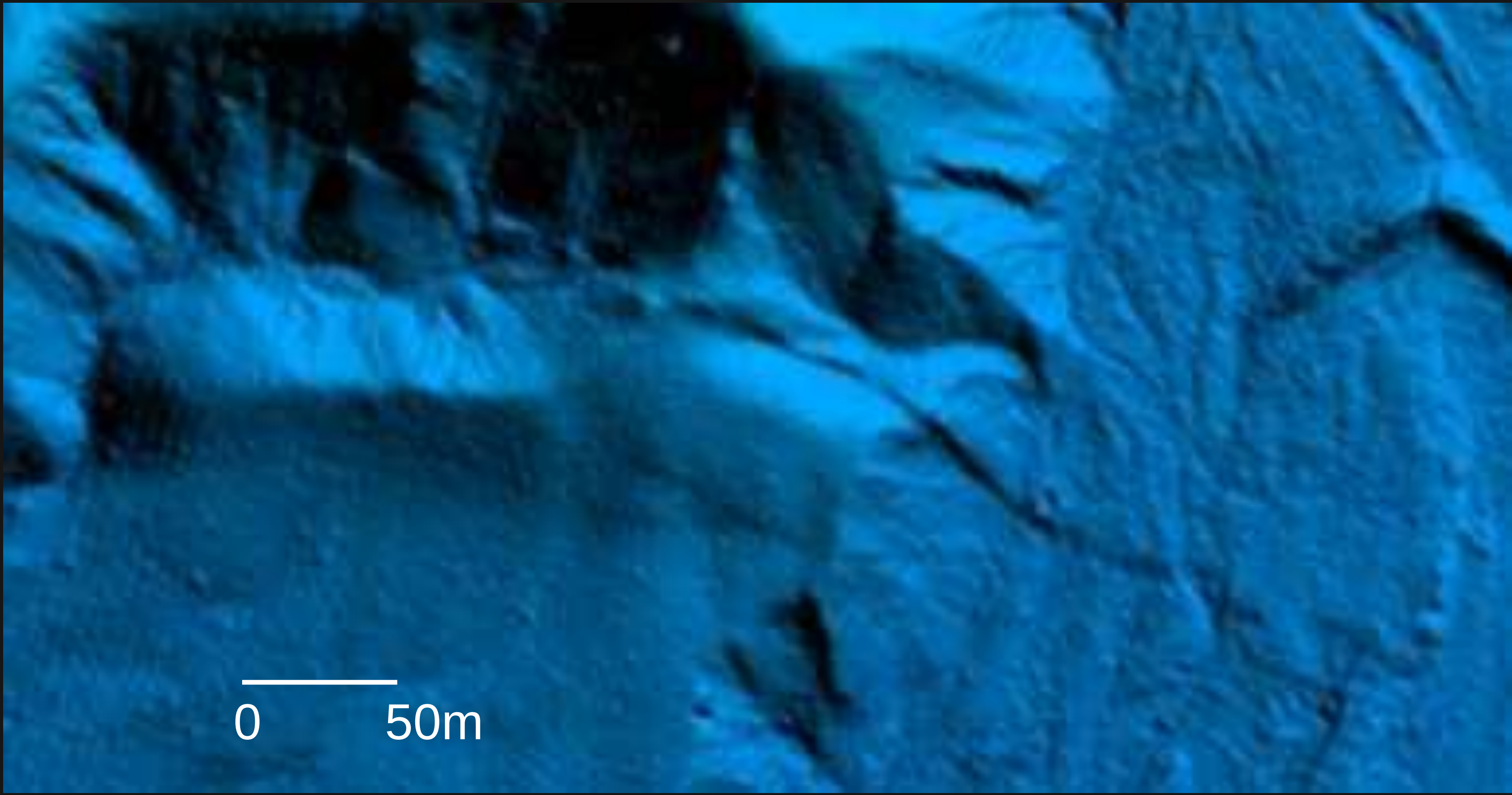
Elsinore fault, Coyote Mts, CA


offset and beheaded channel
2m
fault



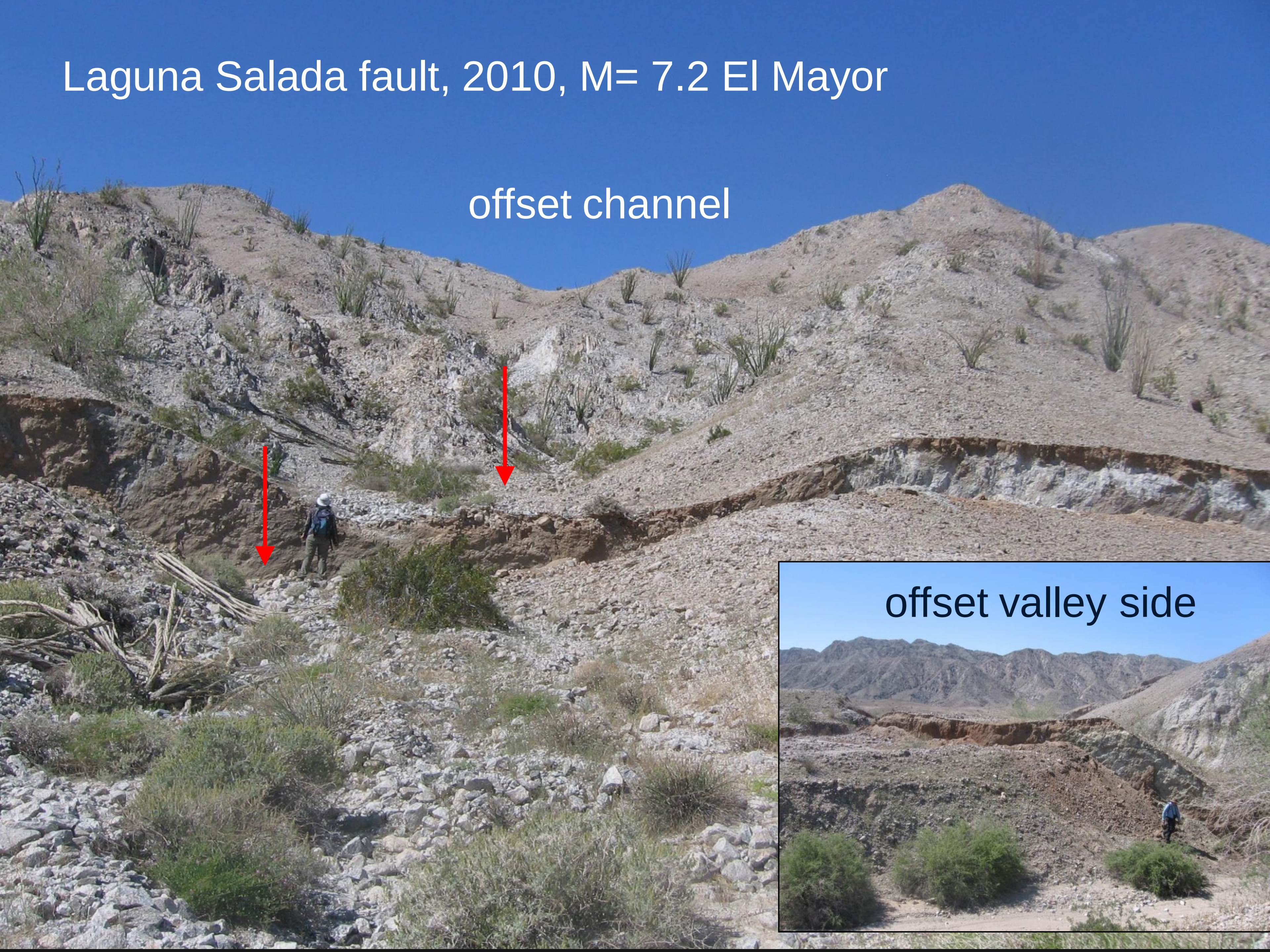
Offset alluvial fans

Elsinore fault, Coyote Mts, CA


0
50m

offset alluvial fan

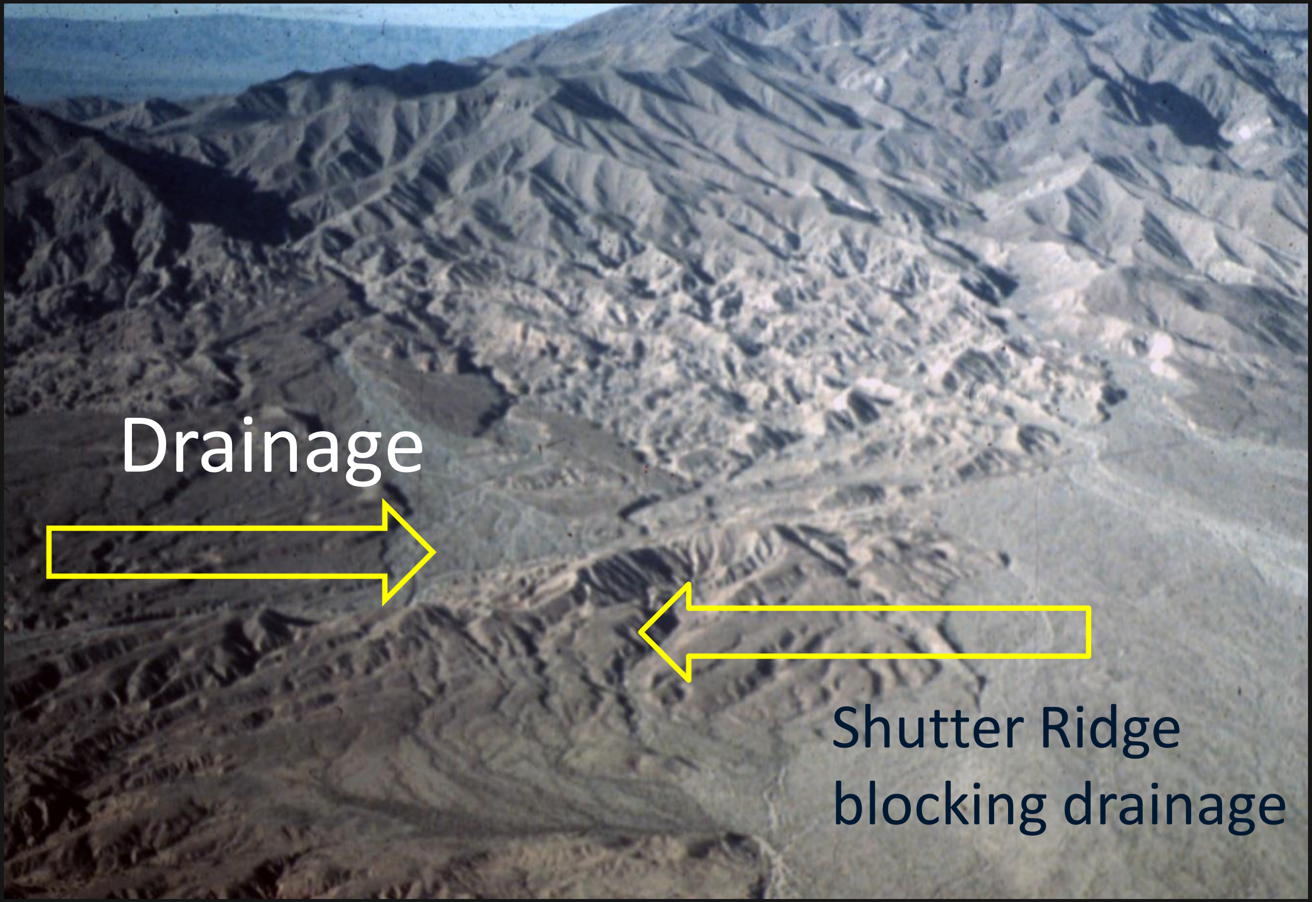
Laguna Salada fault, 2010, M= 7.2 El Mayor



Denali fault. Photo: Lloyd Cluff, 1973

Shutter Ridge

- Ridge moving along the fault blocked the valley



Clark strand of the San Jacinto

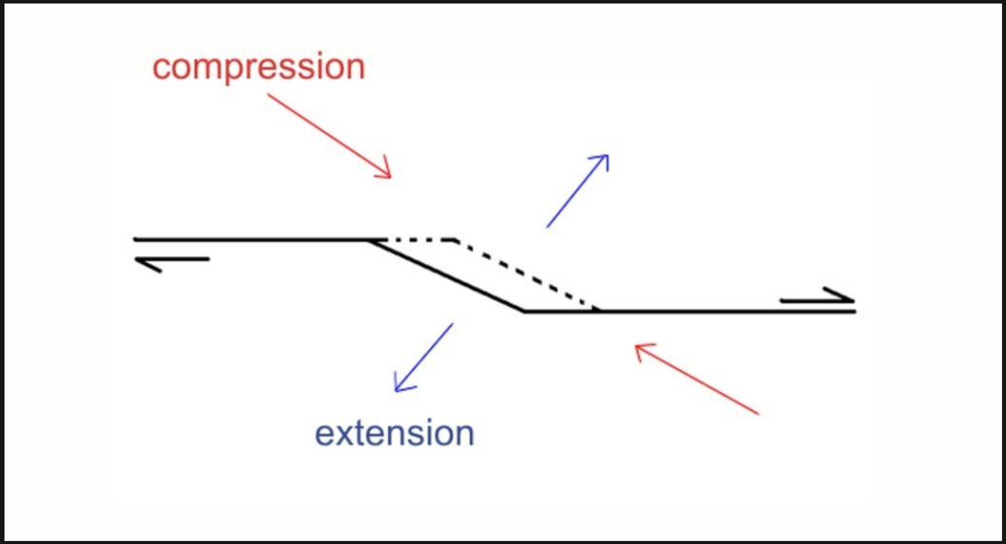
Hector Mine Rupture, 1999

Linear valleys

Linear valleys - related to faulting or just fault-line eroding crushed fault zone rocks

Transtension

- Component of divergence along SS fault (strike-slip)
- Right steps in dextral (right-lateral) SS fault
- Left steps in sinistral (left-lateral) SS fault



Opening causes a “sag,” or pull-apart basin

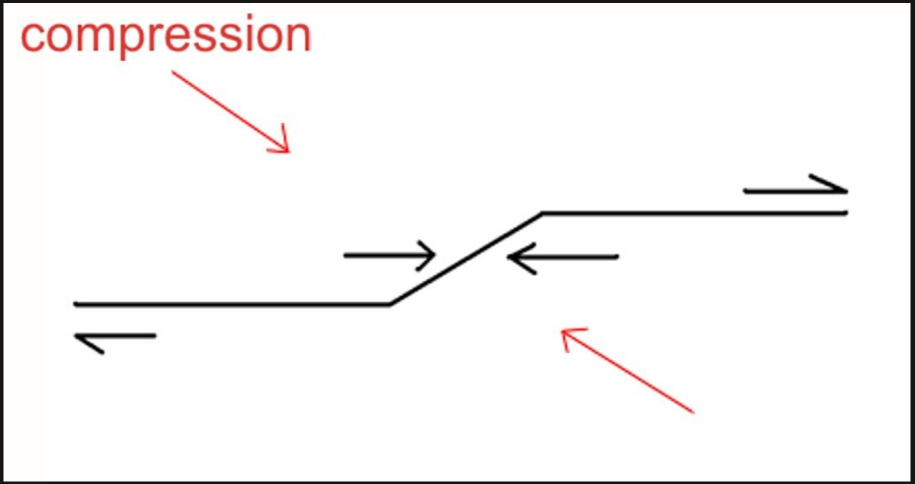
Sag Ponds

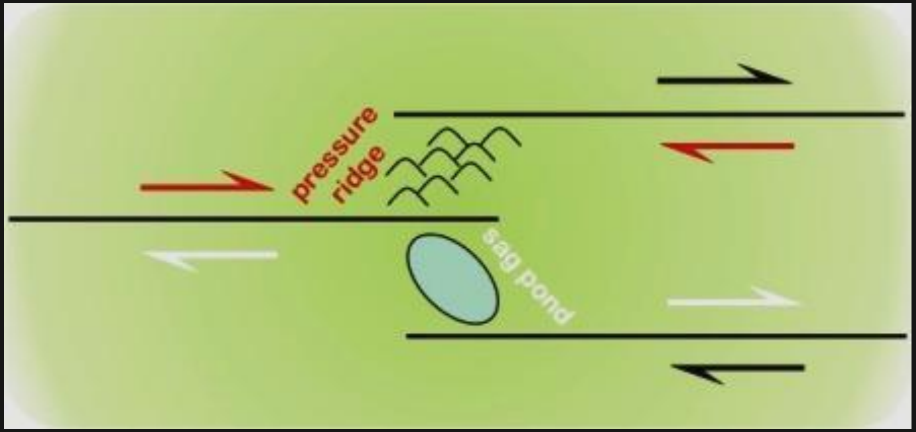
San Andreas

Topographic depression produced by extensional bends or stepovers along a [strike-slip fault](). It may or may not contain water year-round. Synonymous with pull-apart basin.

Transpression

- Component of convergence along SS fault
- Left step in Dextral SS fault
- Right step in Sinistral SS Fault



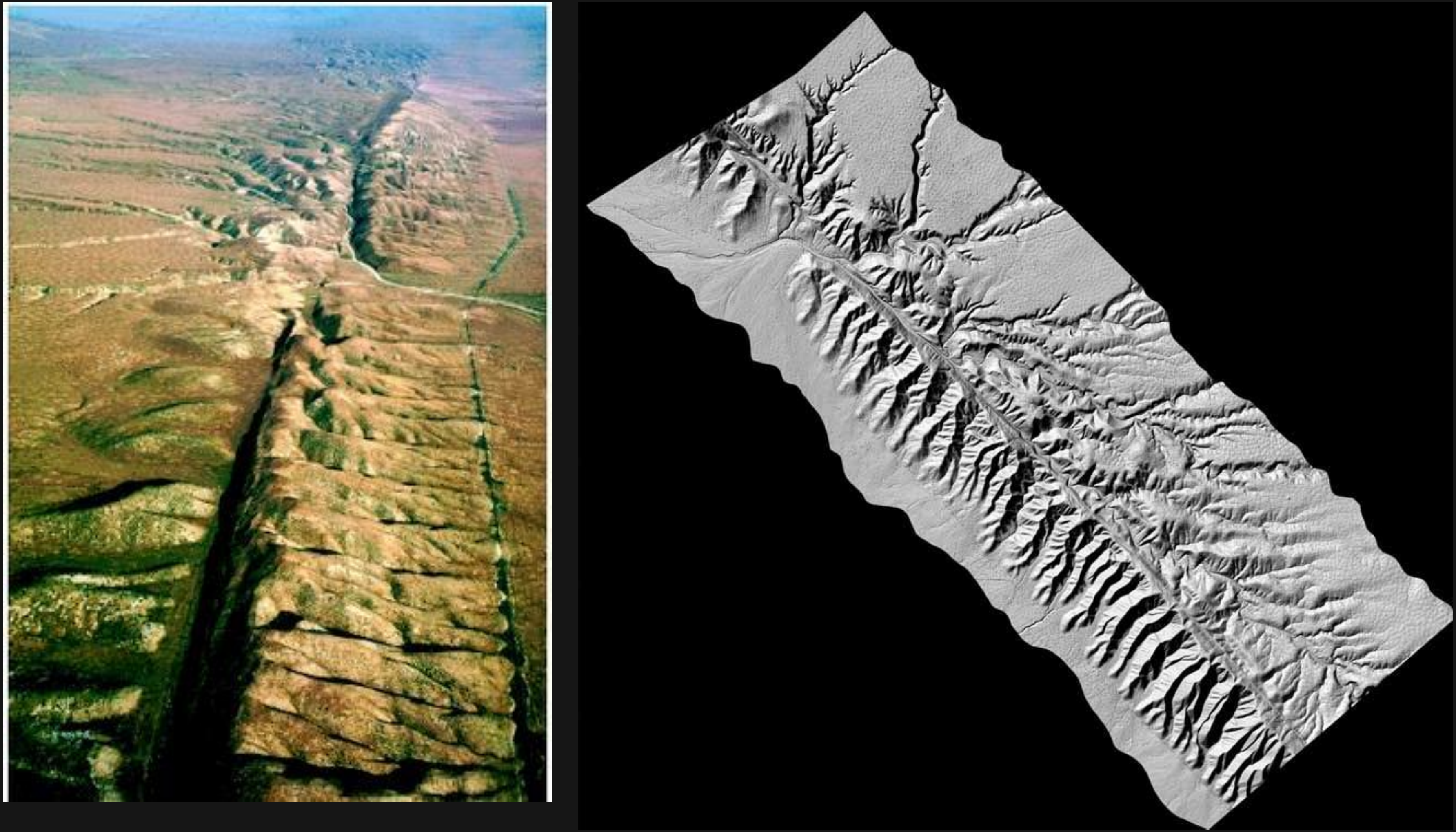


Right-step causes a space problem, and a “pressure ridge” is formed

Pressure ridge

A topographic ridge produced by compressional bends or stepovers along a **strike-slip fault**

Small pressure ridge along SAF in Cholame Valley



Dragon’s Back Pressure Ridge System along the San Andreas

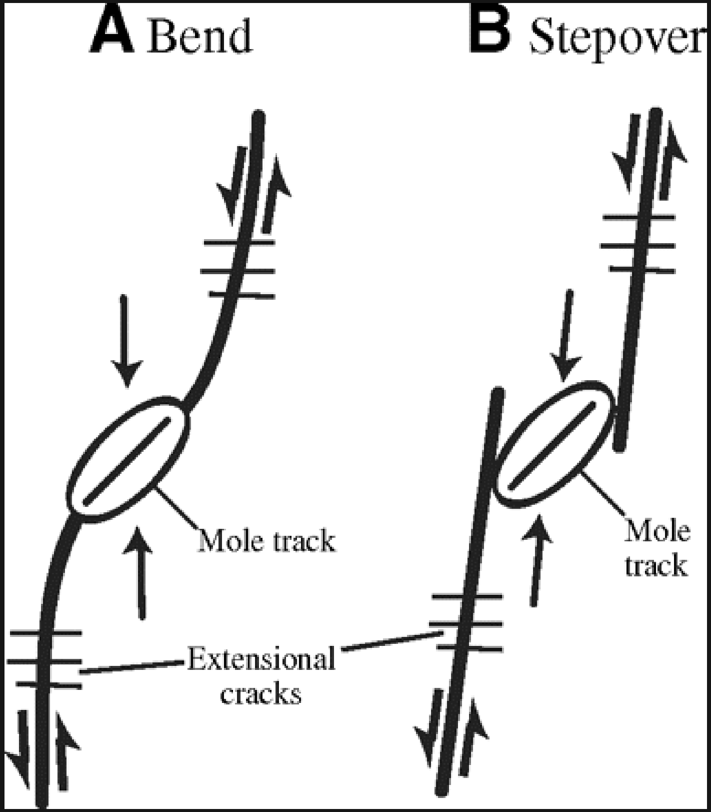
Pressure ridge

Thousands Palms – Indio Hills, San Andreas fault

„Mole track“ structure

Material is extruded along the fault by pressure

Kunlun fault, Tibet, 2001 M = 7.8



SAF, San Francisco 1906, M = 7.9

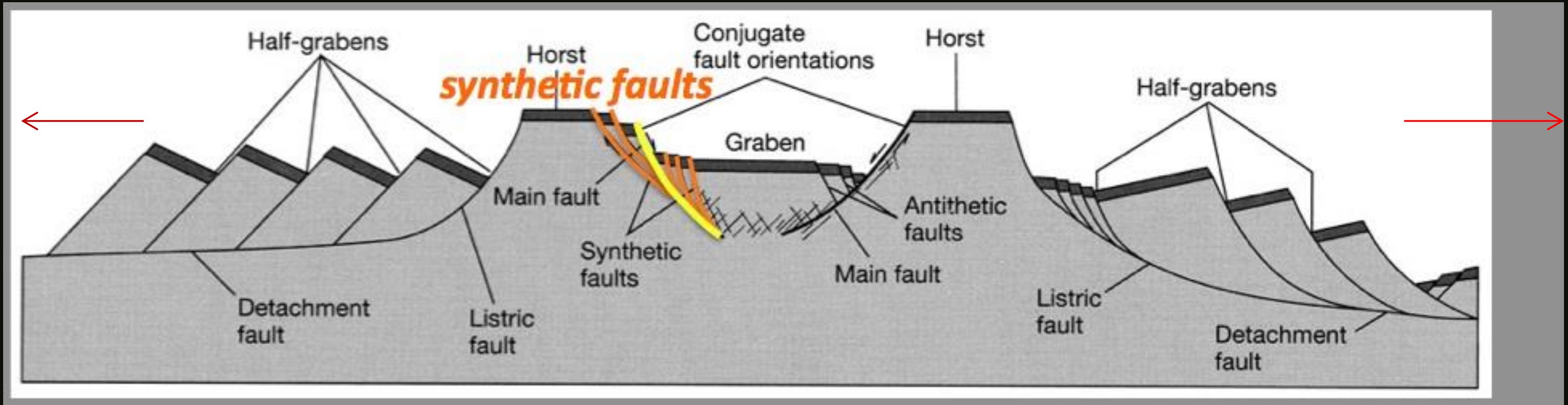
Denali fault, Alaska

Extensional Faulting – normal faults

Displacement accommodated in **normal faults**

- Single, Parallel synthetic, Antithetic

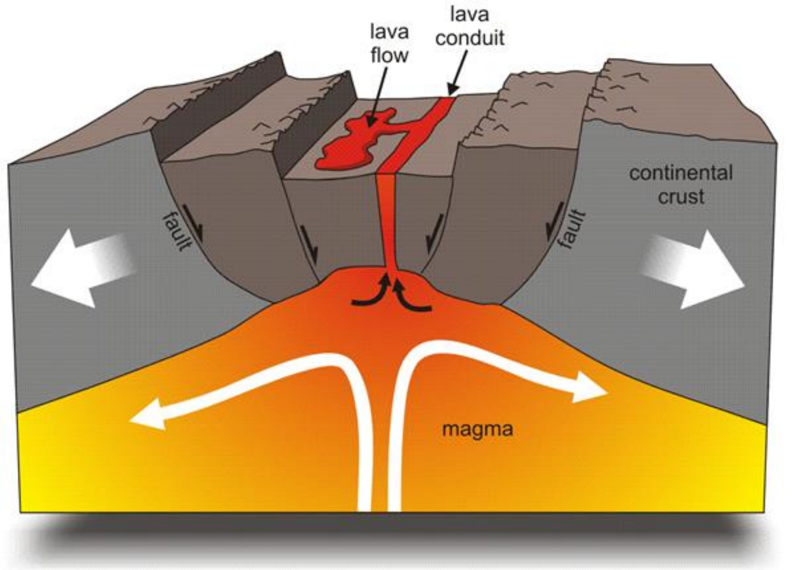
- Primary normal fault (60-70°)
  - Crustal penetrating fault
  - Often has km of displacement
  - Separates linear mountain range from adjacent basin
    - Up-faulted block (horst)
    - Down-faulted block(graben)

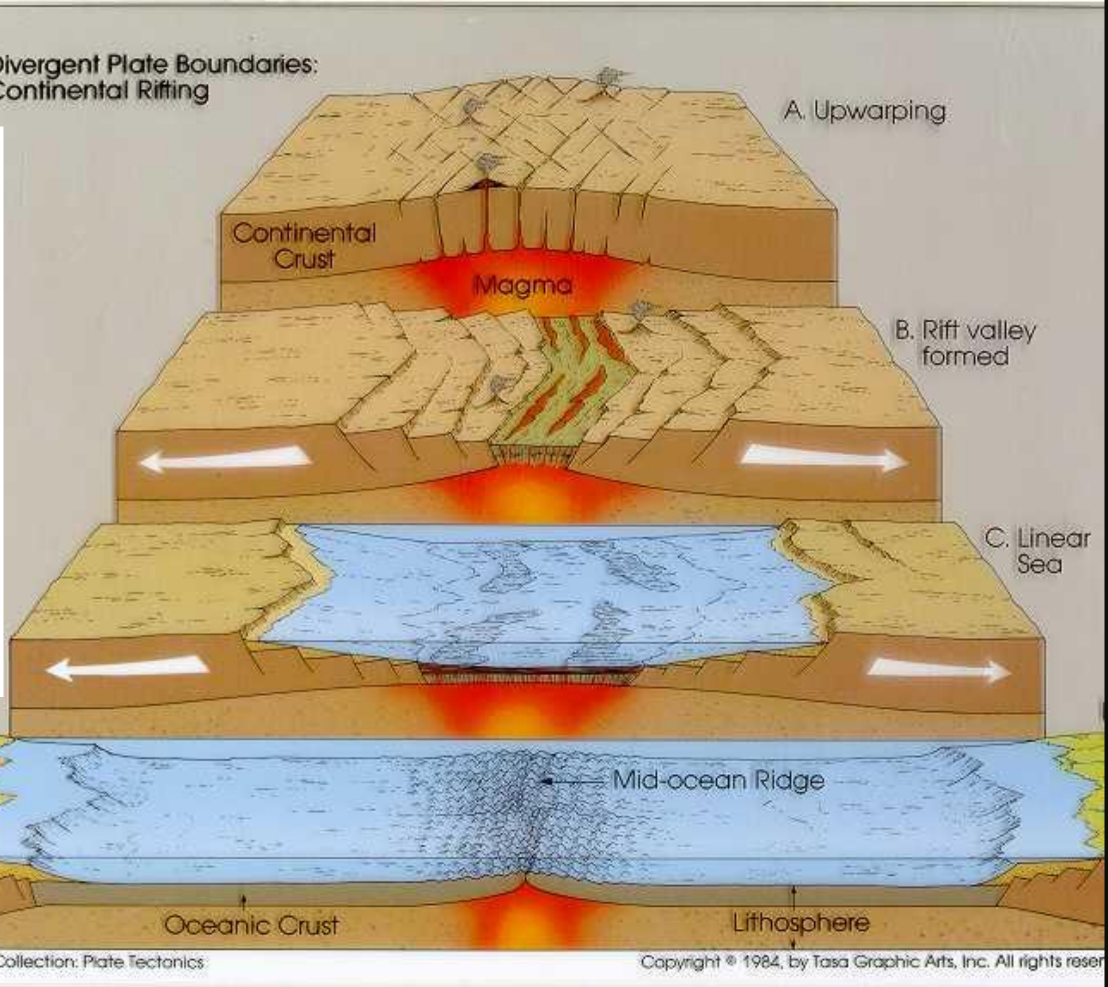


- Subsidiary faults dipping in the same direction as the major fault are <u>synthetic</u>. Those dipping opposite to the major fault are <u>antithetic</u>.

Crustal extension and normal faults – related to the most remarkable topography at regional scale

Rifts valleys





he Tasa Collection: Plate Tectonics

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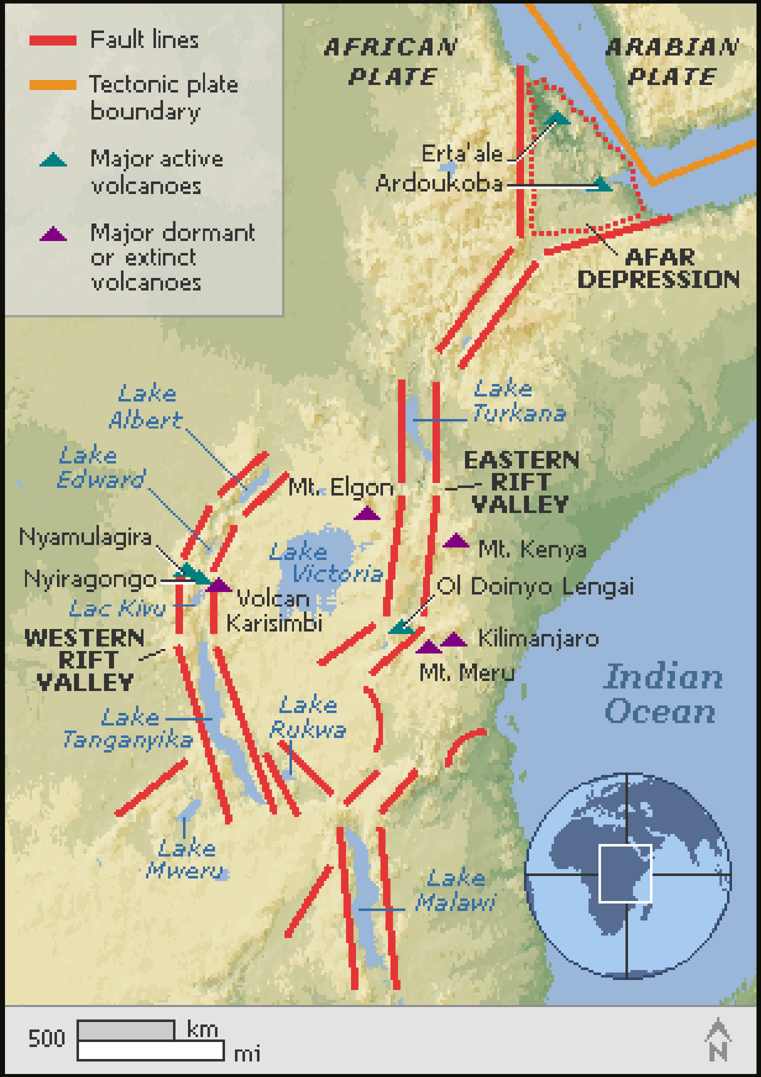
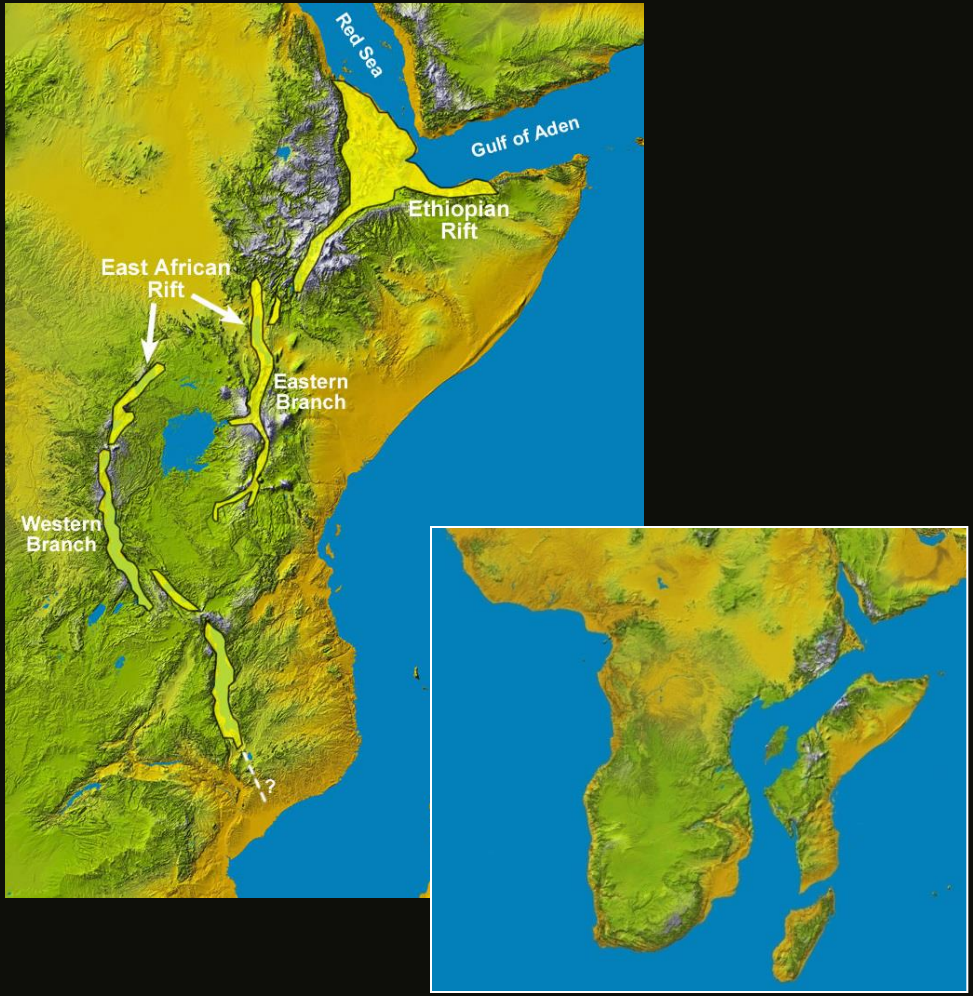
rift – elevated heatflow,
vertical compression,
horizontal extension

East African Rift Valley

active divergence, rift – numerous of normal faults





East African rift in 20 mil years

Hayli Gubbi, shield volcano, crater inside caldera, Afar region, Ethiopia

Normal faults disecting the volcanos, Afar

Massive fissure splits open in the Ethiopian Desert

Rift activity 2009

Escarpments

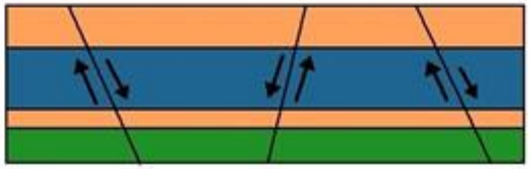
Rift Valley - Tanzania

Main Ethiopian Rift Valley

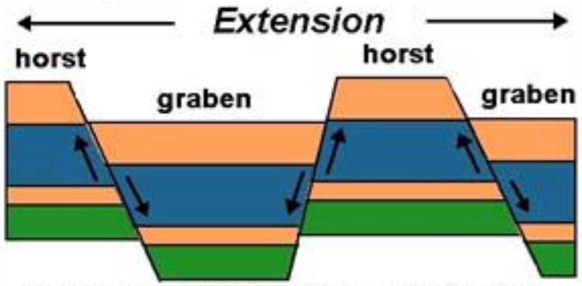
They has been formed during millions years

Textbook horst and graben formation

1. Layered rock units

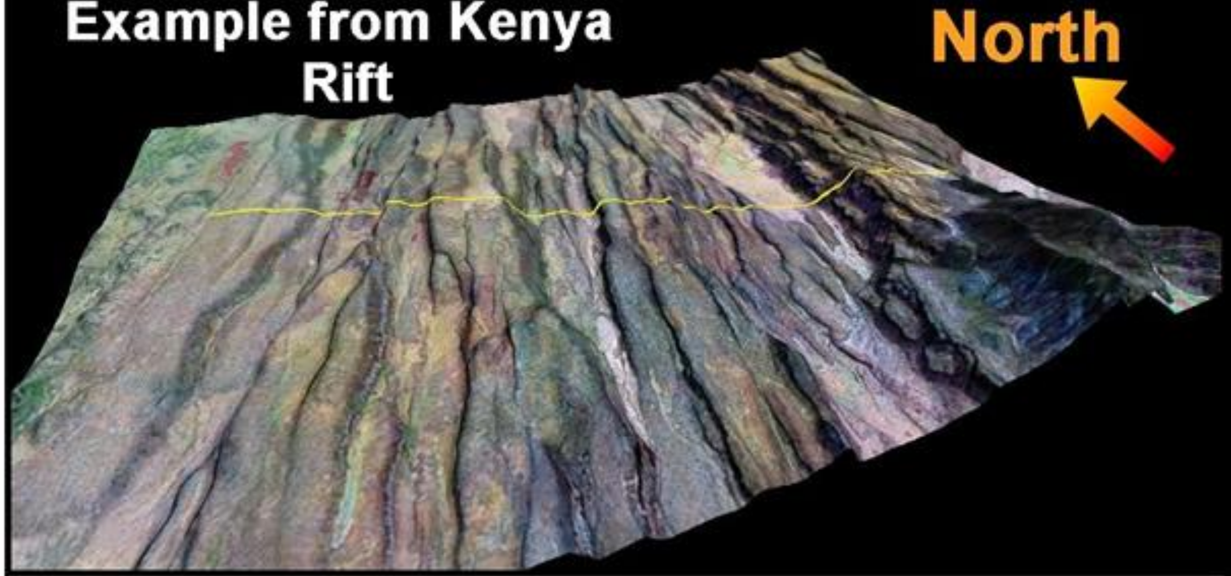


2. Layers are cut by normal faults

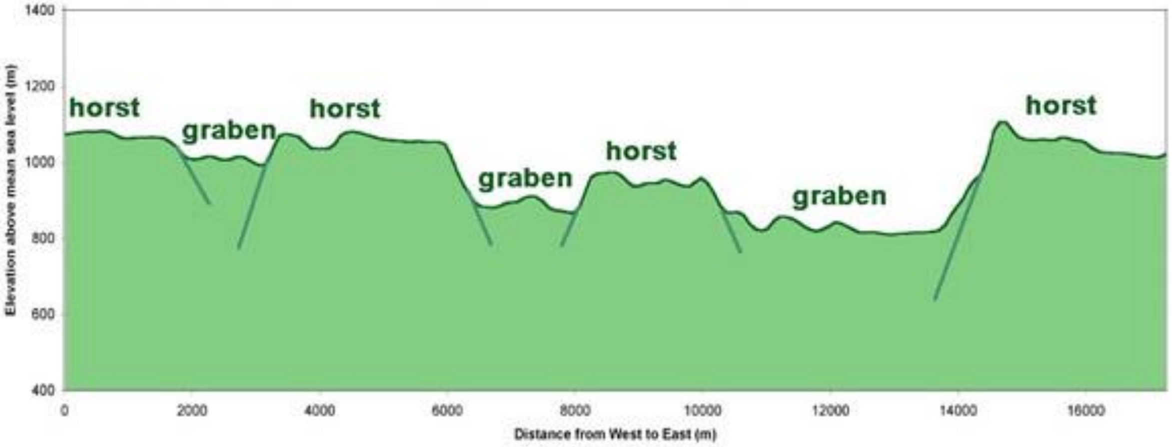


3. Down-dropped blocks are grabens, and upthrown blocks are horsts, note that the extension that occured.

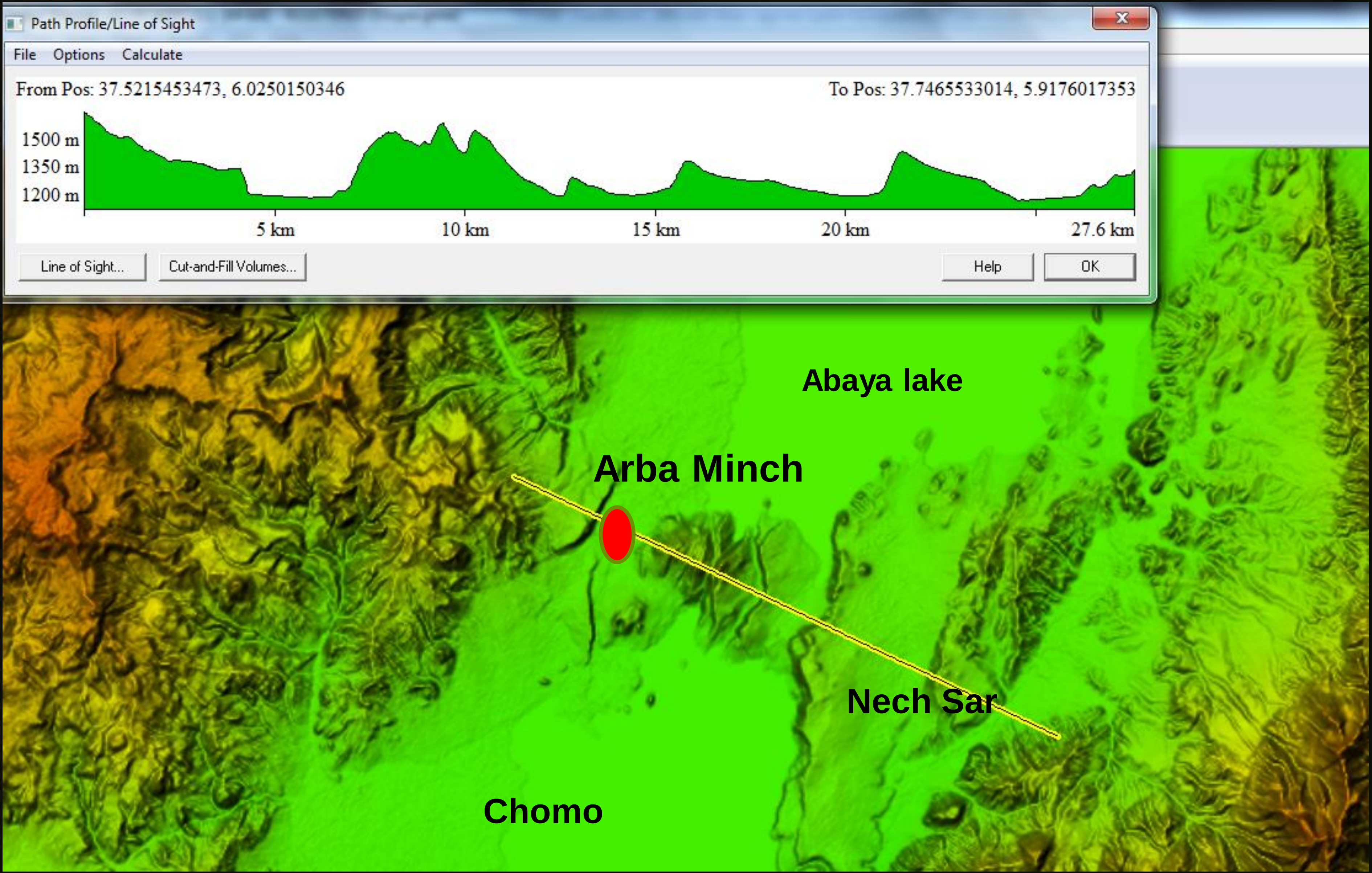
Example from Kenya Rift



Topographic profile along yellow line showing horst and graben structures



Hundreds meters high escarpments in Arba Minch area



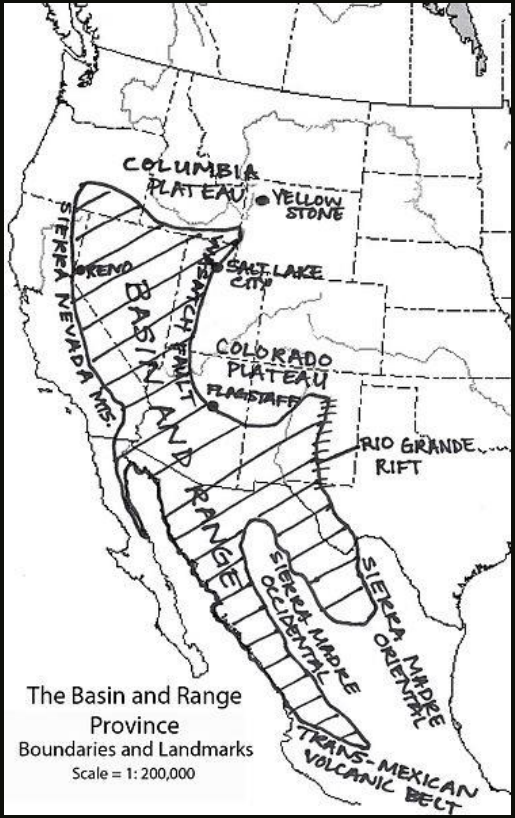
From Pos: 37.5215453473, 6.0250150346

To Pos: 37.7465533014, 5.9176017353

Basin and Range topography

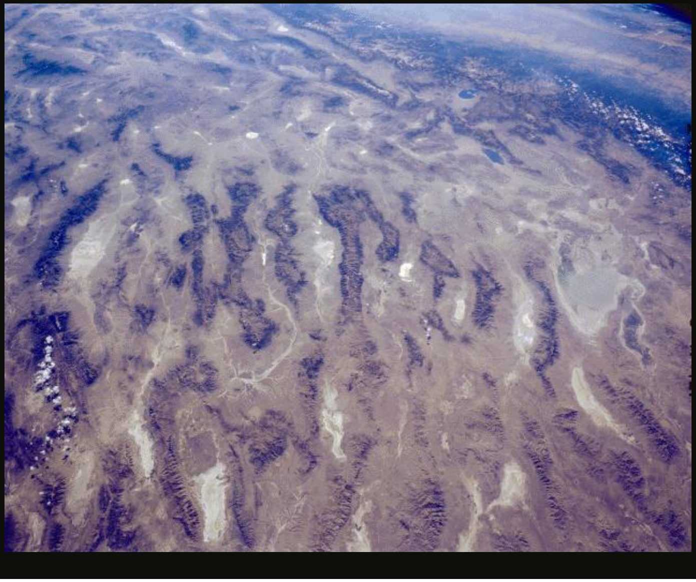
broad extensional faulting

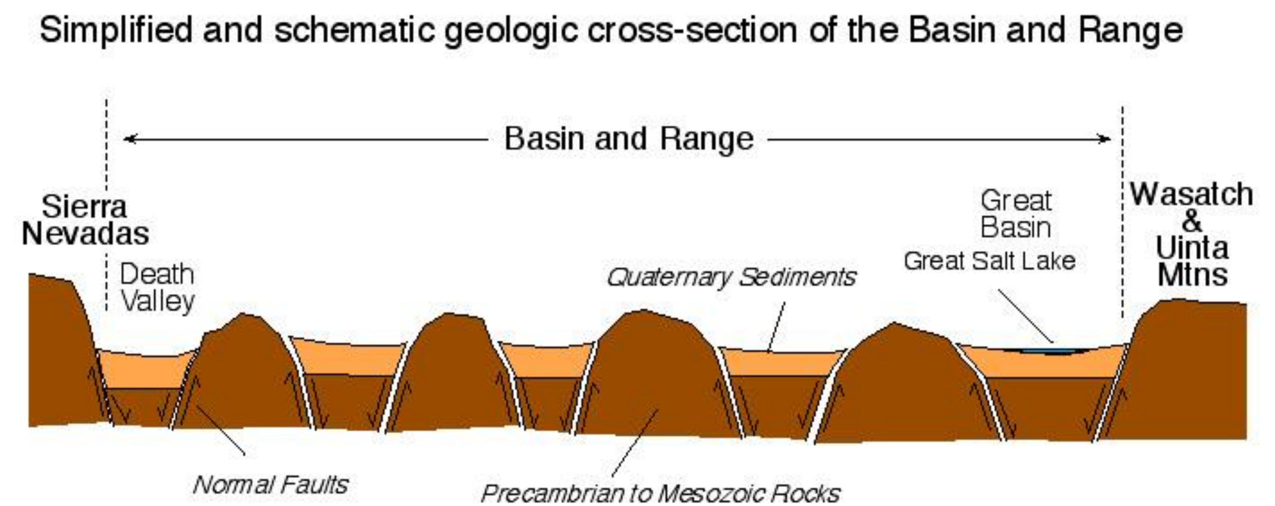
Basin and Range Province



extension and thinning of the lithosphere, listric faults, grabens, horsts

elevated heat flow, geothermal energy



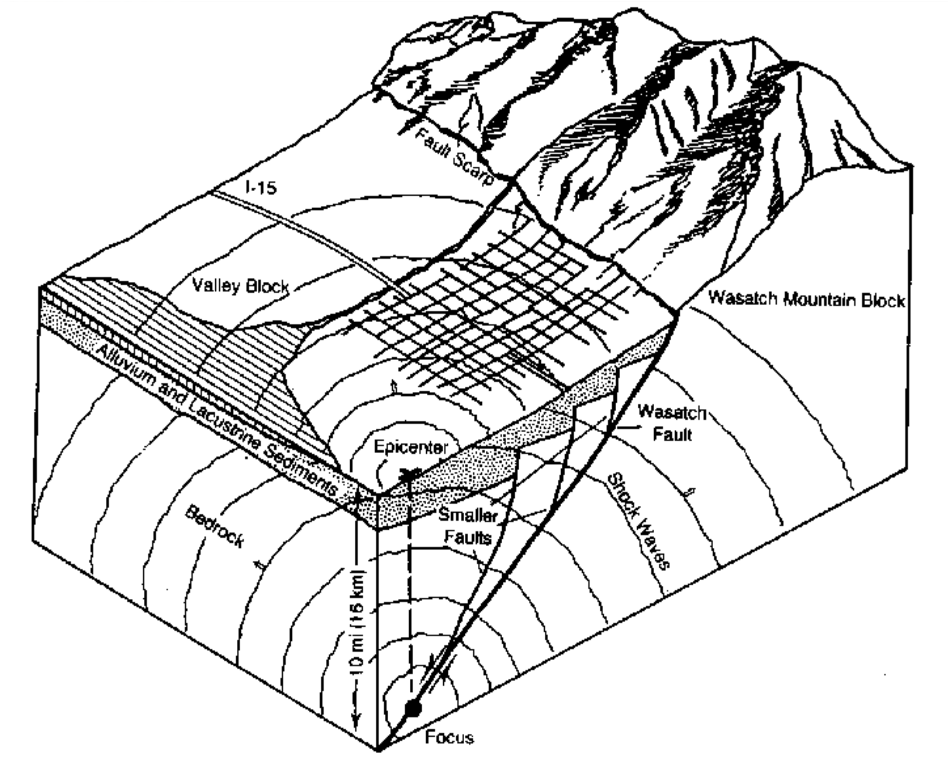

Simplified and schematic geologic cross-section of the Basin and Range

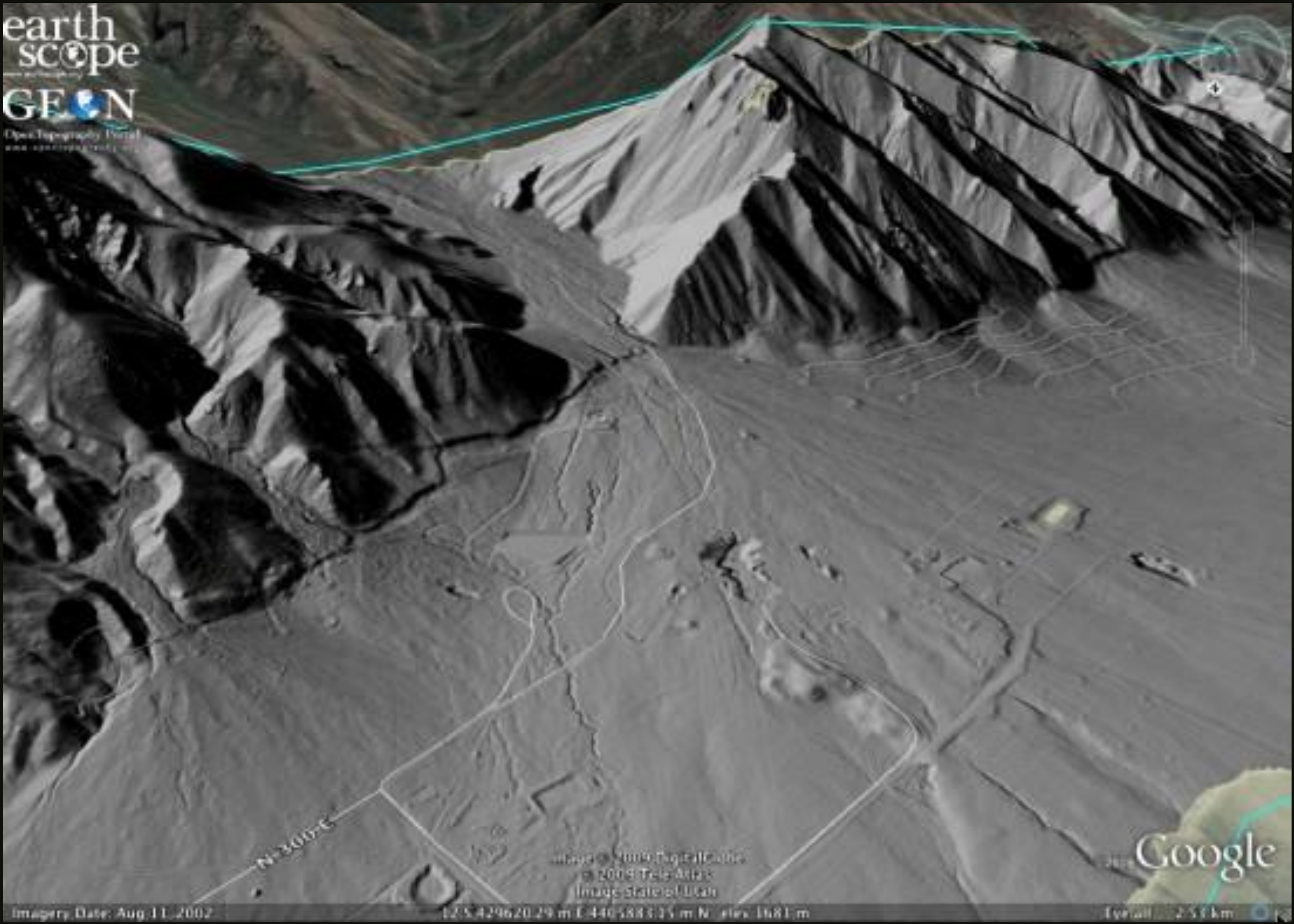
From Sierra Nevada to Wasatch Mts – 800 km

Linear mountain fronts

Linear mountaint front
- repeated earthquakes

The Wasatch Mountains have been uplifted and tilted to the east by movement of the fault. The average rate of uplift along the fault is approximately 1 mm per year.





Scarp on the southern part of the Nephi strand of the Wasatch fault:

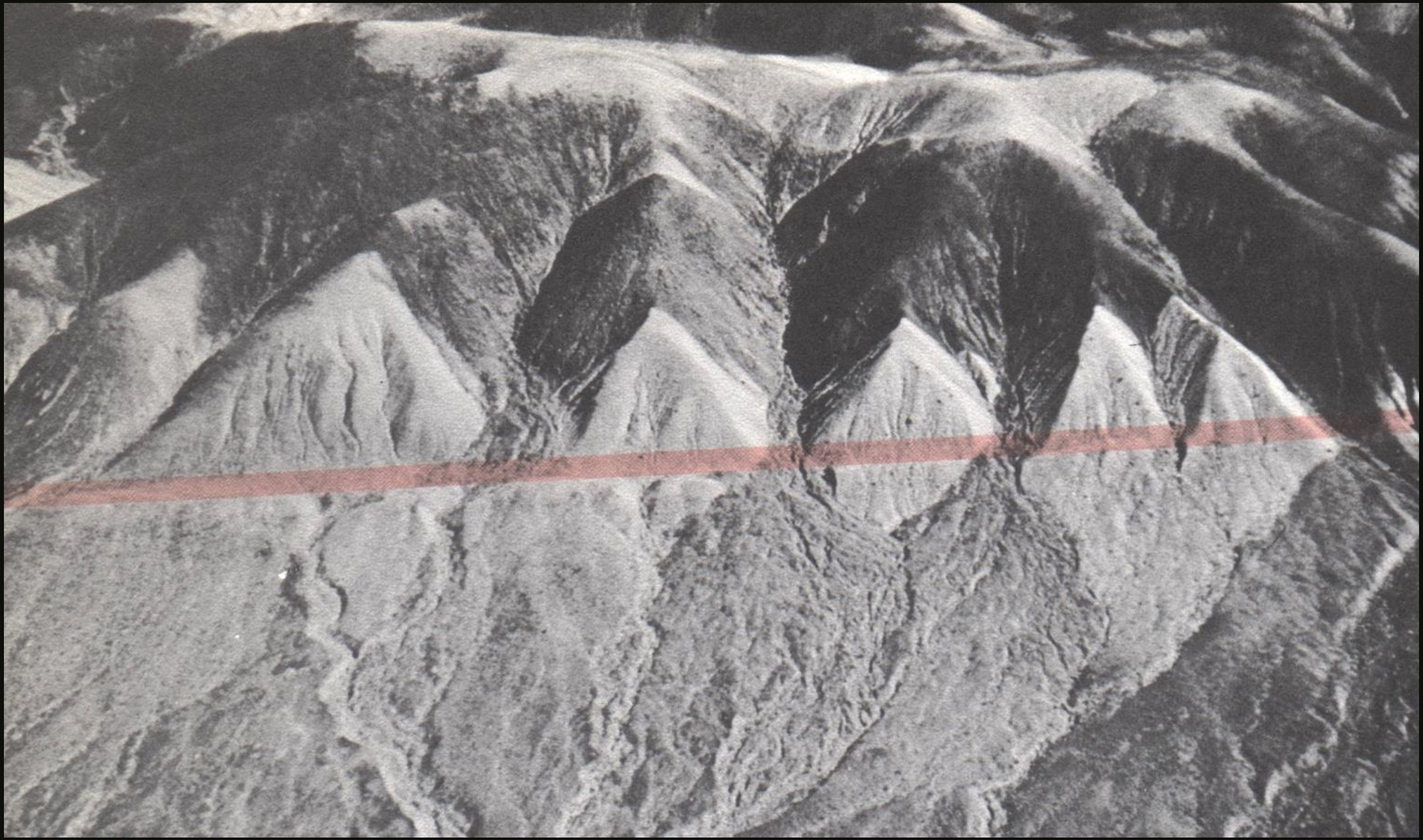
Wasatch fault

Multiple fault scarps (marked by arrows) cut across 16,000 to 18,000-year-old glacial moraines in Salt Lake County.

Some of the scarps - 30 to 40m high, indicating they were formed by repeated large earthquakes (7 to 10) in the past 18,000 years

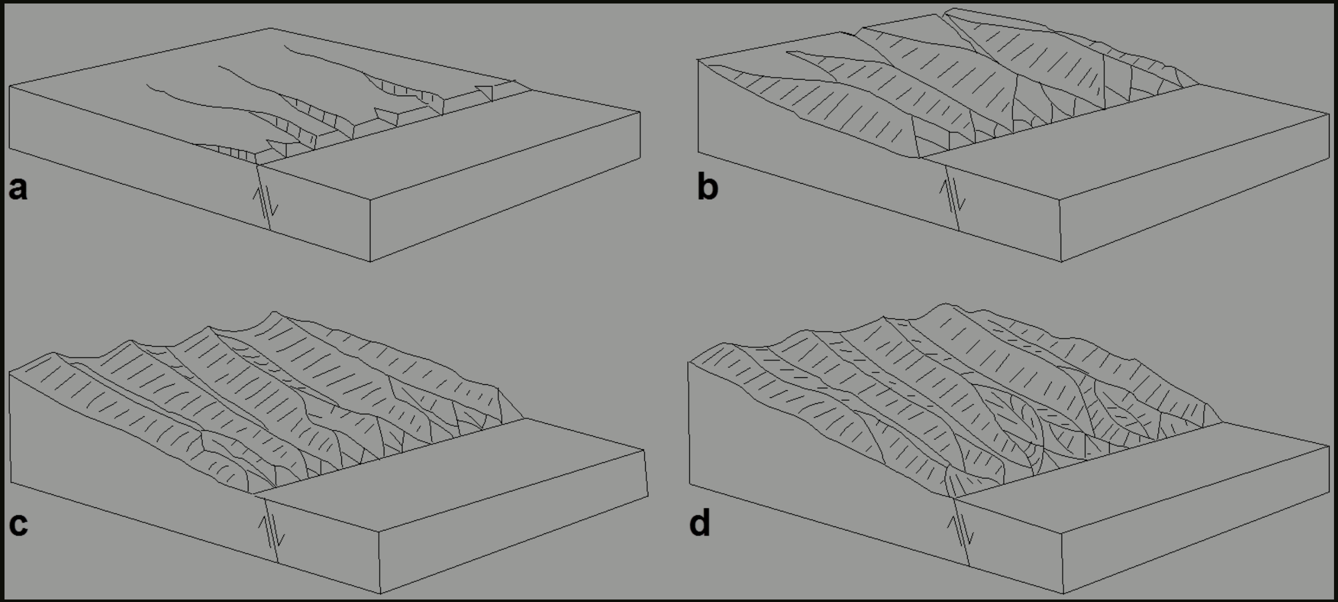
Triangular (trapezoidal) facets

- dissected mountain front by rivers, series of facets - „flatirons“



un-named fault in California, SE from Panamint Valley

Several generation of facets – evolution of mountain front



Anderson (1977)

Repeated episodic movements – origin ot

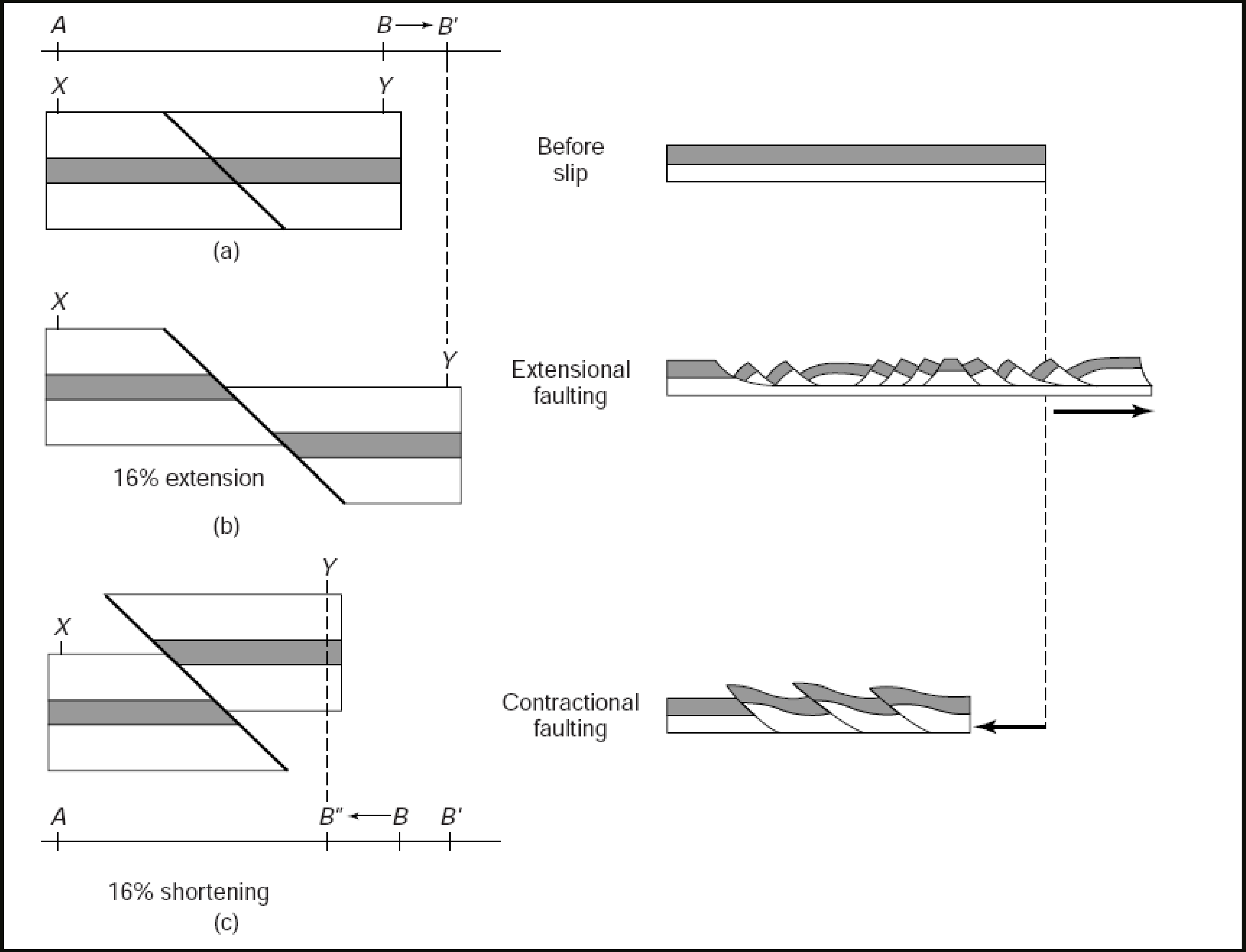
- n–hundreds meters high fault scarp
- fault-controlled mountain front – hundreds kilometers long, up to 1 km high (Stewart, Hancock 1994)

Bloom (1978)

Triangular facets aligned on the fault scarp of Maple Mountain, 15 km south of Provo, Utah. View east. (Photo: H. J. Bissell.)

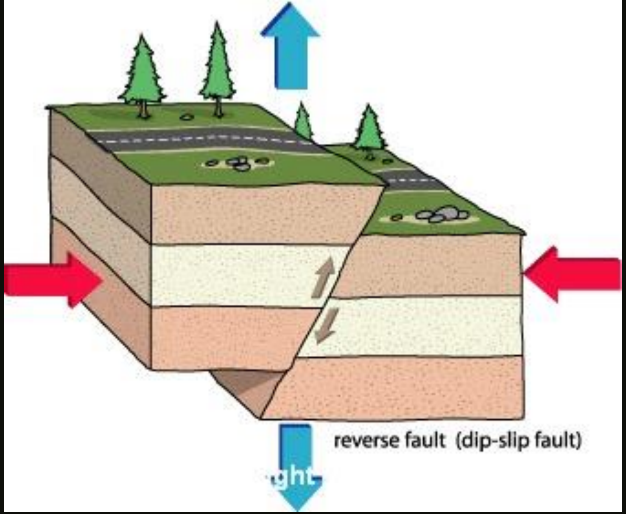
Crustal shortening + thickening

- Crustal shortening is the reduction of the size of the Earth's crust through convergent plate boundary (compression)

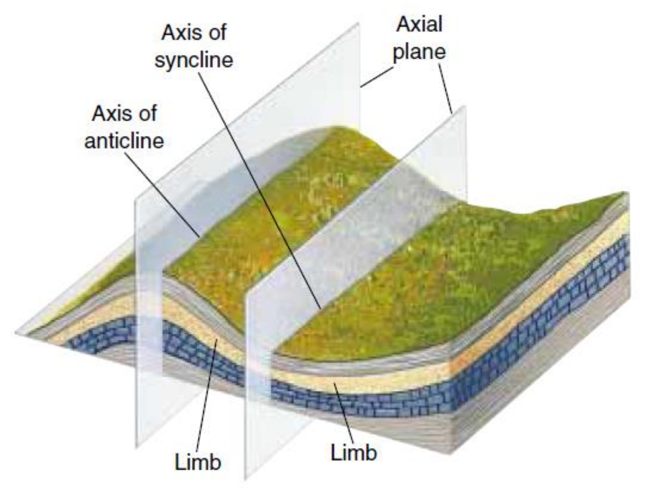


Crustal Shortening

- Implications :
  - Reverse/Thrust Fault



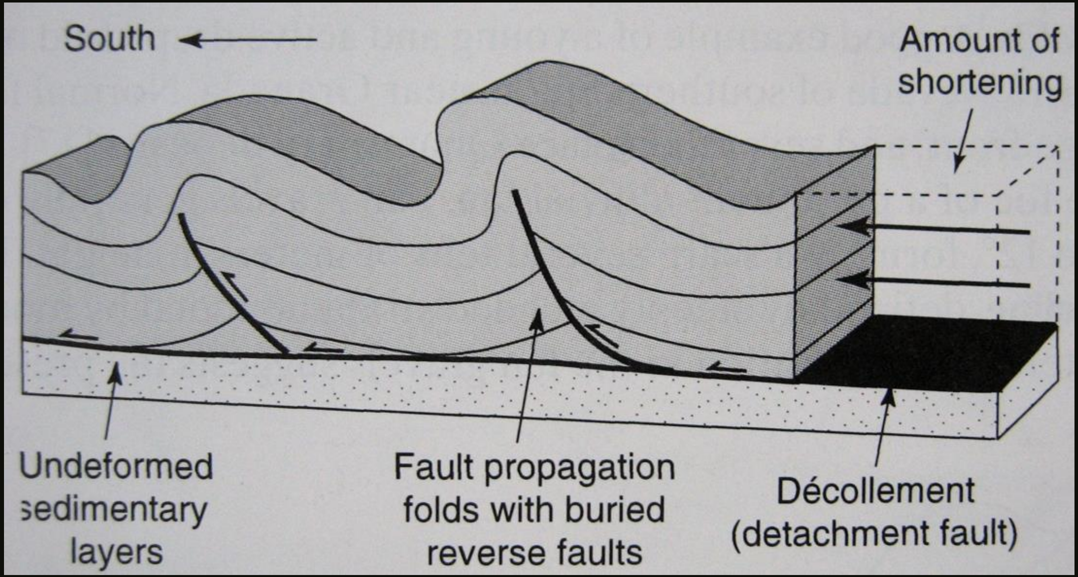
  - Fold

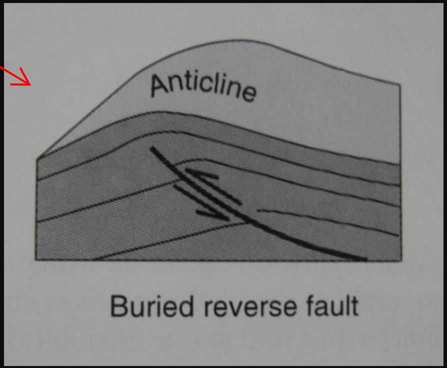


  - Uplift

Thrust faults associated with subduction produce a variety of landforms –
- uplifted coastal terraces, anticlinal hills (upwarped) and synclinal lowlands (downwarped)

Thrust faults – often associated with fold - in **fold-and-thrust belts**
- some of the thrusts and reverse fault may **break the surface** or they remain **hidden** in the core of anticline – **blind reverse fault**



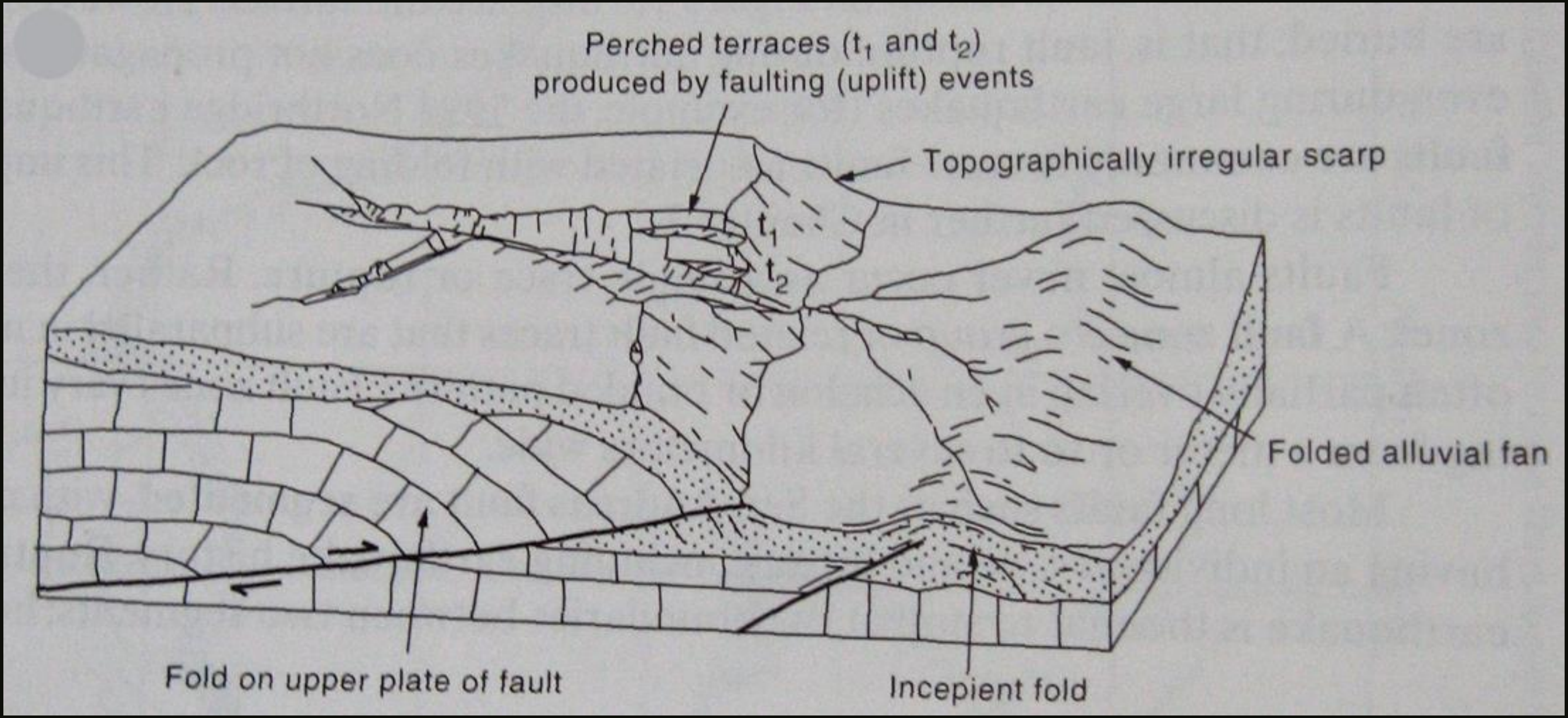


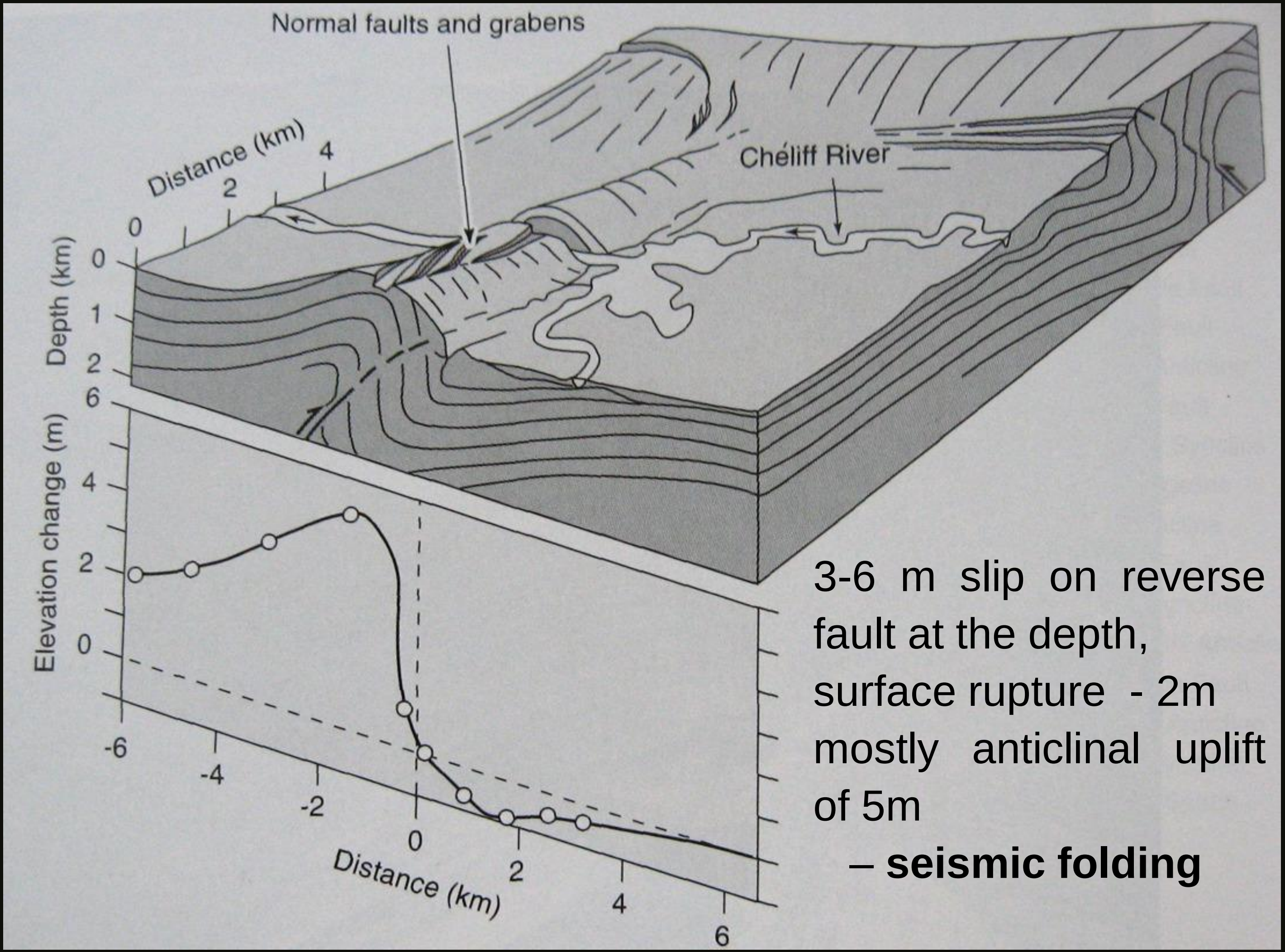
Asymmetric **fault-propagation fold** developed over a décollement

Reverse faults- closely related to folds
Rate of lateral propagation of faults and fold may be sveral times **higher than vertical slip rate** of the fault

Landforms associated with reverse faulting

steep mountain fronts, fault scarps, fold scarps, extensional features, and landslides

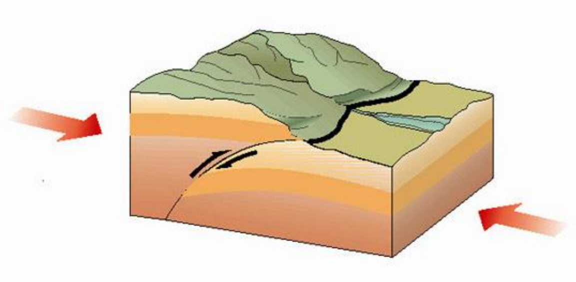




3-6 m slip on reverse fault at the depth,
surface rupture - 2m
mostly anticlinal uplift of 5m
– **seismic folding**

Graph of surface uplift produced by 1980 El Asnam EQ.
The fold was produced by repetaed earthquakes

Bolcked river – formation of a lake with deposition of 0.4 m



Fault scarps

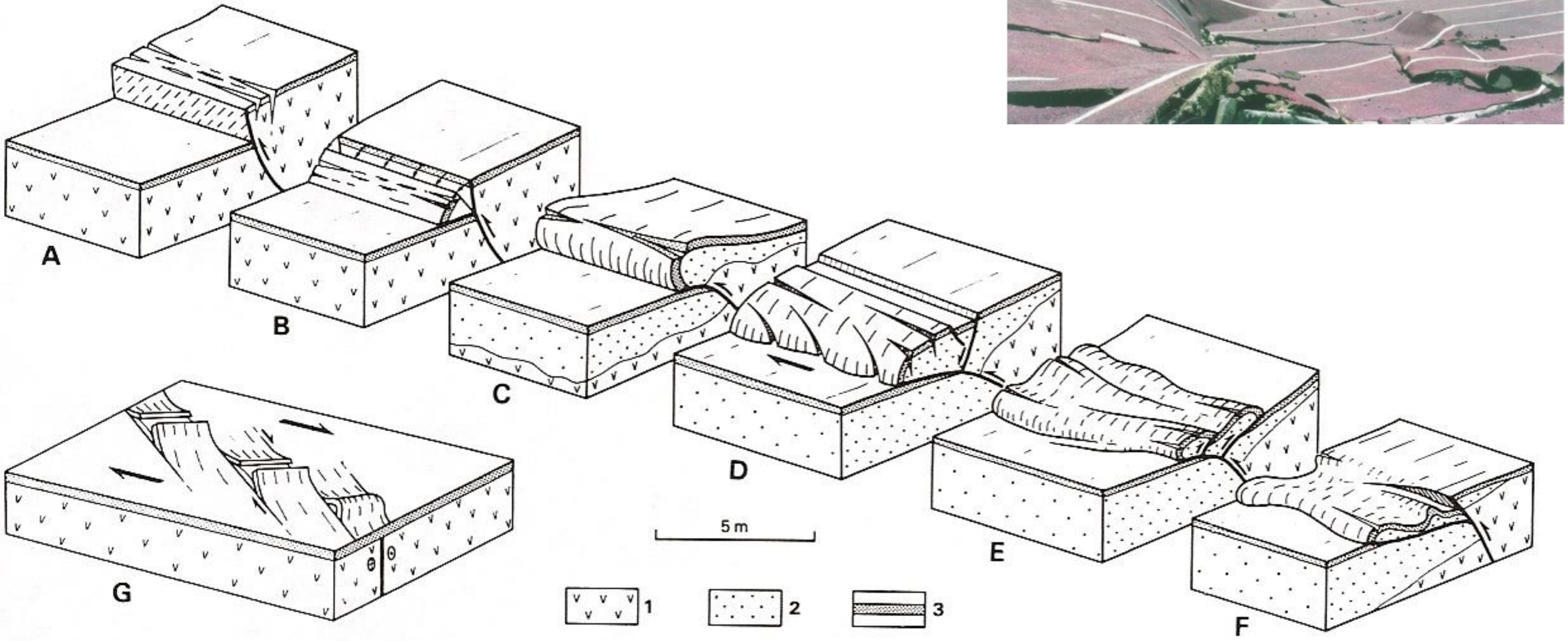
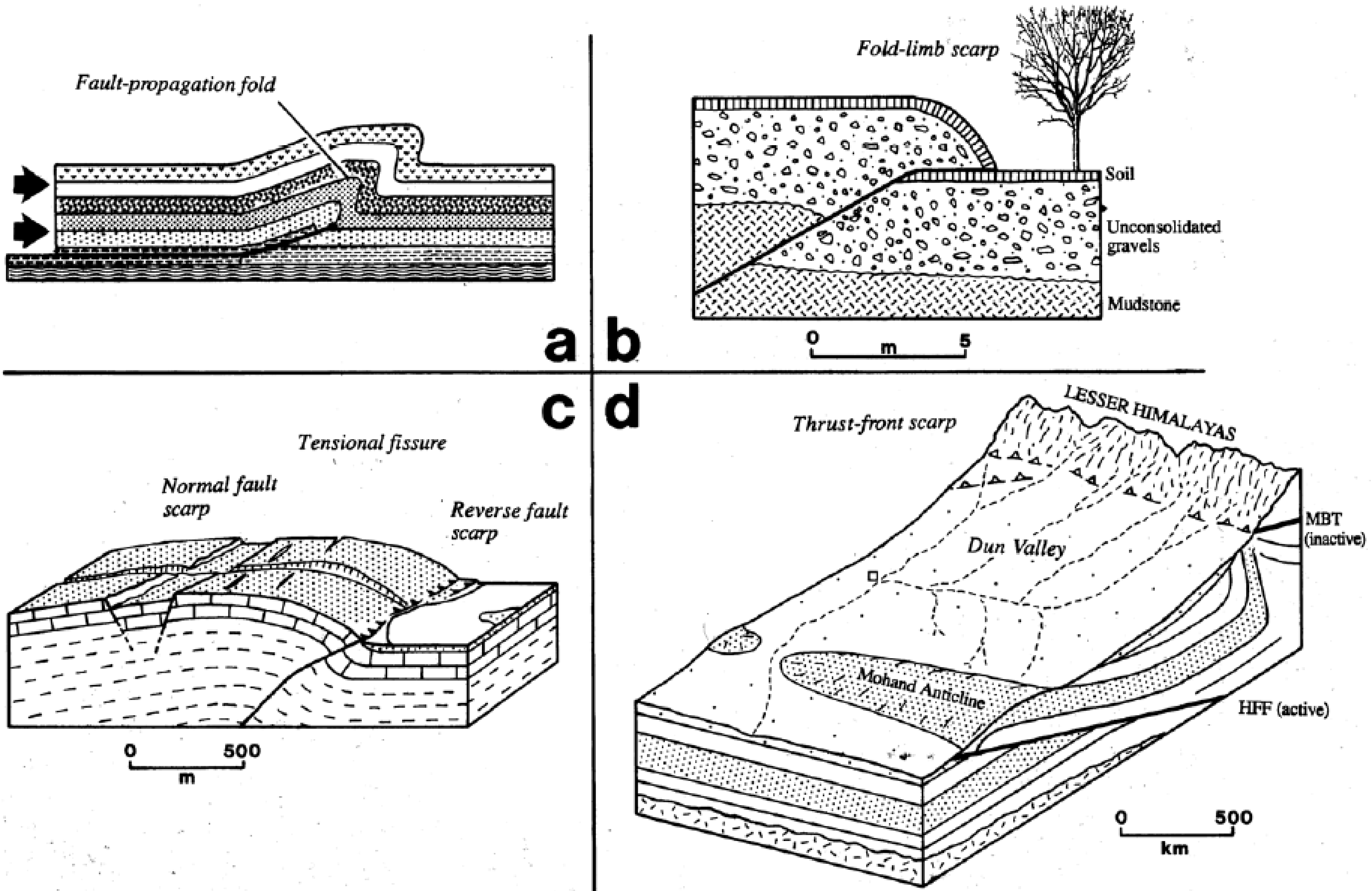


Figure 10–53. Fault-scarp features along the Spitak fault, Armenia. (a) simple thrust scarp; (b) hanging-wall collapse scarp; (c) simple pressure ridge; (d) dextral pressure ridge; (e) back-thrust pressure ridge; (f) low-angle pressure ridge: (g) en échelon pressure ridges. 1, bedrock; 2, soft Quaternary sediment; 3, turf. After Philip et al. (1992).


Fault-propagation fold
a
Fold-limb scarp
Soil
Unconsolidated gravels
Mudstone
0 m 5
b
c
Tensional fissure
Normal fault scarp
Reverse fault scarp
0 500
m
d
Thrust-front scarp
LESSER HIMALAYAS
MBT (inactive)
Dun Valley
Mohand Anticline
HFF (active)
0 500
km

Thompson and Turk, 1998

FIGURE 10.7 An asymmetric, plunging fold (the Sheep Mountain Anticline in Wyoming, USA).