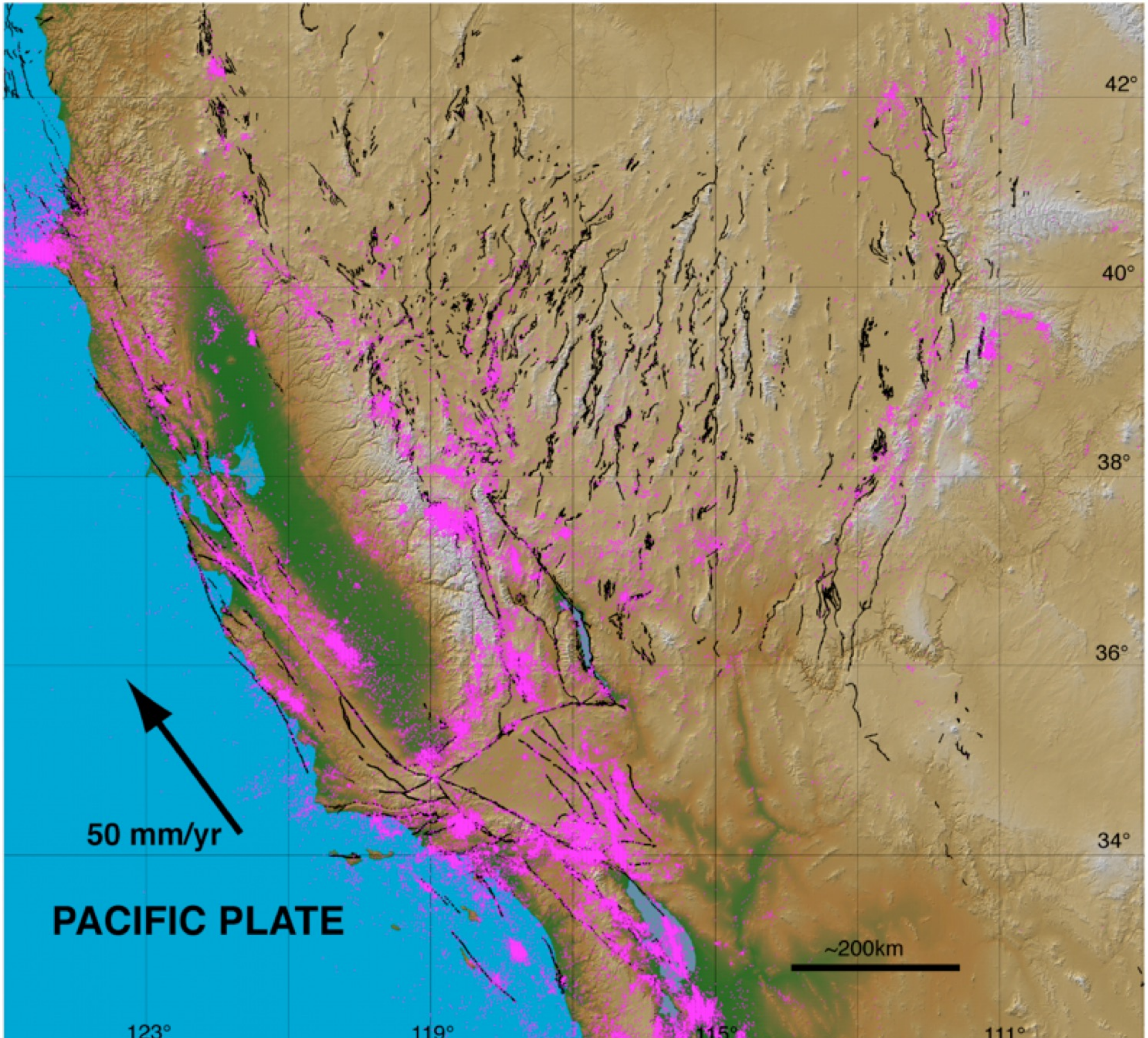


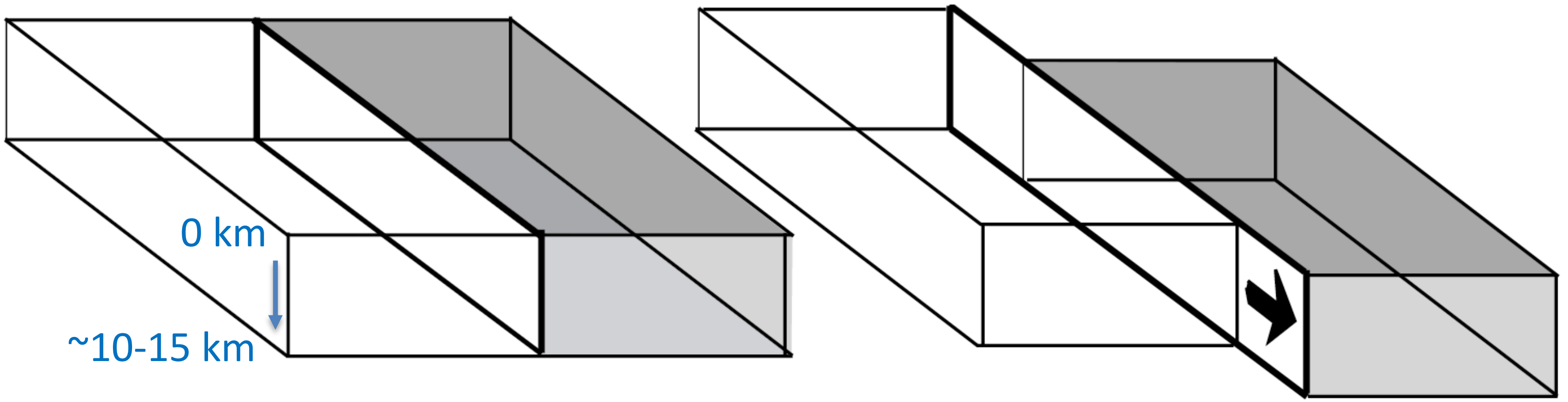
Western US seismicity is imprinted upon a system of active faults – the black lines.

An ‘active’ fault is loosely considered a fault that breaks Quaternary deposits or rocks – with the most active being recorded in offset and deformation of Holocene rocks

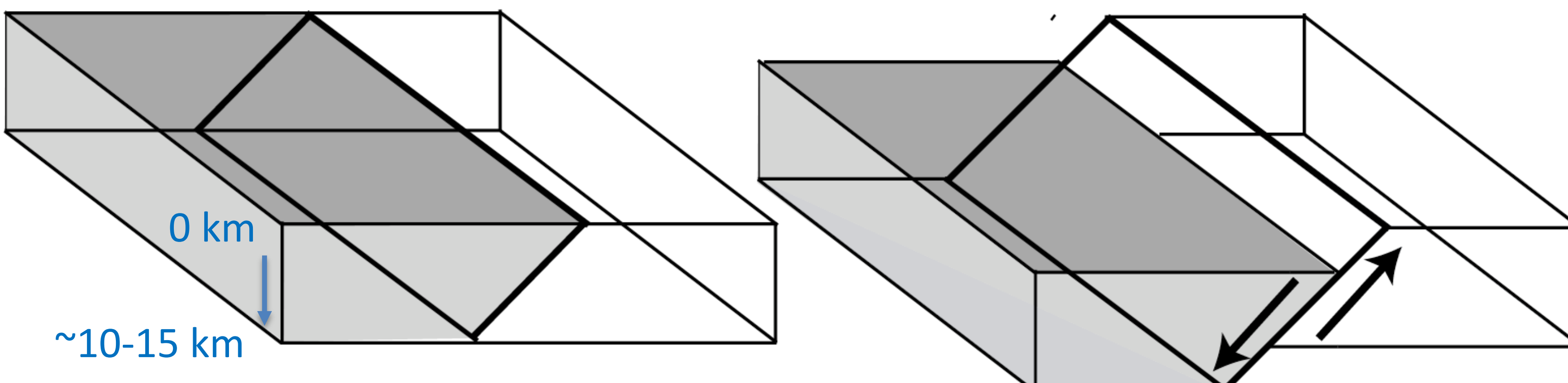
Repeated occurrence of displacement lead to distinct and readily recognized morphology

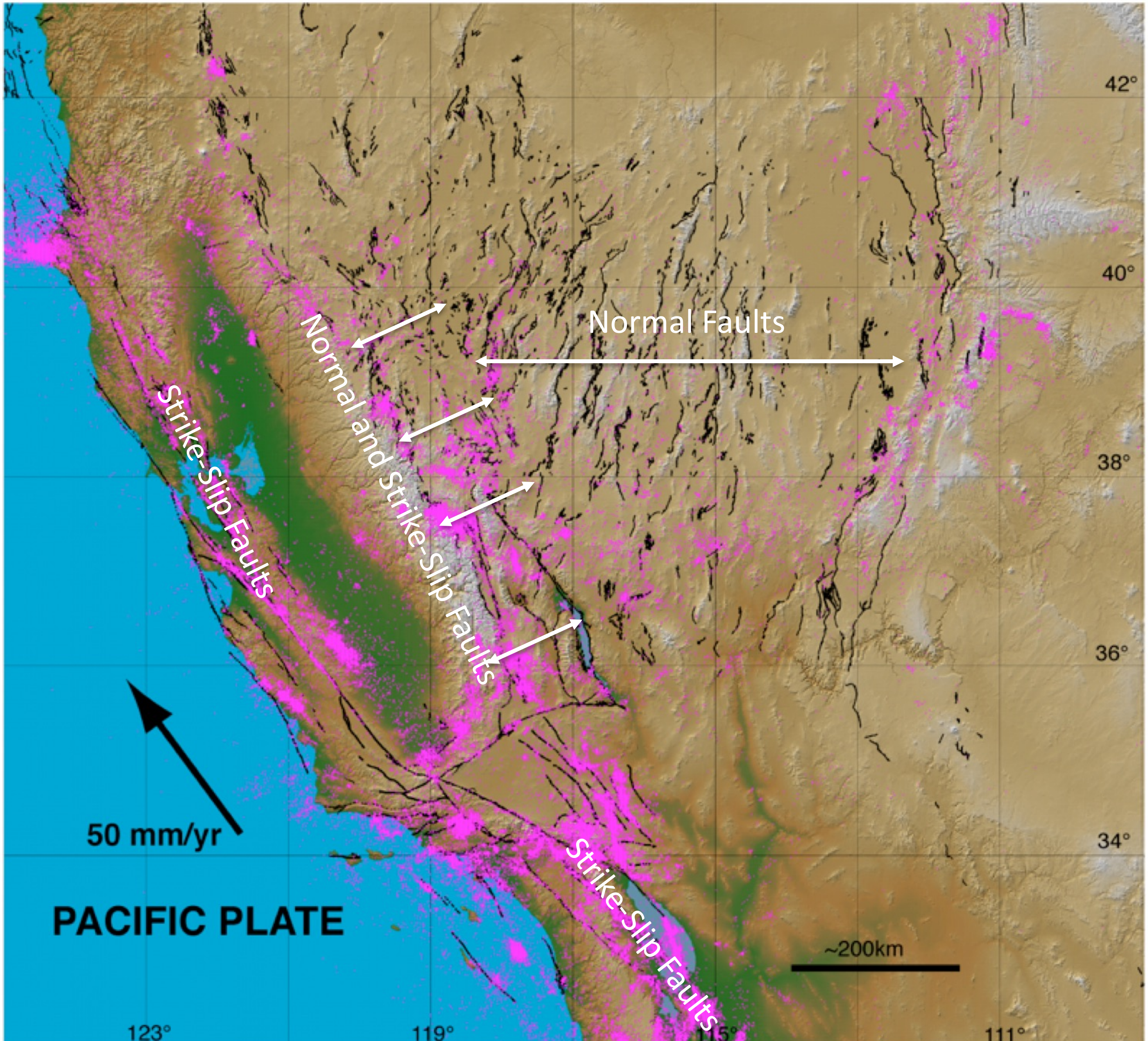
The idea of a 'fault' – quite simple – generally two types in western US.

The first - Strike-slip - where a block of the earth's crust slide sideways with respect to block on other side.



A second - Normal- where on one side of the fault the earth moves up - and down on the other.

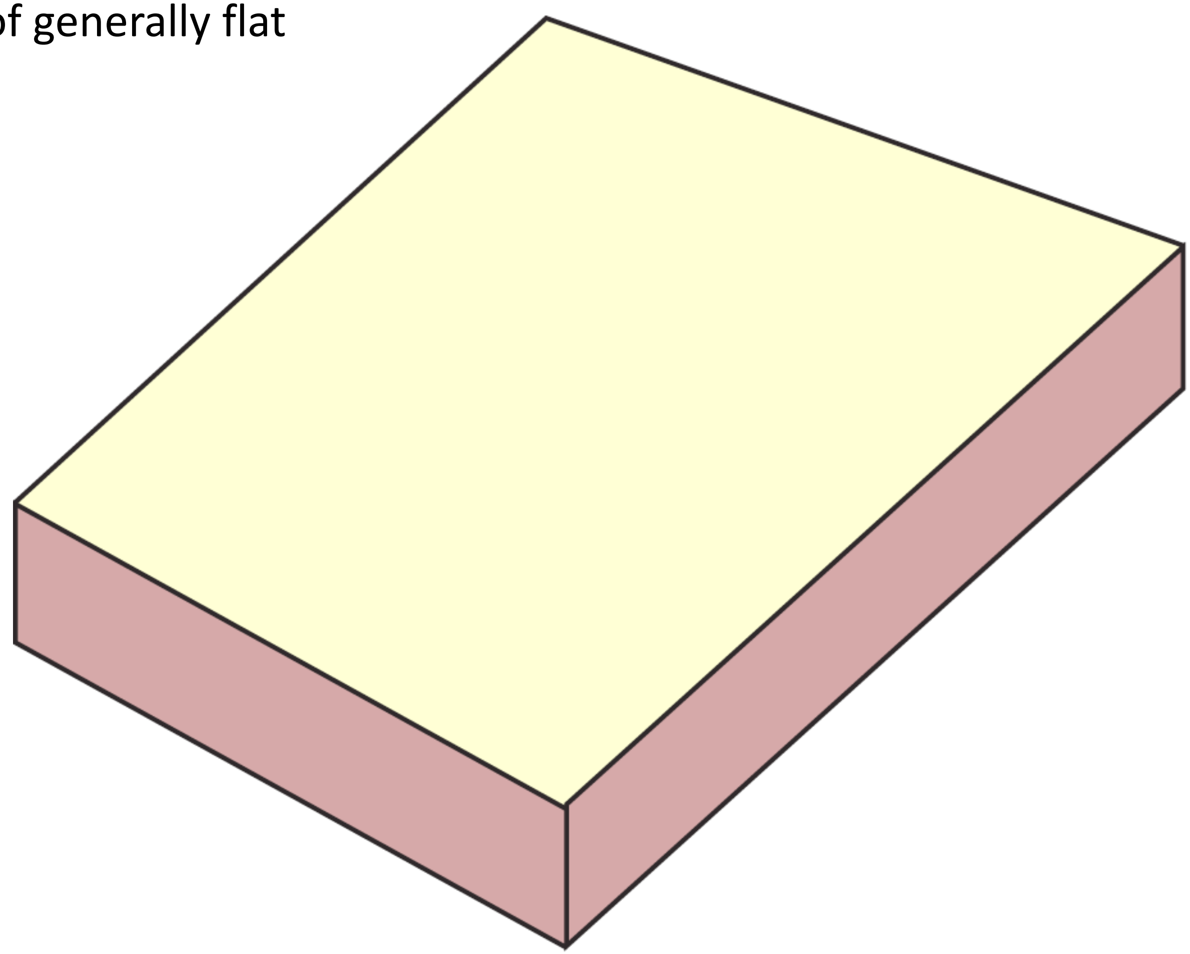




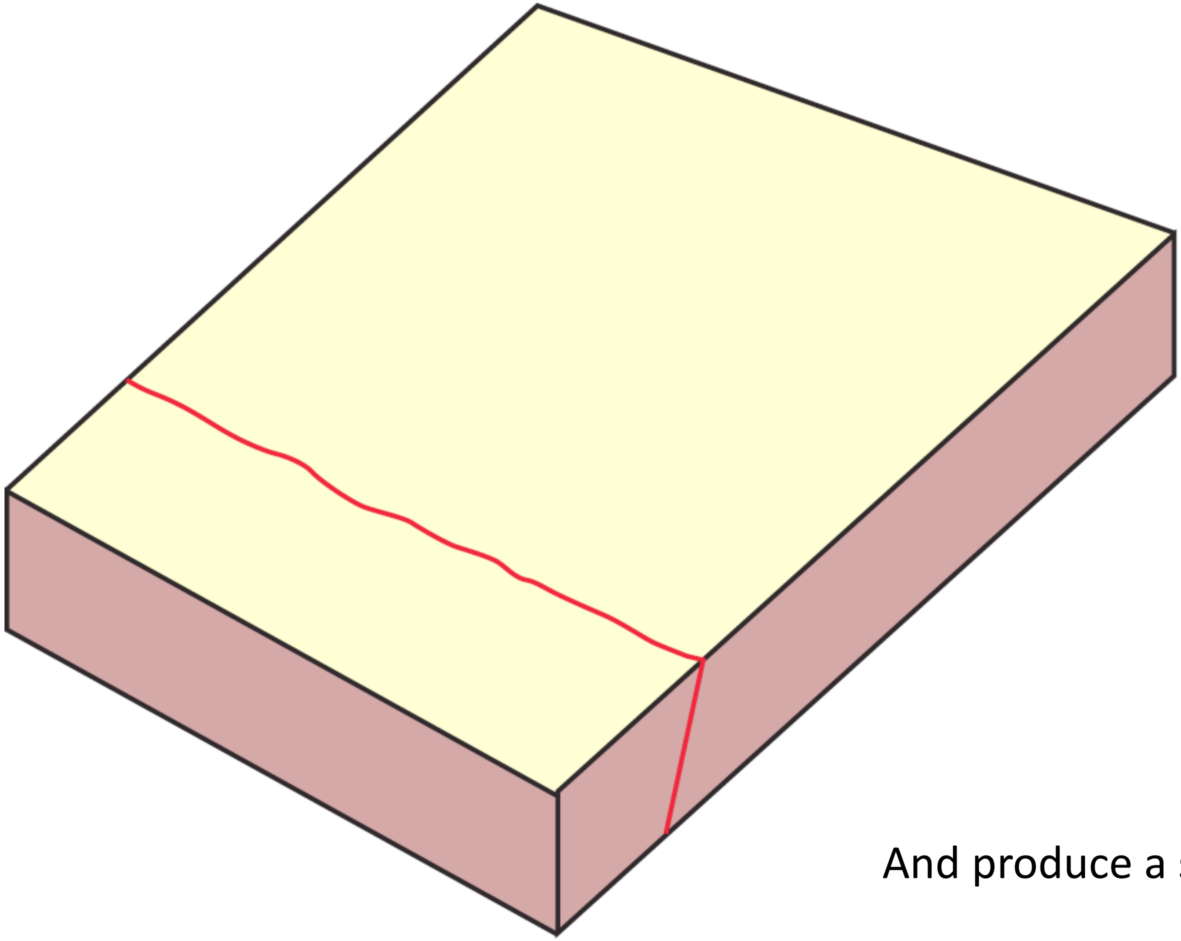
42°
40°
38°
36°
34°
Normal Faults
Normal and Strike-Slip Faults
Strike-Slip Faults
Strike-Slip Faults
50 mm/yr
PACIFIC PLATE
~200km
123°
119°
115°
111°

Consider what happens when a normal fault interacts with surface during the course of repeated earthquake displacements....

Take a piece of generally flat ground

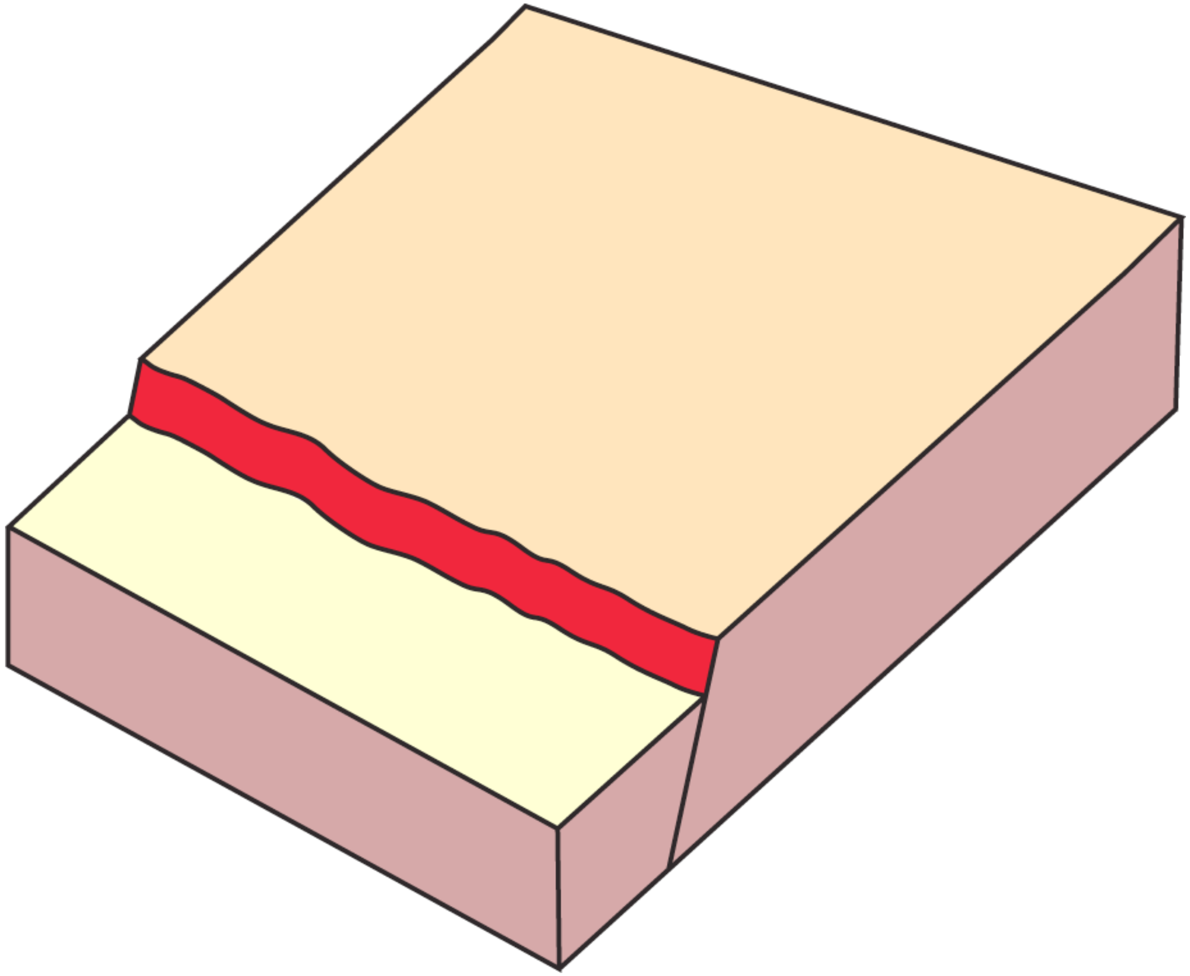


Let the fault slip…

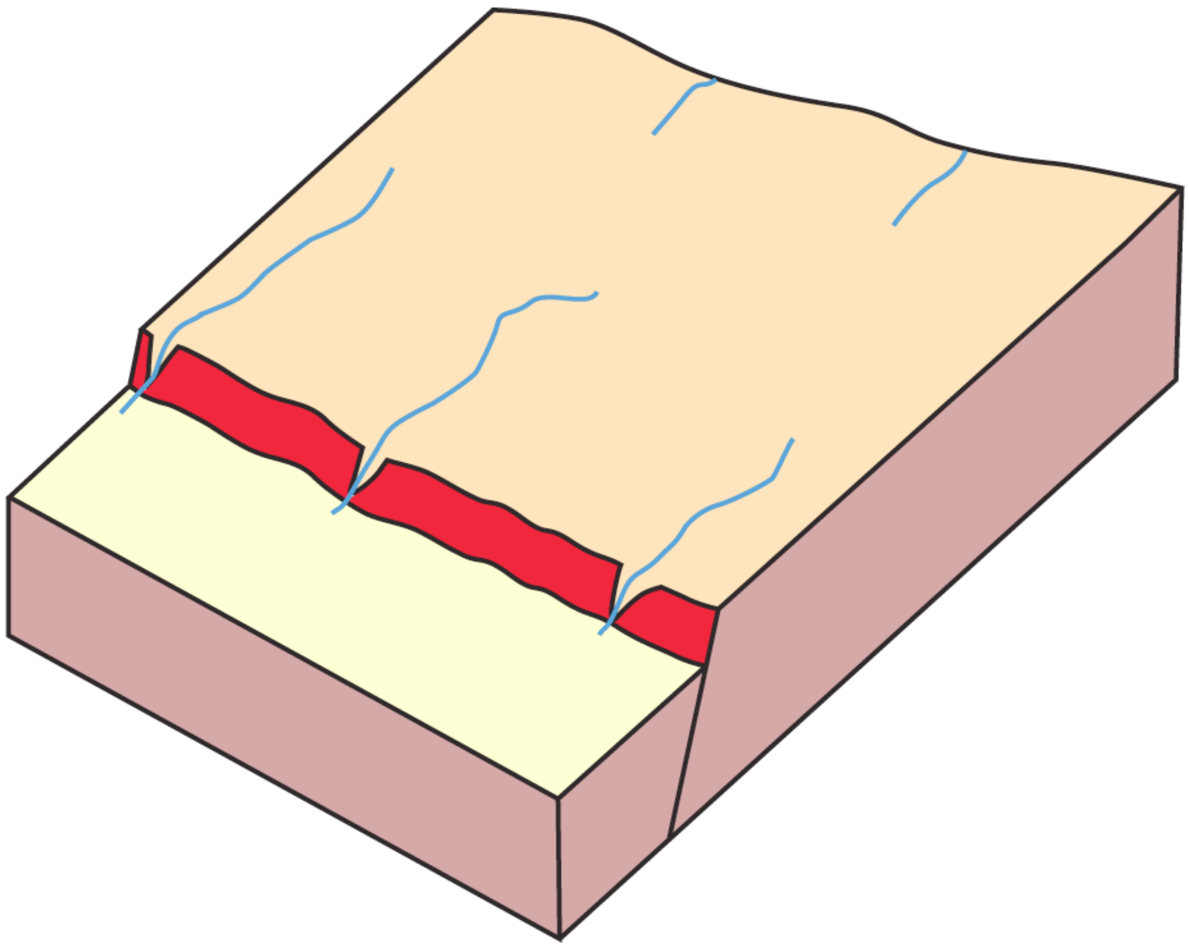


And produce a scarp…

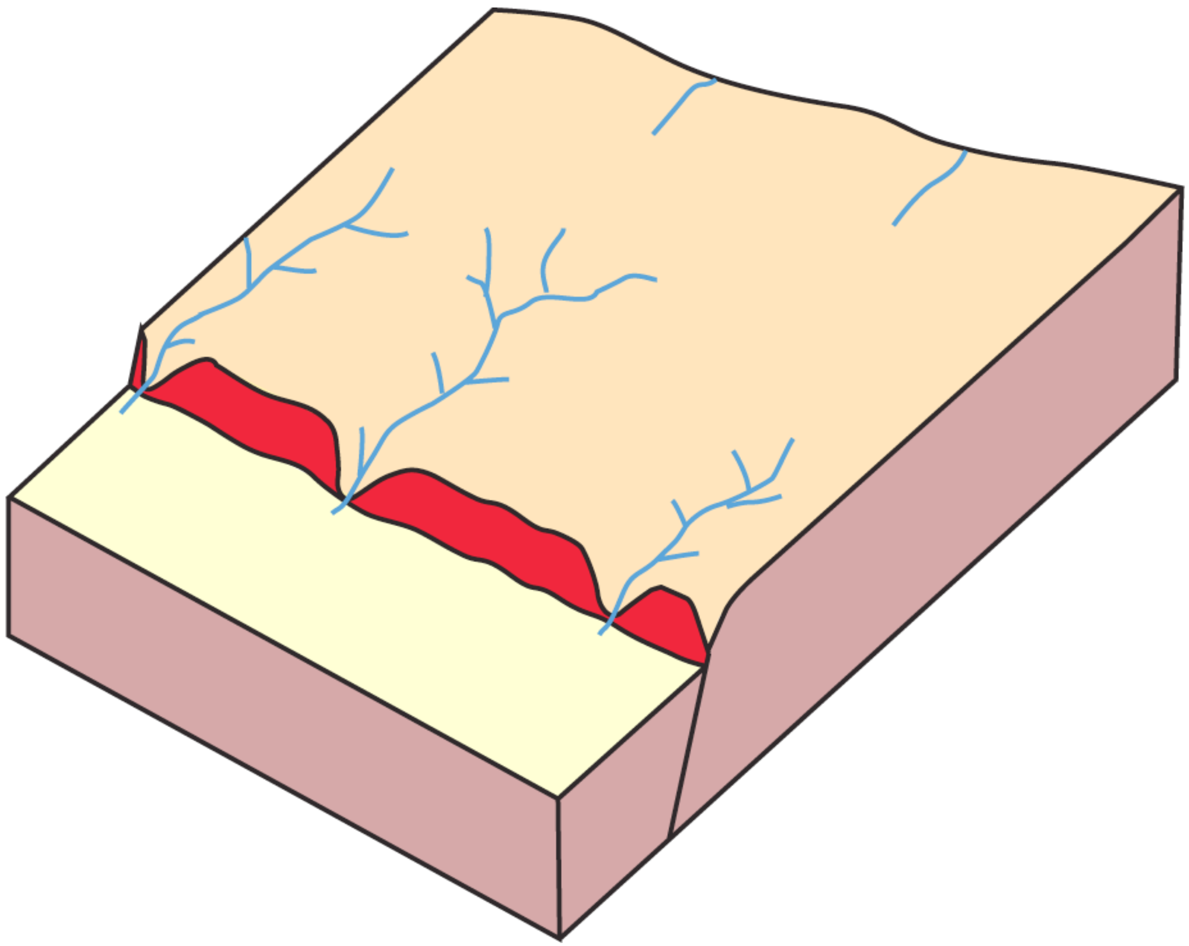
Now what happens… say, if it rains…..



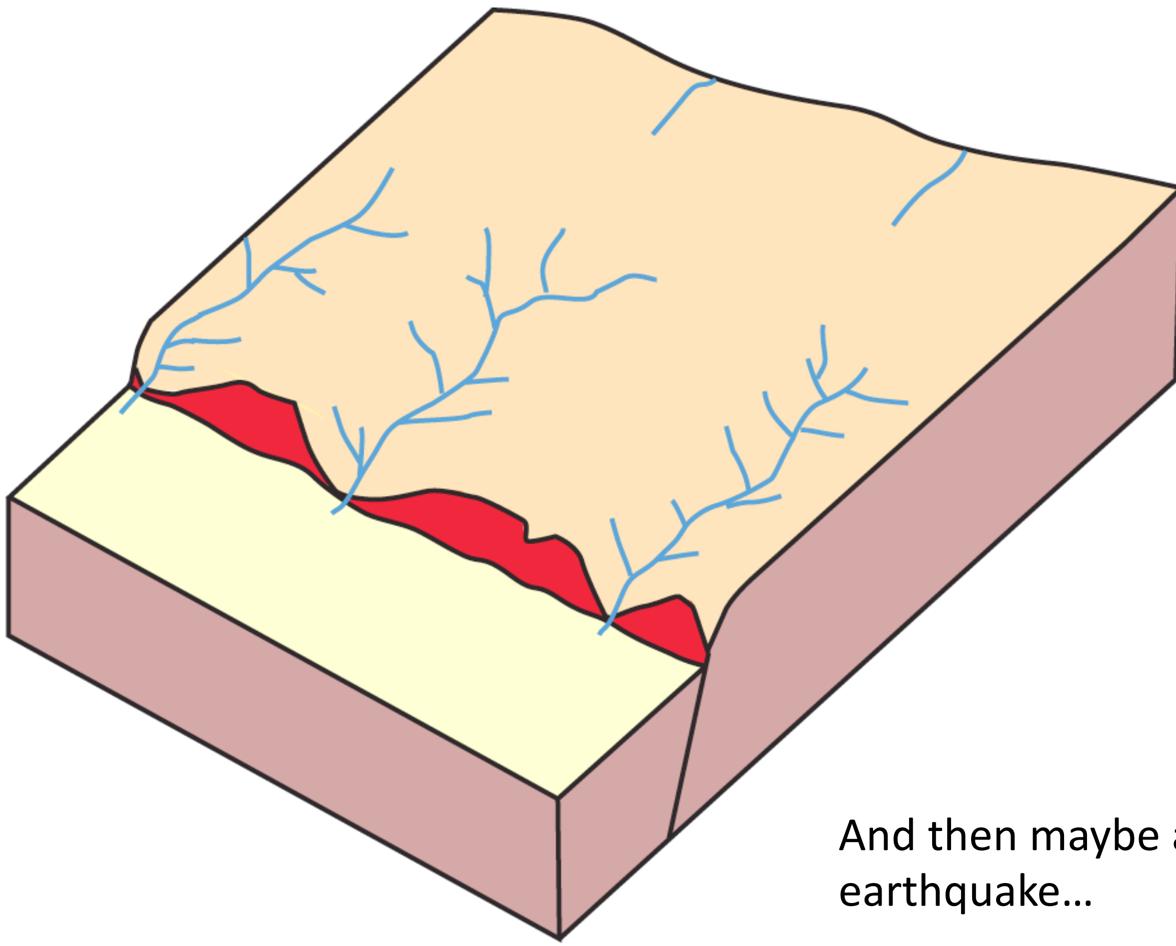
We get a little erosion….incision of the scarp



More rain - more incision -

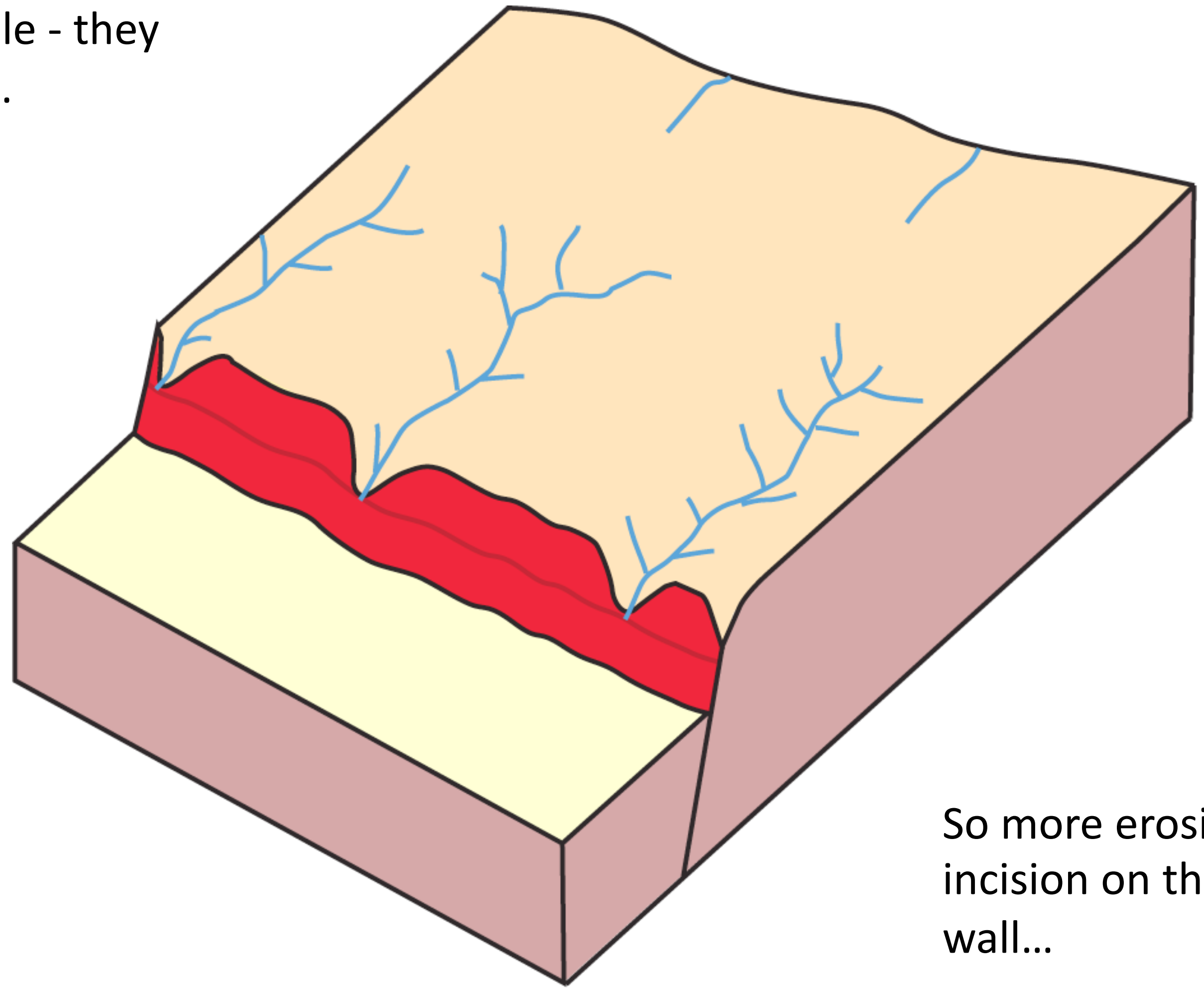


And development of small drainage basins…

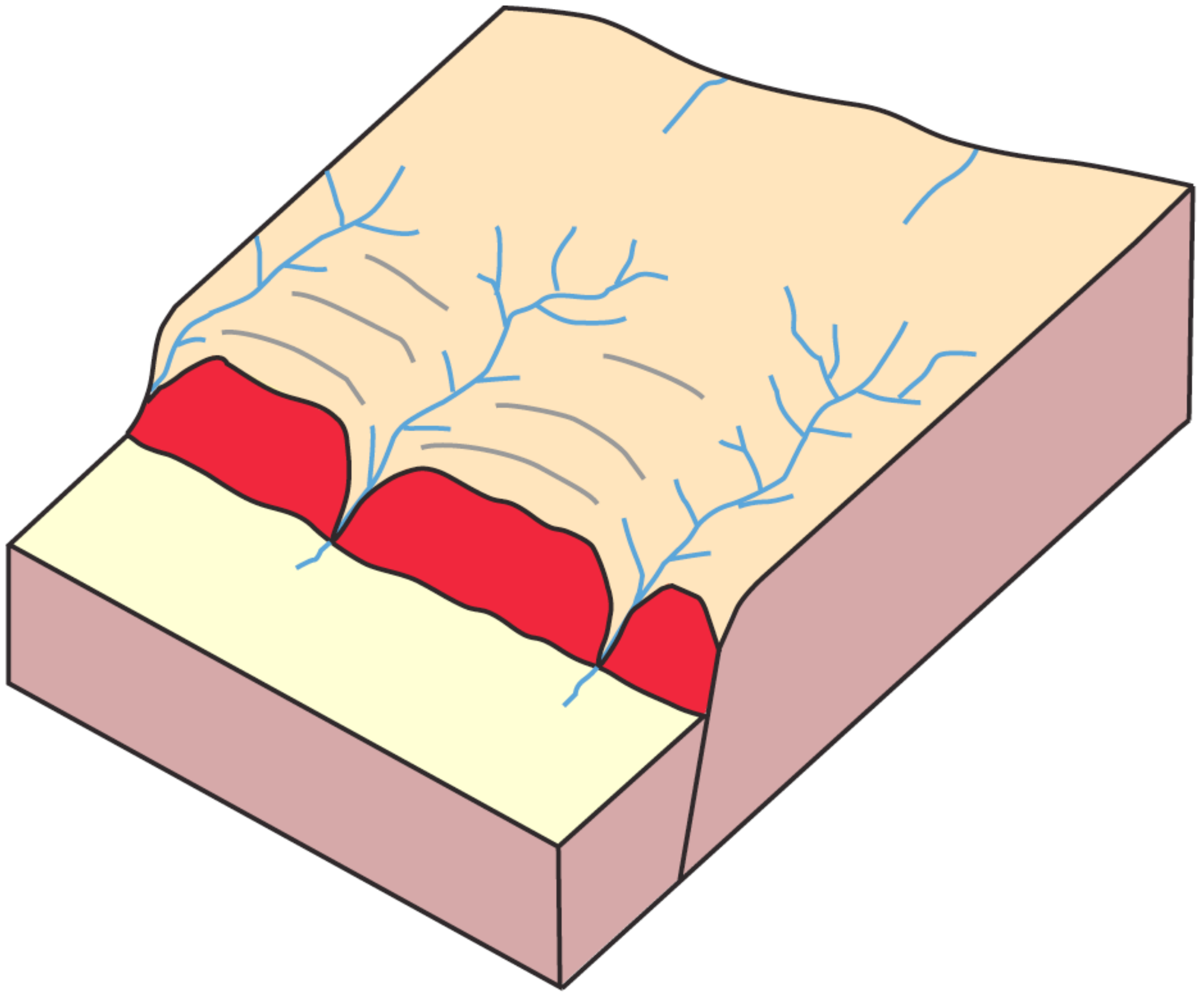


And then maybe another earthquake…

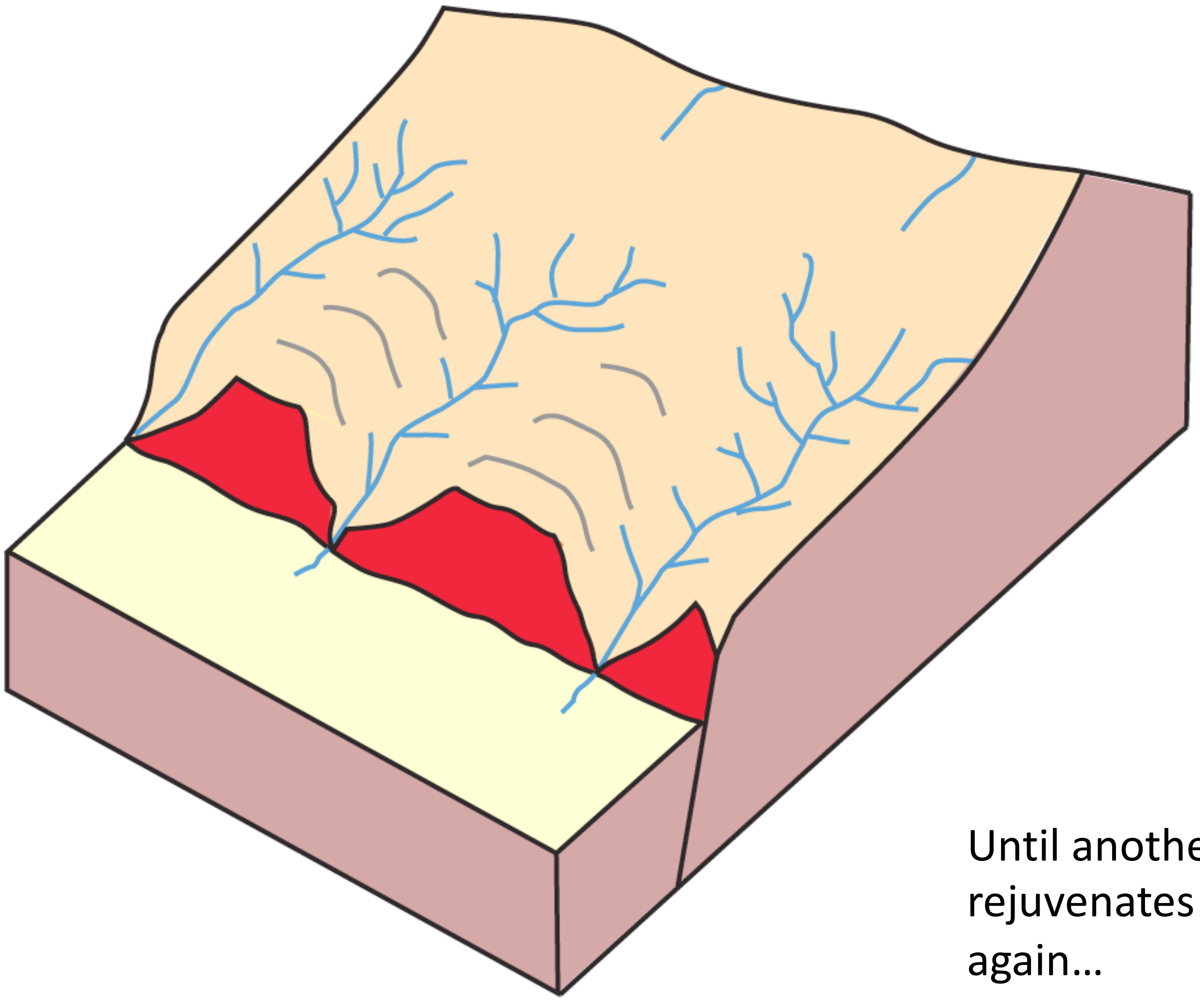
And the streams no longer have their longitudinal profile - they are out of grade…



So more erosion and incision on the hanging wall…

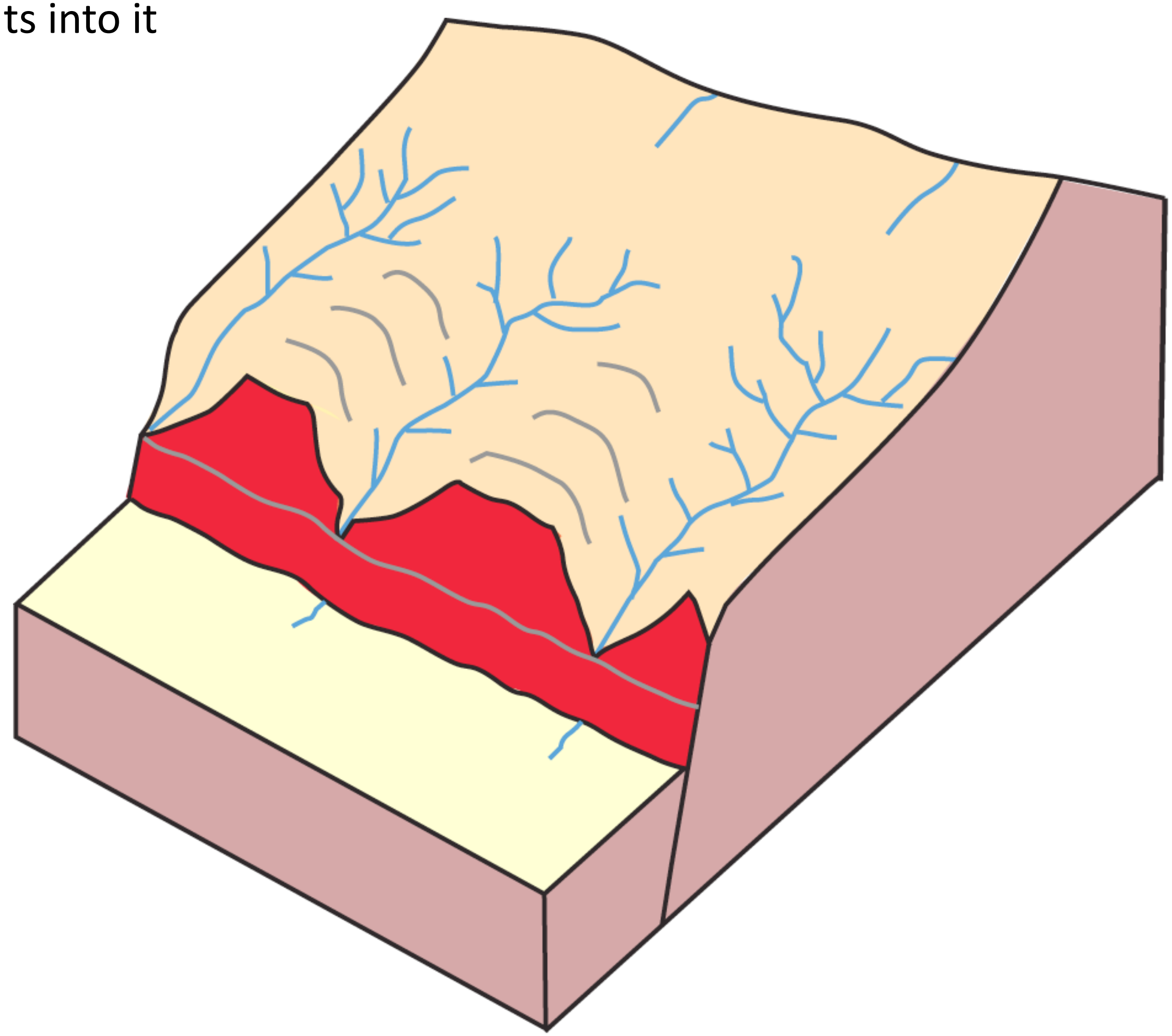


And the process continues

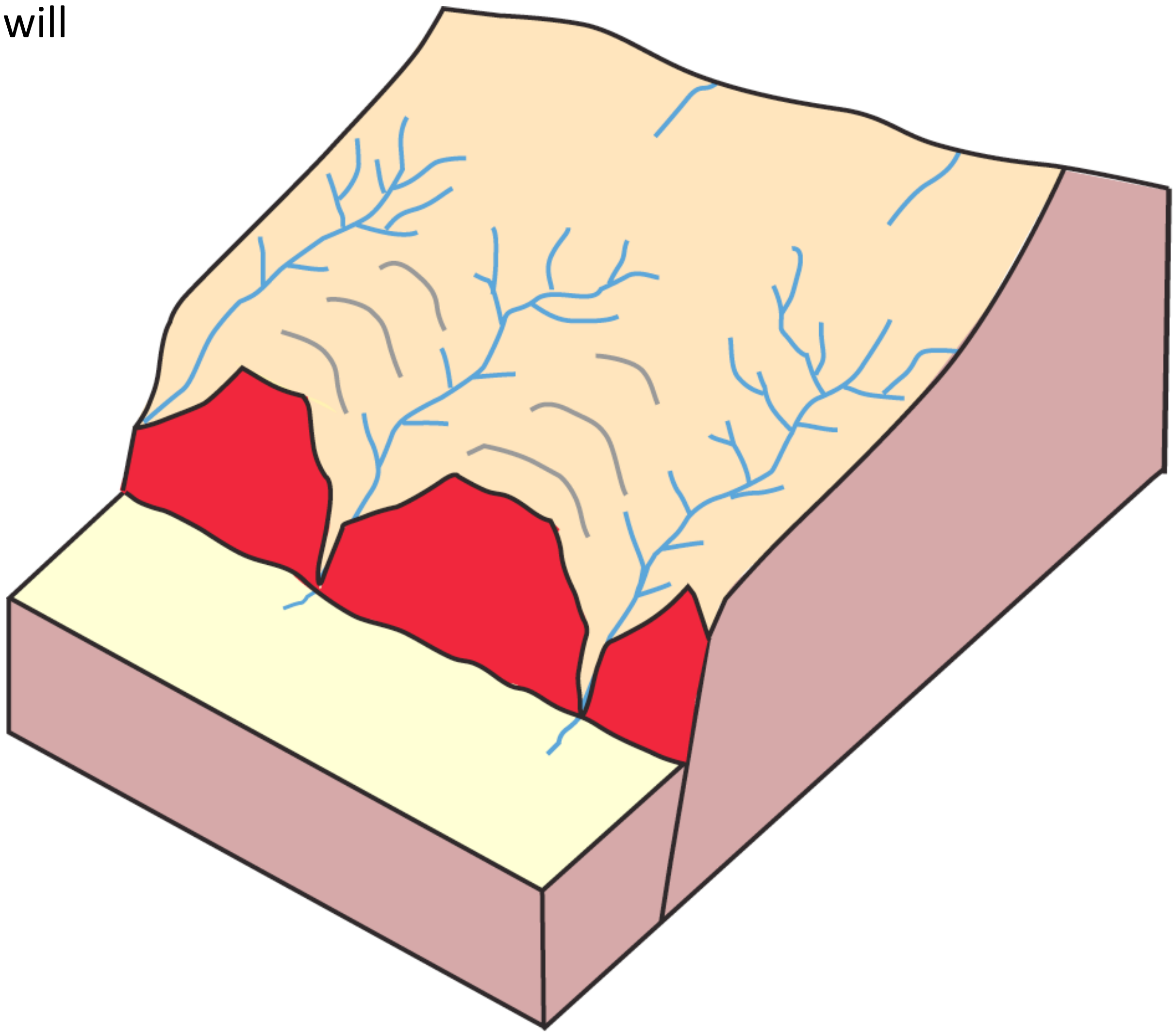


Until another earthquake rejuvenates things again…

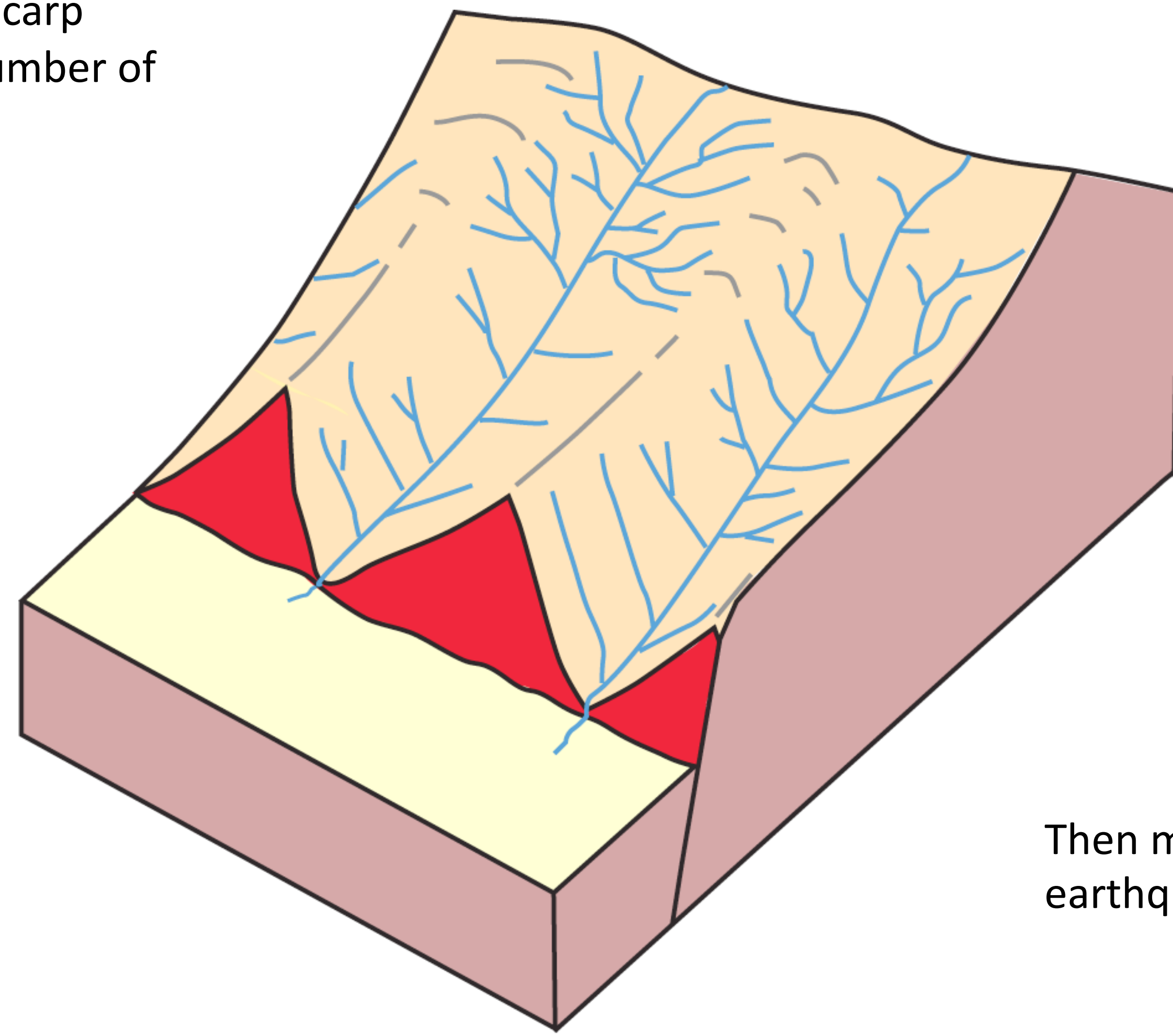
The mountain goes ‘up’
- the incision cuts into it



More incision - the drainage basins will grow…

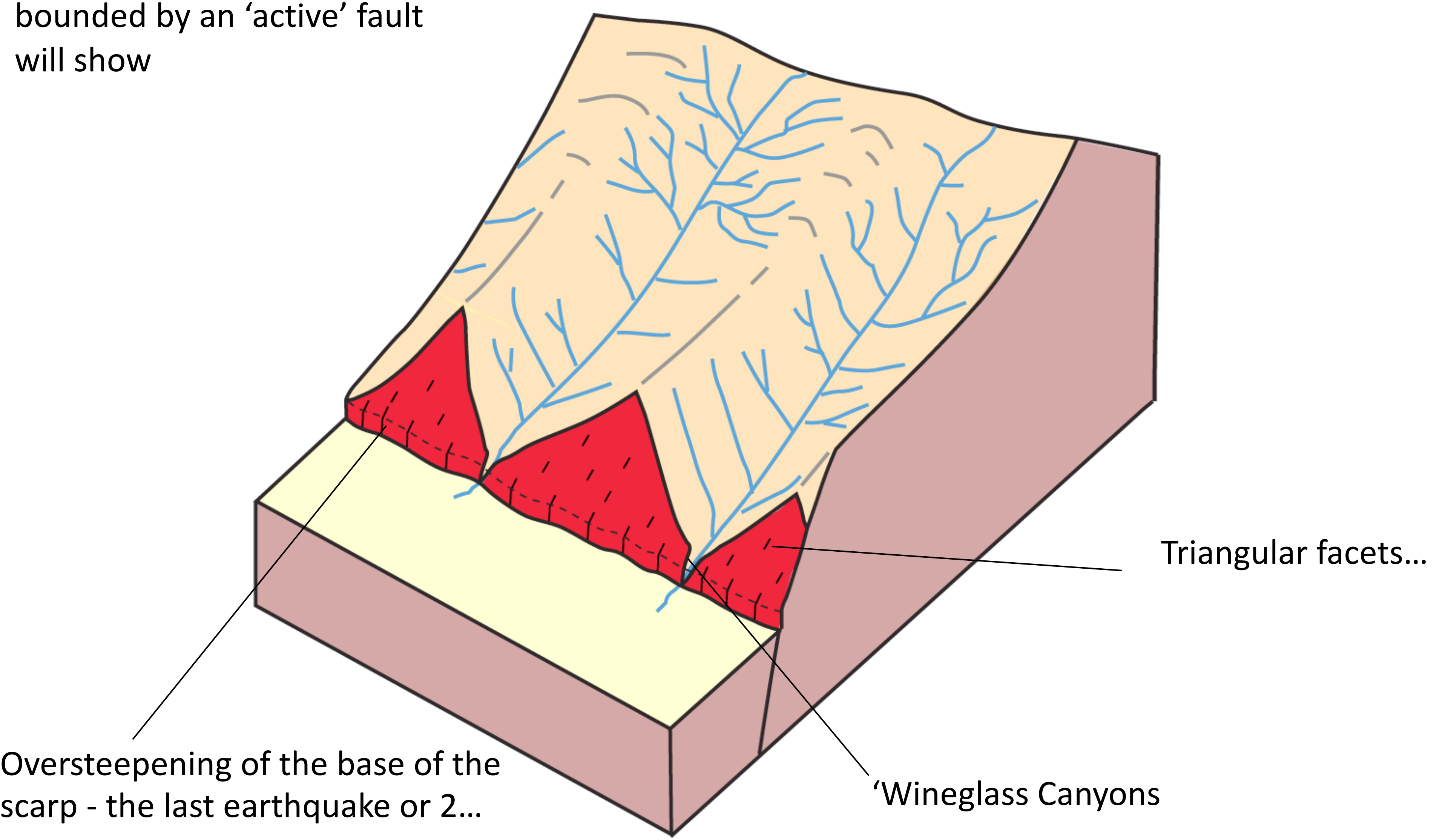


Until the ridges are sharp and the scarp appears as a number of triangles…

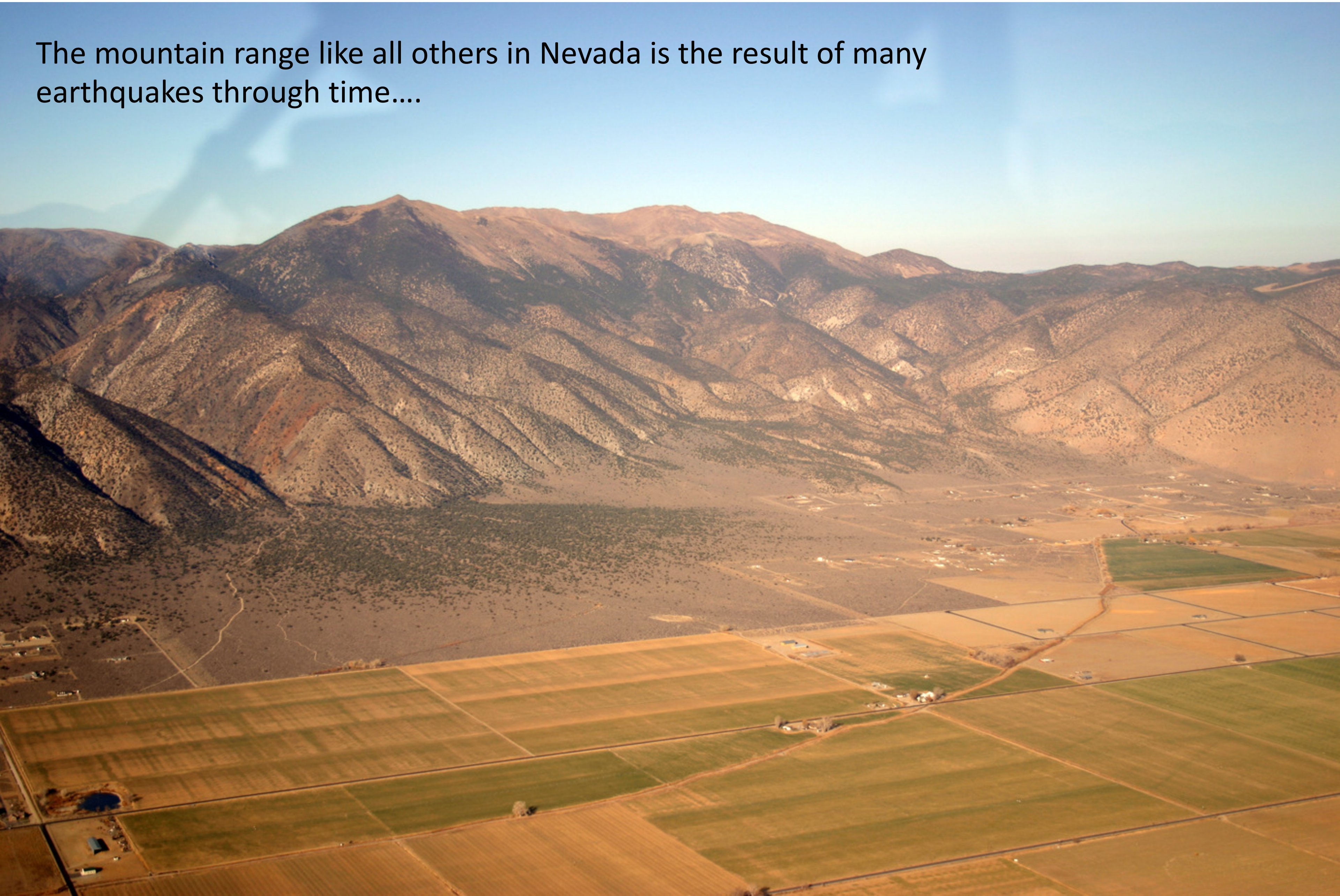


Then maybe another earthquake…

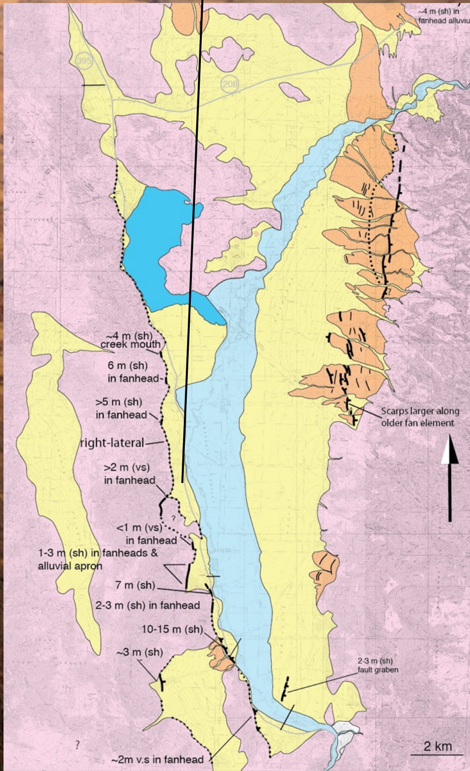
And a mountain front bounded by an ‘active’ fault will show

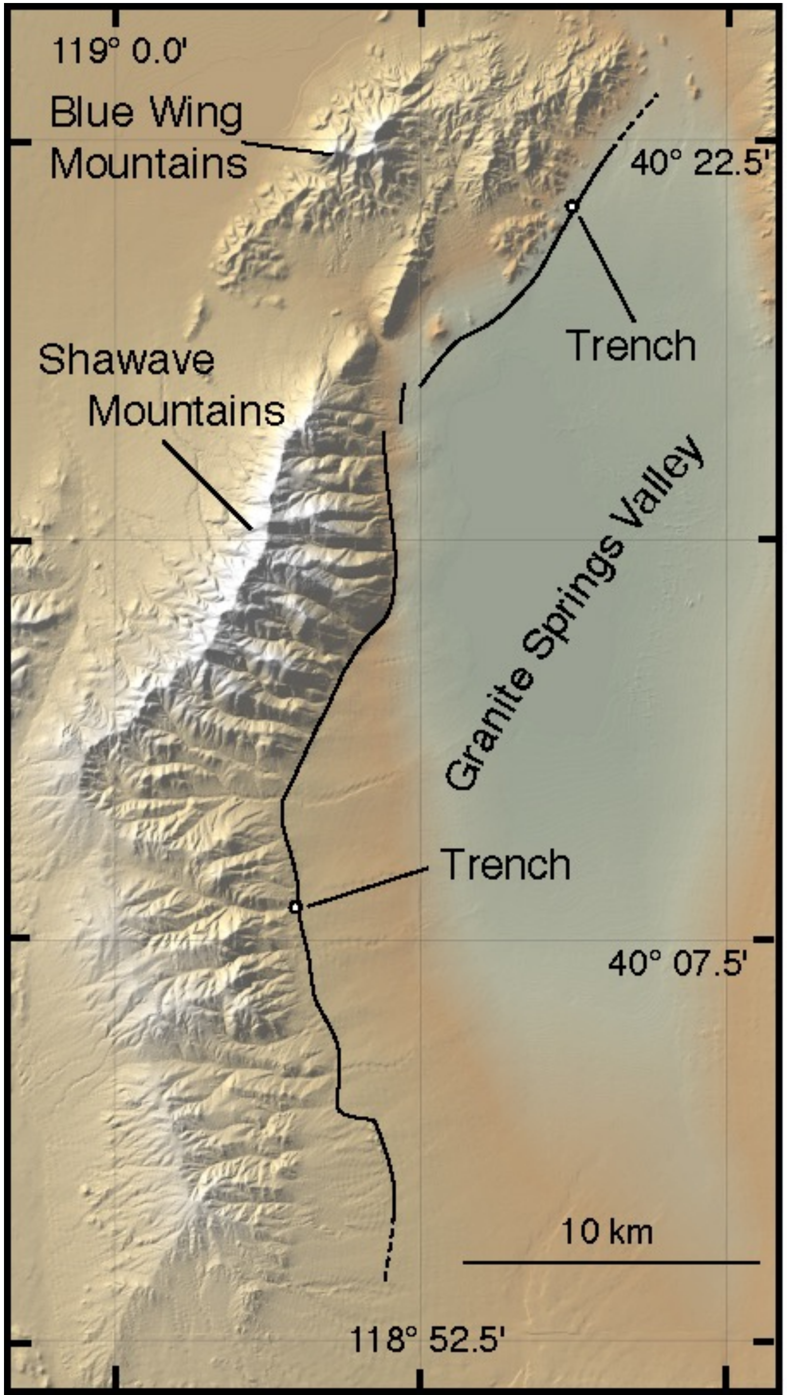


View westward across Smith Valley to Pine Nuts…




View north toward Topaz Lake
Next slide


~4 m (sh) creek mouth
6 m (sh) in fanhead
>5 m (sh) in fanhead
right-lateral
>2 m (vs) in fanhead
<1 m (vs) in fanhead
1-3 m (sh) in fanheads & alluvial apron
7 m (sh)
2-3 m (sh) in fanhead
10-15 m (sh)
~3 m (sh)
~2m v.s in fanhead
Scarps larger along older fan element
2-3 m (sh) fault graben
2 km


119° 0.0'
Blue Wing Mountains
40° 22.5'
Trench
Shawave Mountains
Granite Springs Valley
Trench
40° 07.5'
10 km
118° 52.5'

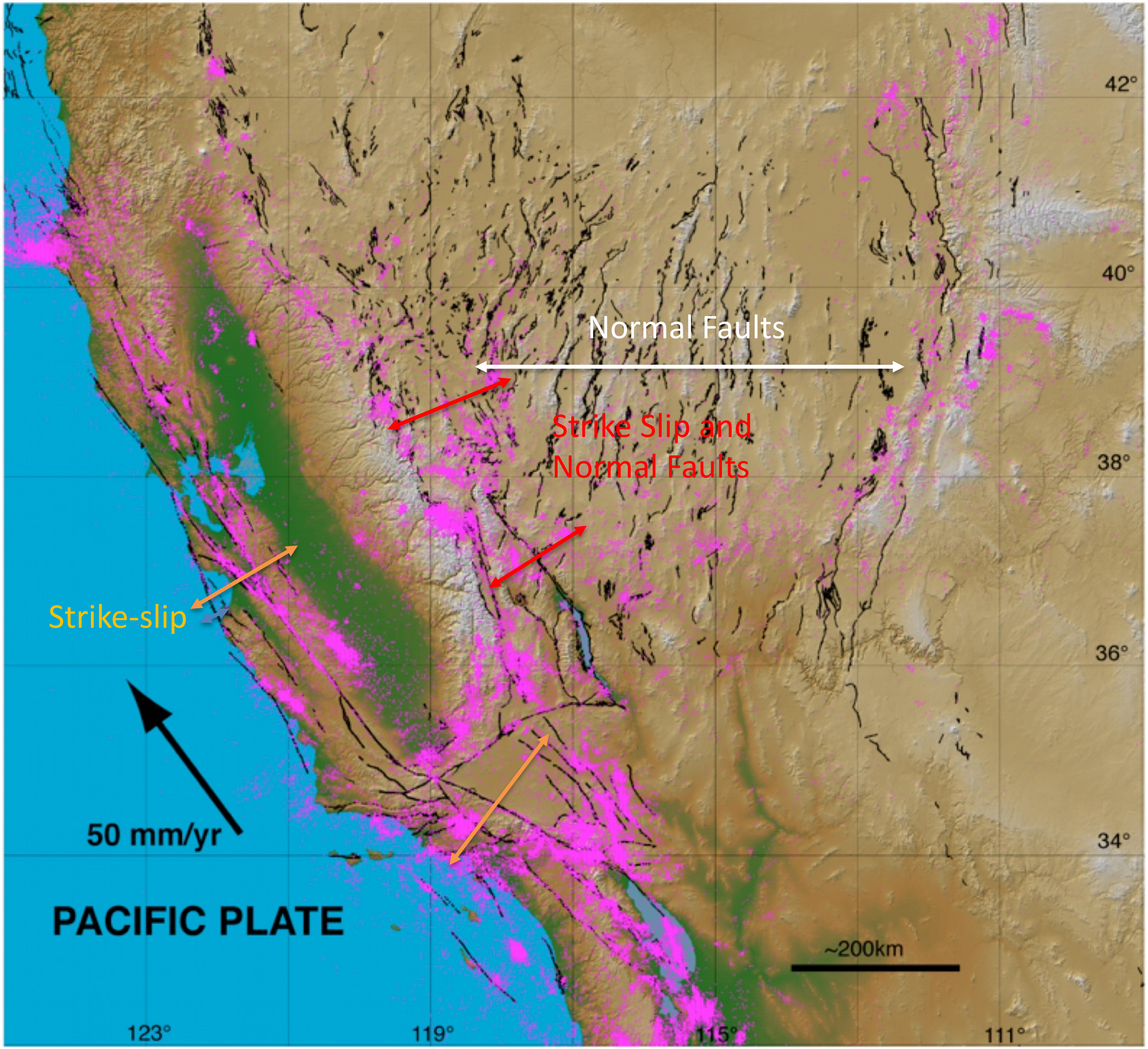

Trench


Trench

Peavine

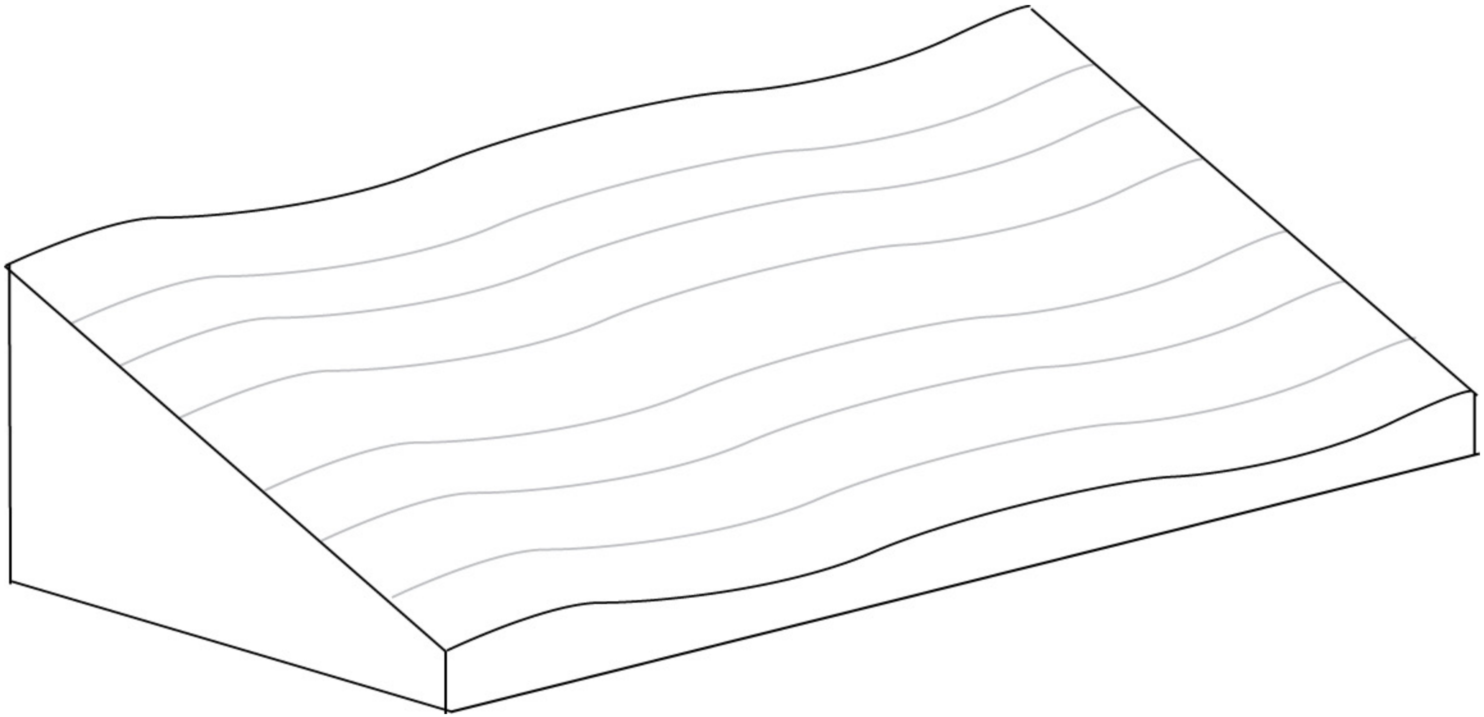
Carson City/Valley – Genoa fault

Slide Mtn Mt. Rose

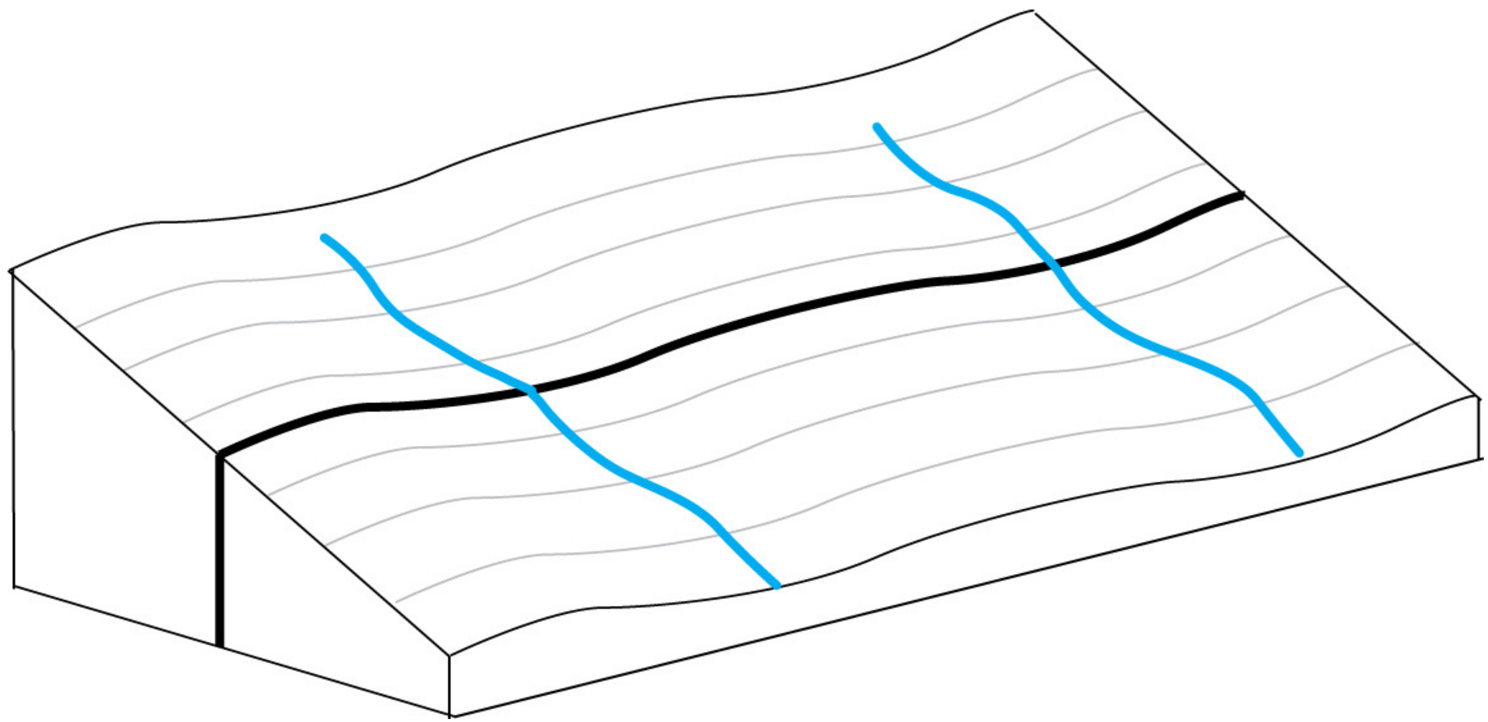

Normal Faults
Strike Slip and
Normal Faults
Strike-slip
50 mm/yr
PACIFIC PLATE
~200km
42°
40°
38°
36°
34°
123°
119°
115°
111°

Morphology- shape

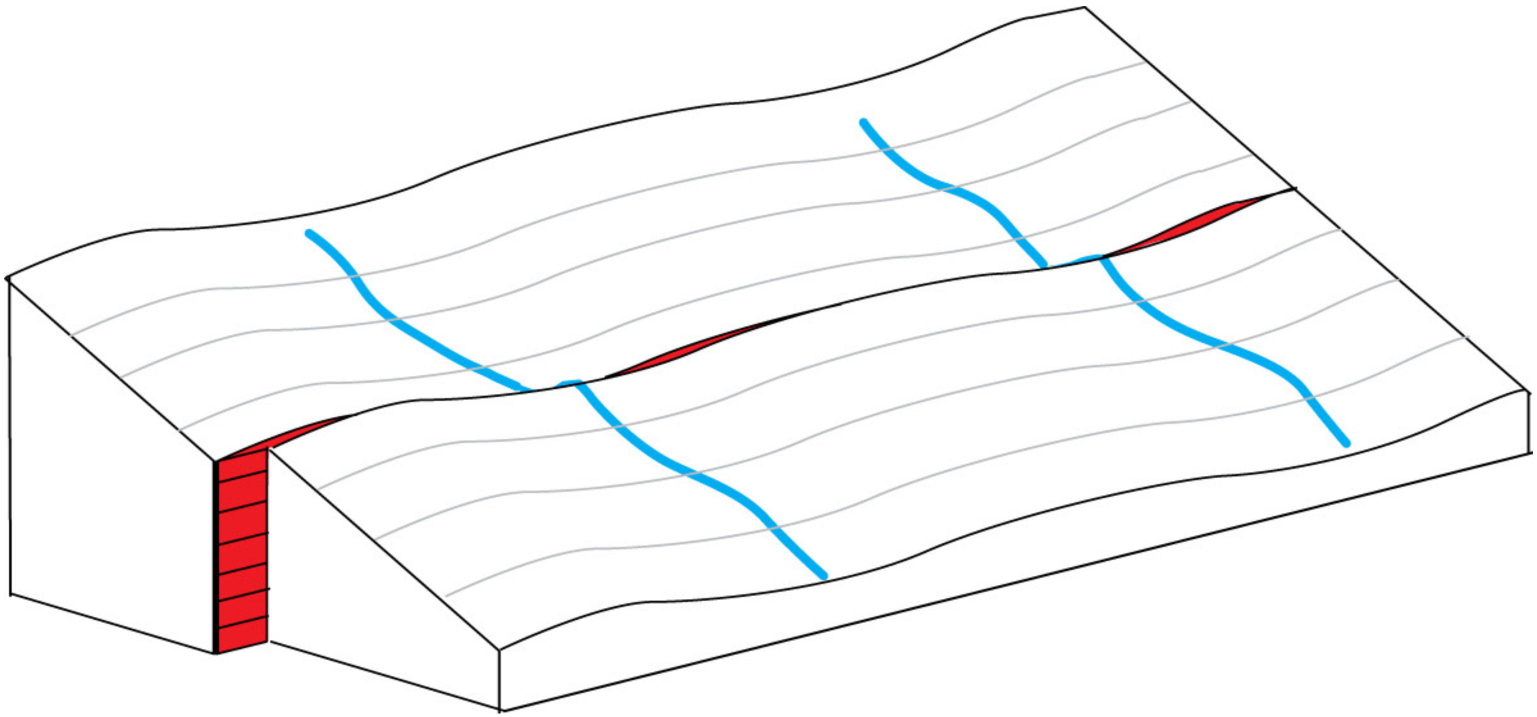
Geomorphology - processes that shape earth surface



Consider relatively smooth sloping surface

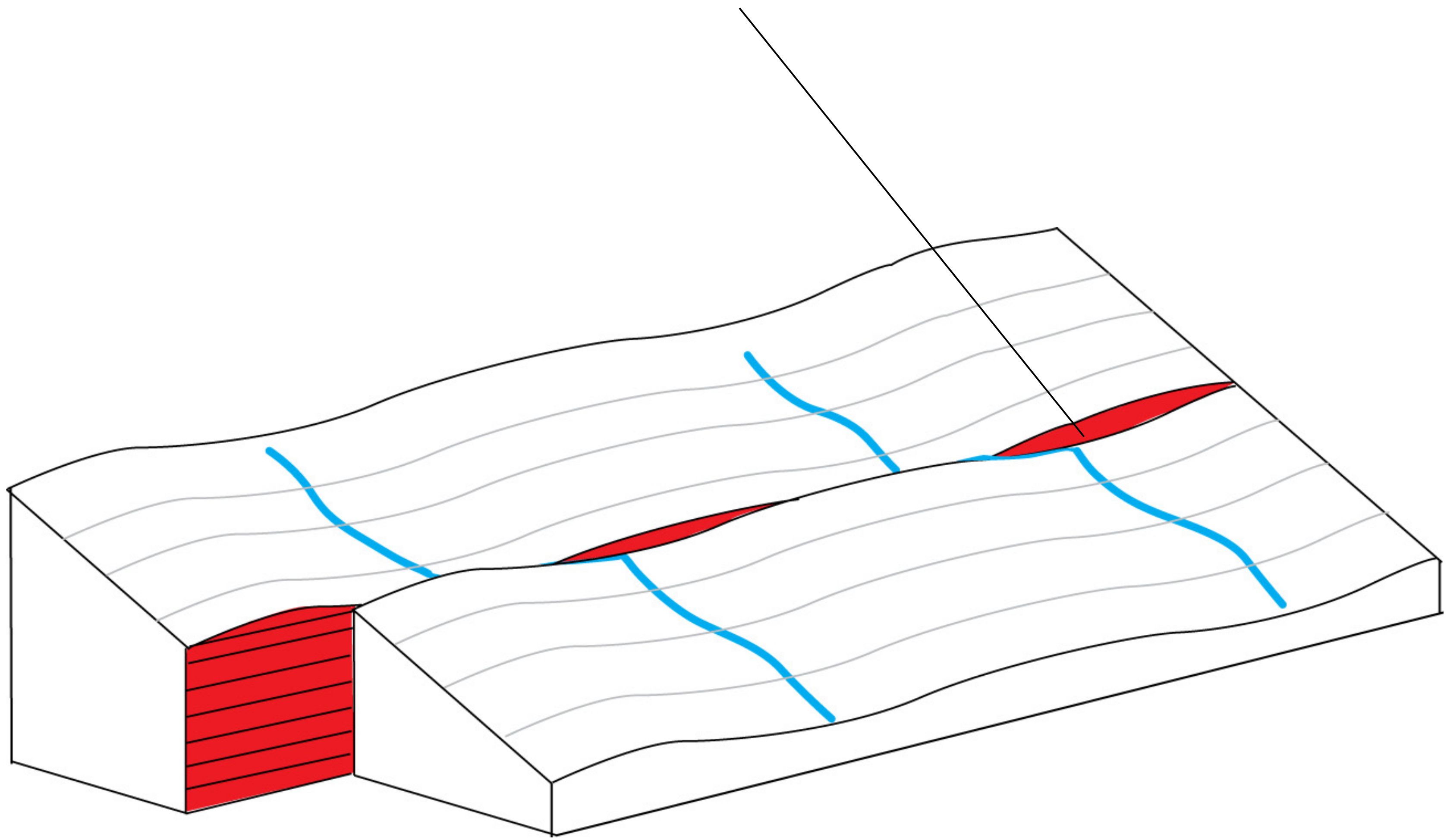


Introduce a fault and some streams flowing down the surface

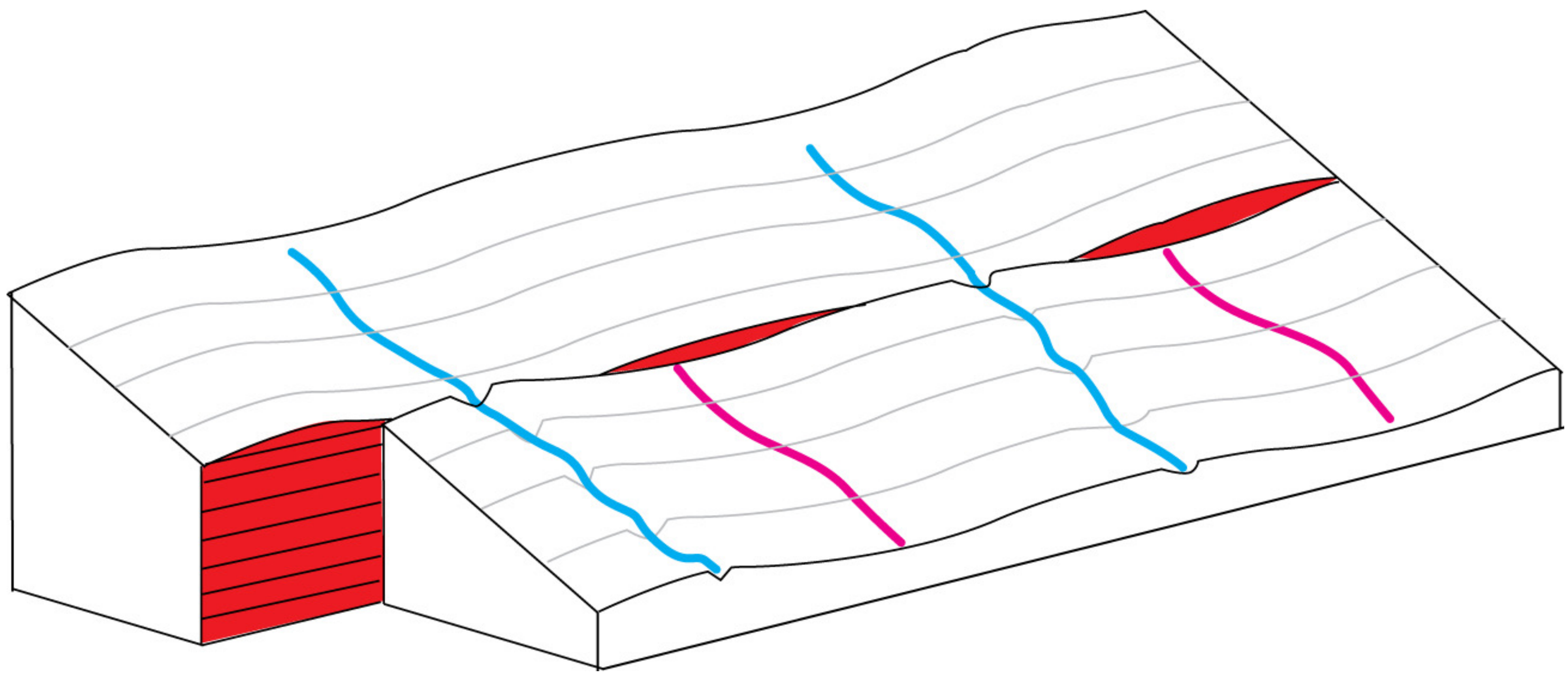


Let earth slip laterally (horizontally) across the fault - an earthquake

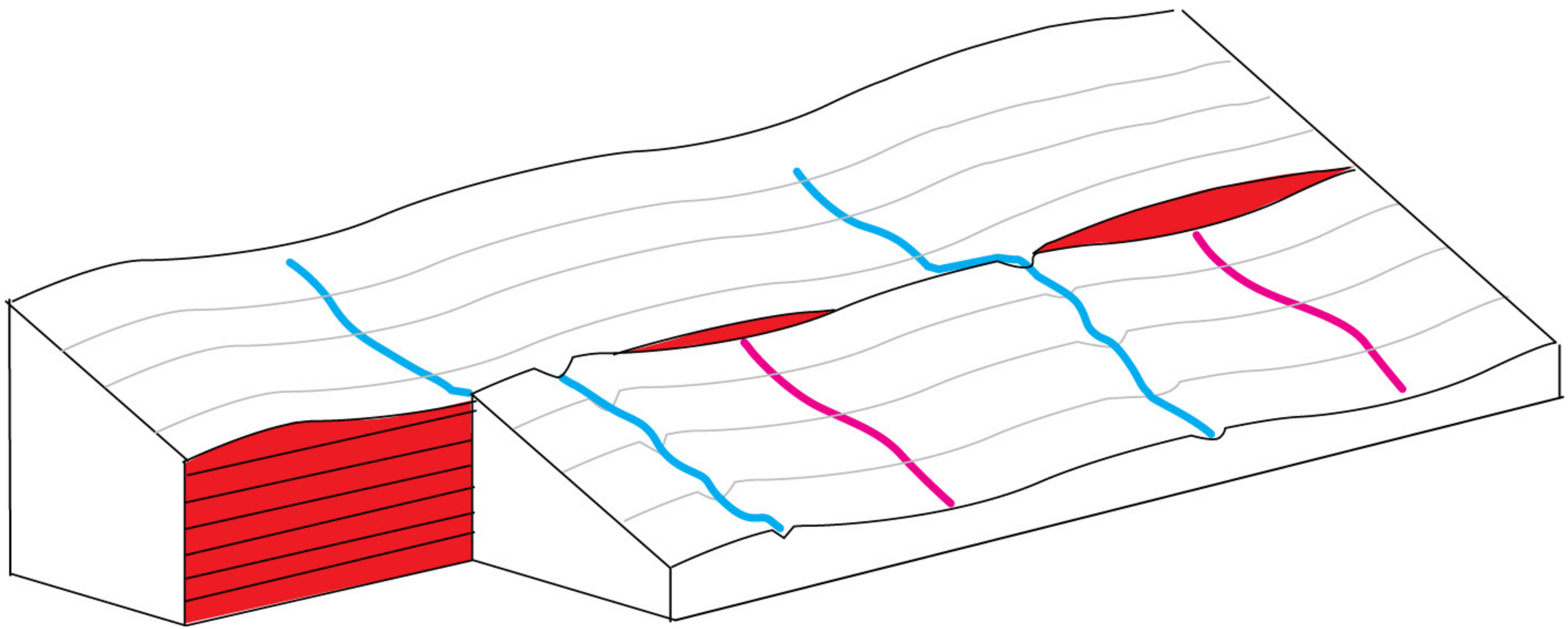
Scarp - abrupt change in topography....



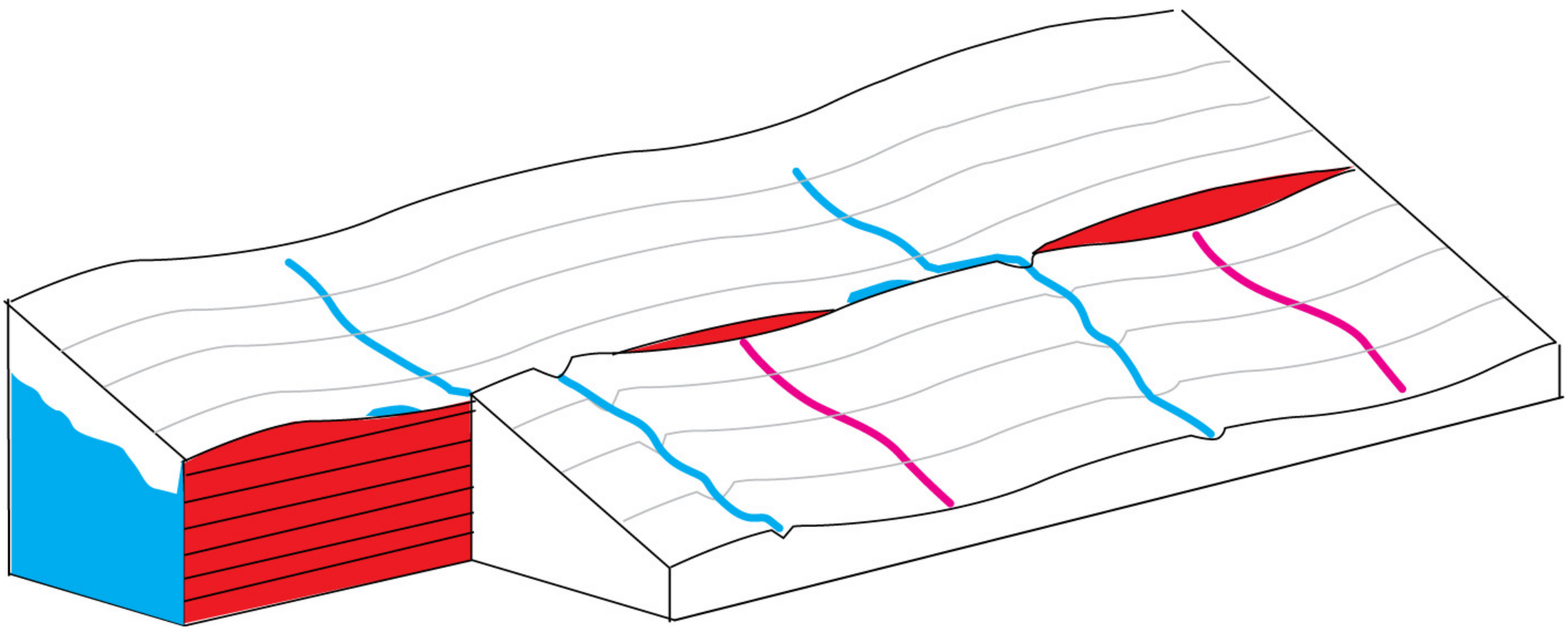
and again.. another earthquake



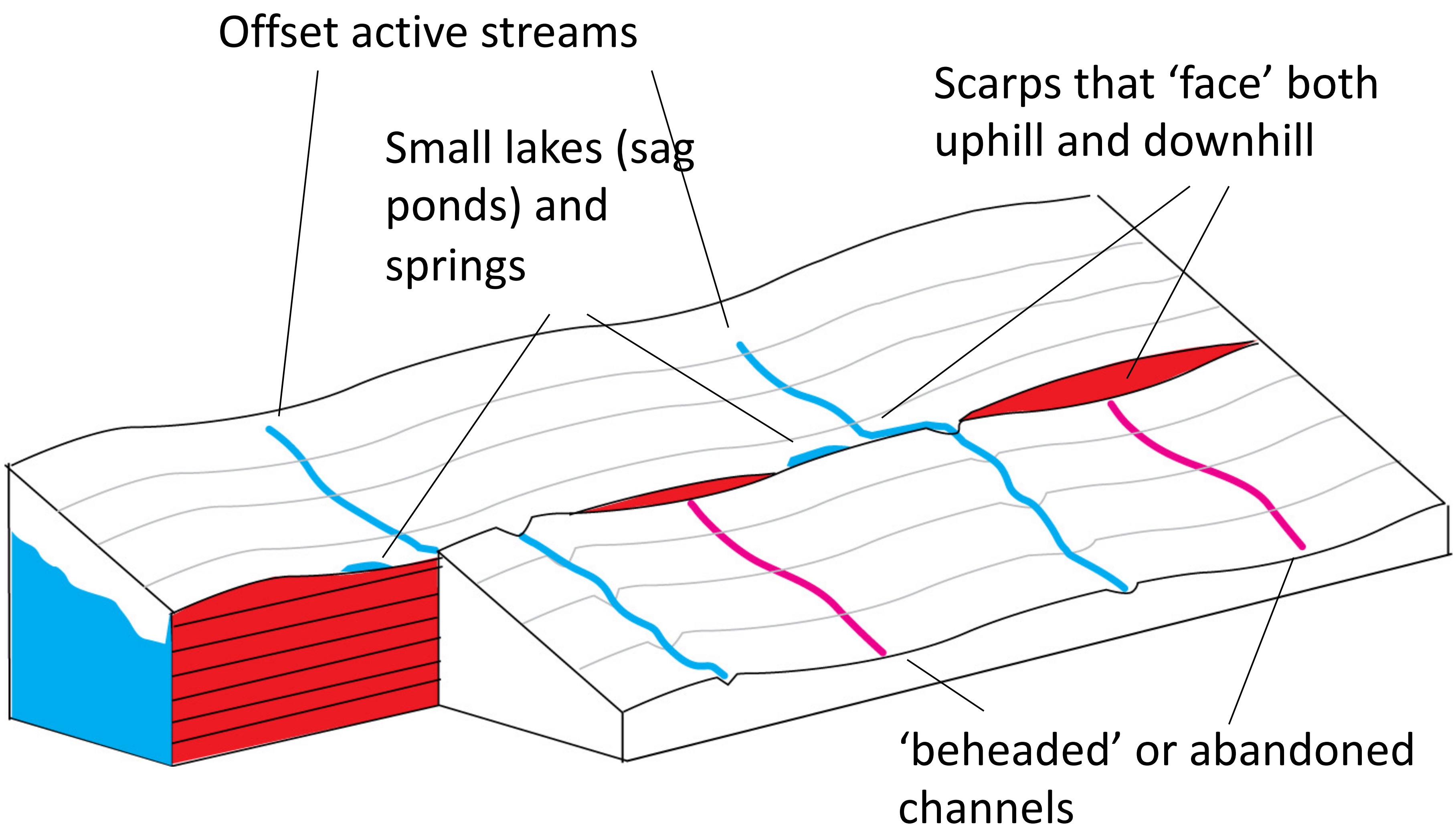
and then maybe a bigger than usual rain…



and then let earth slip some more laterally…

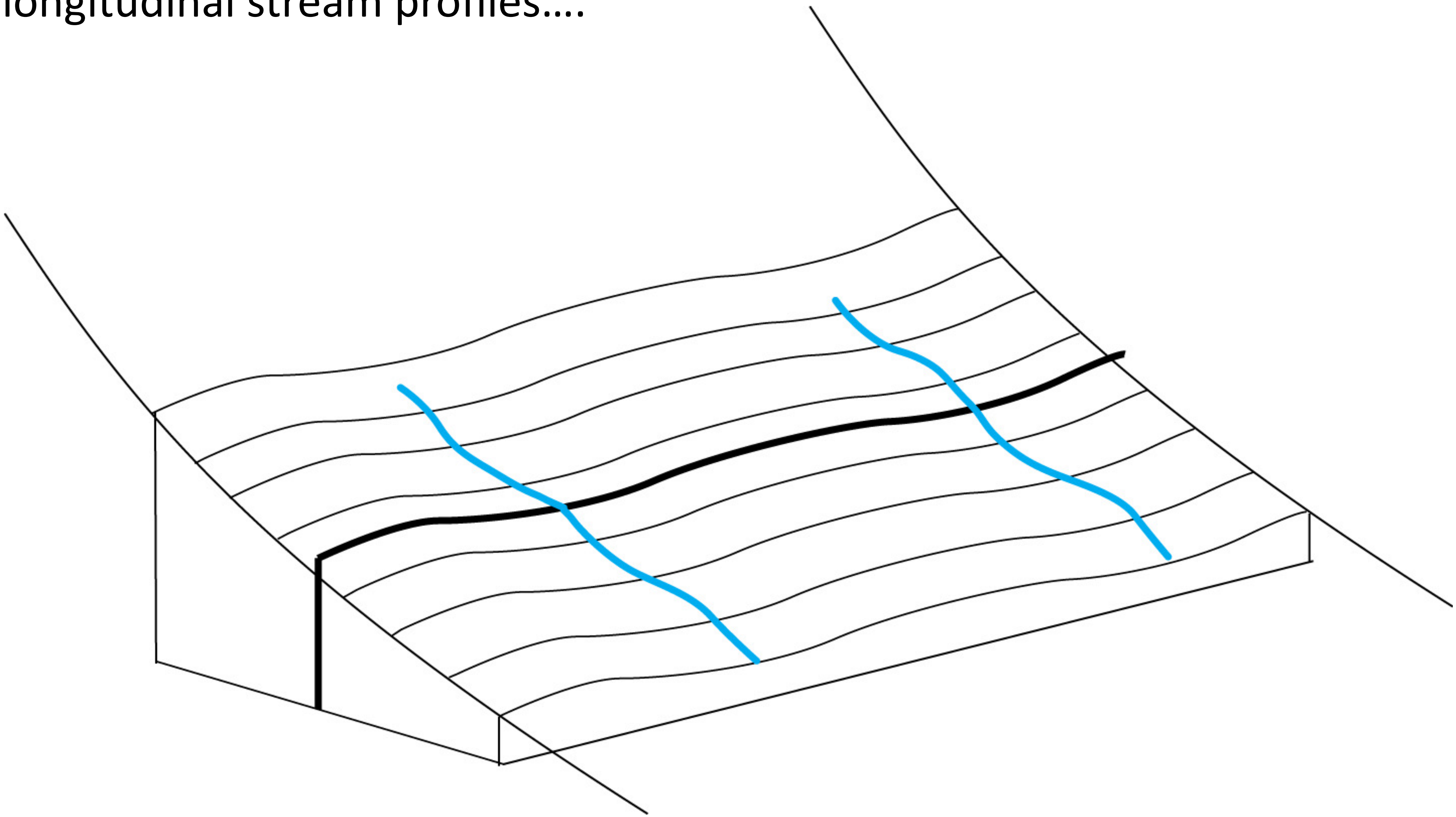


and then think about the water table too...

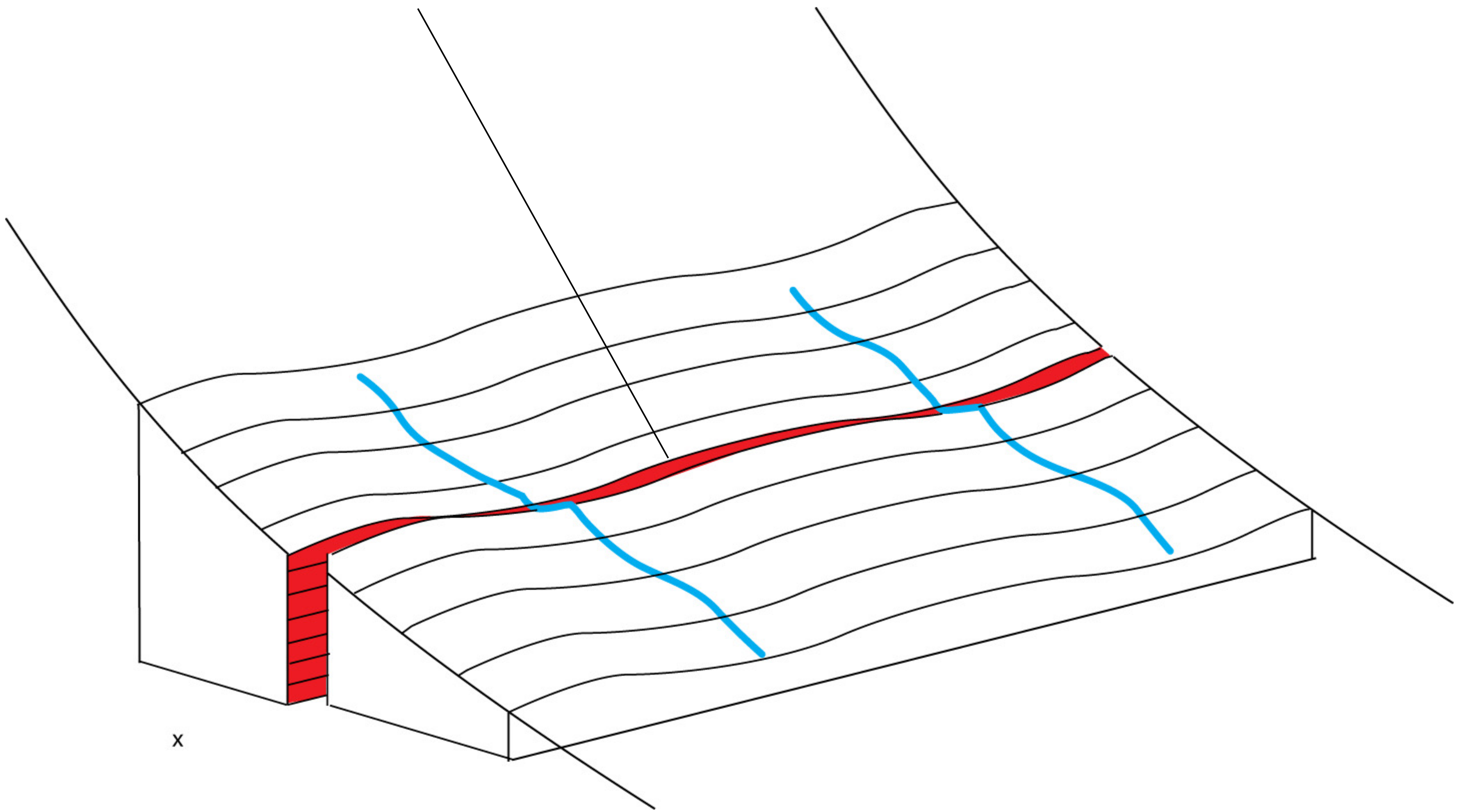


What are we left with? How has shape changed?

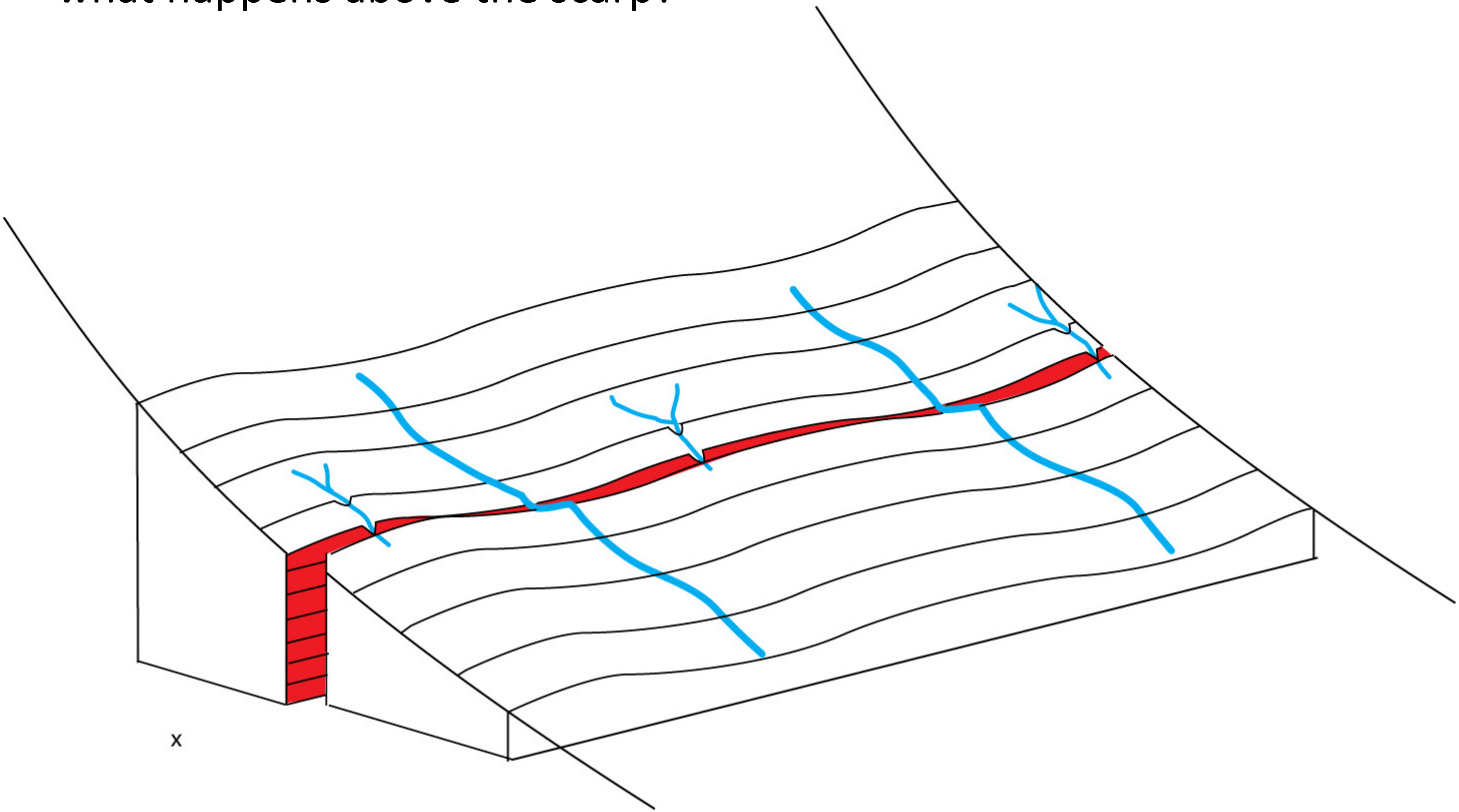
Now - let's suppose that there is also some vertical displacement - and recall idea of base-level and longitudinal stream profiles….



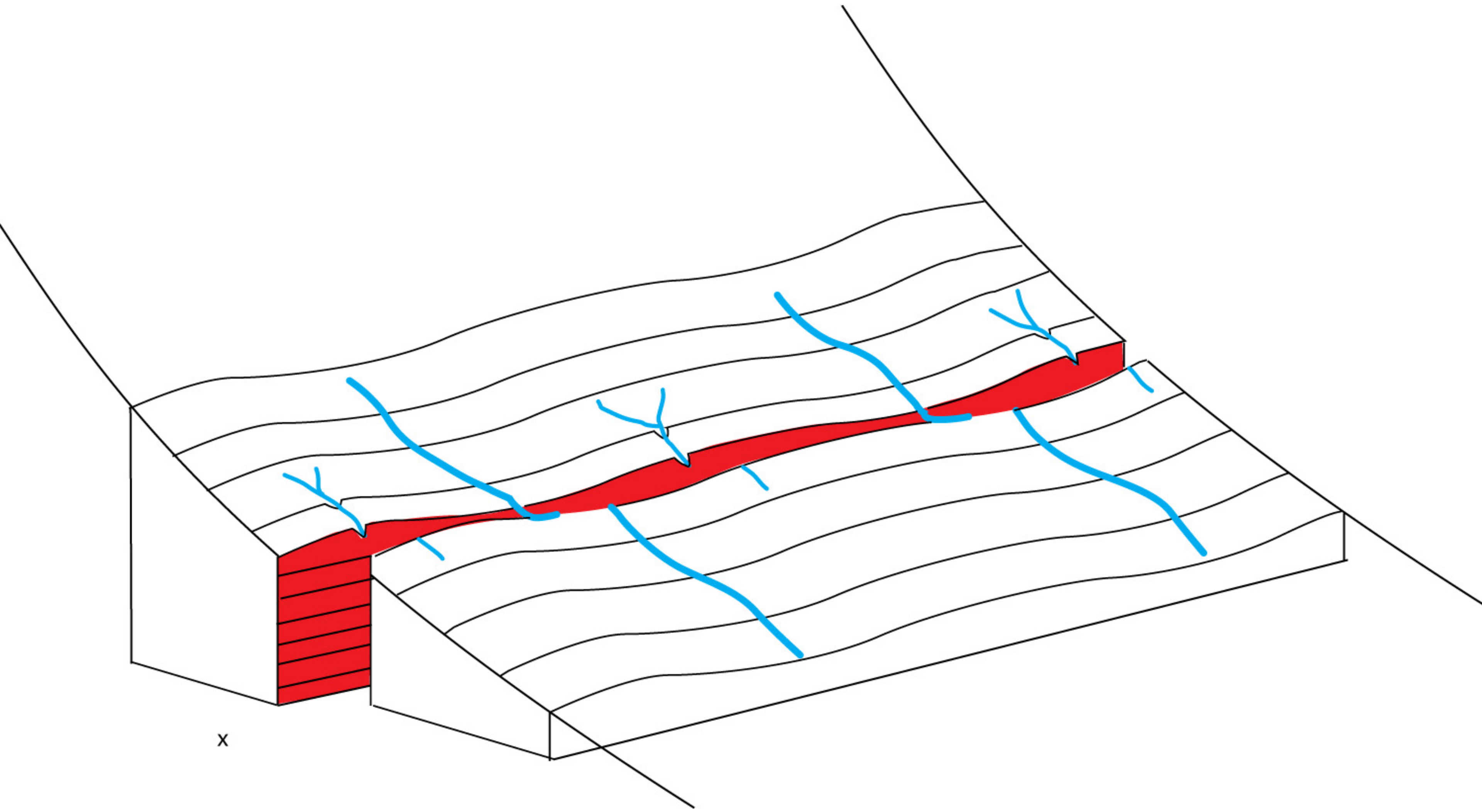
The displacement makes only scarps that face one-way in the downhill direction



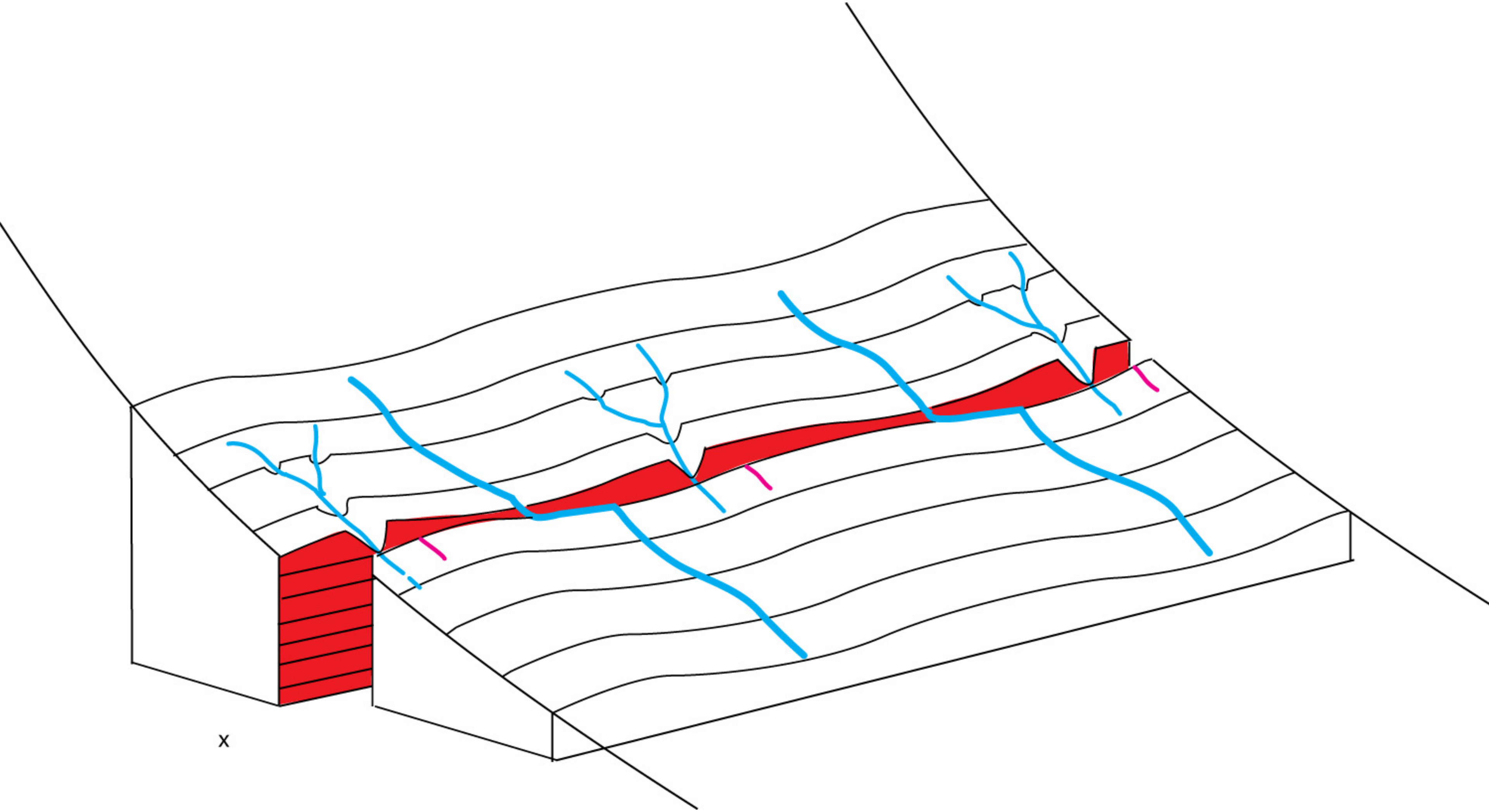
Now we add a little more rain - and what happens above the scarp?



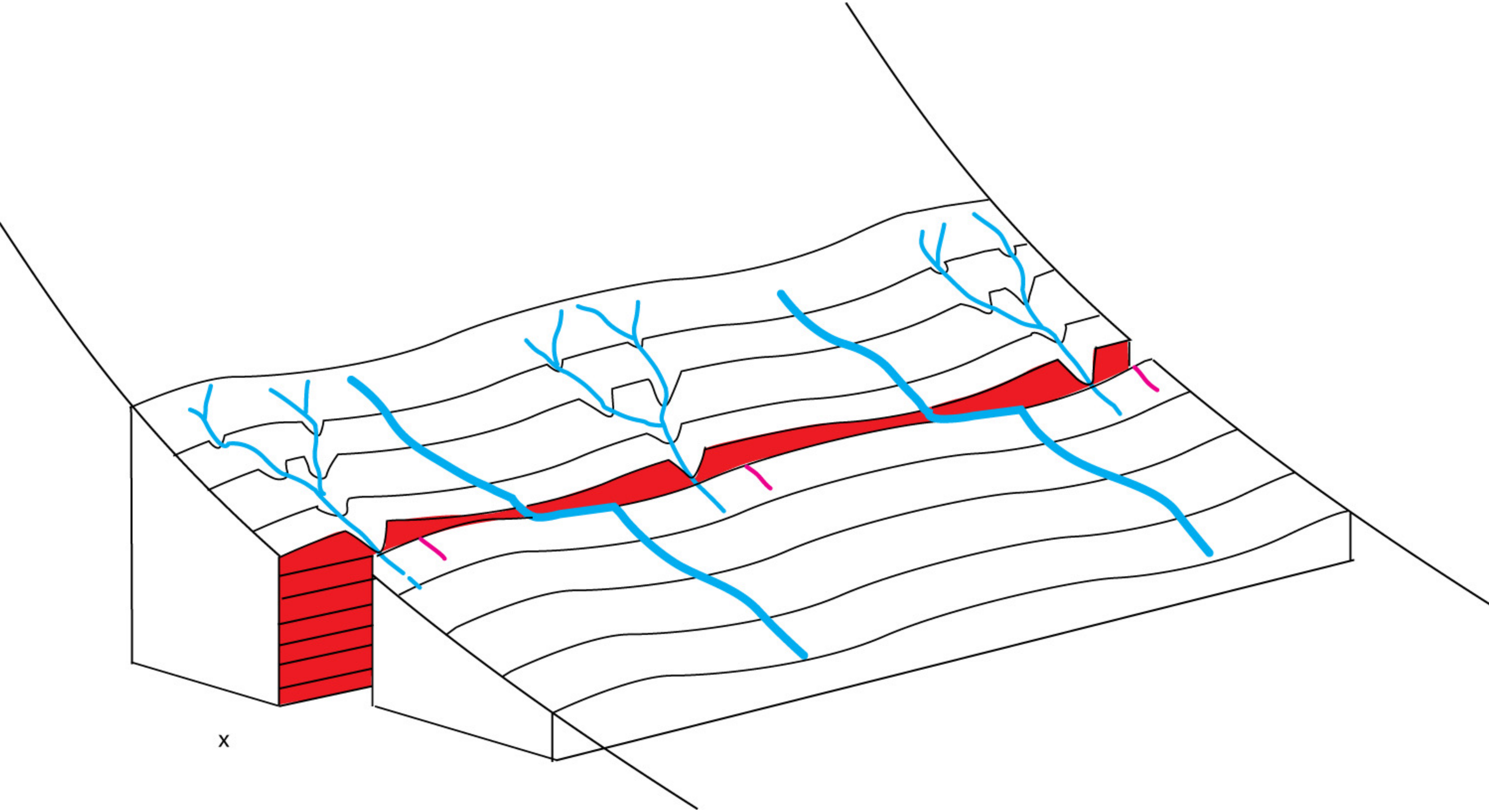
And let things slip again in an earthquake (or two- or three…



And let time pass and the processes that go with it - more rain and erosion….

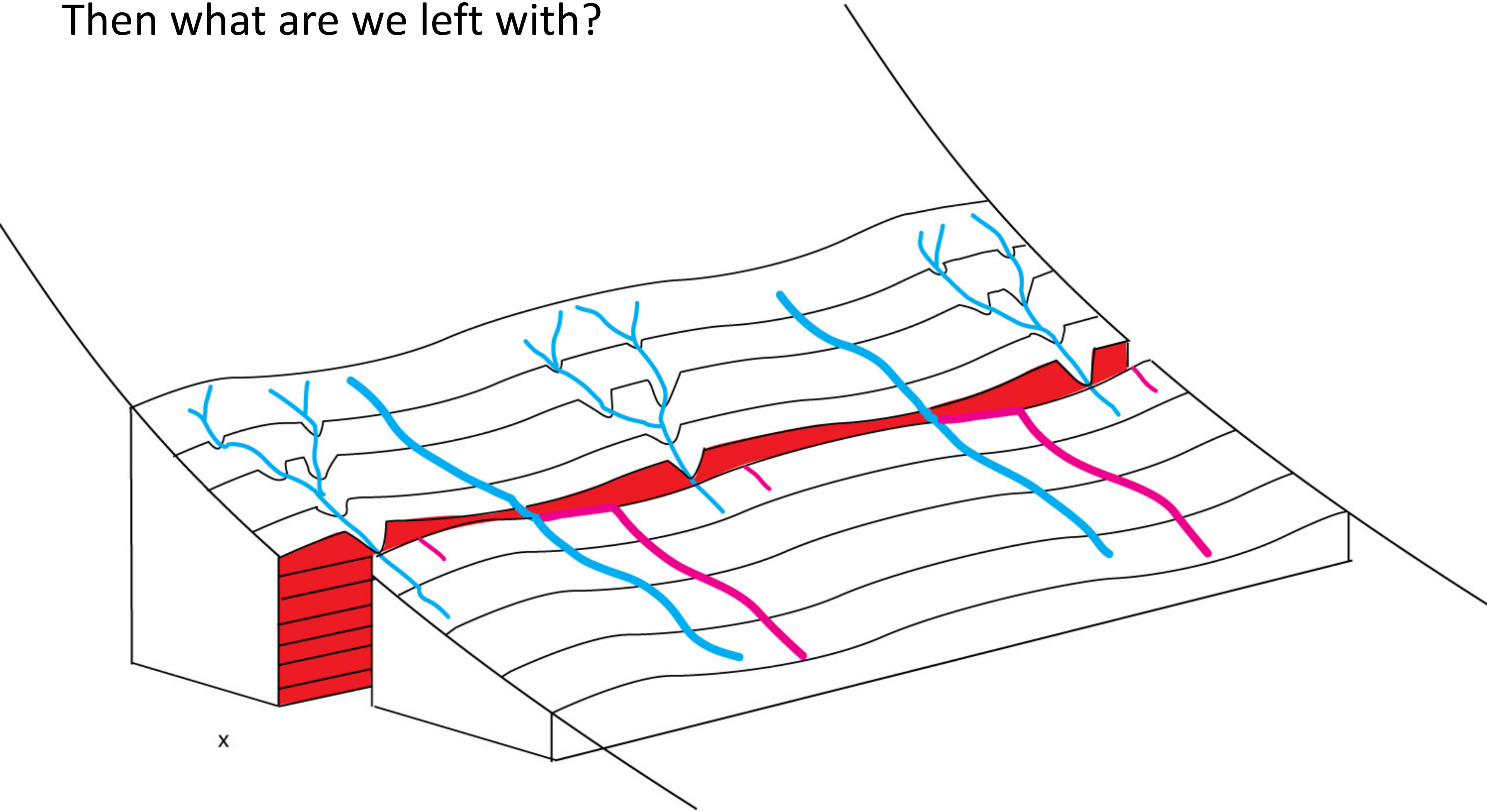


and more time...

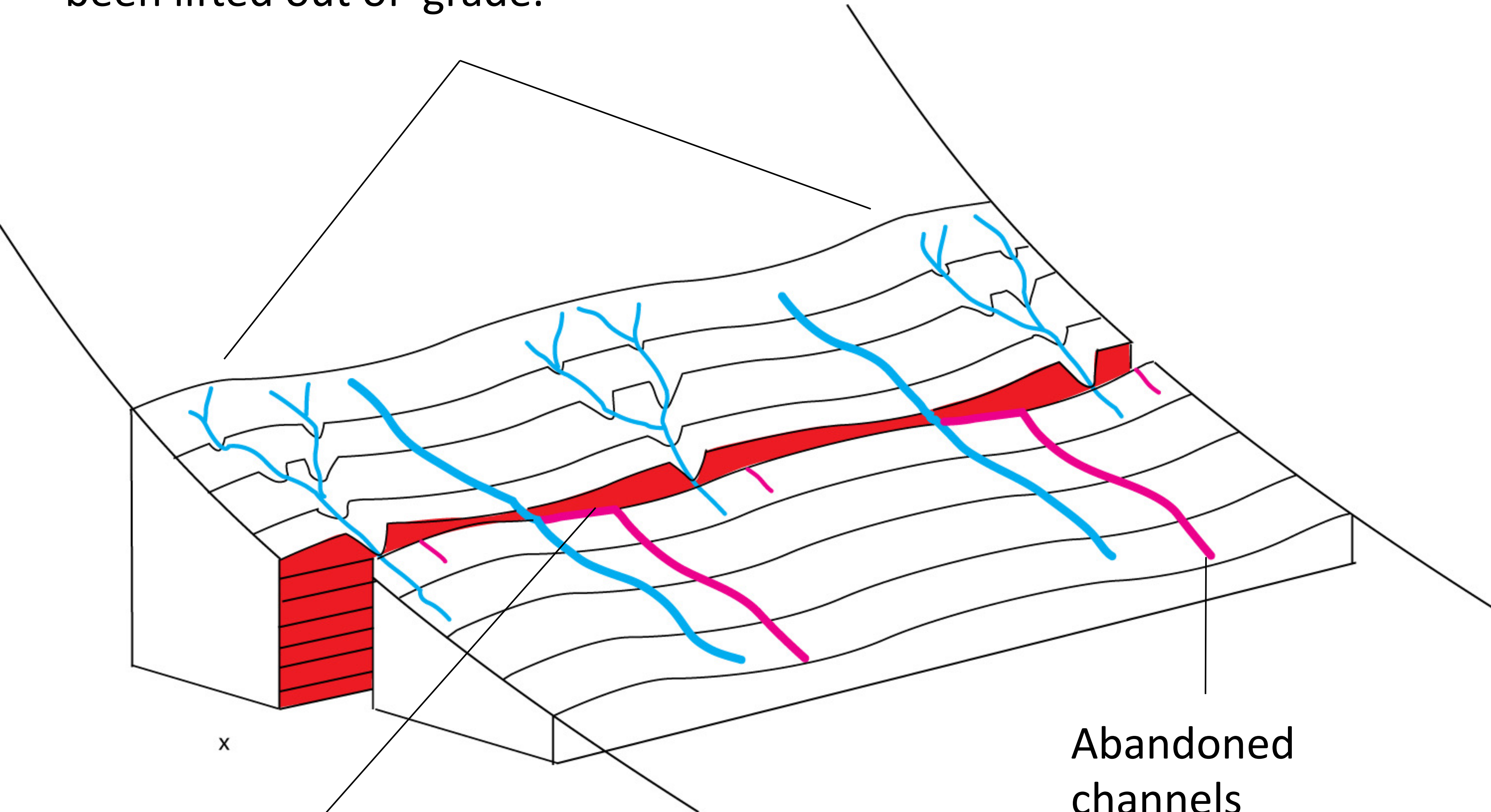


And then maybe a bigger than usual storm….

Then what are we left with?

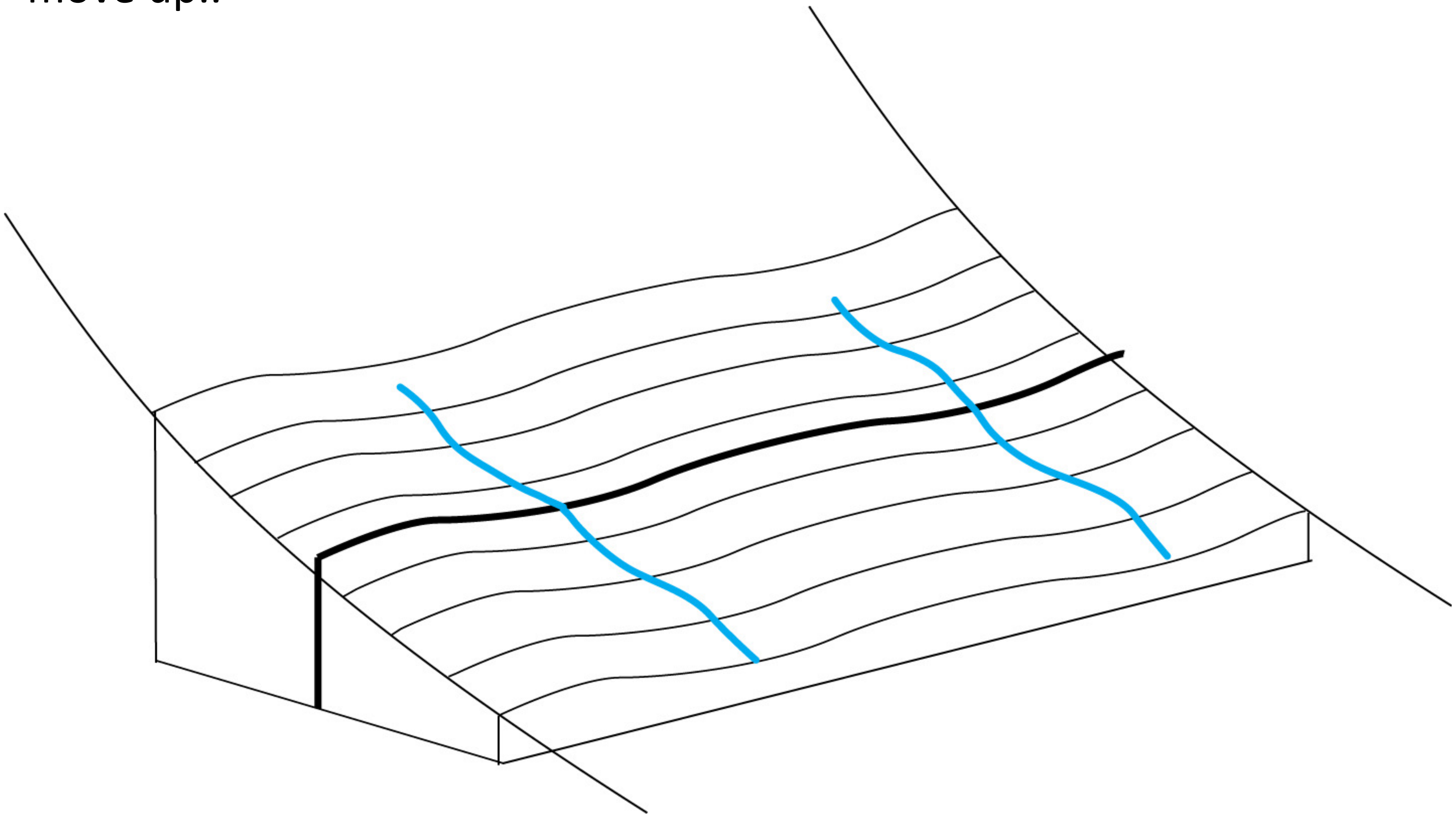


Terrain above the fault that is incised by streams where it has been lifted out of ‘grade.

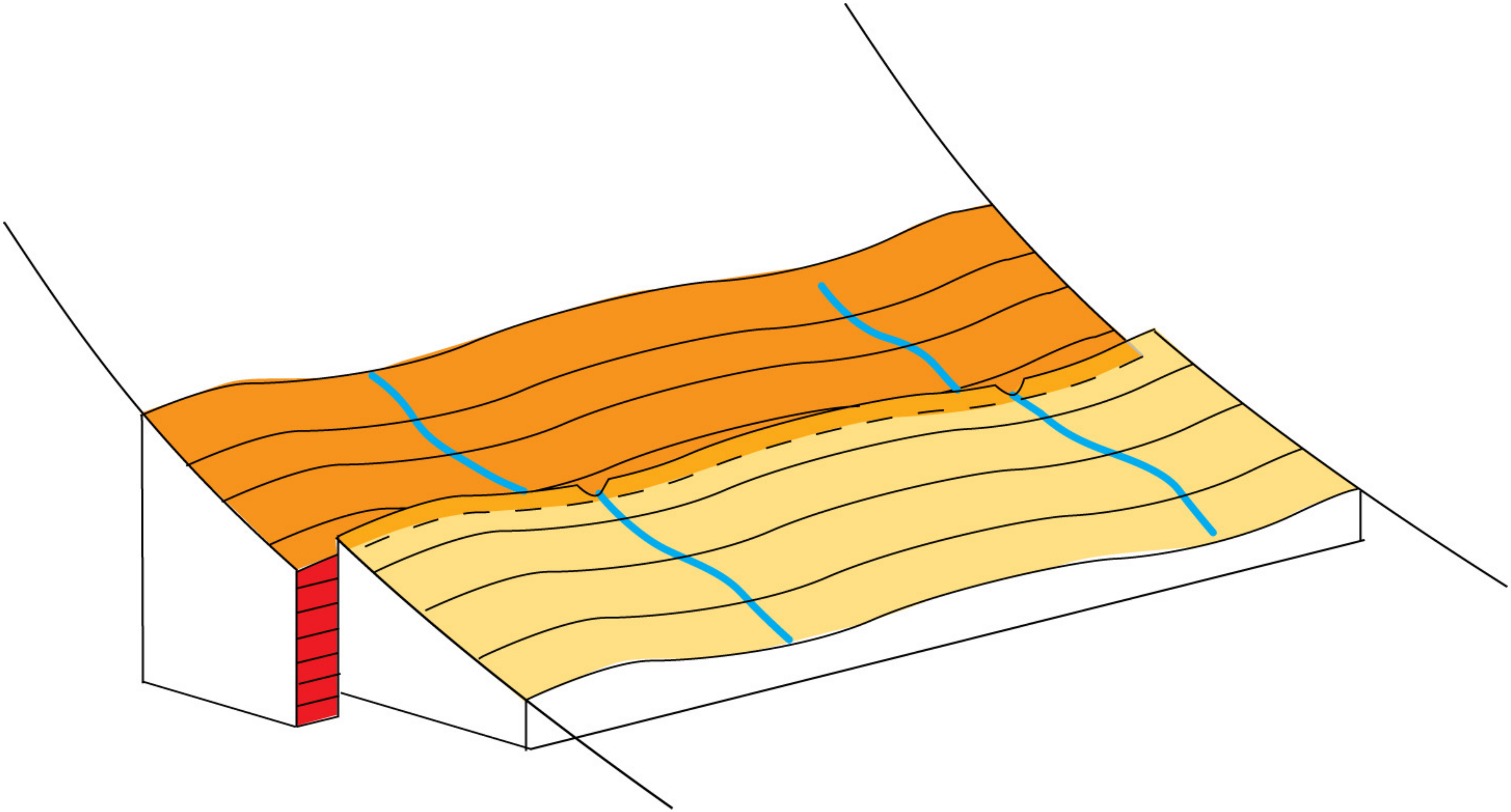


Scarps that tend to ‘face’ downhill

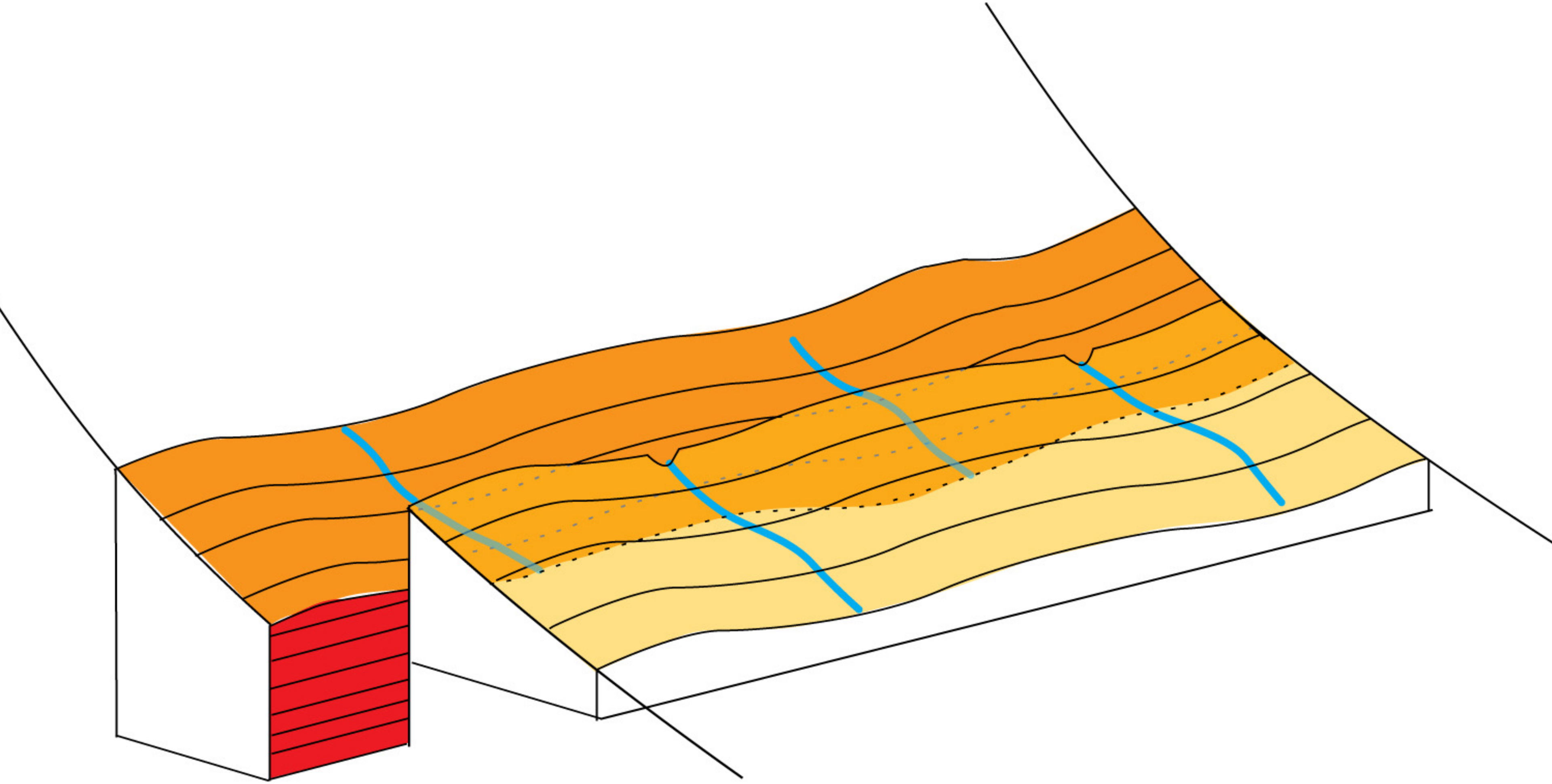
Let's start again - but let downhill side move up..



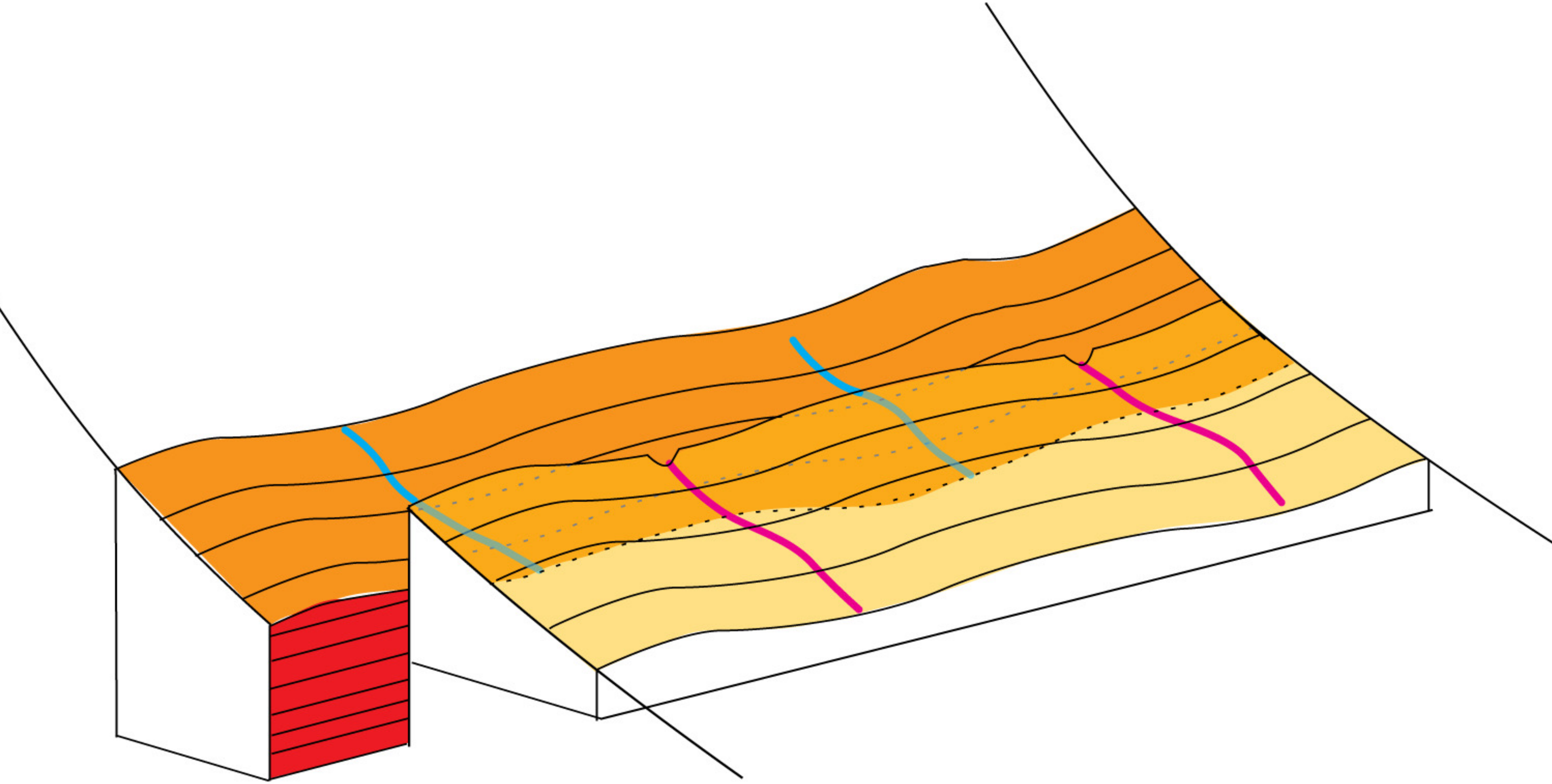
Now all scarps 'face' uphill…



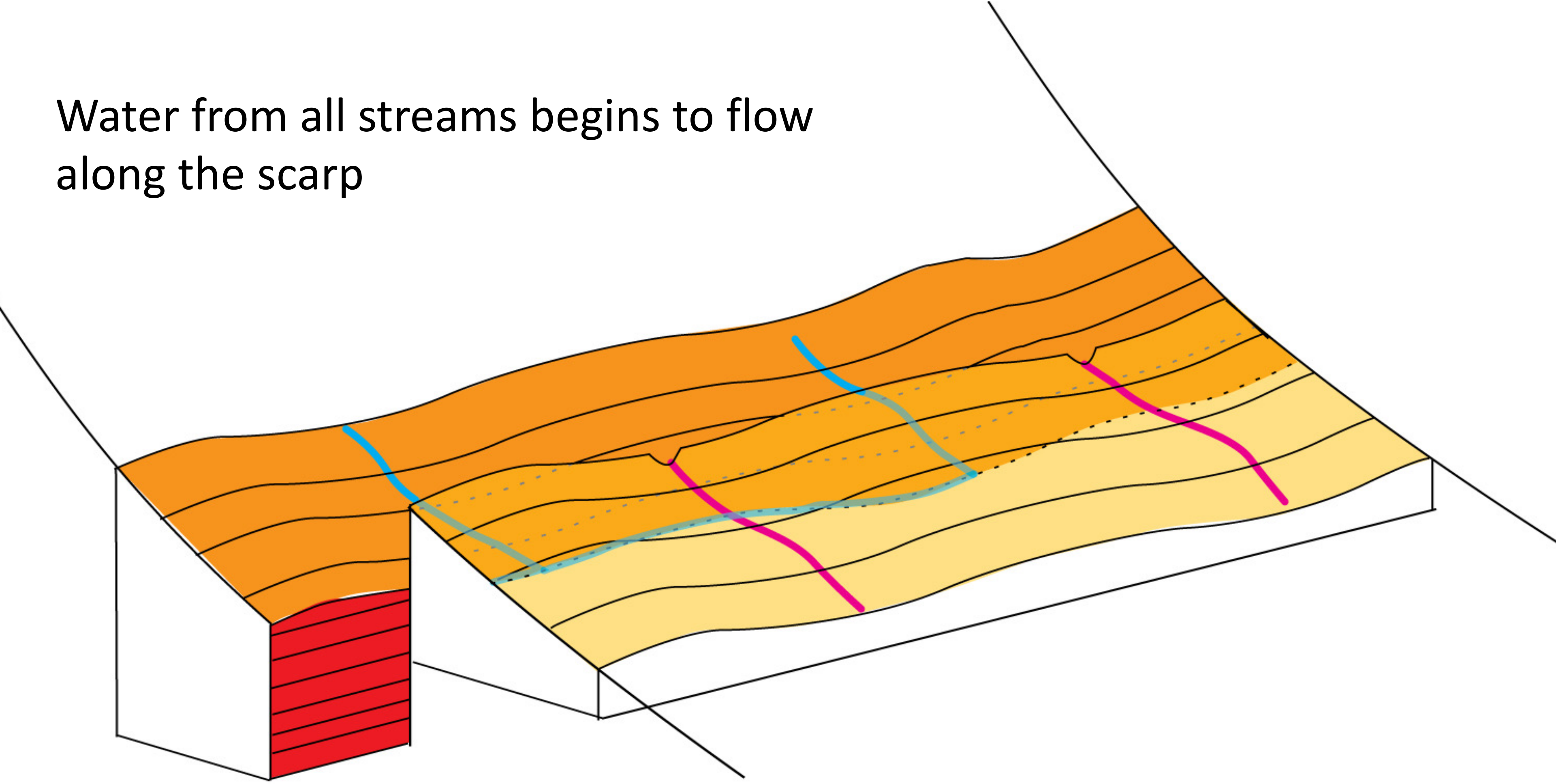
Let it slip even more …. What's gonna happen…



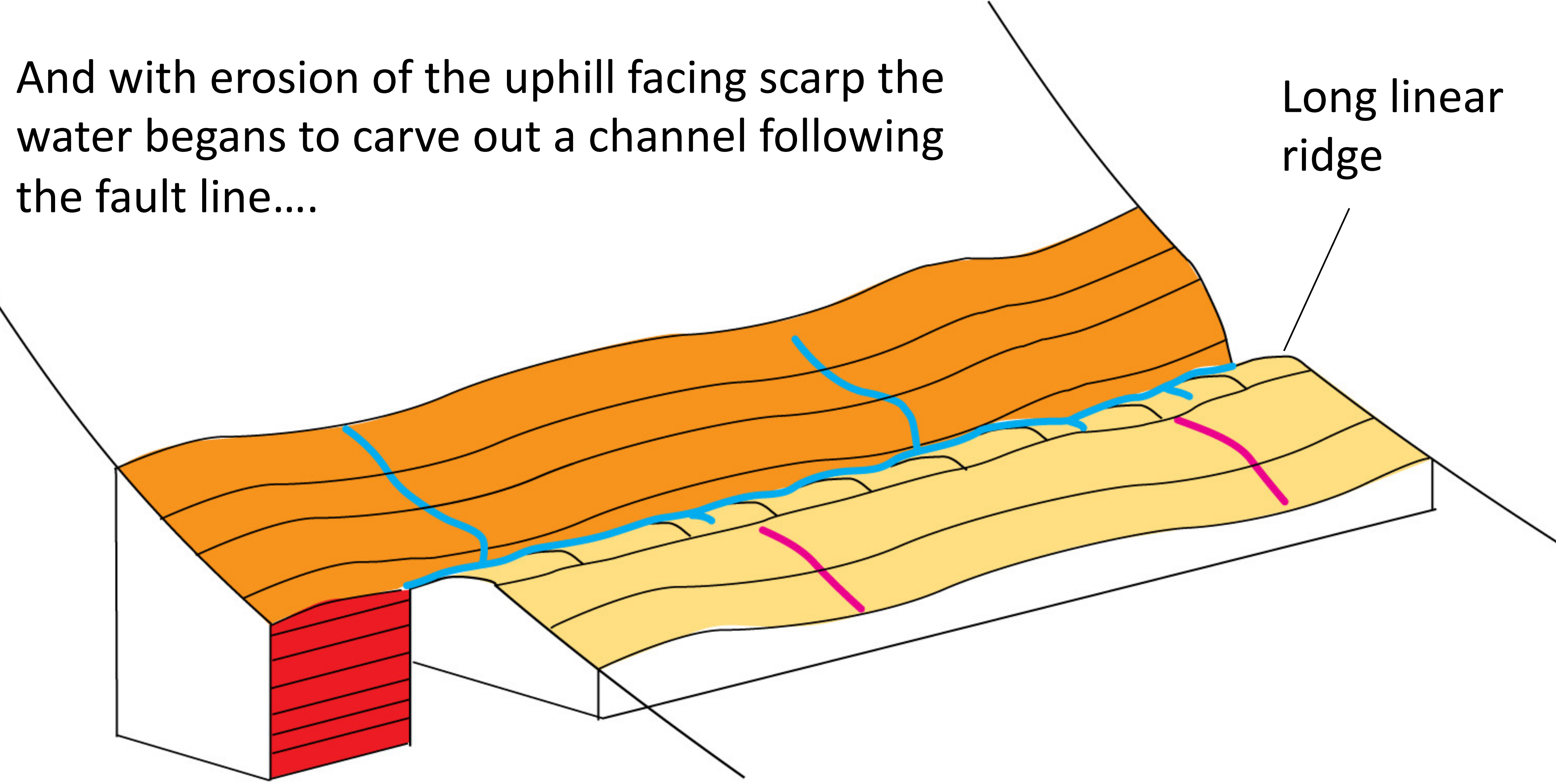
Water cannot flow past the scarp - streams on downhill side now abandoned….

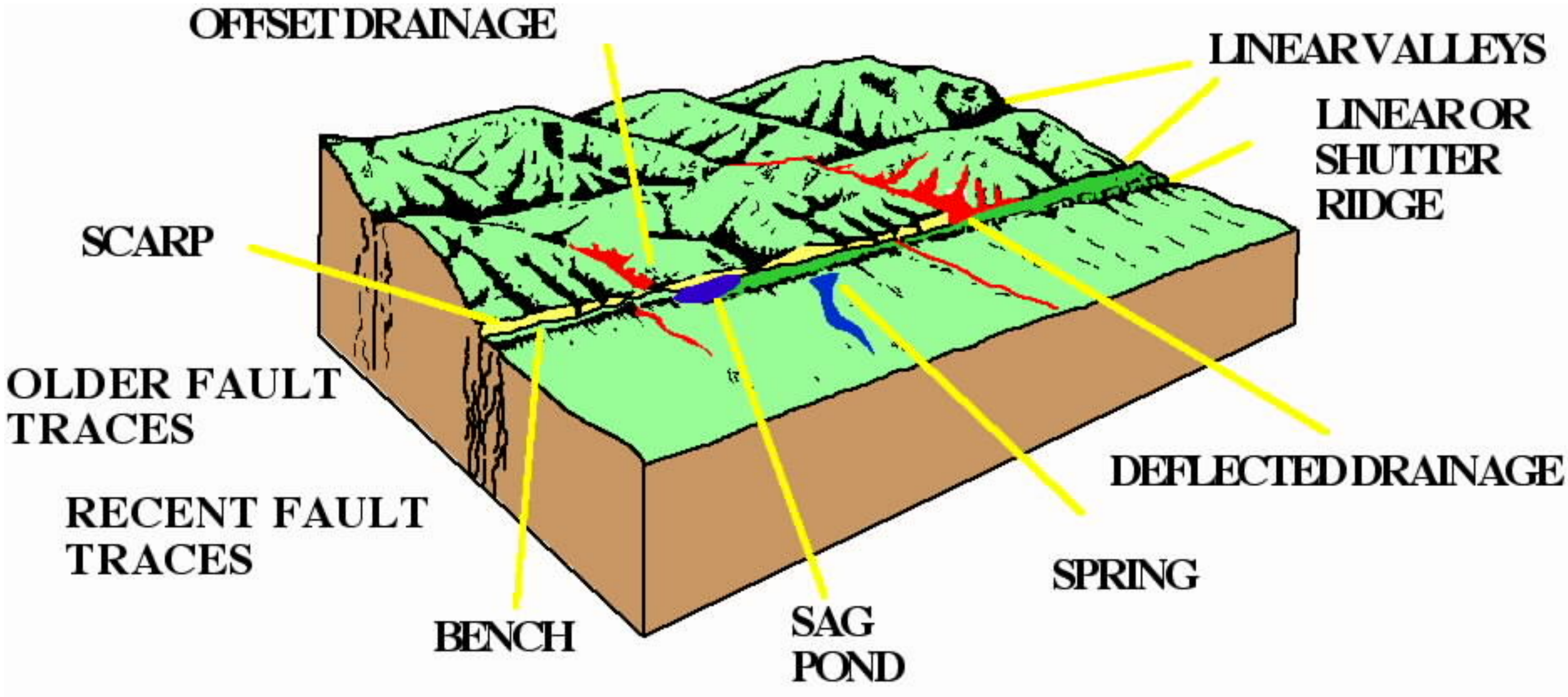


Water from all streams begins to flow along the scarp

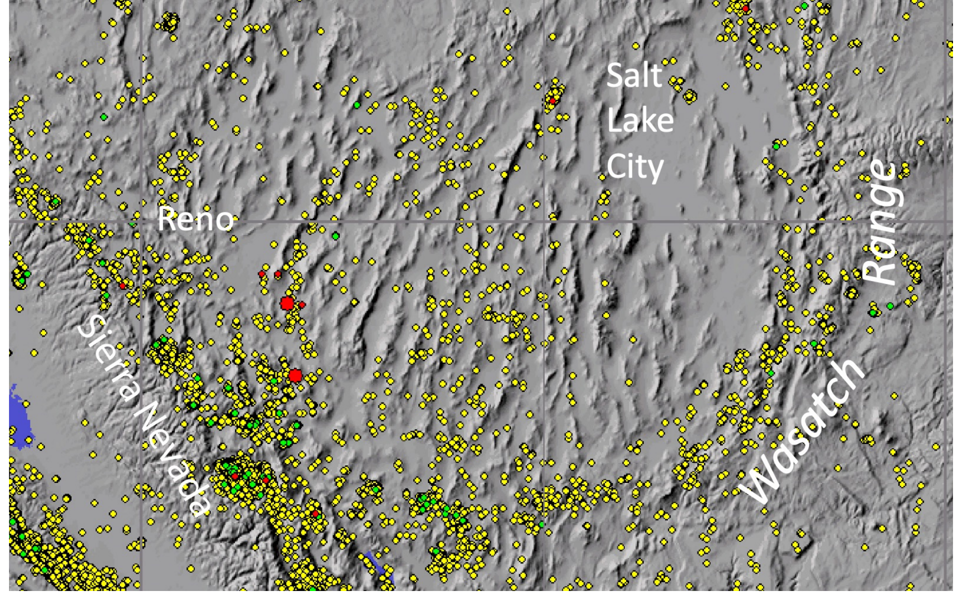


And with erosion of the uphill facing scarp the water begans to carve out a channel following the fault line….

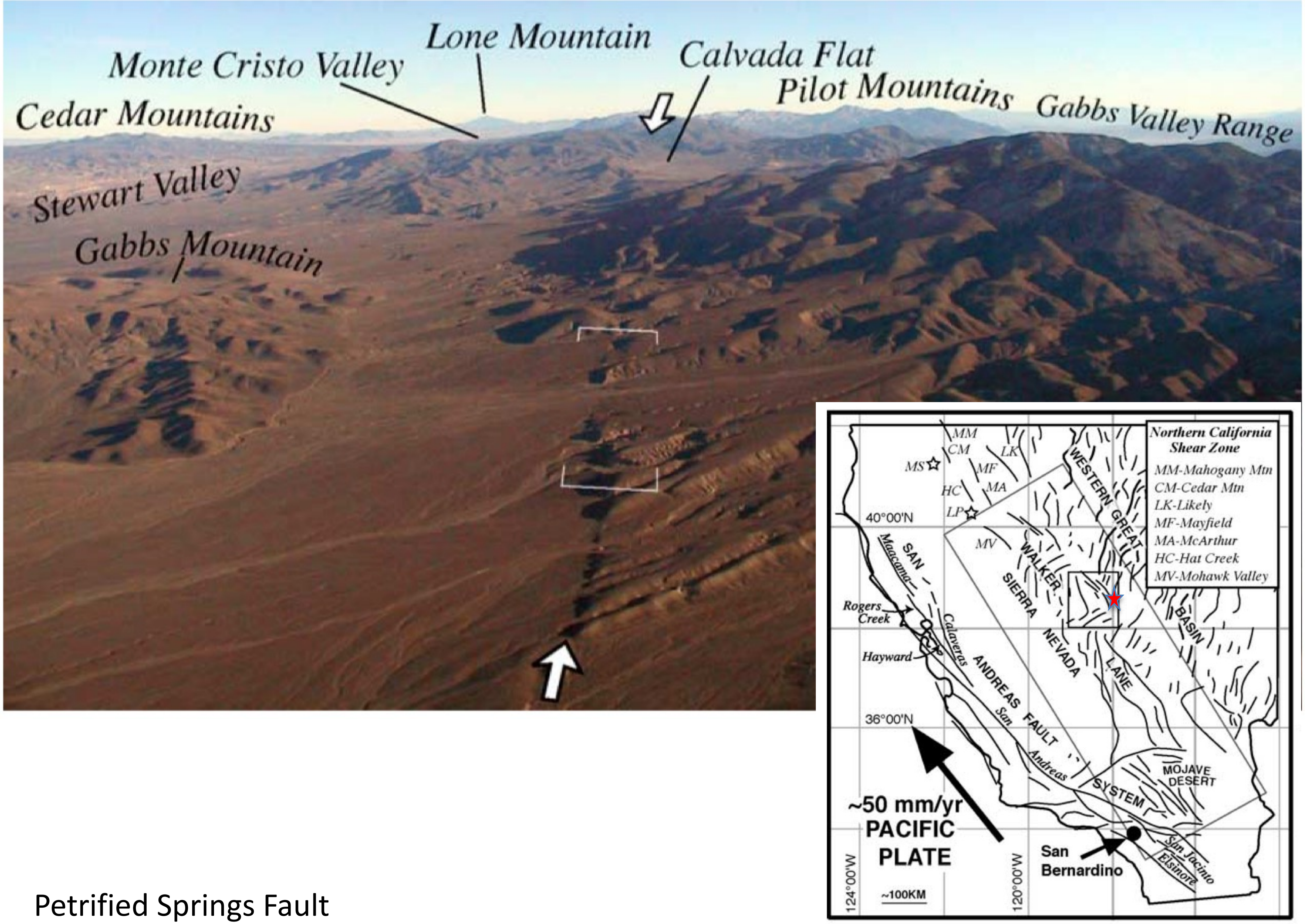




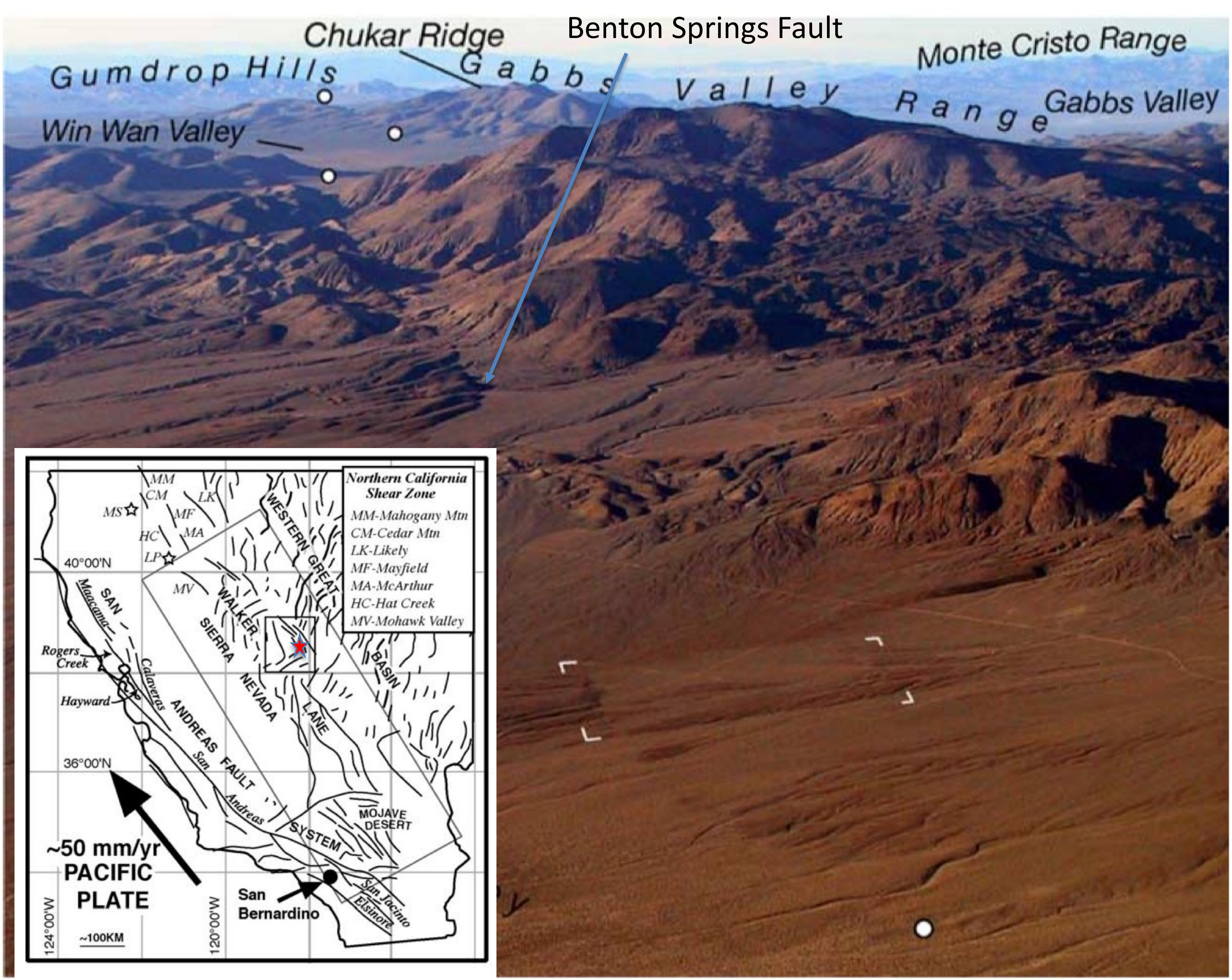
MORPHOLOGY OF STRIKE-SLIP FAULT ZONES



A morphologic and physiographic expression quite different from Basin and Range normal faulting

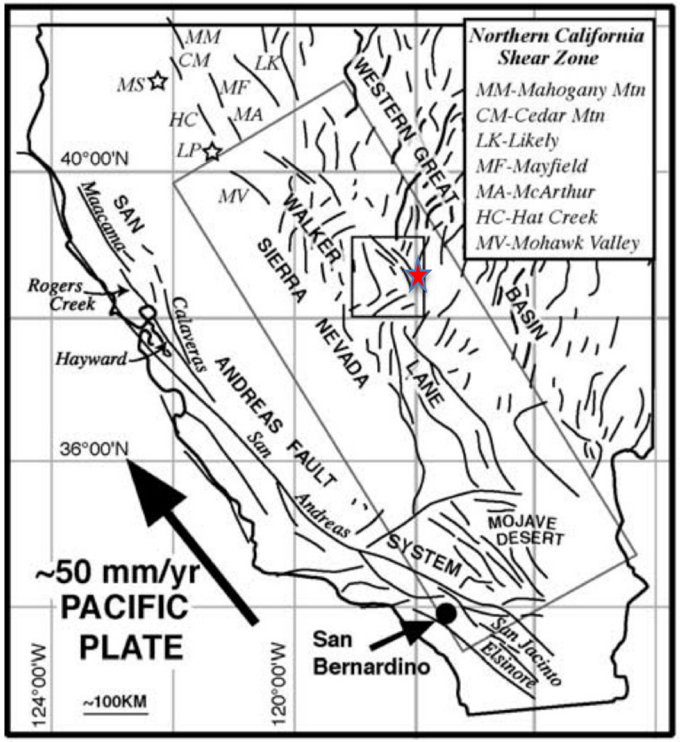


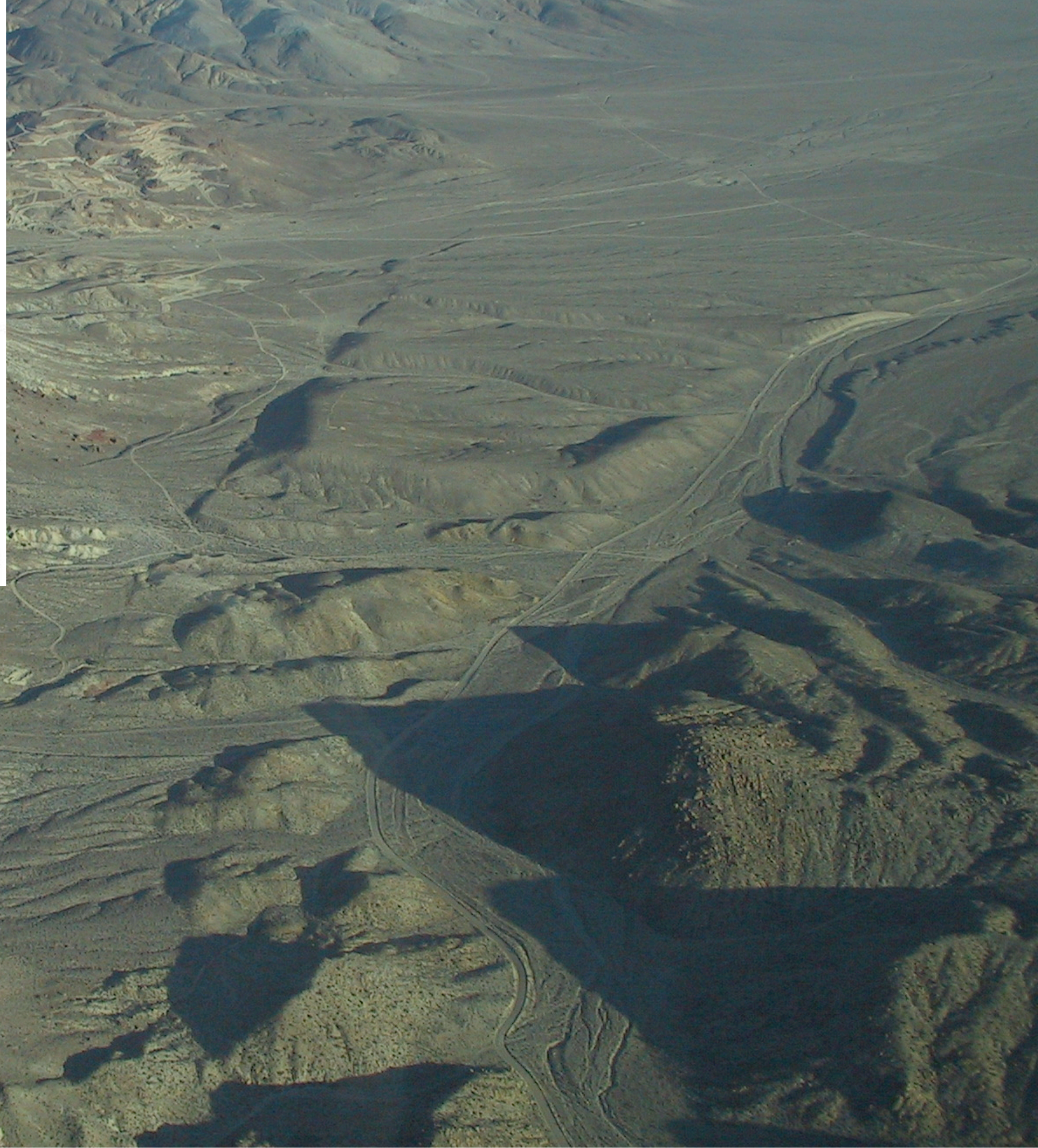
Petrified Springs Fault



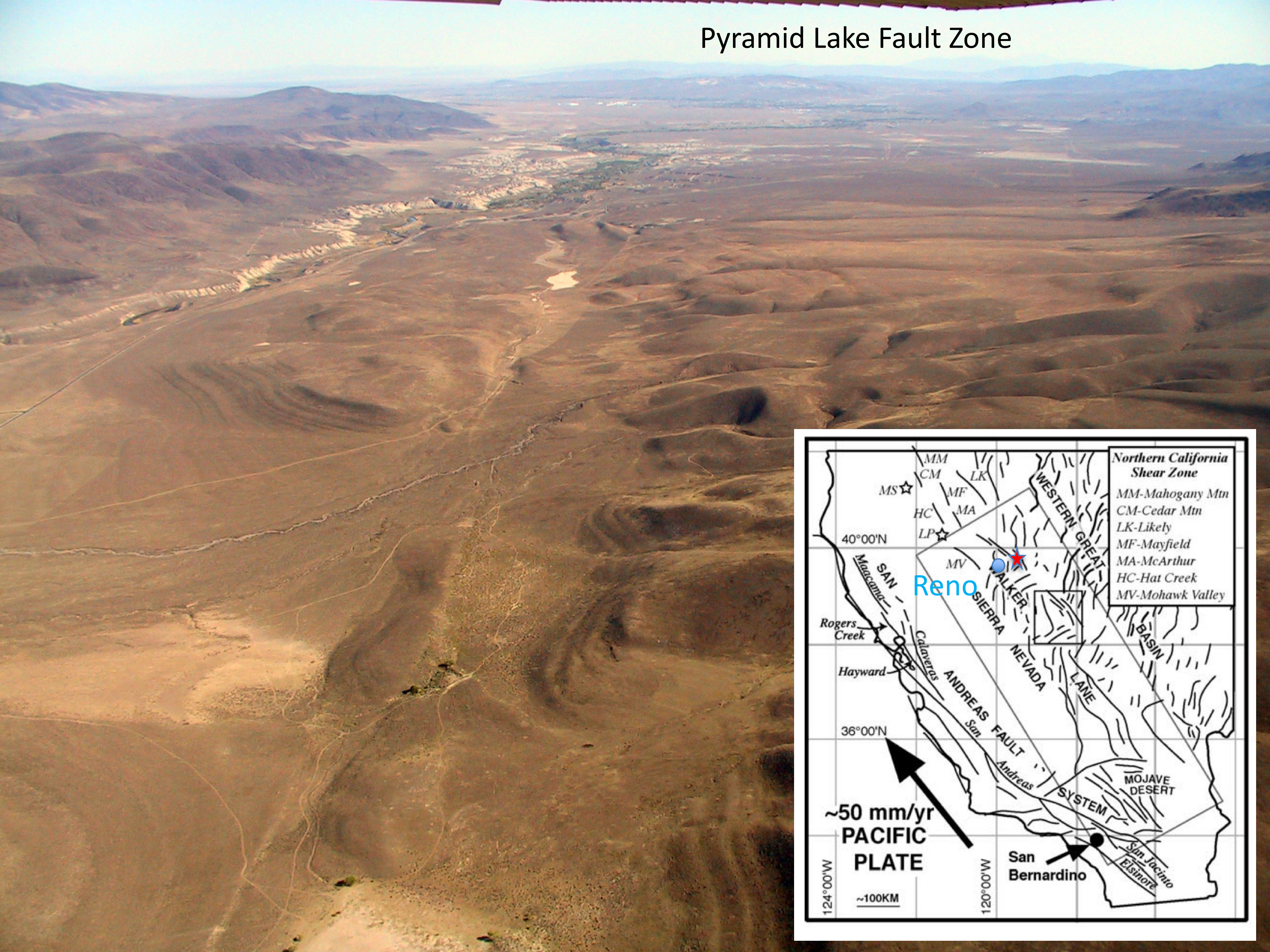
Benton Springs Fault
Chukar Ridge
Gumdrop Hills
Gabbs Valley Range
Monte Cristo Range
Gabbs Valley
Win Wan Valley
Northern California Shear Zone
MM-Mahogany Mtn
CM-Cedar Mtn
LK-Likely
MF-Mayfield
MA-McArthur
HC-Hat Creek
MV-Mohawk Valley
MM
CM
LK
MS
MF
MA
HC
LP
MV
40°00'N
36°00'N
124°00'W
120°00'W
WESTERN GREAT BASIN
WALKER LANE
SIERRA NEVADA
SAN ANDREAS FAULT SYSTEM
Maacama
Rogers Creek
Hayward
Calaveras
San Andreas
MOJAVE DESERT
San Jacinto
Elsinore
San Bernardino
~50 mm/yr
PACIFIC PLATE
~100KM

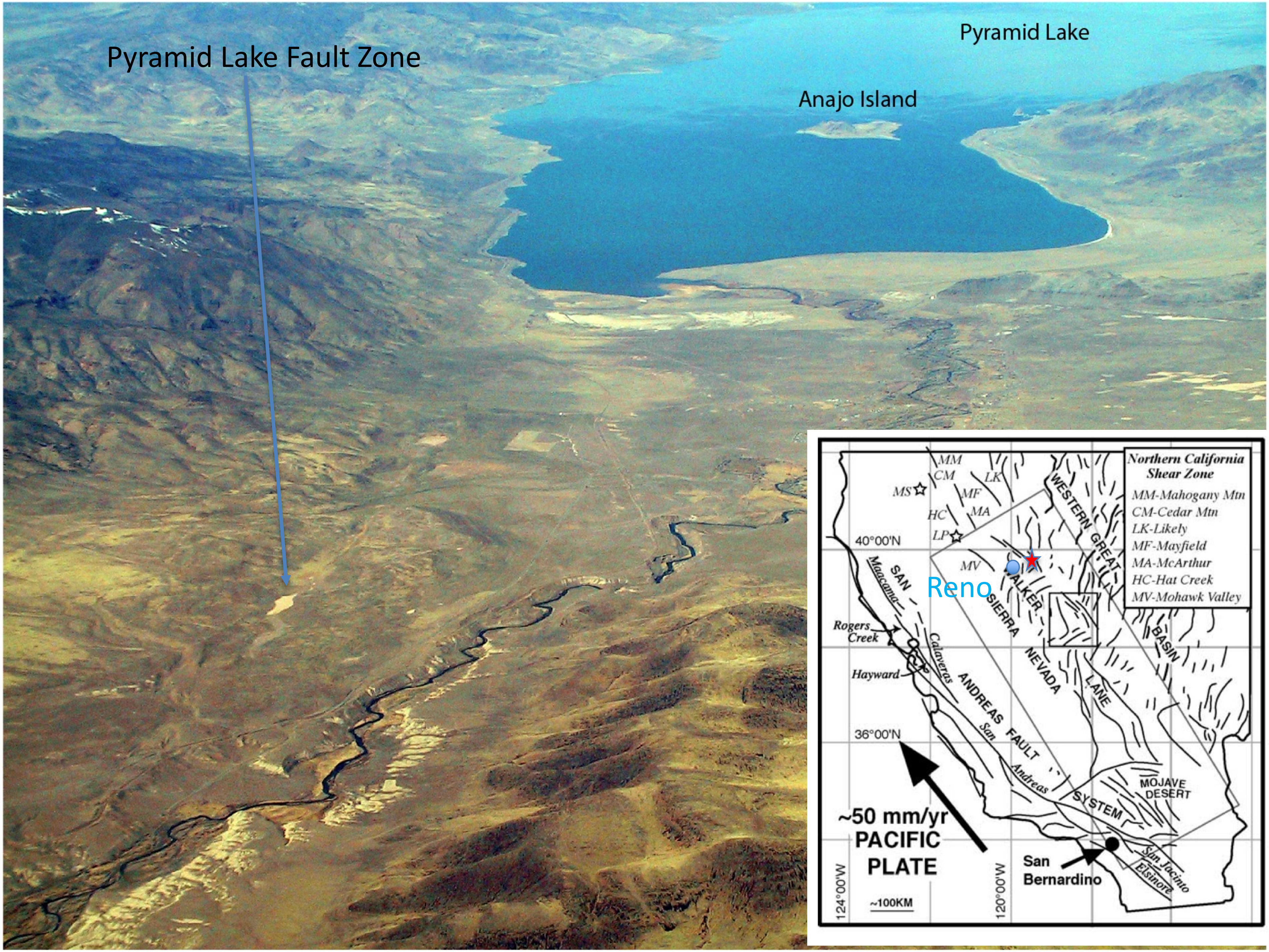
Benton Springs

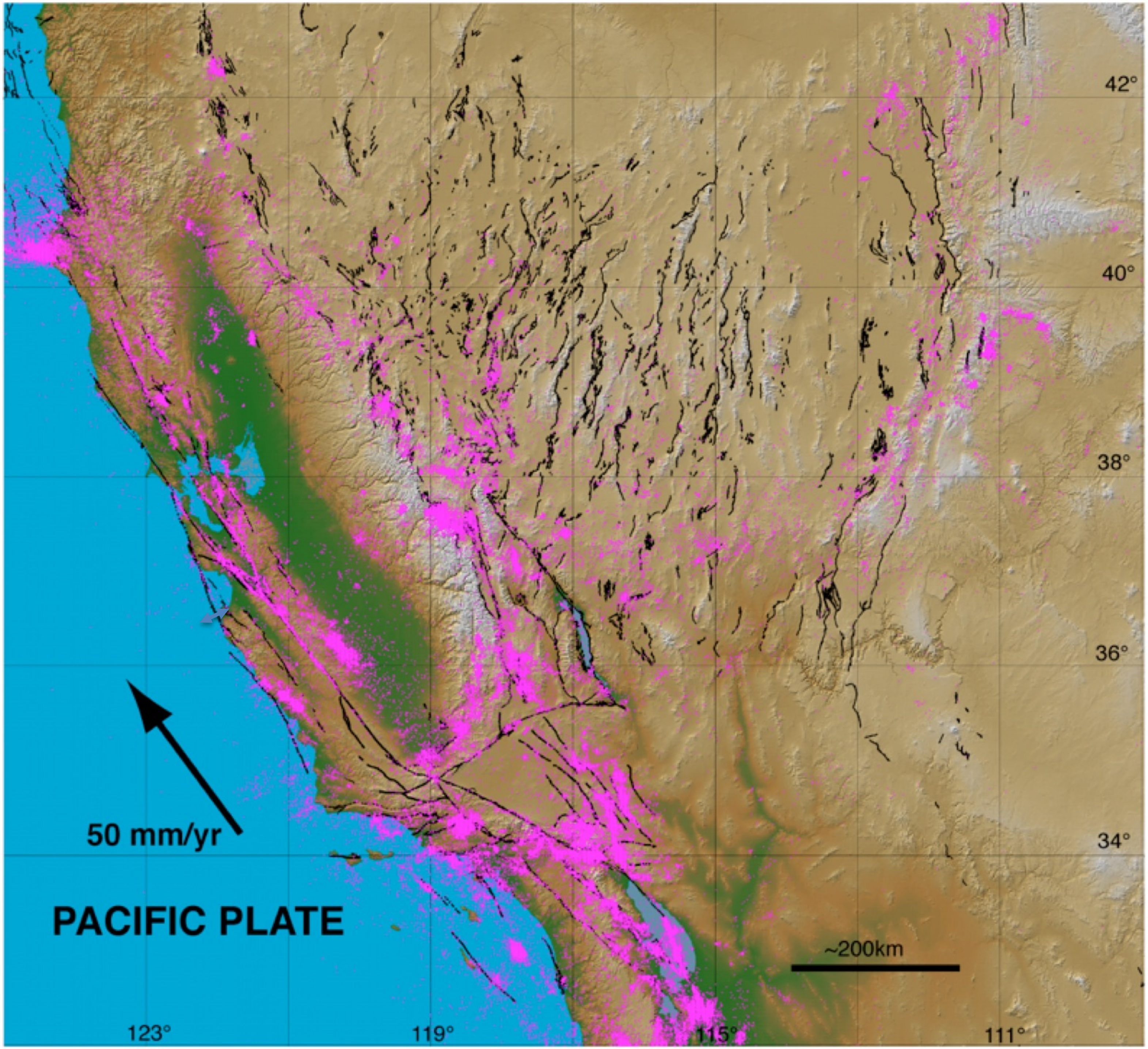




Pyramid Lake Fault Zone

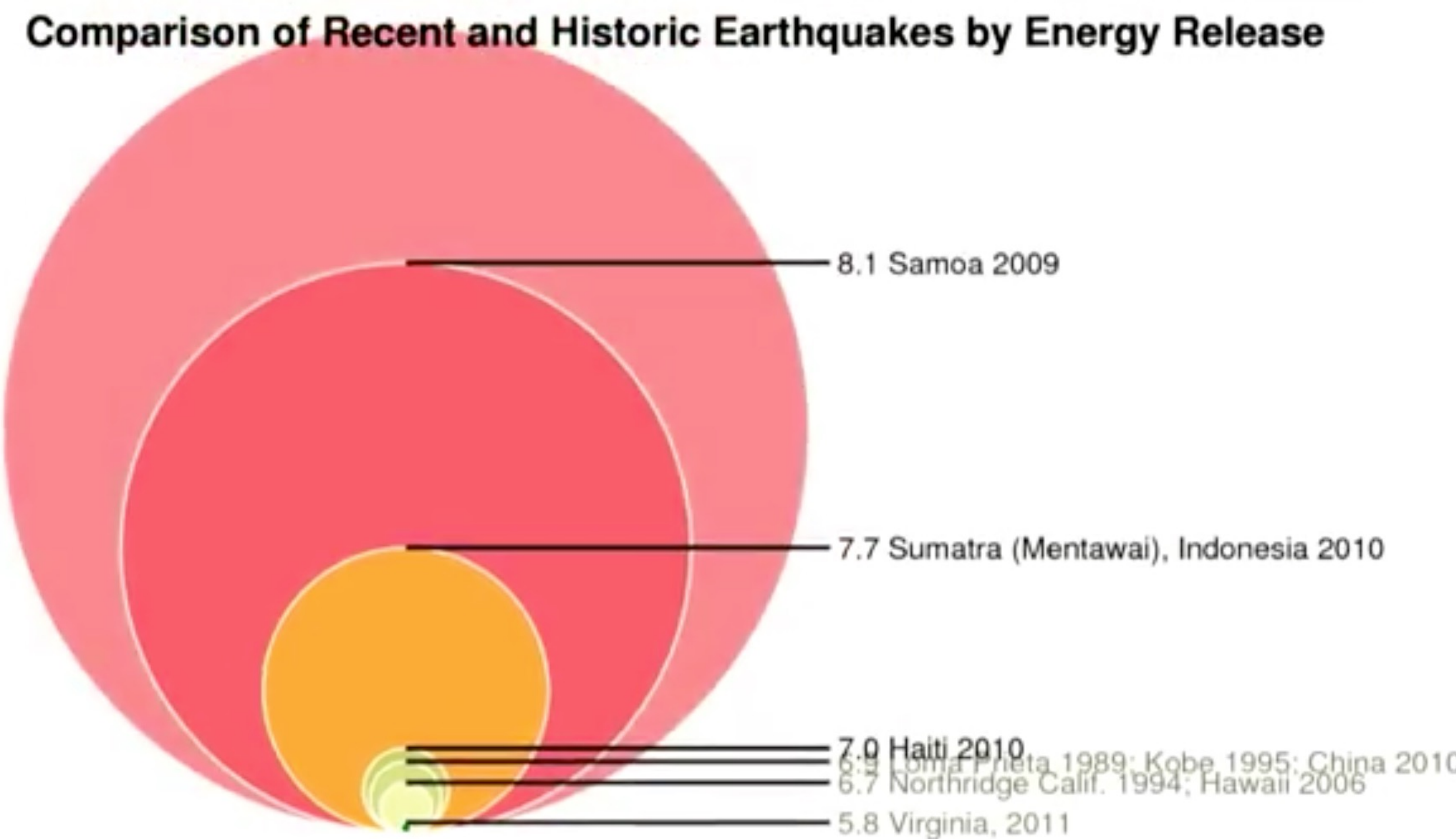


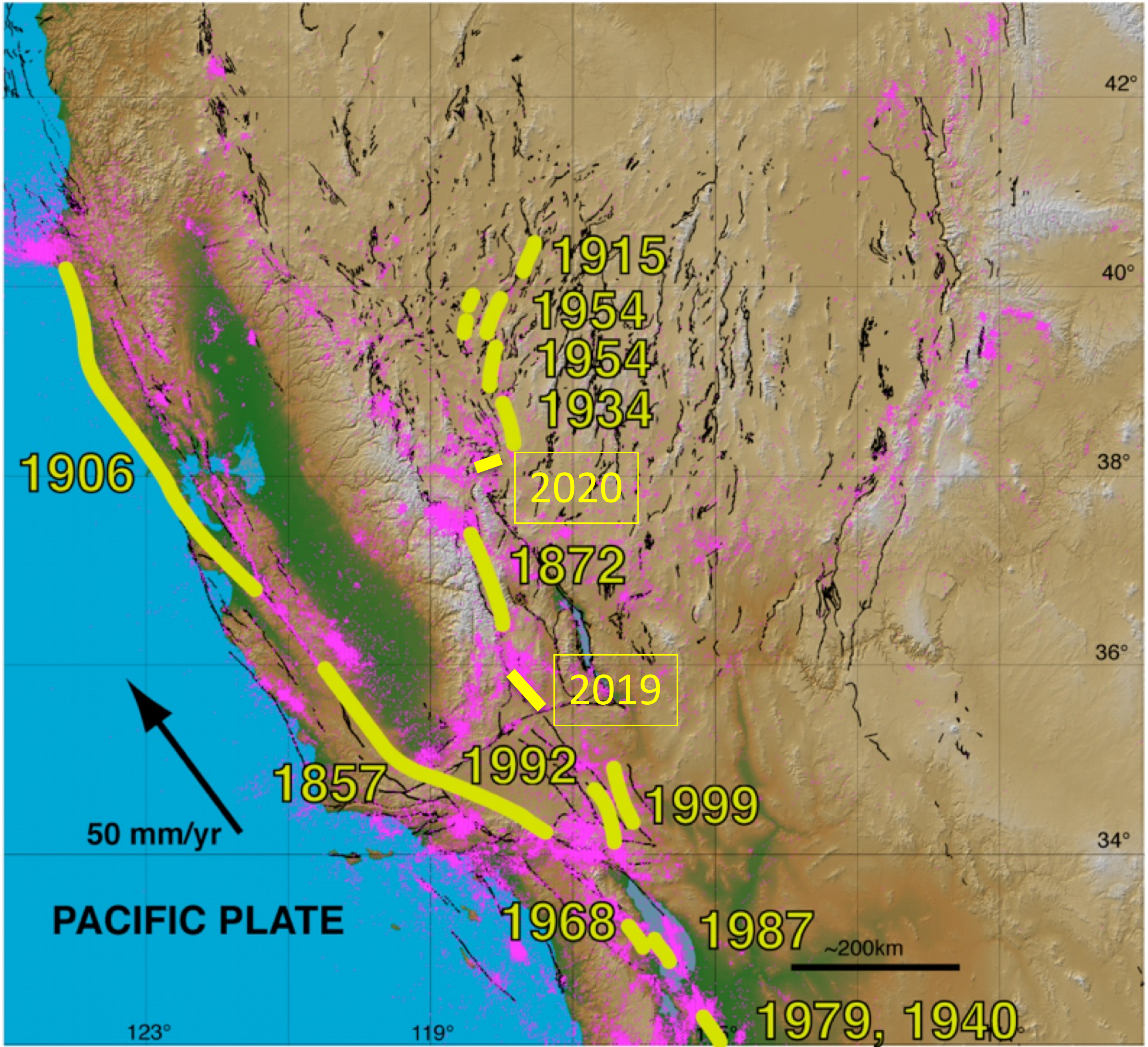

Pyramid Lake Fault Zone
Pyramid Lake
Anajo Island
Northern California Shear Zone
MM-Mahogany Mtn
CM-Cedar Mtn
LK-Likely
MF-Mayfield
MA-McArthur
HC-Hat Creek
MV-Mohawk Valley
MM
CM
LK
MS
MF
MA
HC
LP
MV
40°00'N
36°00'N
124°00'W
120°00'W
Reno
SAN ANDREAS FAULT SYSTEM
WALKER
SIERRA NEVADA
WESTERN GREAT BASIN
LANE
Maacama
Rogers Creek
Hayward
Calaveras
San Andreas
MOJAVE DESERT
San Jacinto
Elsinore
San Bernardino
~50 mm/yr
PACIFIC PLATE
~100KM



So that's where the black lines come from....

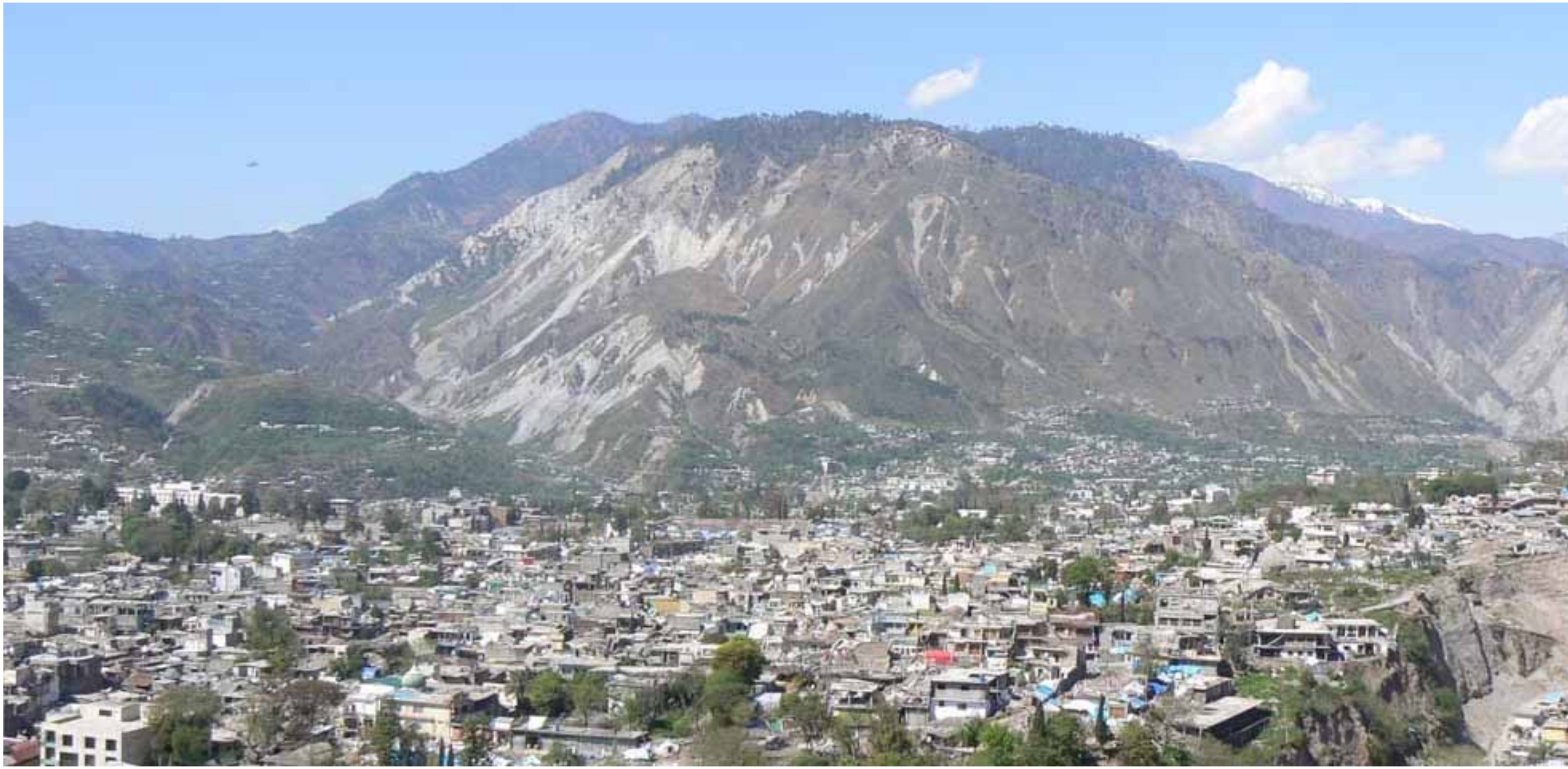
The little earthquakes do not accommodate much deformation relative to larger…





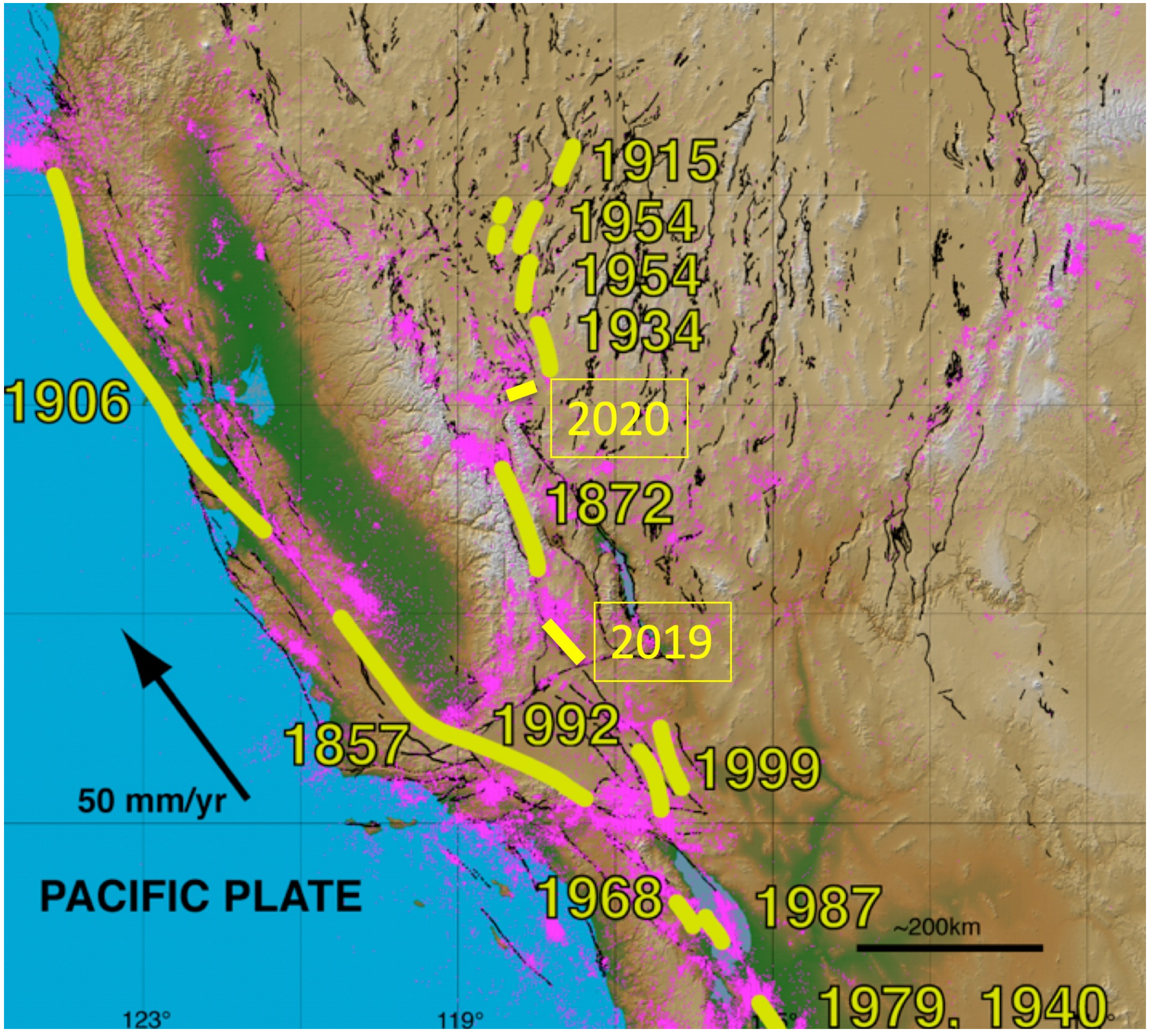
1915
1954
1954
1934
2020
1906
1872
2019
1992
1857
1999
50 mm/yr
PACIFIC PLATE
1968
1987
~200km
1979, 1940
42°
40°
38°
36°
34°
123°
119°

Balakot after the earthquake



Muzaffarabad town after the earthquake

The geomorphic expression of large earthquake ruptures is also clear – and it is from that the yellow lines denoting location of earthquakes arises



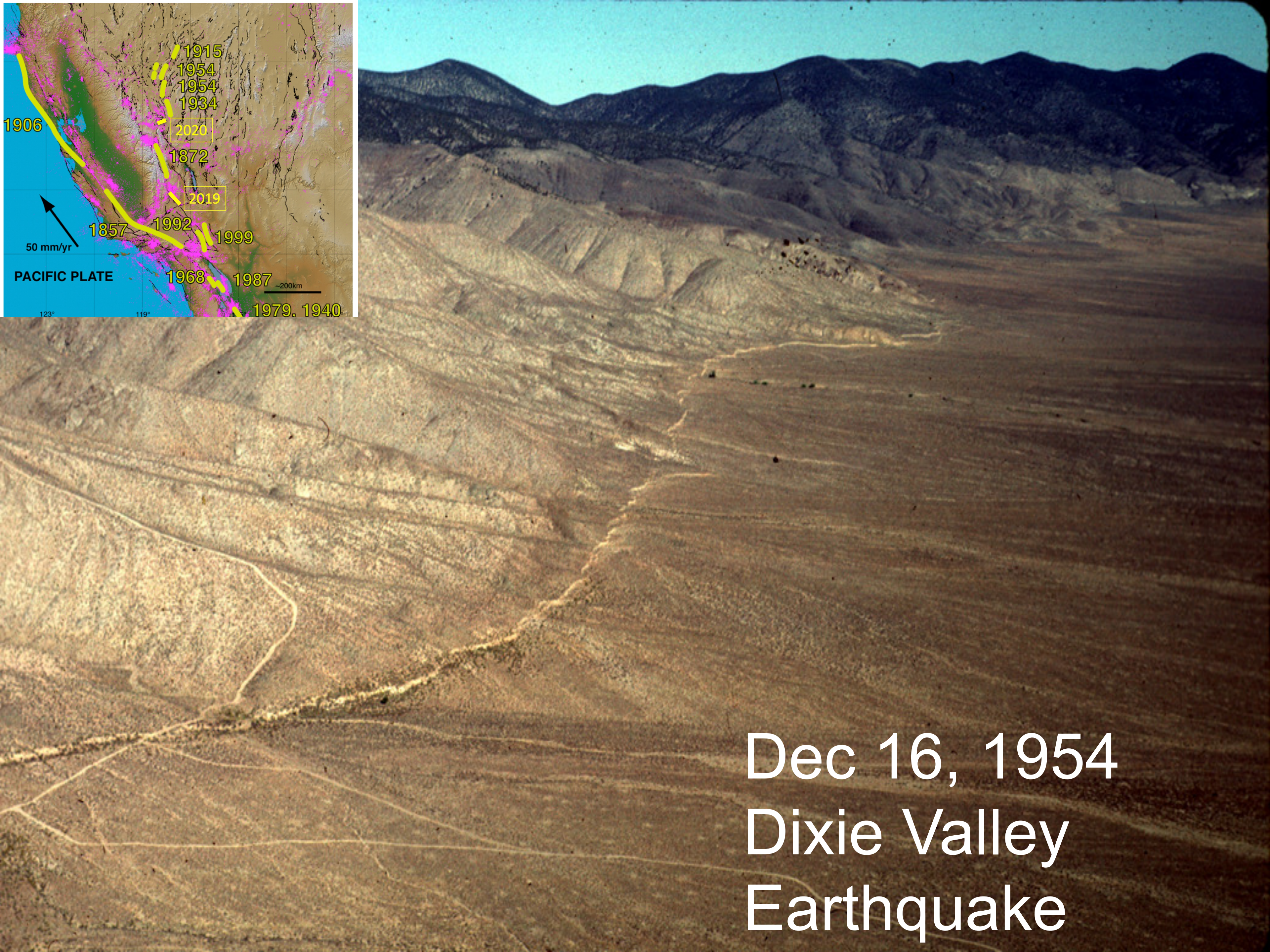
1857 San Andreas

Oct 16, 1999
Hector Mine


Nov 23, 1987
Superstition Hills
1915
1954
1954
1934
2020
906
1872
2019
1857
1992
1999
50 mm/yr
PACIFIC PLATE
1968
1987
~200km
1979, 1940
123°
119°

July 5, 2019
Ridgecrest


1915
1954
1954
1934
1906
2020
1872
2019
1857
1992
1999
50 mm/yr
PACIFIC PLATE
1968
1987
~200km
1979, 1940
123°
119°

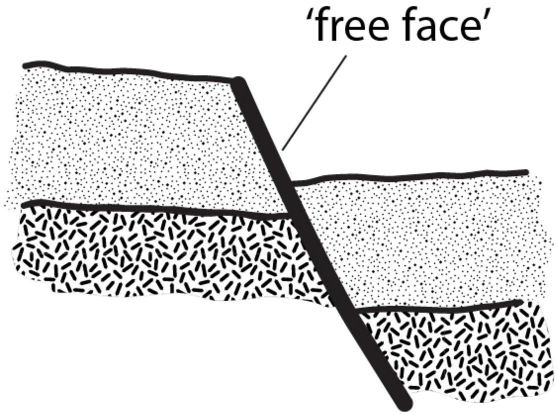

1915
1954
1954
1934
2020
1906
1872
2019
1992
1857
1999
50 mm/yr
PACIFIC PLATE
1968
1987
~200km
1979, 1940
123°
119°
Dec 16, 1954
Dixie Valley
Earthquake

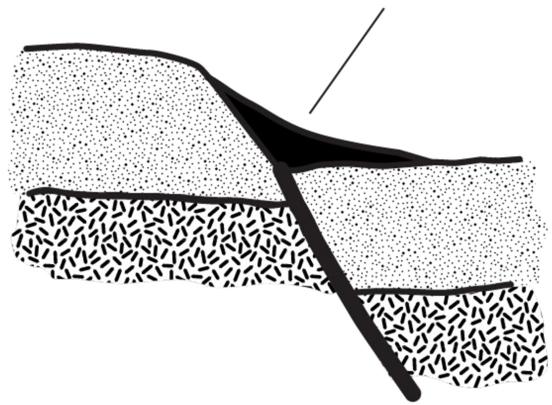
Dec 16, 1954 Dixie Valley Earthquake


GMC
CASE
Trench

Single Event Scarp

Displacement → Erosion of Scarp Crest and Creation of Wedge of Colluvium



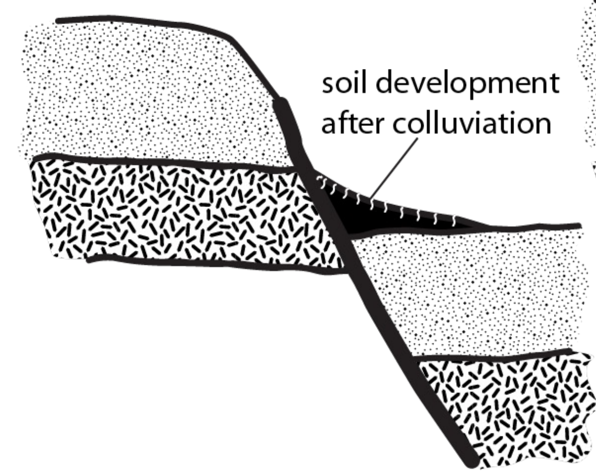


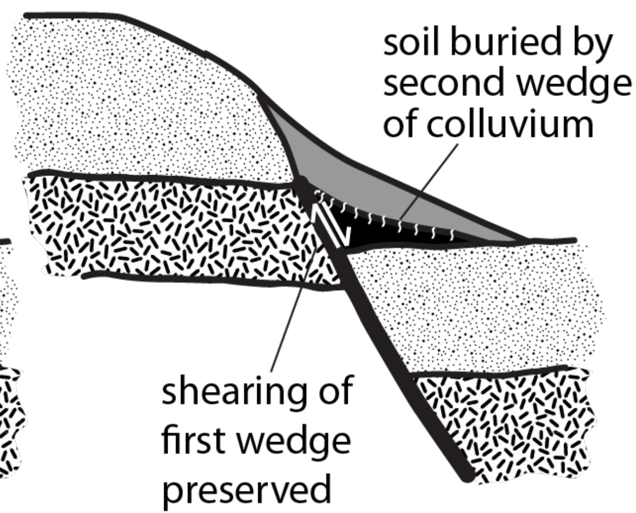
Multiple Event Scarp

2nd Displacement
Shears 1st Wedge of Colluvium
Creates New Free Face Steeper
Than Older Eroded Scarp

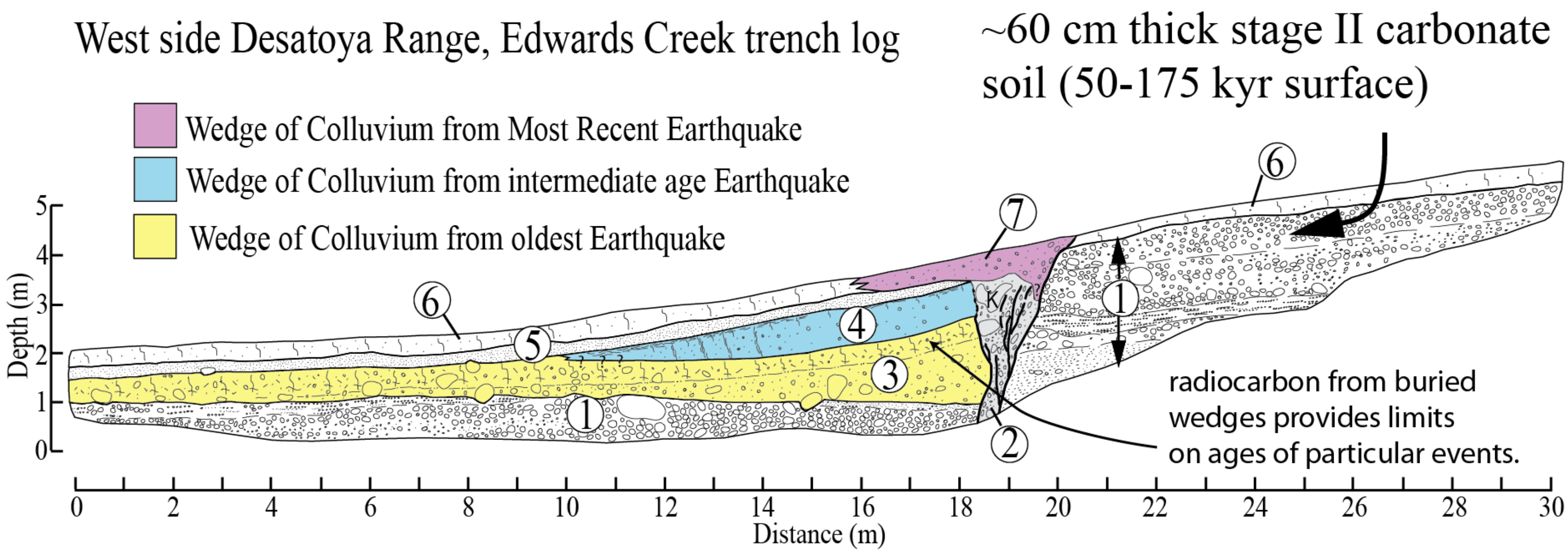
→

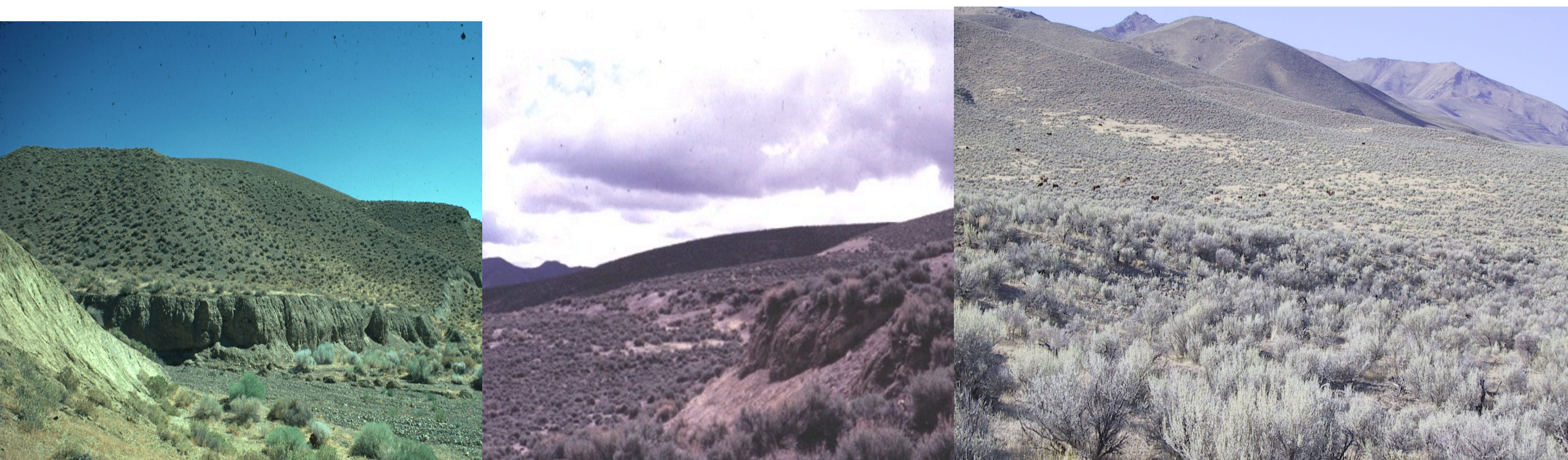
Further Erosion of Scarp Crest
Creation of 2nd Wedge of Colluvium
Buried Soil developed on 1st Wedge
Records Time Between Displacements



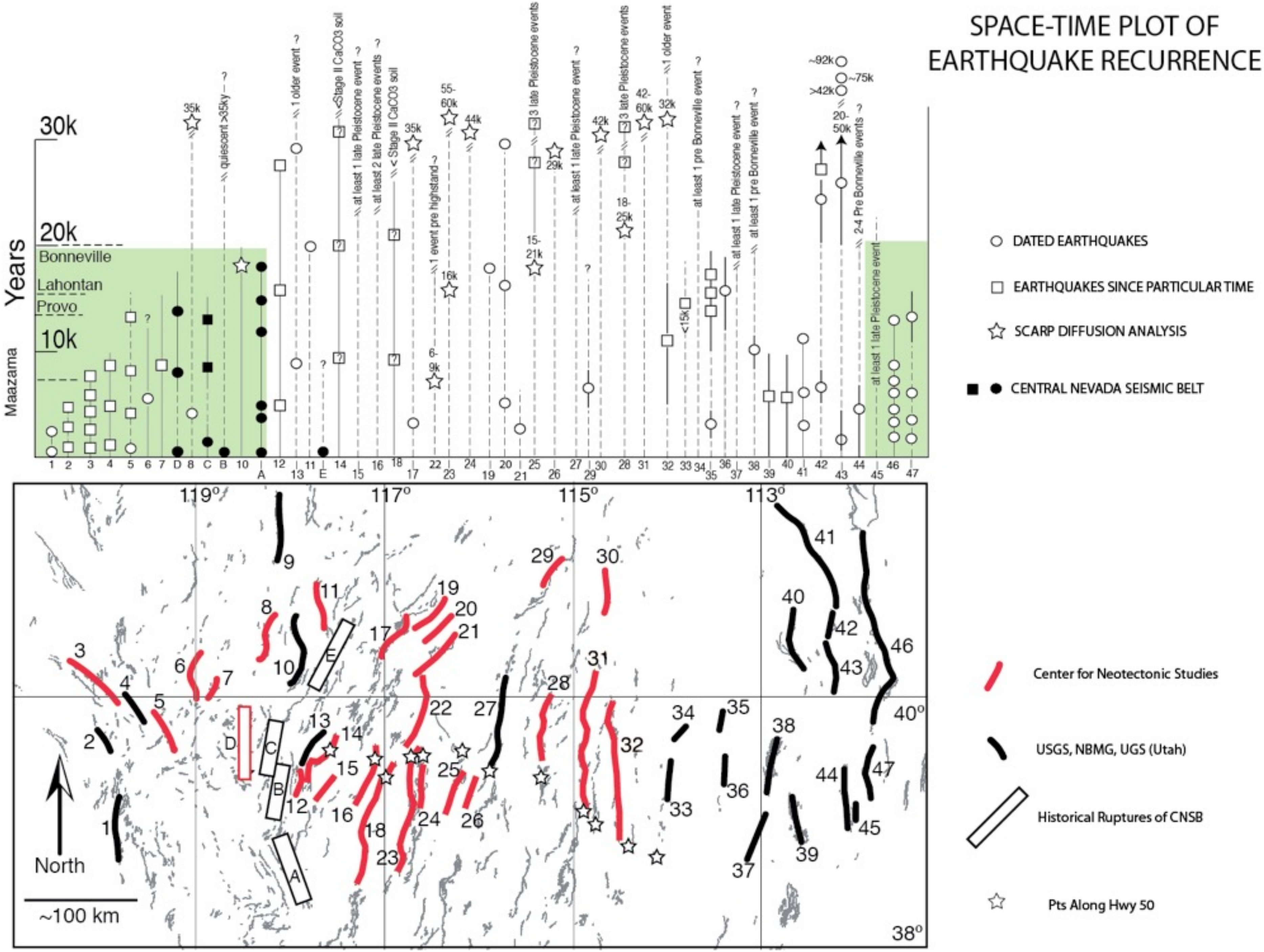


West side Desatoya Range, Edwards Creek trench log

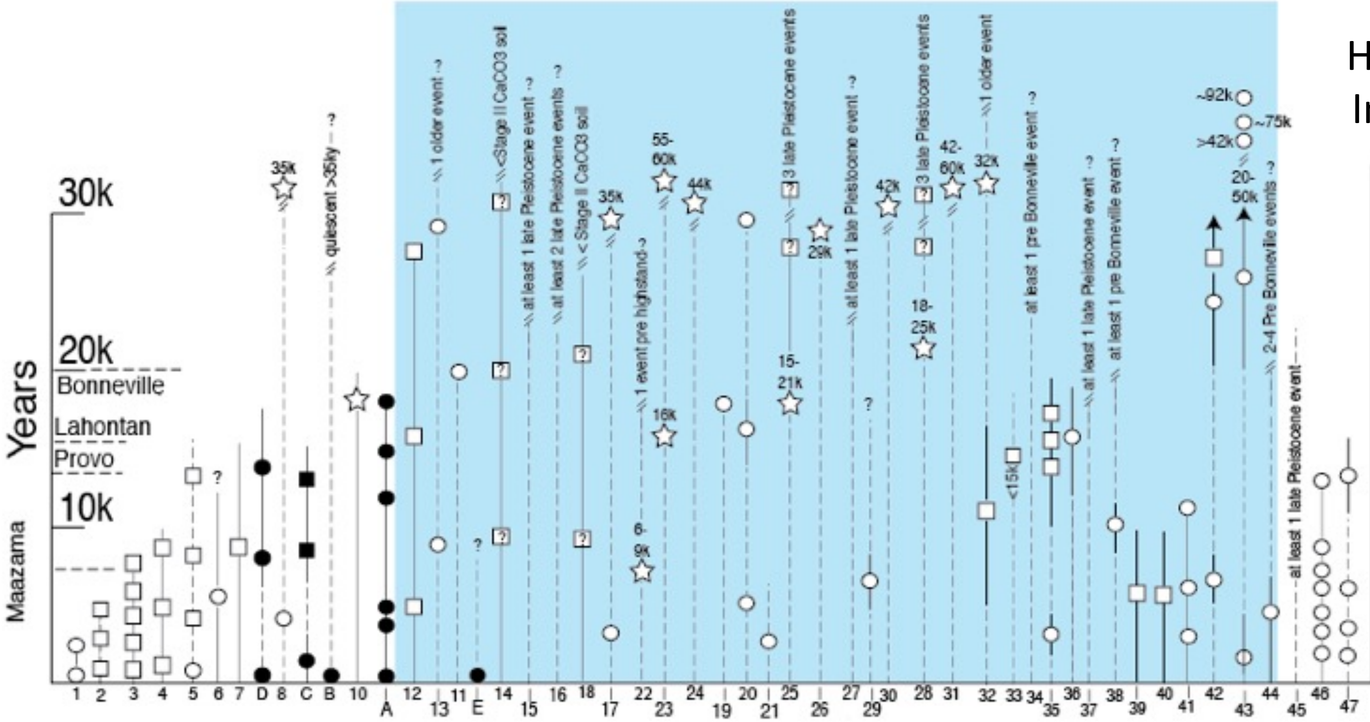




Three steps in time evolution of fault scarp


SPACE-TIME PLOT OF EARTHQUAKE RECURRENCE
Years
30k
20k
10k
Bonneville
Lahontan
Provo
Maazama
DATED EARTHQUAKES
EARTHQUAKES SINCE PARTICULAR TIME
SCARP DIFFUSION ANALYSIS
CENTRAL NEVADA SEISMIC BELT
119°
117°
115°
113°
40°
38°
North
~100 km
Center for Neotectonic Studies
USGS, NBMG, UGS (Utah)
Historical Ruptures of CNSB
Pts Along Hwy 50

Horizontal Extension Across Interior of Basin and Range

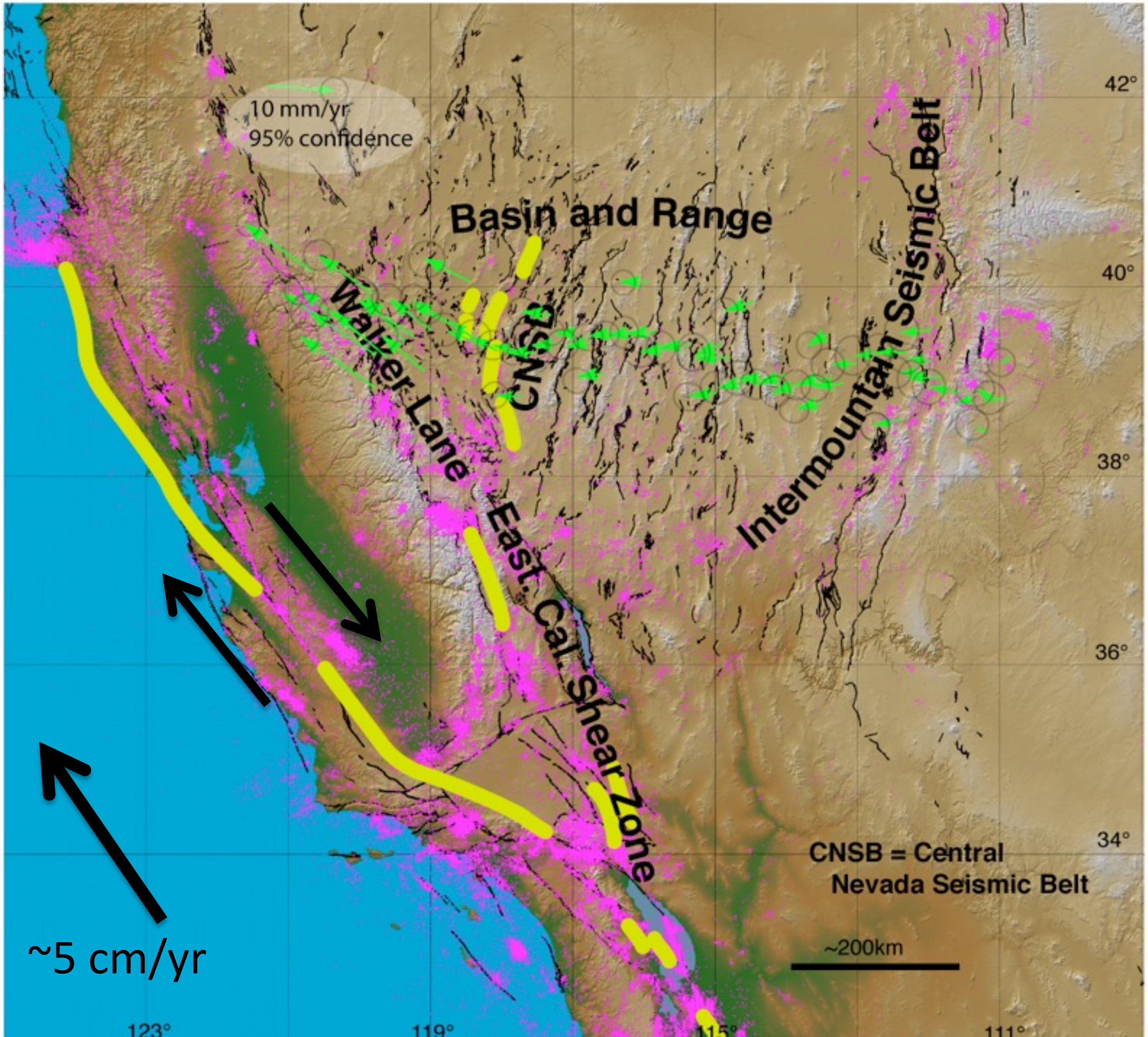


Fault	Vertical Separation **(60 ky)**	Extension	Strike	E-W Component of Extension
13. Clan Alpine	6 m	3.5 m	27°	3.1 m
.	.	.	.	.
.	.	.	.	.
SUM	91.3 m	58.5 m		48.4 m

48. 4 m / 60 ky = 0.8 mm/yr

Fault	Vertical Separation **(20 ky)**	Extension	Strike	E-W Component of Extension
13. Clan Alpine	1.2 m	0.7 m	27°	0.6 m
.	.	.	.	.
.	.	.	.	.
SUM	35.4 m	24.5 m		19.3 m

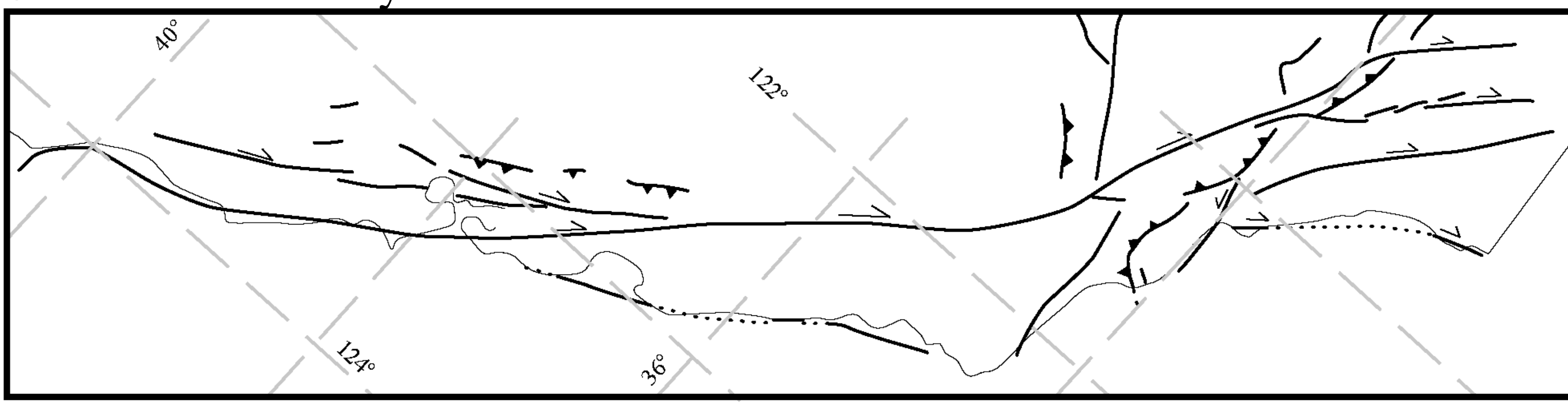
19.3 m / 20 ky = 1.0 mm/yr



About 3.5 cm/yr of ~5 cm/yr right-lateral transform motion is taken up on the San Andreas System, the remainder is distributed on faults of the Walker Lane and Basin and Range, with the majority of that on faults of the Walker Lane

Walker Lane fault system

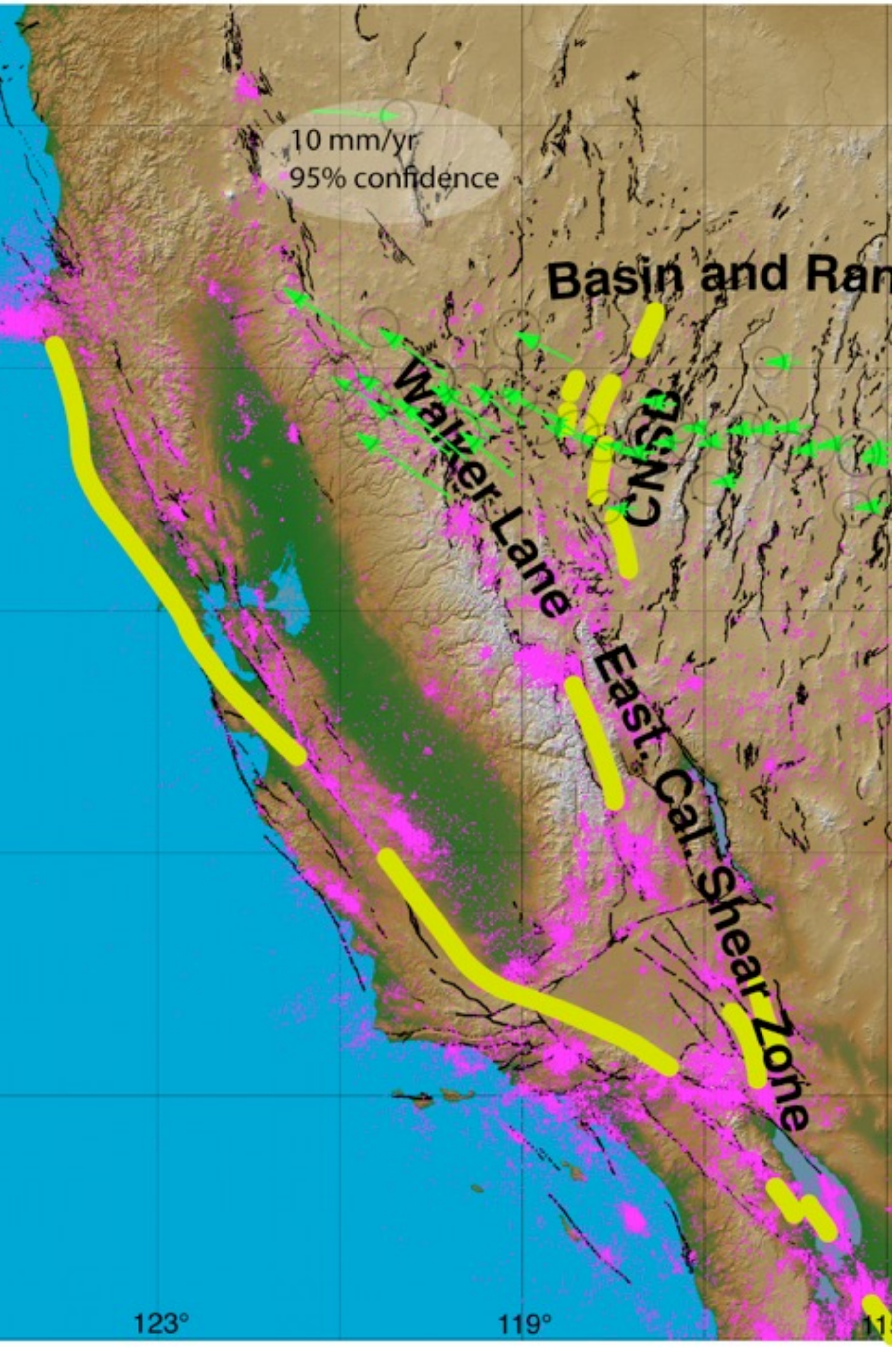
San Andreas fault system

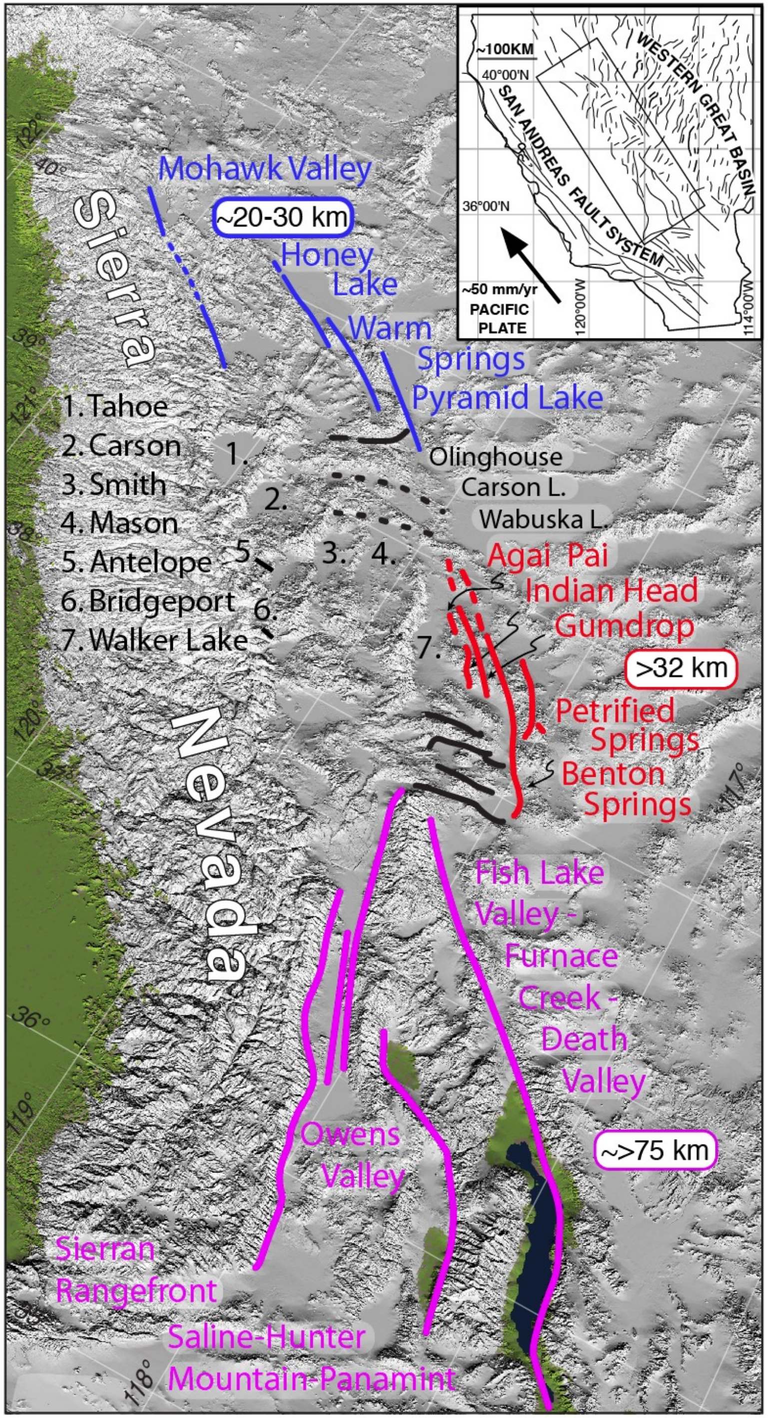


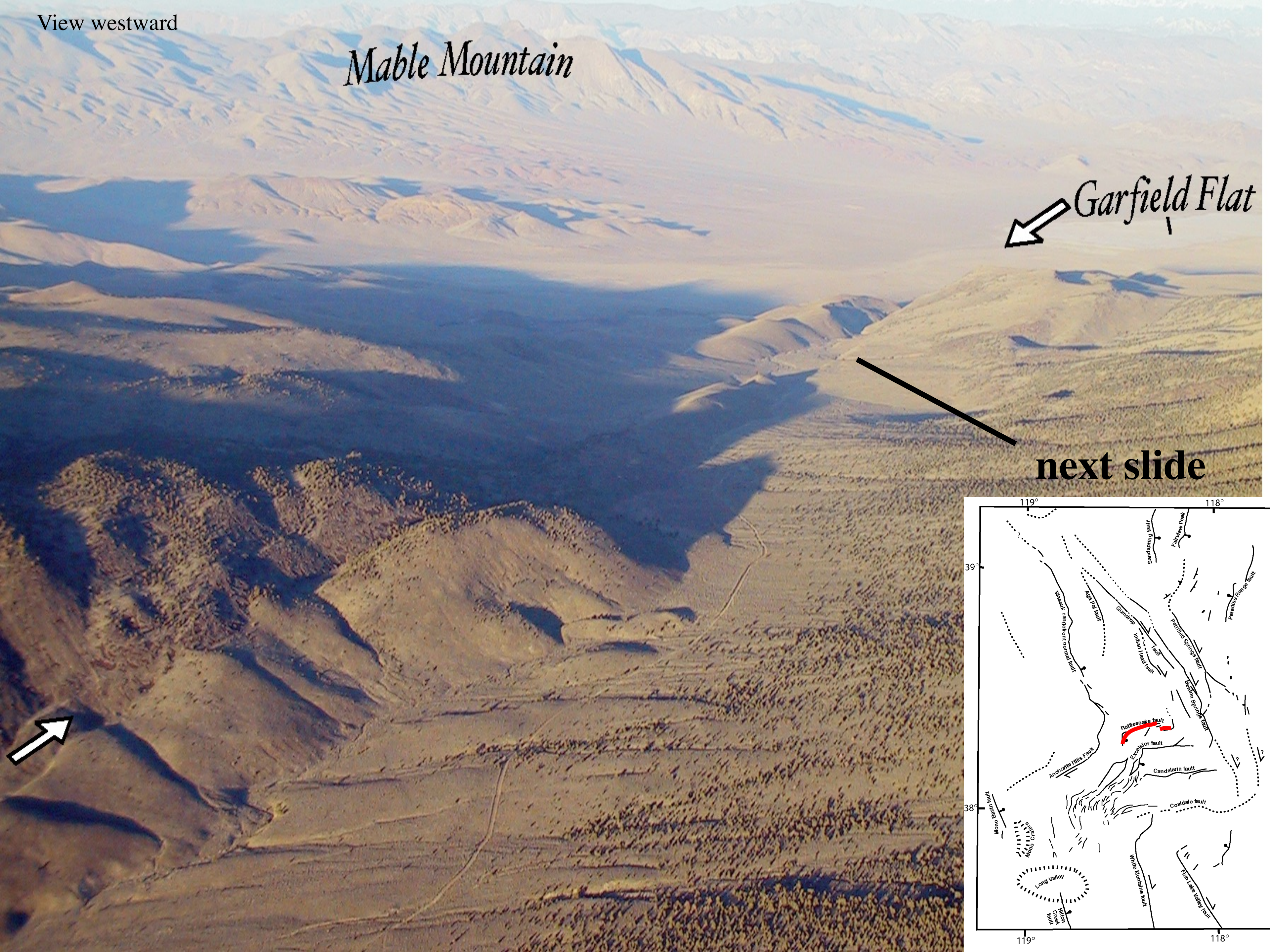
The Walker Lane is a more complex fault system than the San Andreas

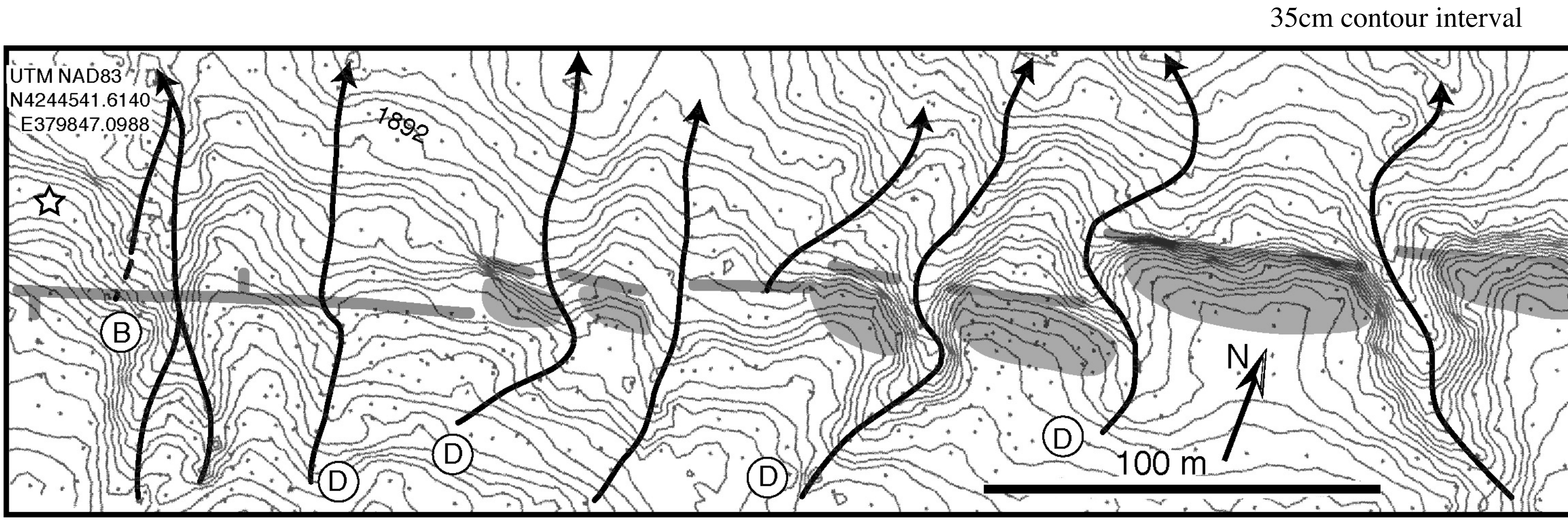
San Andreas has accommodated much more strike-slip

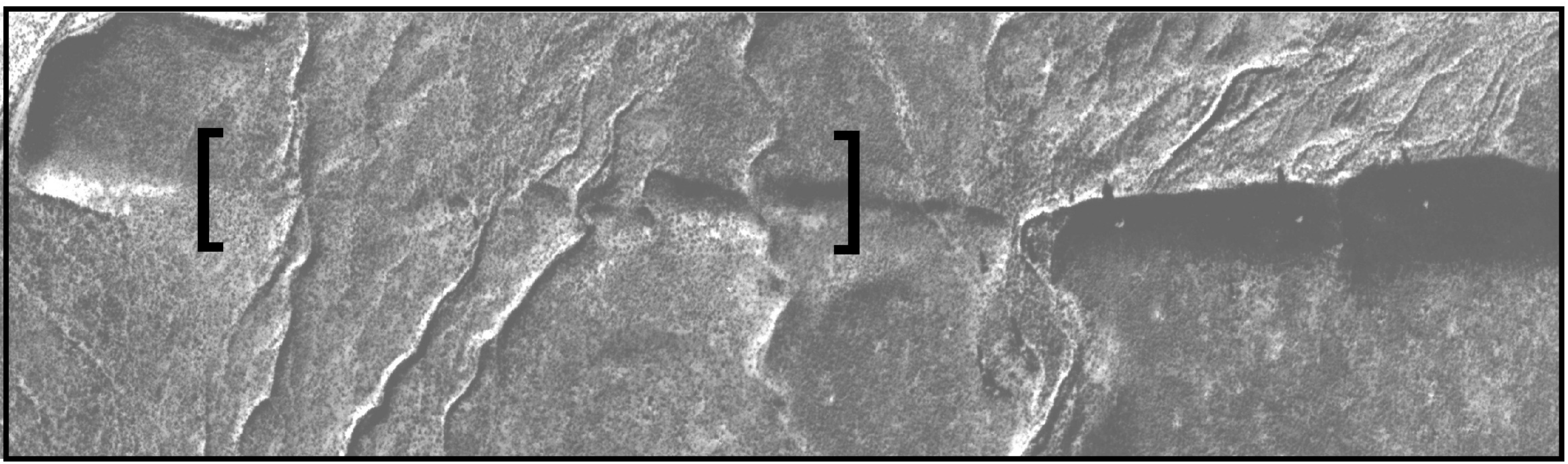
Walker Lane is Transtensional – San Andreas Transpressional

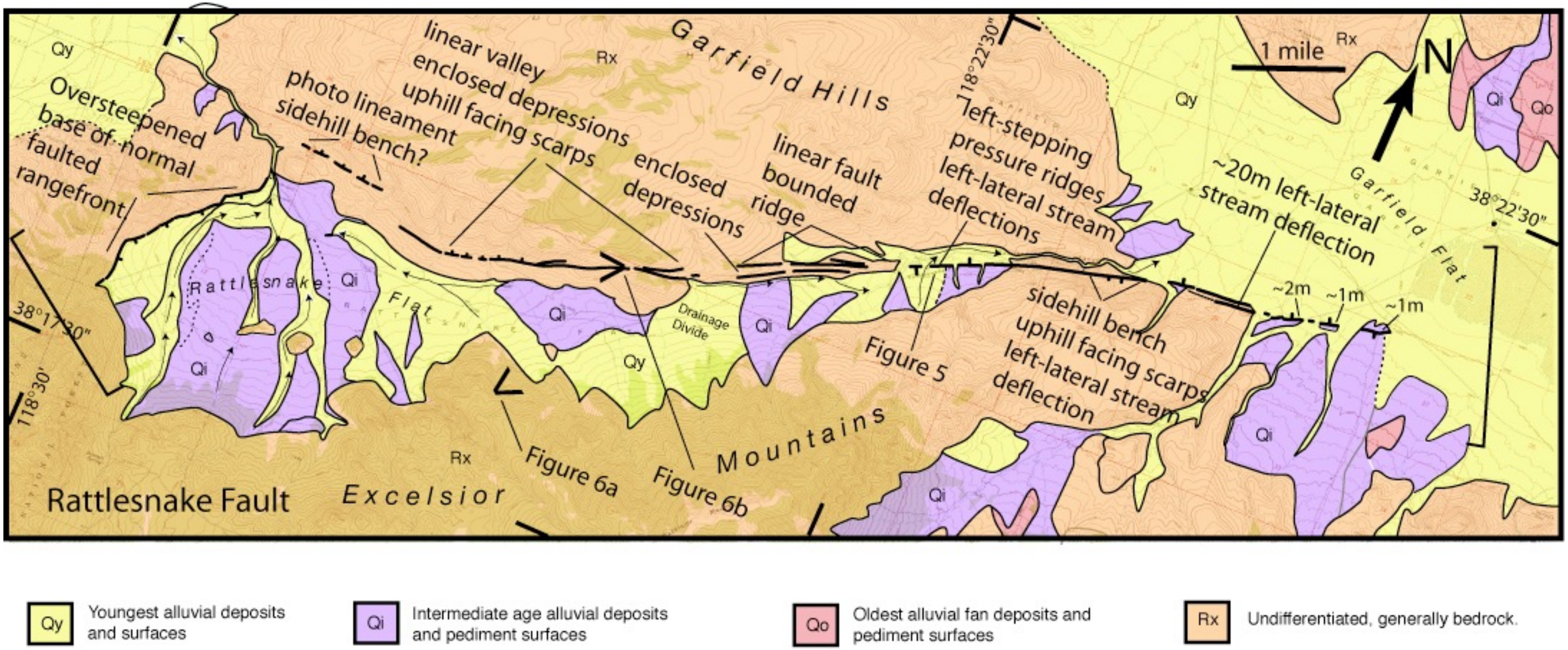

10 mm/yr
95% confidence
Basin and Ran
Walker Lane
CNSB
East. Cal. Shear Zone
123°
119°

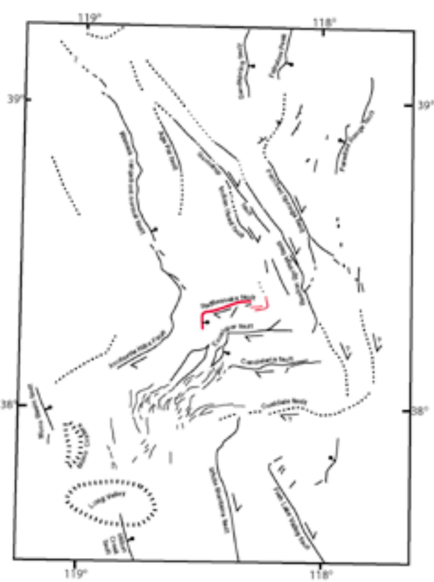

Mohawk Valley
~20-30 km
Honey Lake
Warm Springs
Pyramid Lake
Sierra
1. Tahoe
2. Carson
3. Smith
4. Mason
5. Antelope
6. Bridgeport
7. Walker Lake
Olinghouse
Carson L.
Wabuska L.
Agai Pai
Indian Head
Gumdrop
>32 km
Petrified Springs
Benton Springs
Nevada
Fish Lake Valley - Furnace Creek - Death Valley
Owens Valley
~>75 km
Sierran Rangefront
Saline-Hunter Mountain-Panamint
~100KM
40°00'N
36°00'N
SAN ANDREAS FAULT SYSTEM
WESTERN GREAT BASIN
~50 mm/yr
PACIFIC PLATE
120°00'W
114°00'W

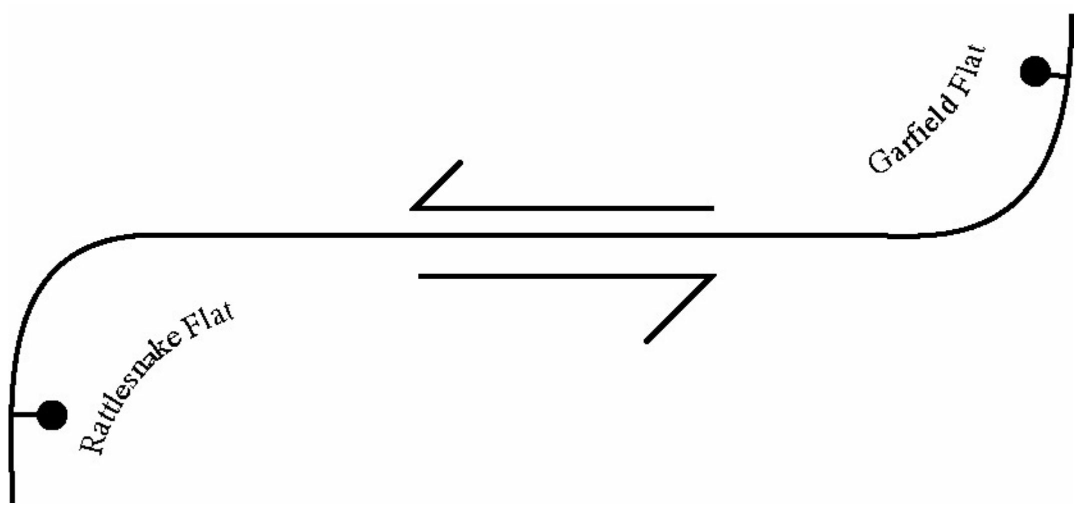

View westward
Mable Mountain
Garfield Flat
next slide
119°
118°
39°
38°
Sandspring fault
Fairview Peak
Paradise Range fault
Wassuk rangefront normal fault
Aga Pai fault
Gumdrop
Indian Head fault
fault
Petrified Springs fault
Benton Springs fault
Rattlesnake fault
Excelsior fault
Anchorite Hills Fault
Candelaria fault
Coaldale fault
Mono Basin fault
Mono Craters
Long Valley
Hilton Creek fault
White Montains fault
Fish Lake Valley fault


35cm contour interval
UTM NAD83
N4244541.6140
E379847.0988
1892
B
D
D
D
D
N
100 m

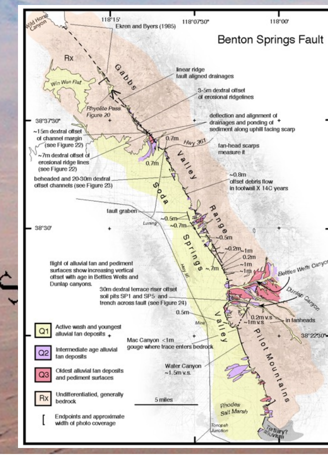


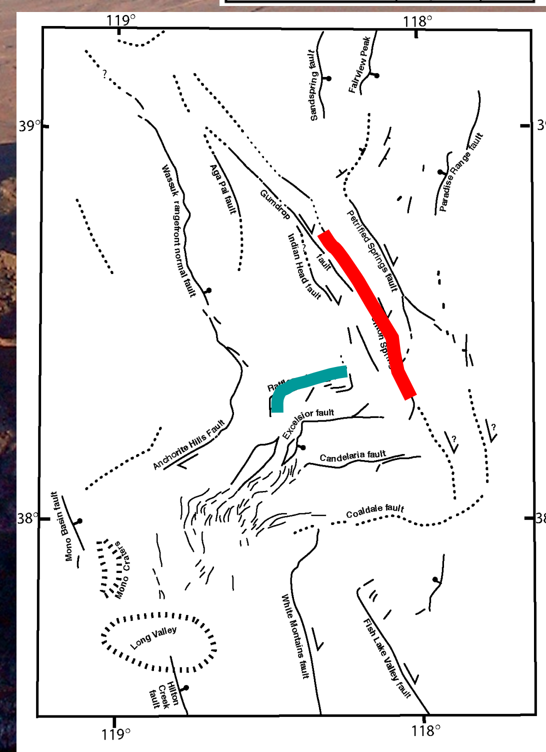

Rattlesnake Fault
Garfield Hills
Excelsior Mountains
Rattlesnake Flat
Garfield Flat
1 mile
N
Qy
Qi
Qo
Rx
38°17'30"
118°30'
118°22'30"
38°22'30"
Oversteepened base of normal faulted rangefront
photo lineament
sidehill bench?
linear valley
enclosed depressions
uphill facing scarps
enclosed depressions
linear fault bounded ridge
left-stepping pressure ridges
left-lateral stream deflections
~20m left-lateral stream deflection
sidehill bench
uphill facing scarps
left-lateral stream deflection
Drainage Divide
Figure 5
Figure 6a
Figure 6b
~2m
~1m
~1m
Qy Youngest alluvial deposits and surfaces
Qi Intermediate age alluvial deposits and pediment surfaces
Qo Oldest alluvial fan deposits and pediment surfaces
Rx Undifferentiated, generally bedrock.

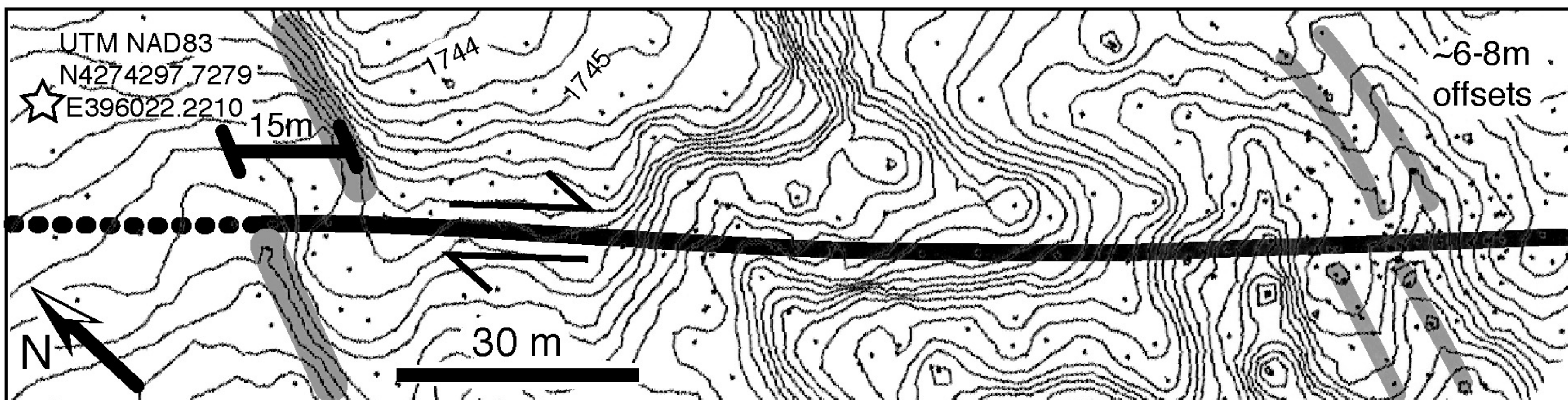



Garfield Flat
Rattlesnake Flat

View south along Benton Springs Fault

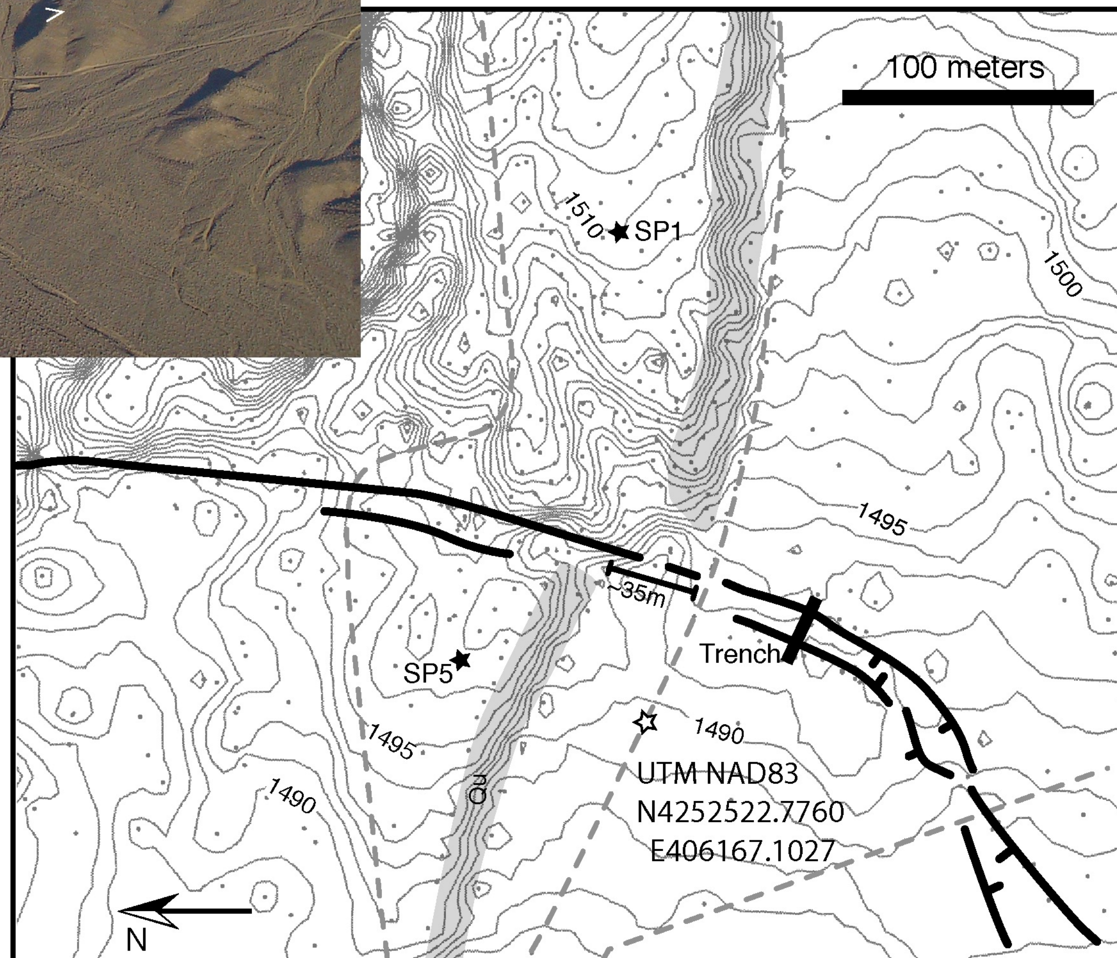






50cm contour interval

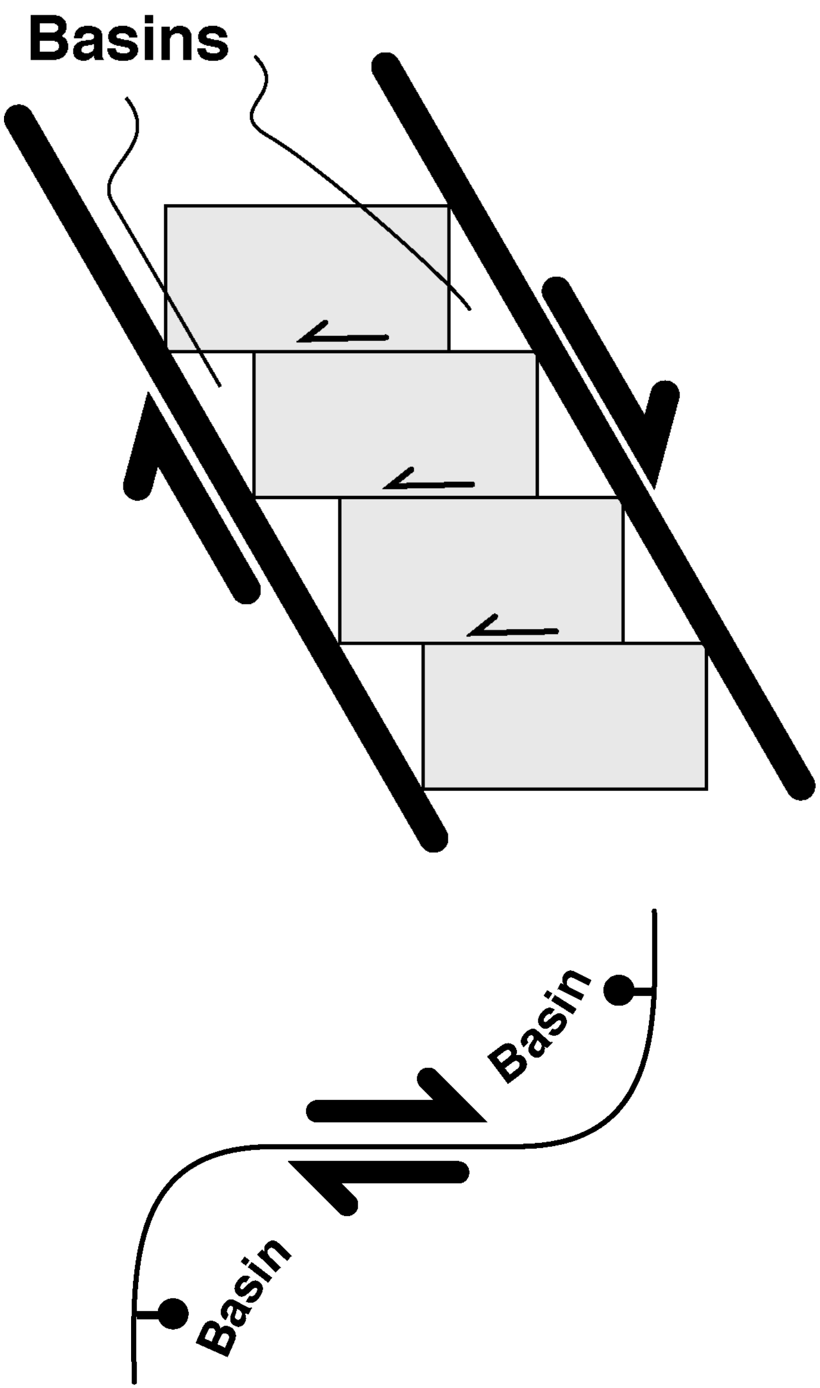
and another way how we learn of how fast faults are moving….

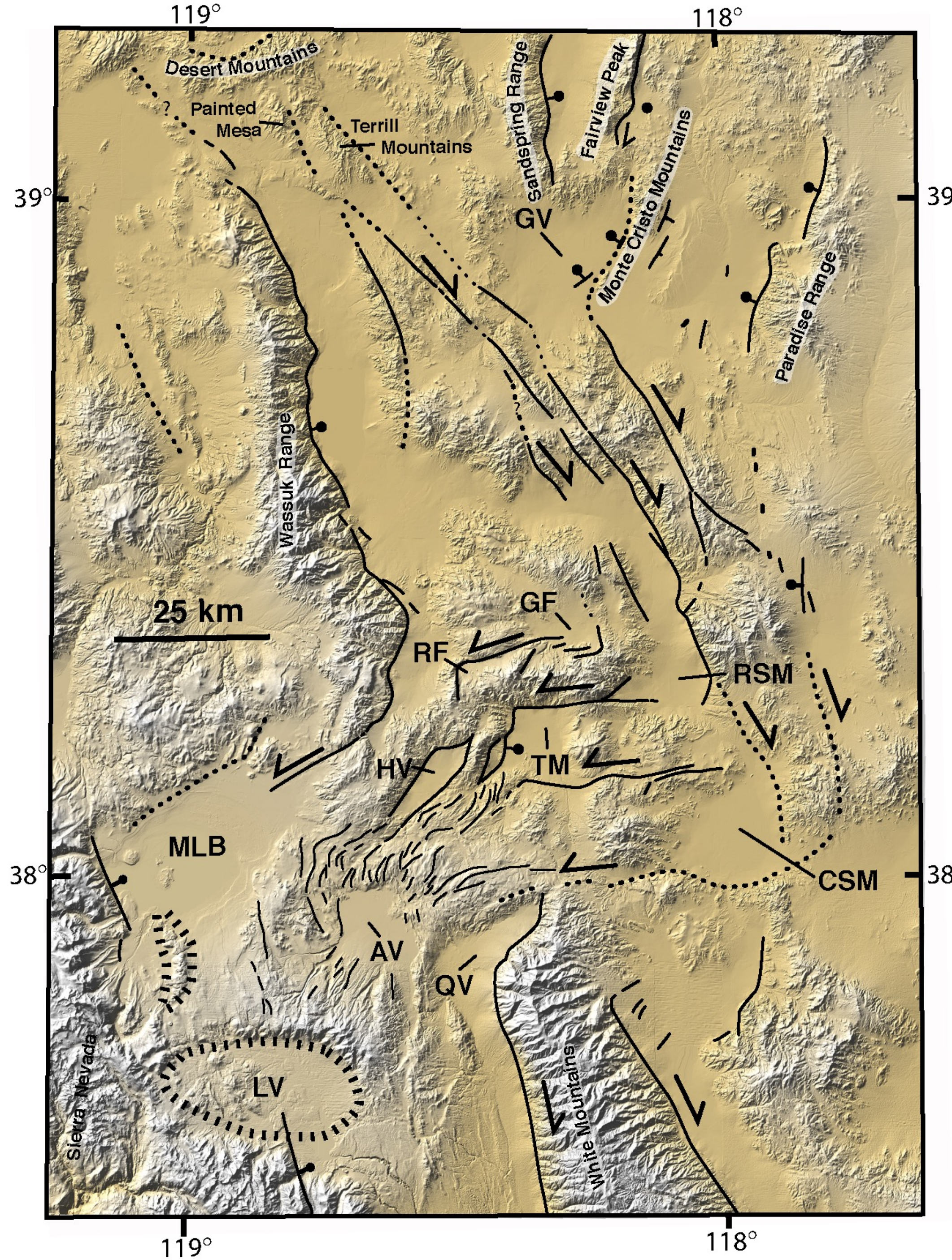


1 meter contour interval

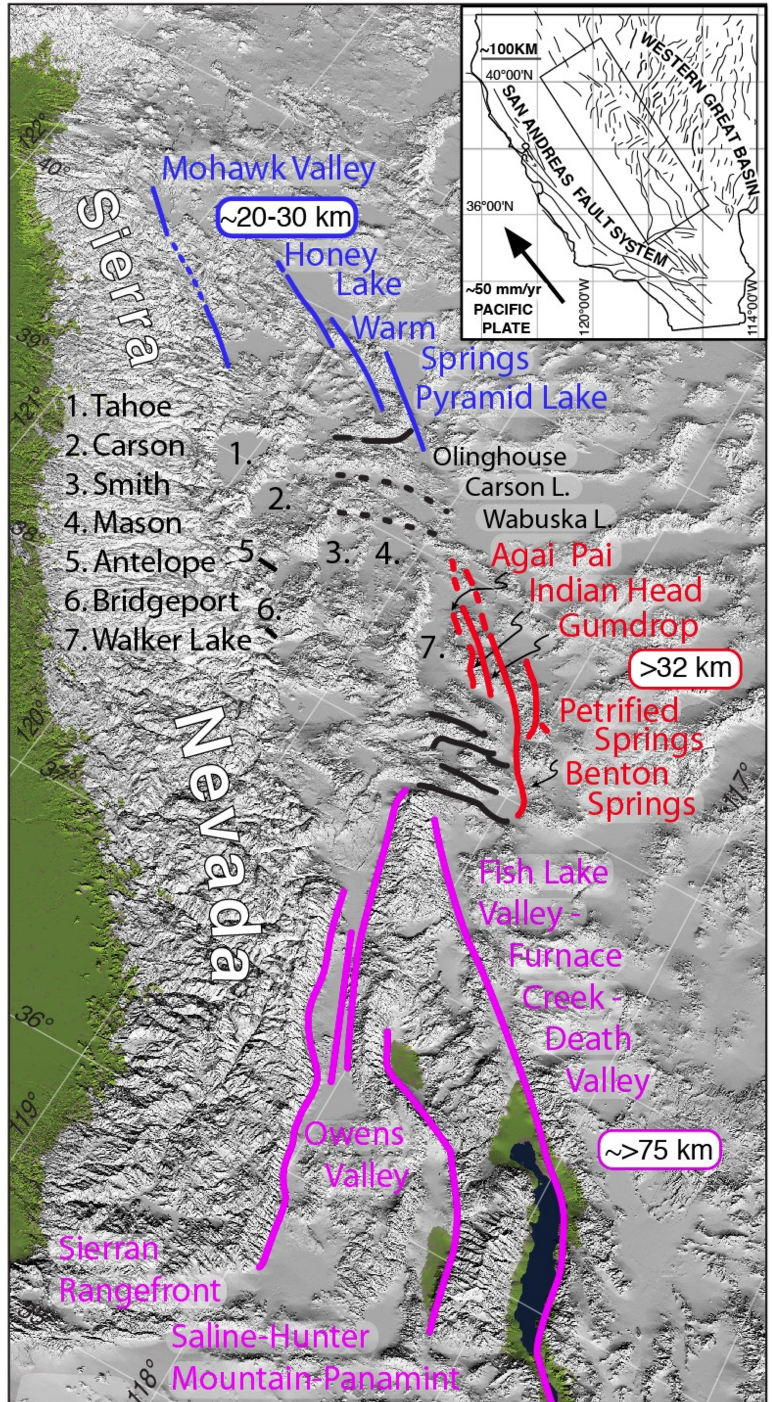
With
knowledge of the age of the surface that is offset (stars) – 35k years
And
Knowledge of amount surface offset by fault (35 m)

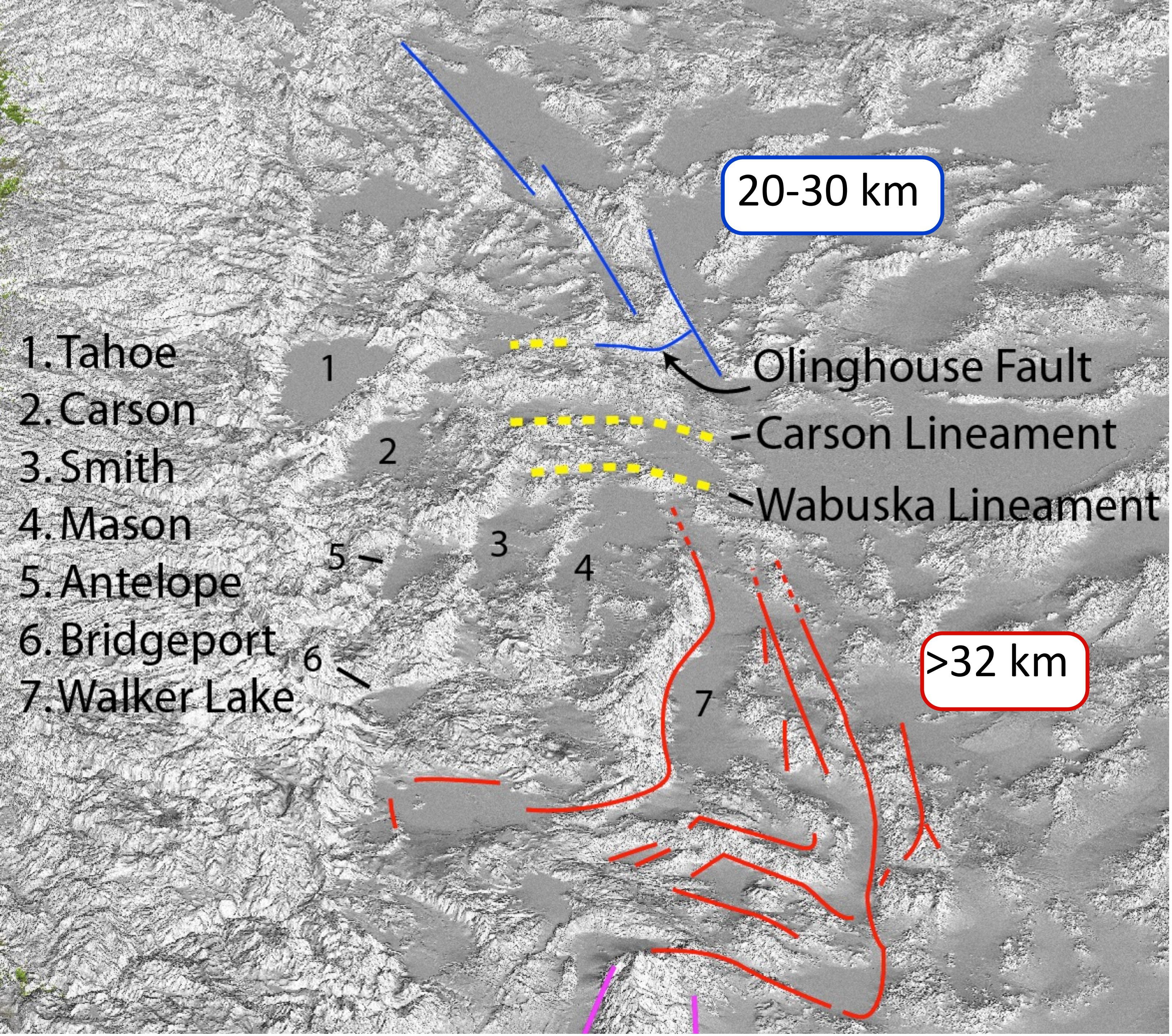
Realize fault is moving on average about 1 mm/yr strike-slip right -lateral


Basins
Basin
Basin

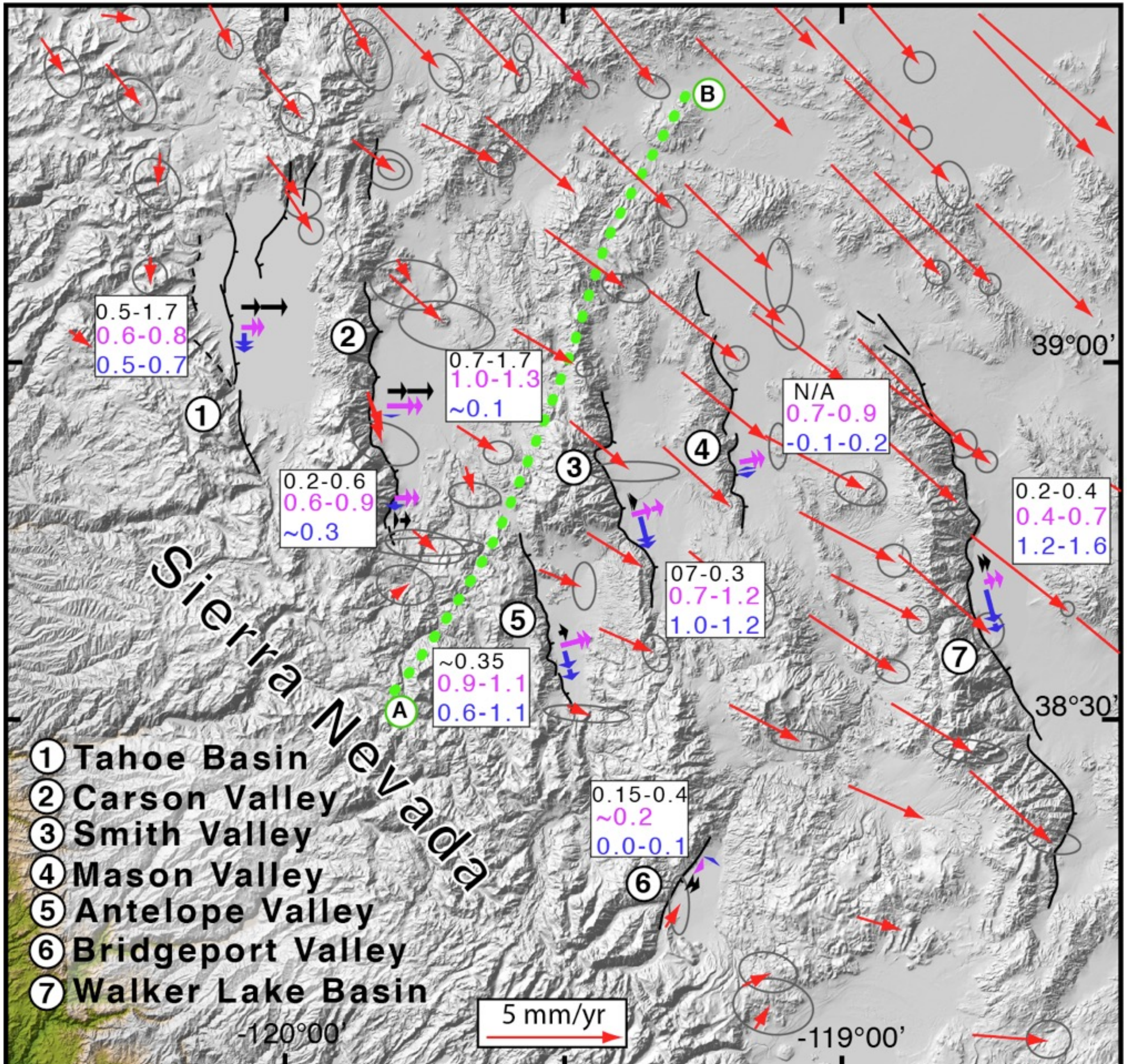

119°
118°
39°
38°
Desert Mountains
Painted Mesa
Terrill Mountains
Sandspring Range
Fairview Peak
Monte Cristo Mountains
Paradise Range
GV
Wassuk Range
25 km
GF
RF
RSM
HV
TM
MLB
CSM
AV
QV
LV
Sierra Nevada
White Mountains

moving north now.....

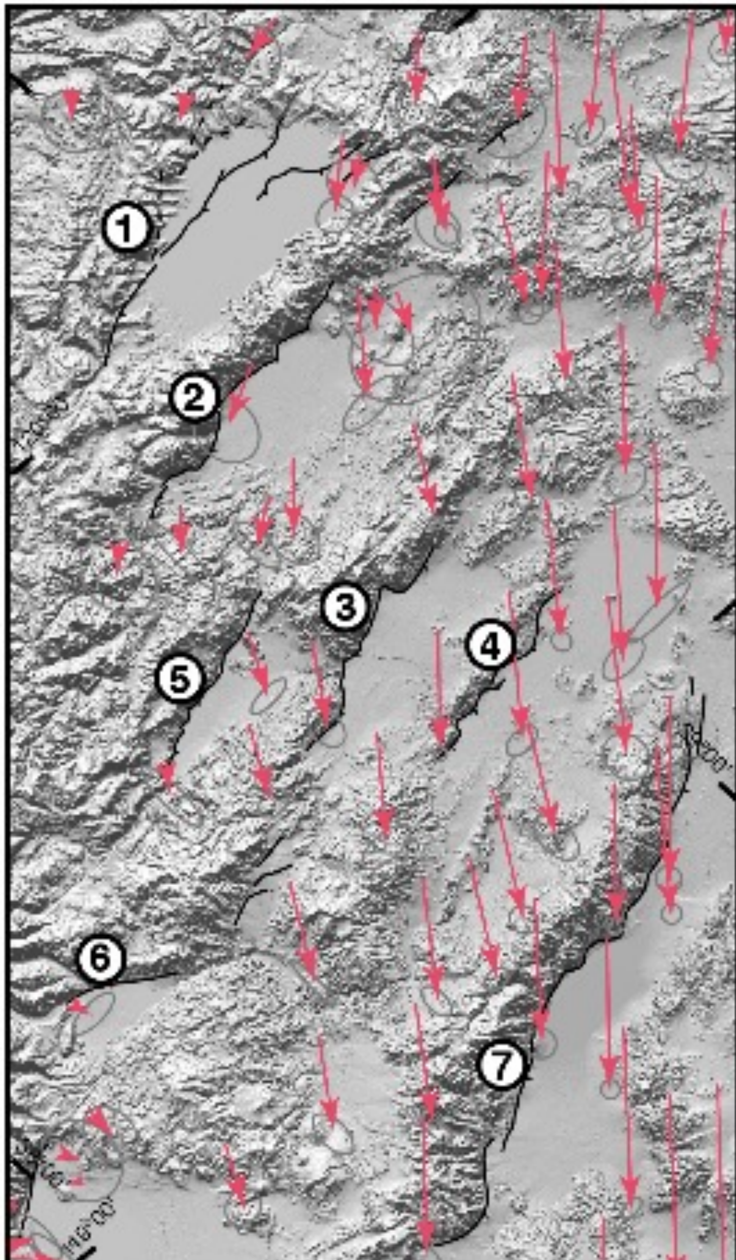


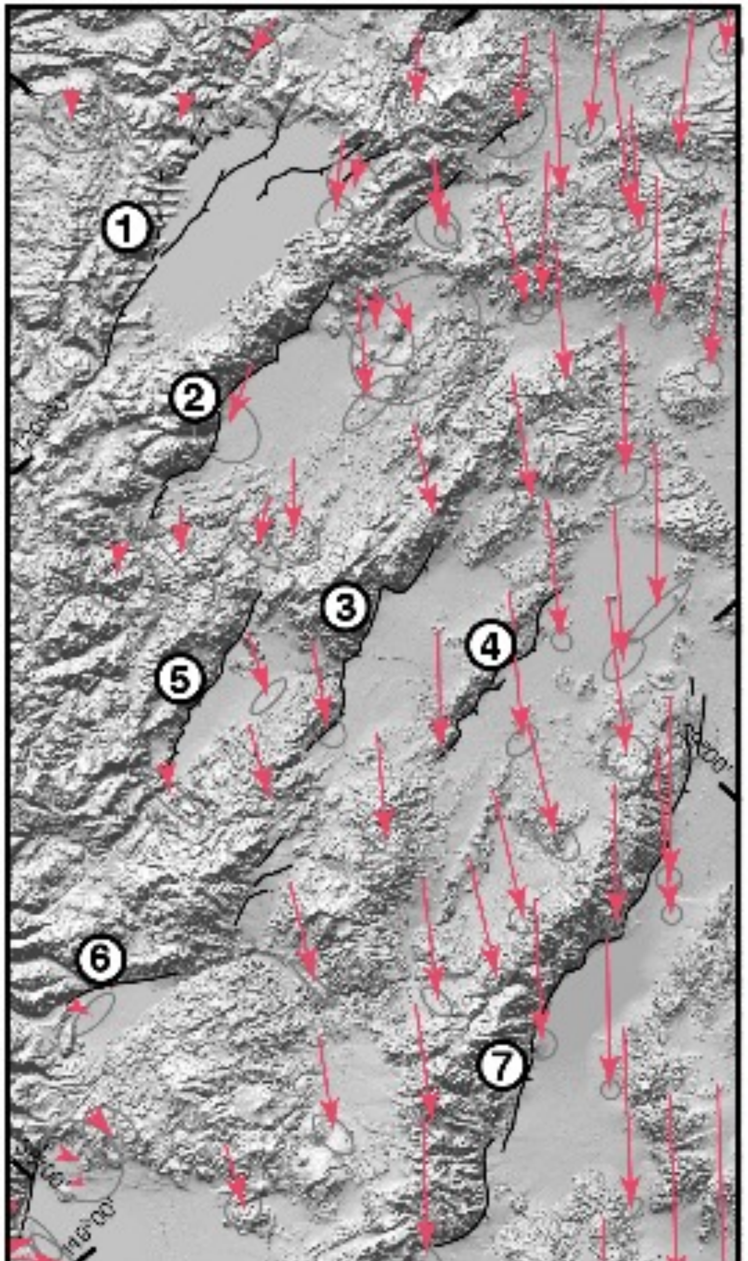


1. Tahoe
2. Carson
3. Smith
4. Mason
5. Antelope
6. Bridgeport
7. Walker Lake
20-30 km
Olinghouse Fault
Carson Lineament
Wabuska Lineament
>32 km
1
2
3
4
5
6
7

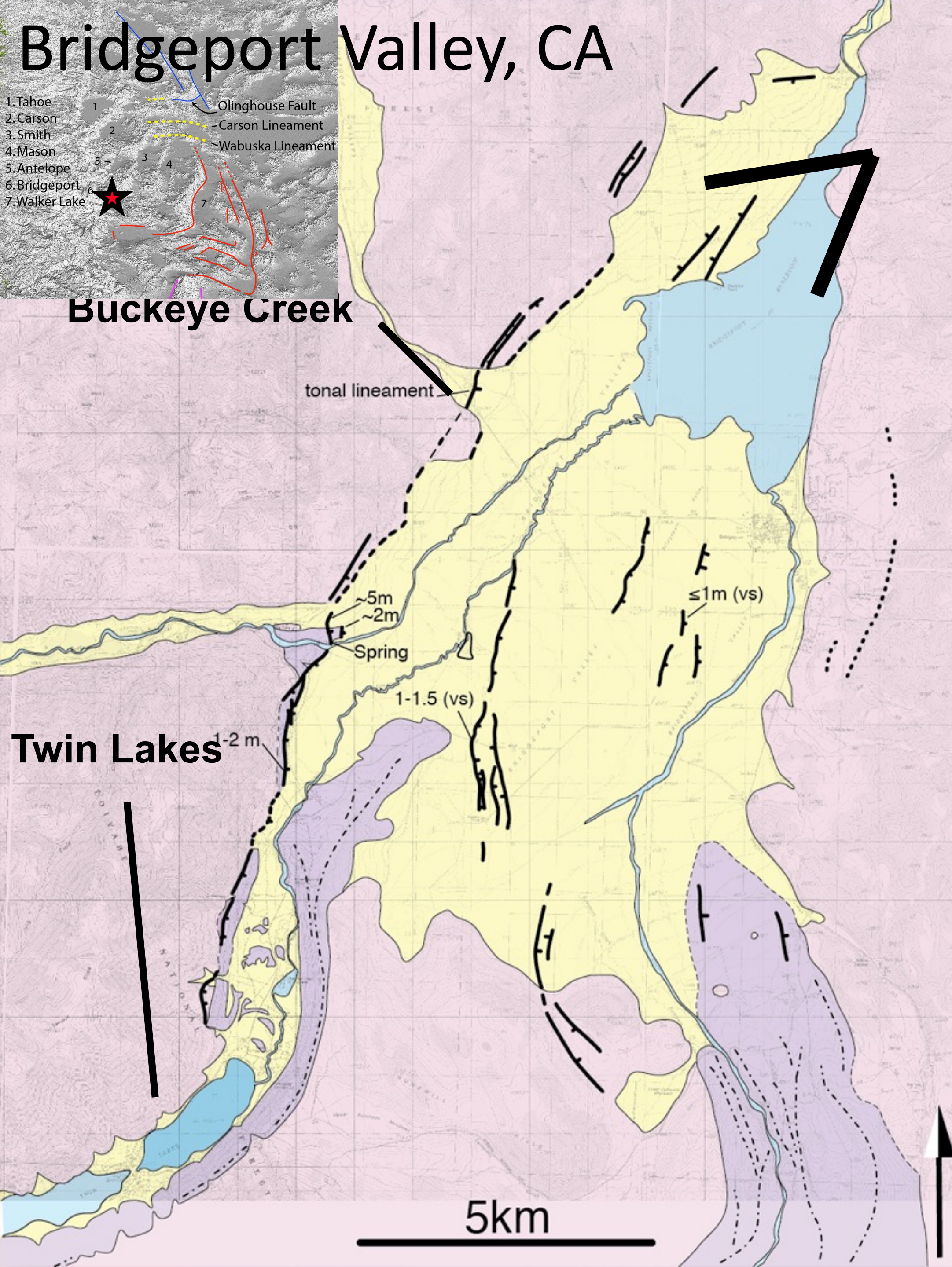


B
A
39°00'
38°30'
-120°00'
-119°00'
0.5-1.7
0.6-0.8
0.5-0.7
0.7-1.7
1.0-1.3
~0.1
0.2-0.6
0.6-0.9
~0.3
N/A
0.7-0.9
-0.1-0.2
0.2-0.4
0.4-0.7
1.2-1.6
.07-0.3
0.7-1.2
1.0-1.2
~0.35
0.9-1.1
0.6-1.1
0.15-0.4
~0.2
0.0-0.1
Sierra Nevada
1 Tahoe Basin
2 Carson Valley
3 Smith Valley
4 Mason Valley
5 Antelope Valley
6 Bridgeport Valley
7 Walker Lake Basin
5 mm/yr

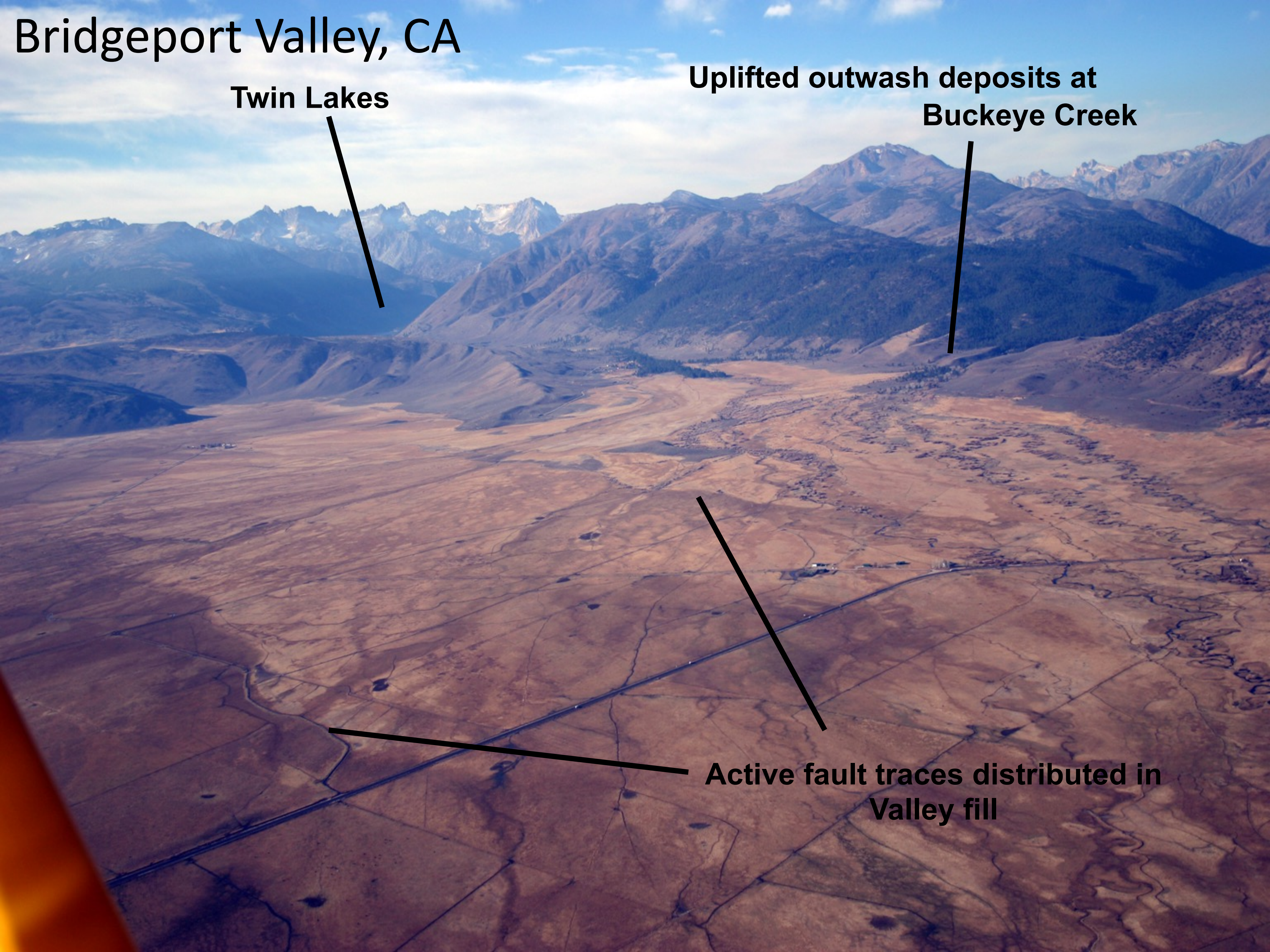

1
2
3
4
5
6
7


1
2
3
4
5
6
7

Bridgeport Valley, CA

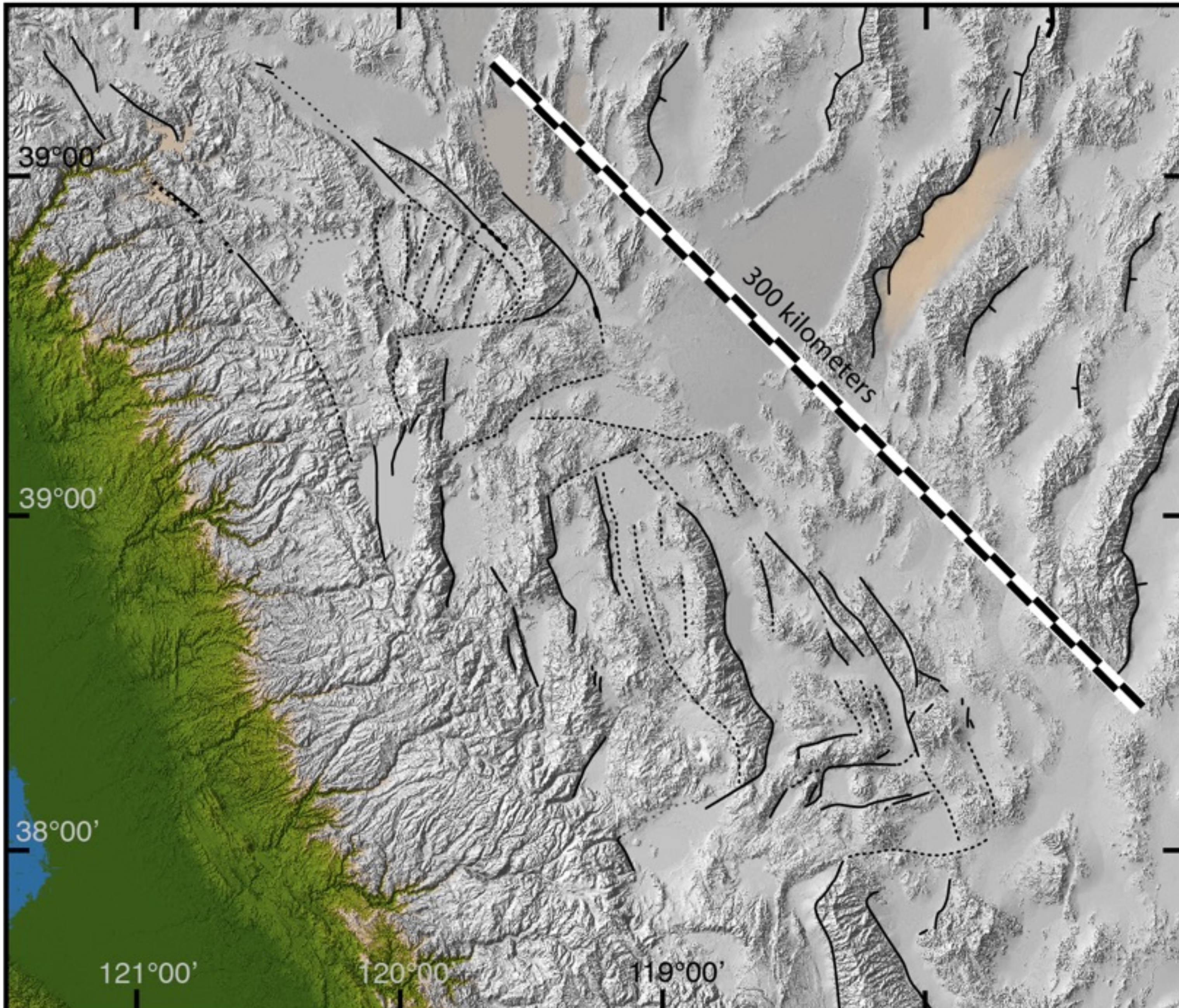


Bridgeport Valley, CA



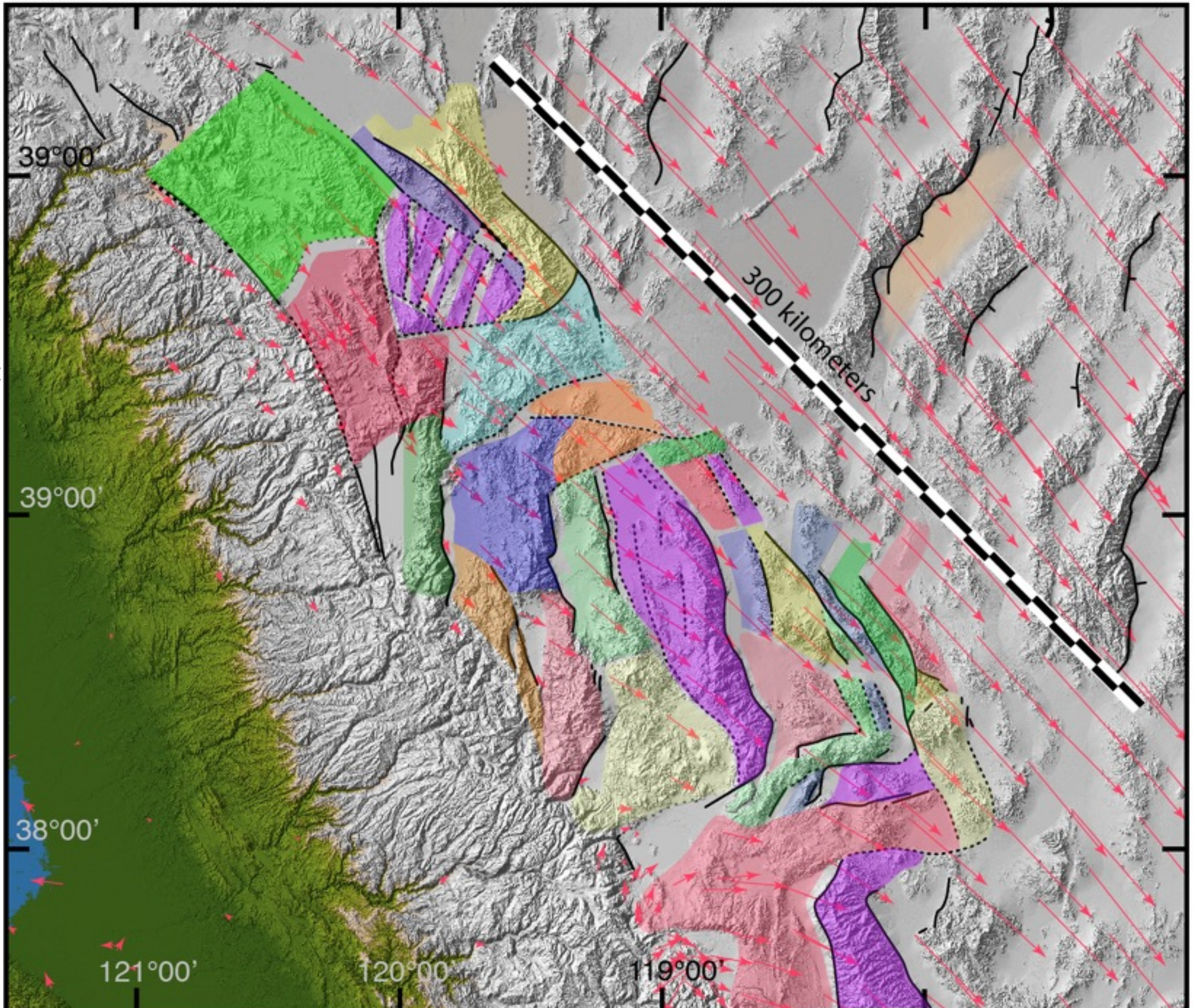

~4 m (sh) in
fanhead alluviu
395
208
~4 m (sh)
creek mouth
6 m (sh)
in fanhead
>5 m (sh)
in fanhead
right-lateral
>2 m (vs)
in fanhead
<1 m (vs)
in fanhead
1-3 m (sh) in fanheads &
alluvial apron
7 m (sh)
2-3 m (sh) in fanhead
10-15 m (sh)
~3 m (sh)
~2m v.s in fanhead
Scarps larger along
older fan element
2-3 m (sh)
fault graben
2 km
Sample sites

Topo with Faults



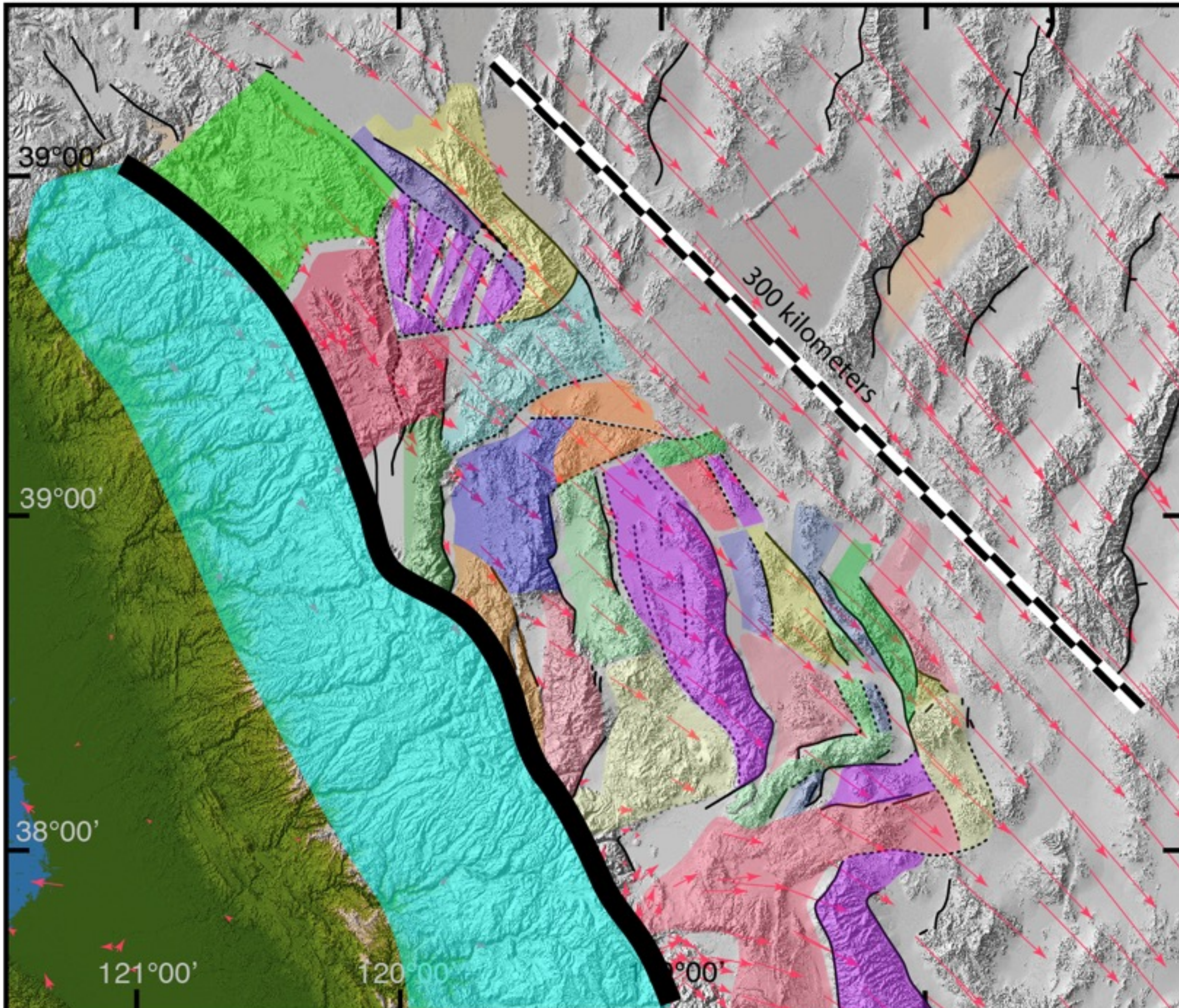
and to that add division of crustal terranes based on faults and physiography

and geodetic displacement rate vectors with respect to stable Sierra Nevada



02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

and to that a simplified boundary to the Sierra Nevada



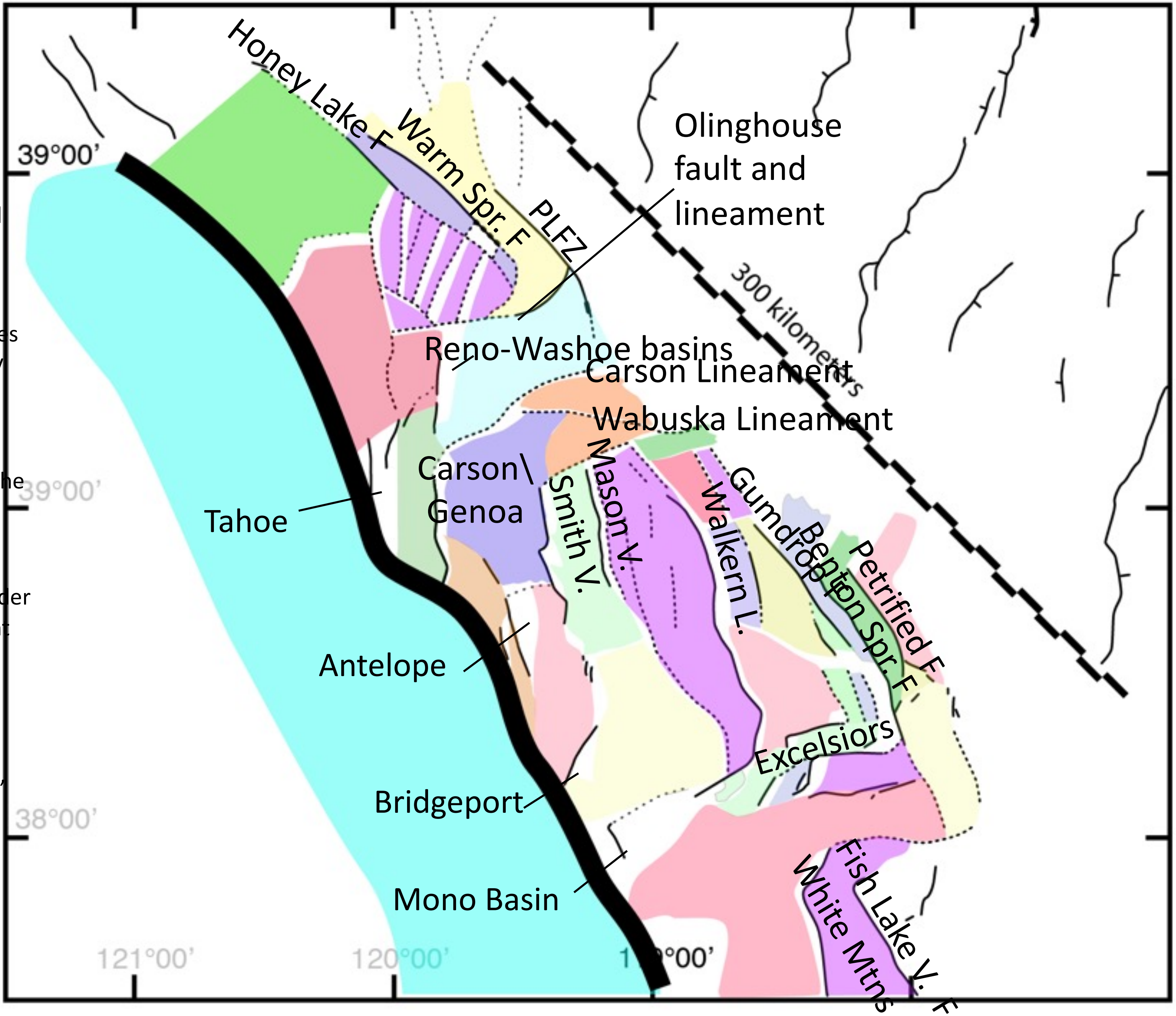
02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

remove physiography for clarity

amount of extension producing the basins observed in physiography is delineated by white areas between terranes and bounded by active faults.

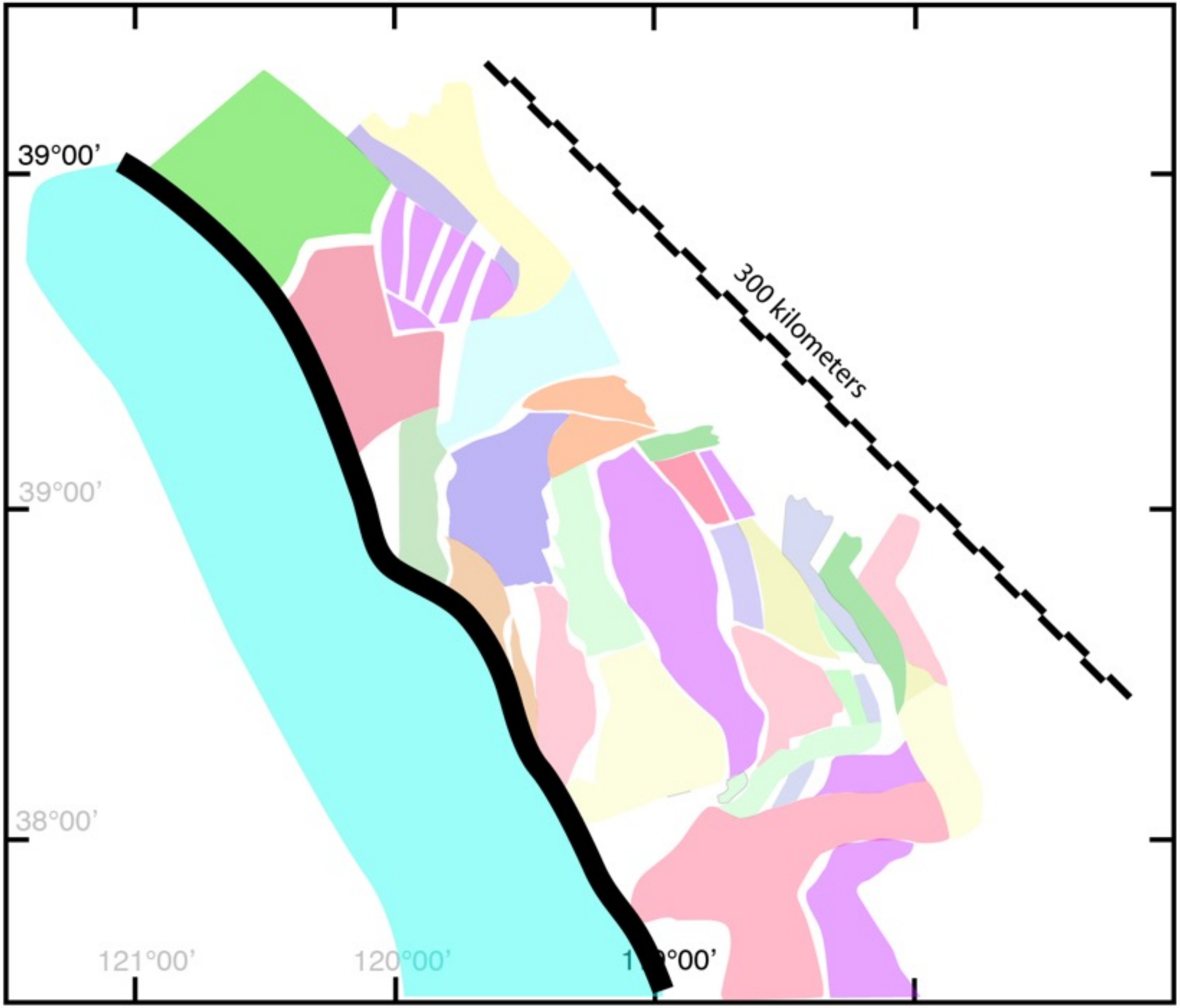
because of sedimentation the width of physiographic basins will invariably be wider than the amount of extension producing them

extension in tahoe, antelope, and bridgeport basins is exaggerated for clarity of basin shape and my interest...



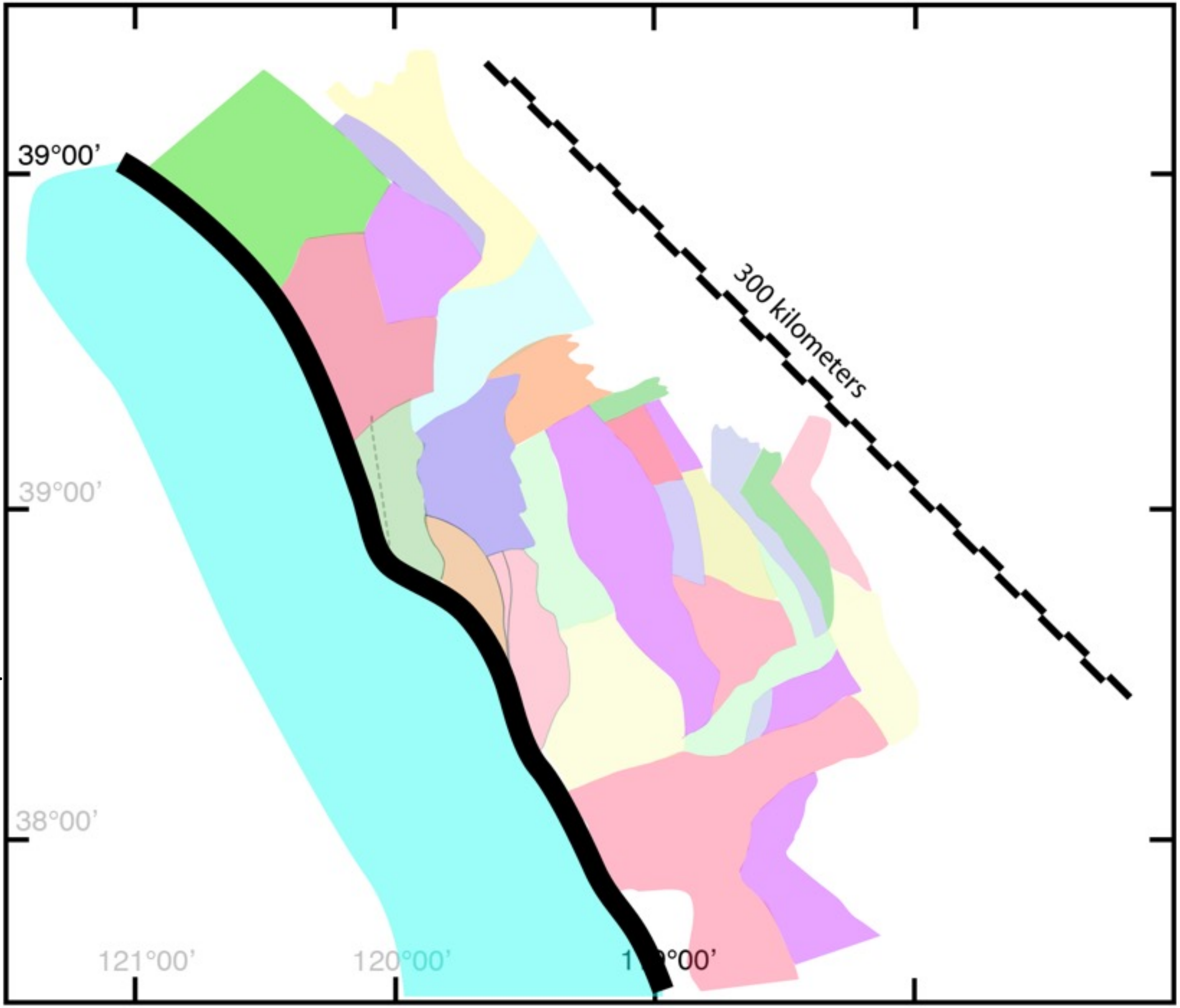
02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

Remove Faults and verbage for clarity



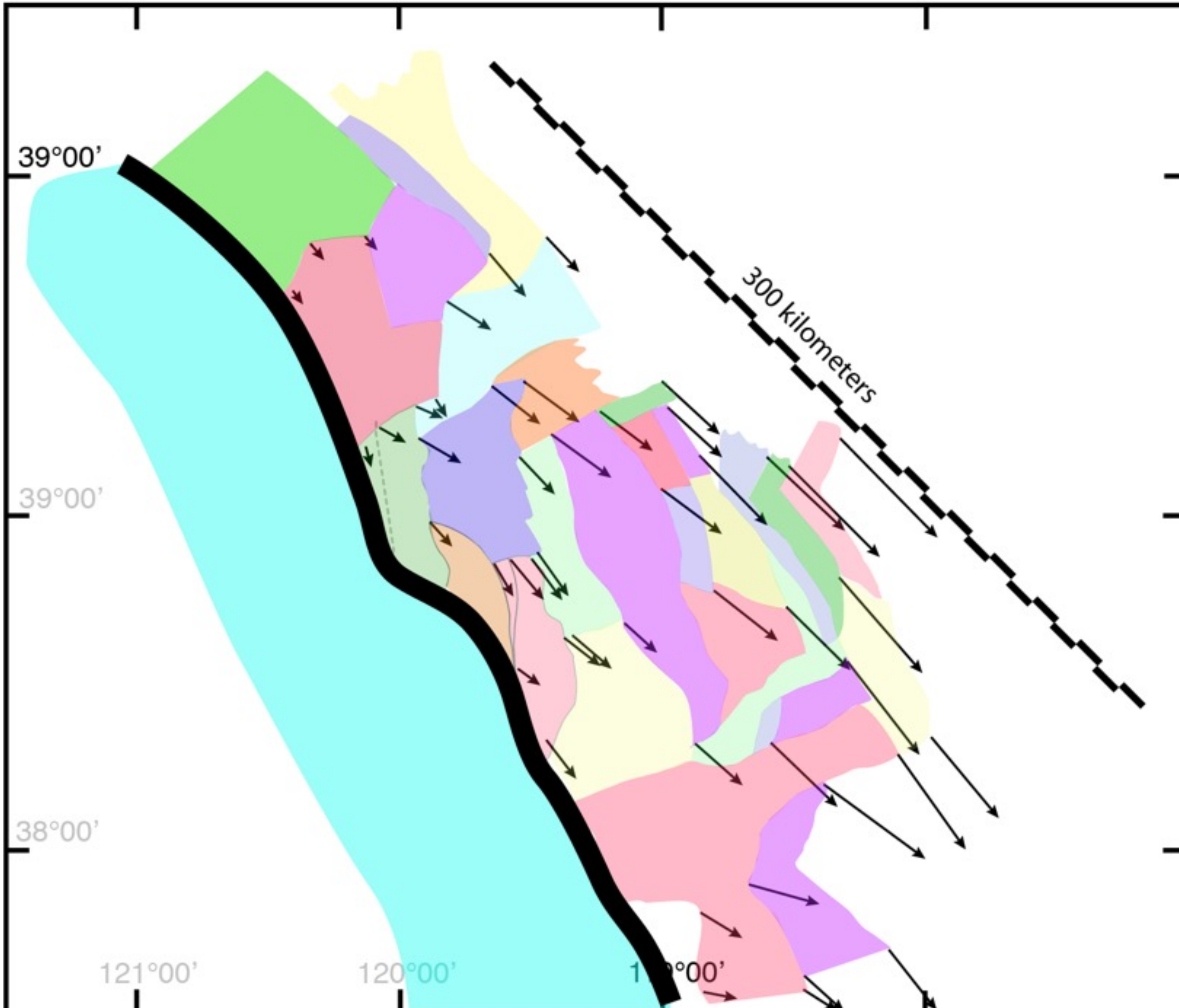
now move blocks
to eliminate ‘white spaces’ - the basins between faults...

Note the extra added width of the Tahoe and Antelope basins -
if not done, the extension associated with each basin
will be overestimated...
said this already



02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

The black arrows indicate the motion points on the blocks would need to move to return to position of last slide (or 'to get to where they are today')



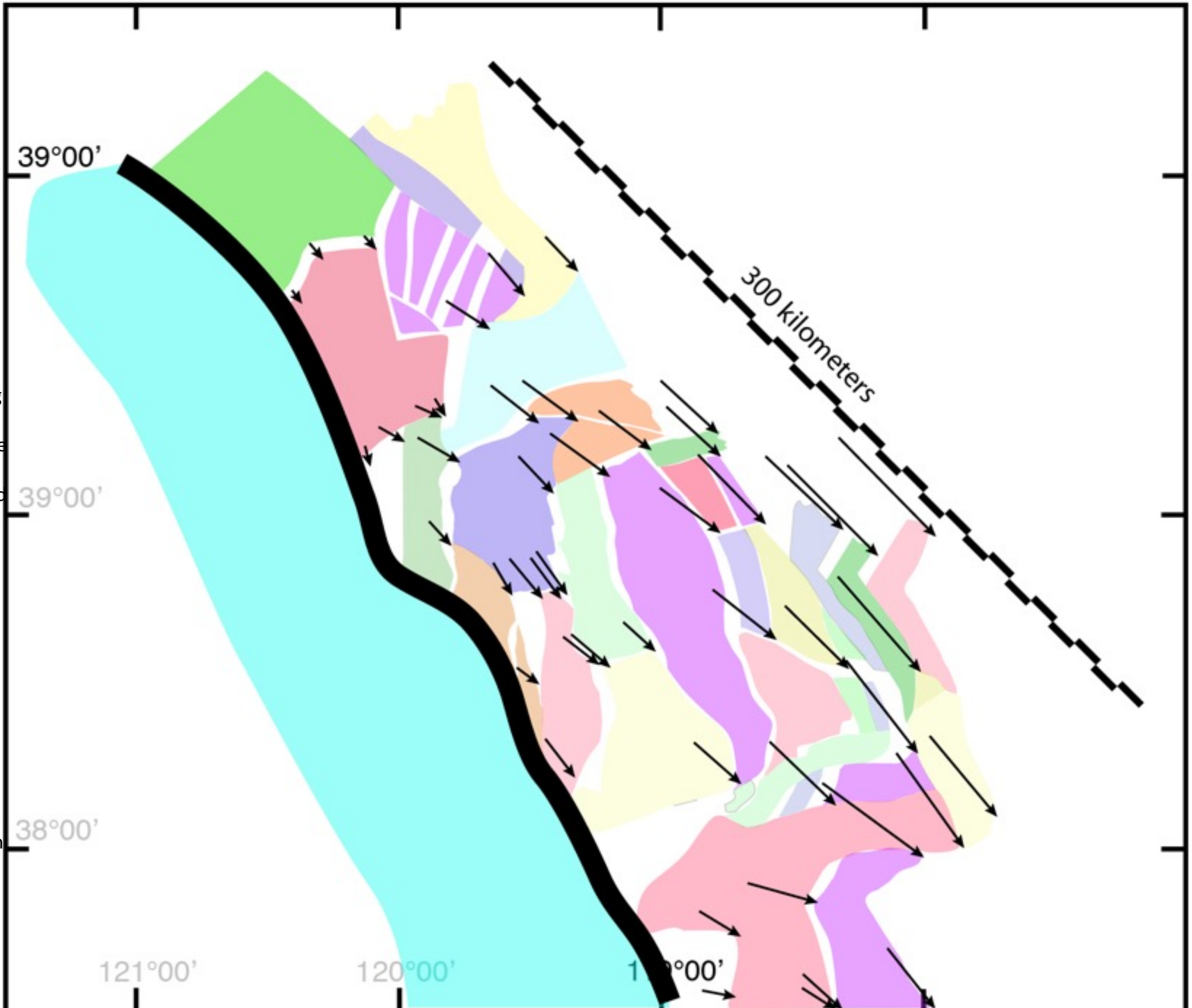
Same black arrows

The non pointed end
of each arrow thus represents from where the particular point at the
arrow tip came from....

if it is assumed the geodetic strain accumulation field has been operating since the point in time all blocks were connected - the black arrows should be oriented similar to today geodetic vectors...

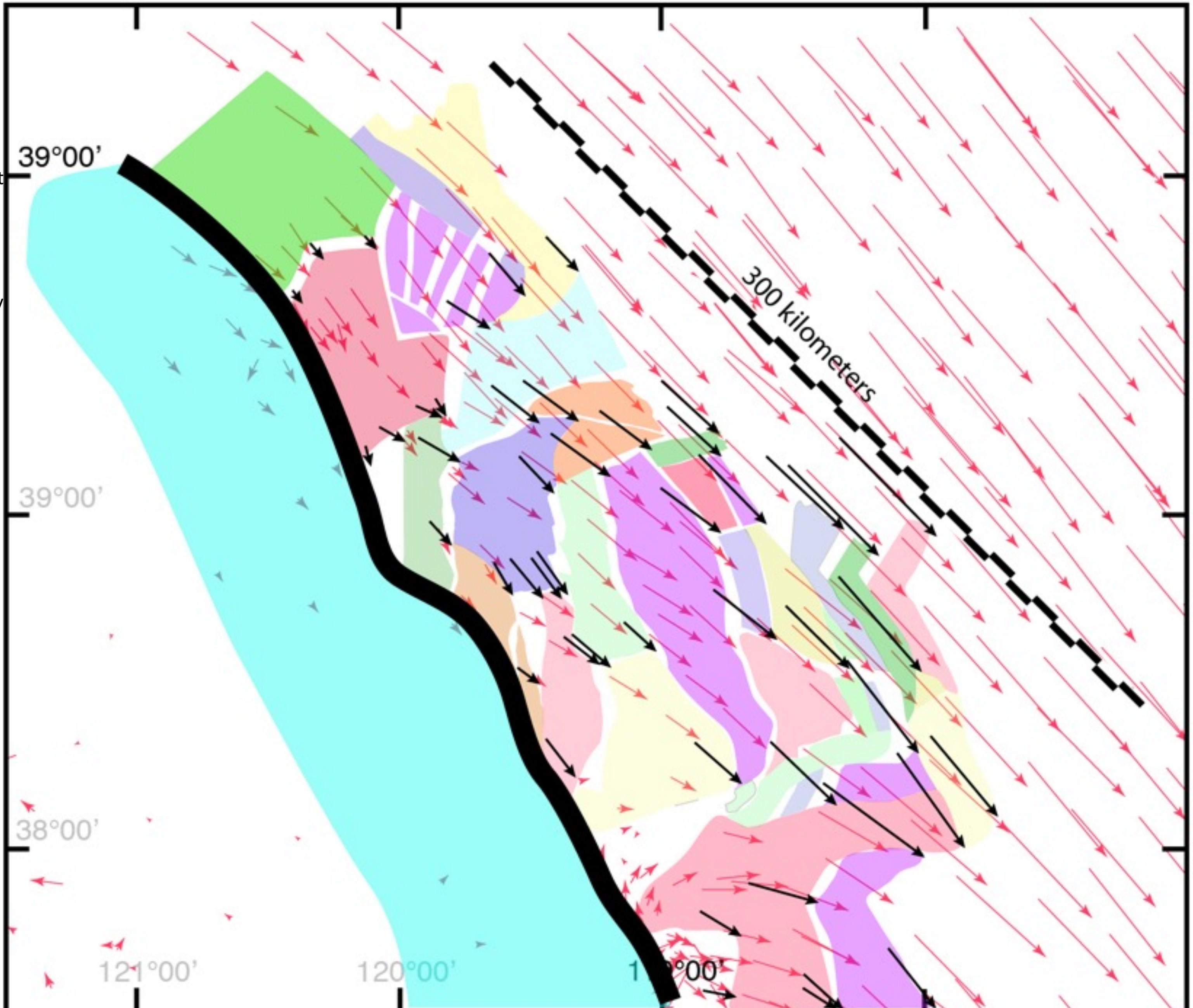
this is of course a big assumption - but
seems the most reasonable...

as with geology cumulative displacement is on order or ~20-30 km to north and 40-50 to the south



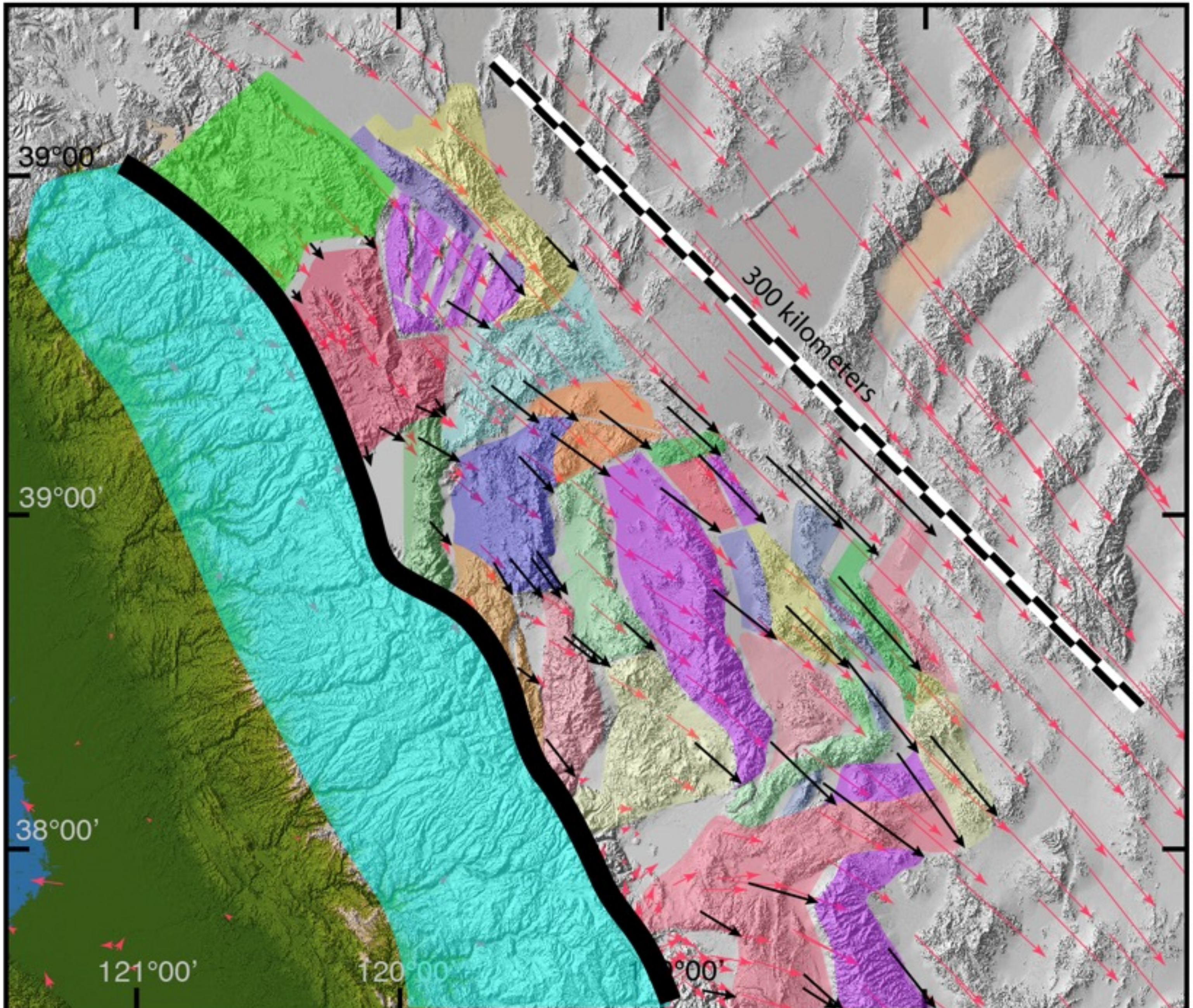
Red arrows are geodetic vectors with respect to Sierra Nevada - don't have scale on this plot but largest is about 1 cm/yr...

Scale of black arrows not the same! They are cumulative displacement of blocks...



02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

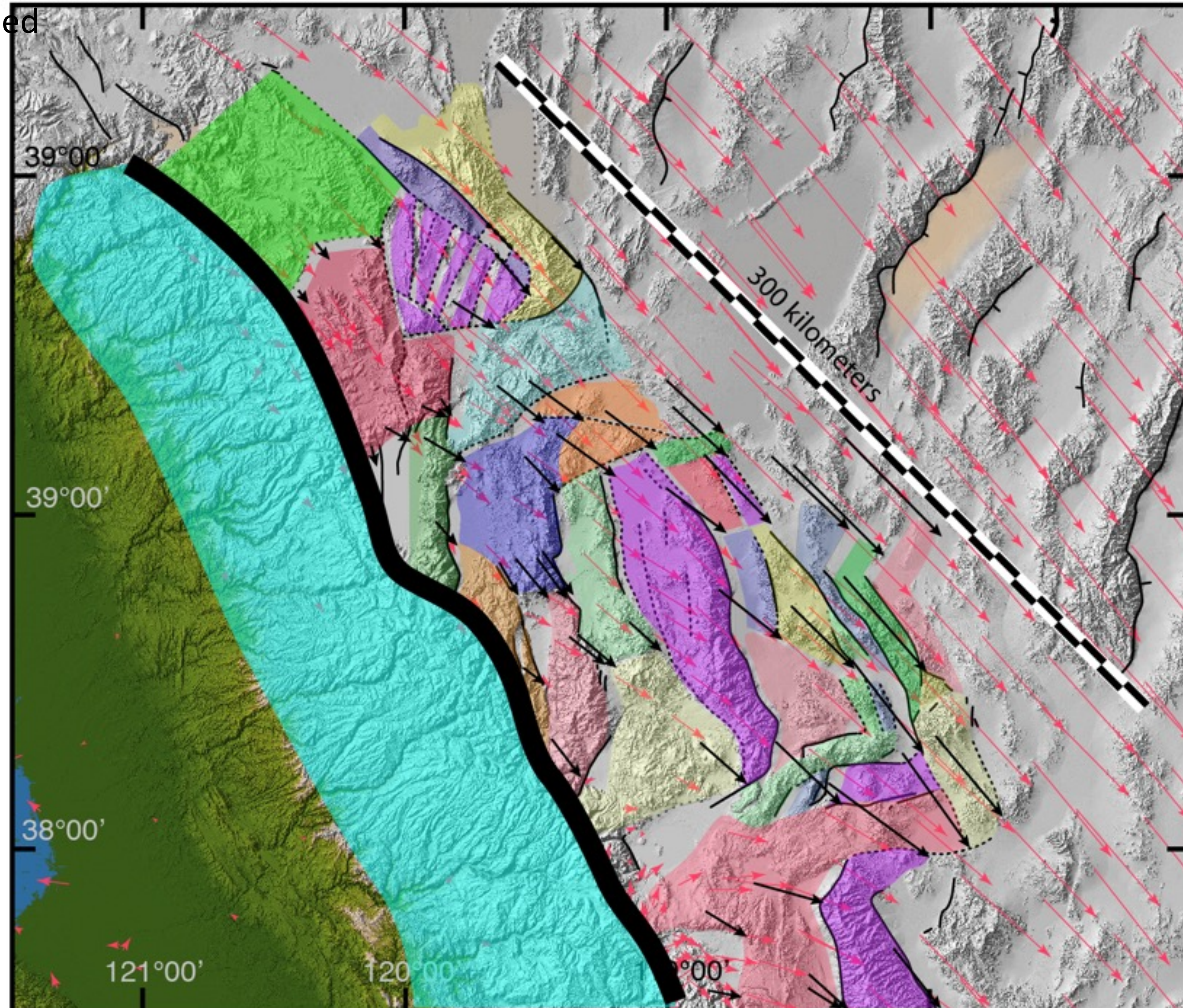
bservations of
evious slide placed
n
ysiogrpahic map



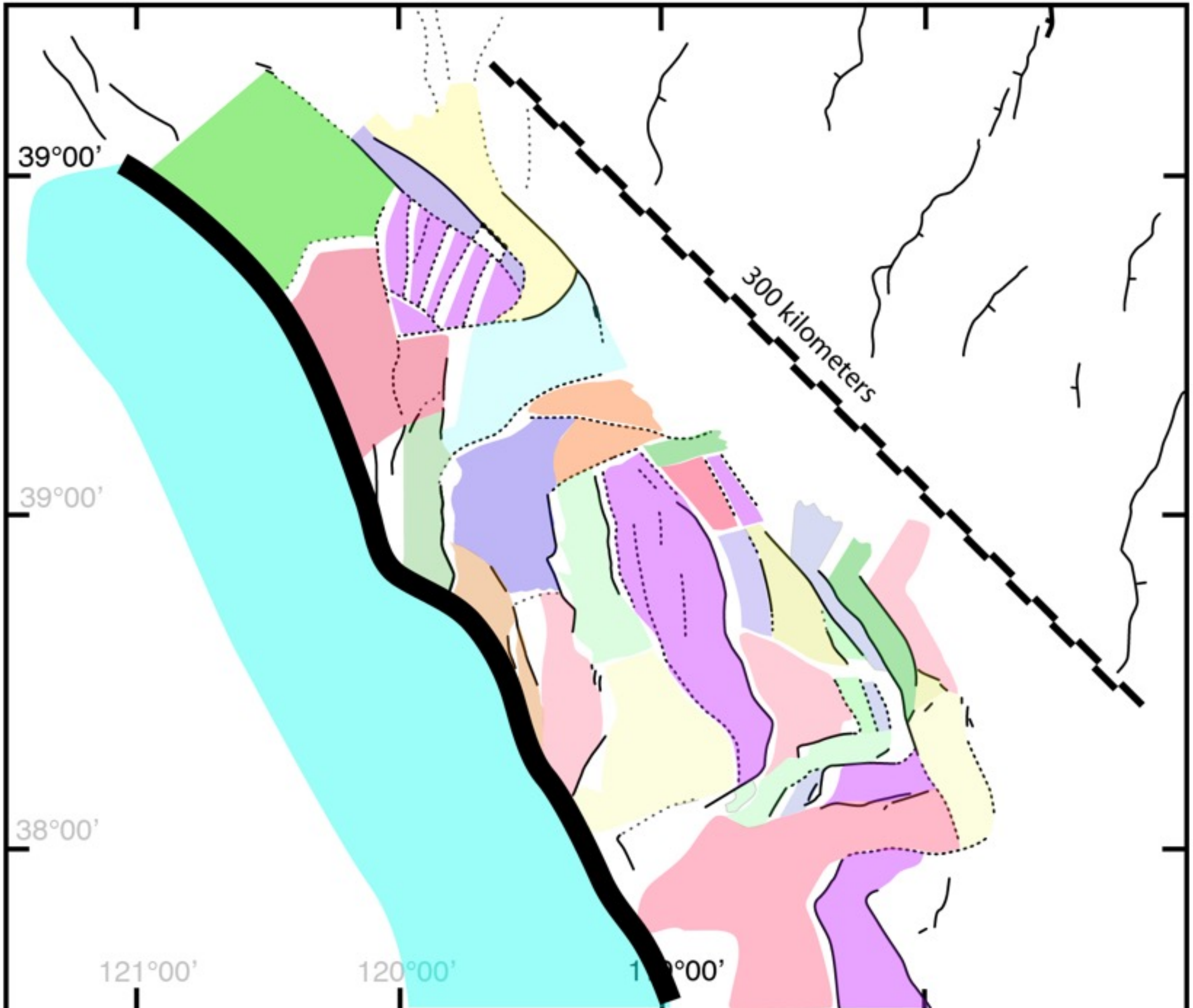
edropper

02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

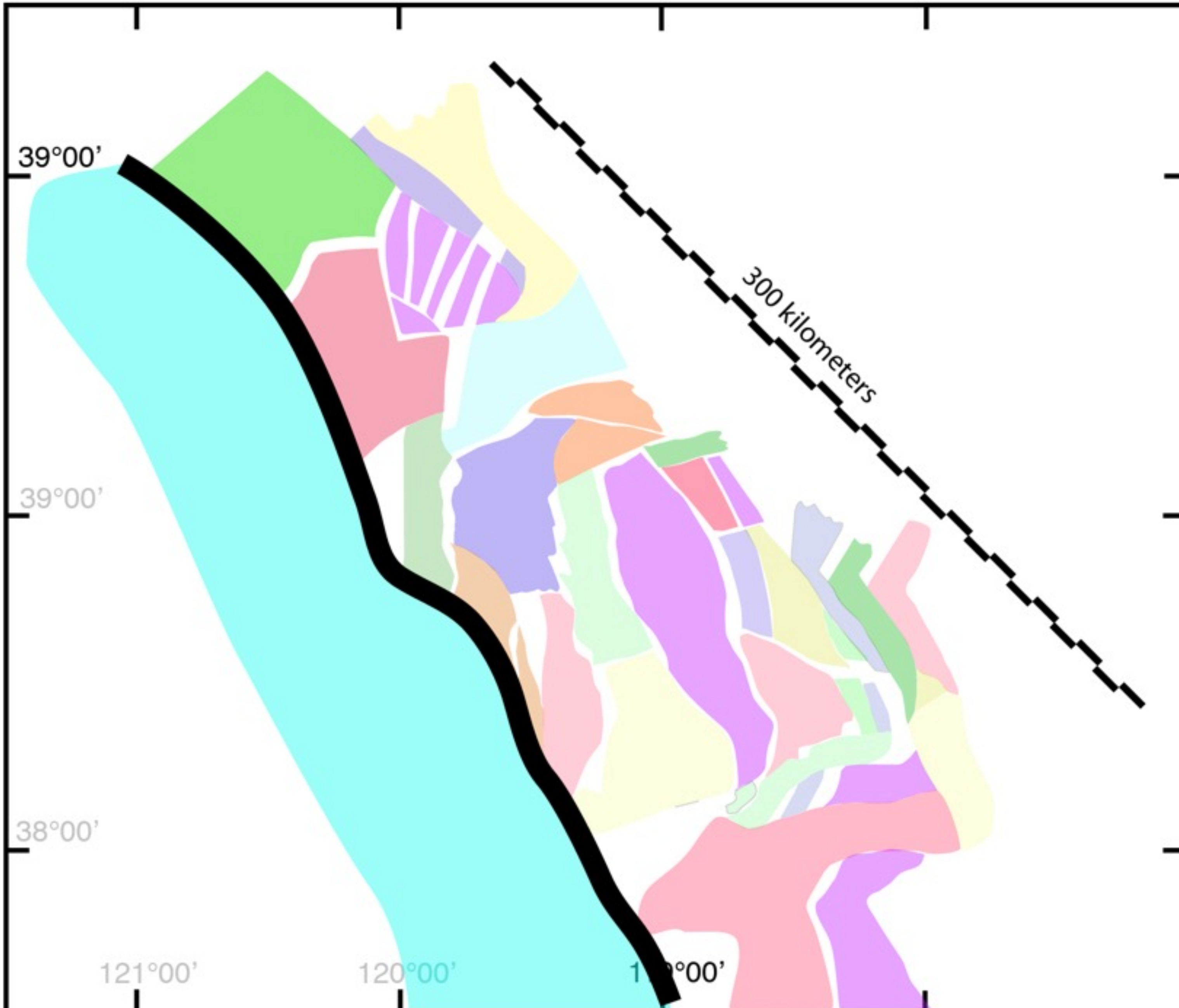
Faults added



physiography
now
removed...



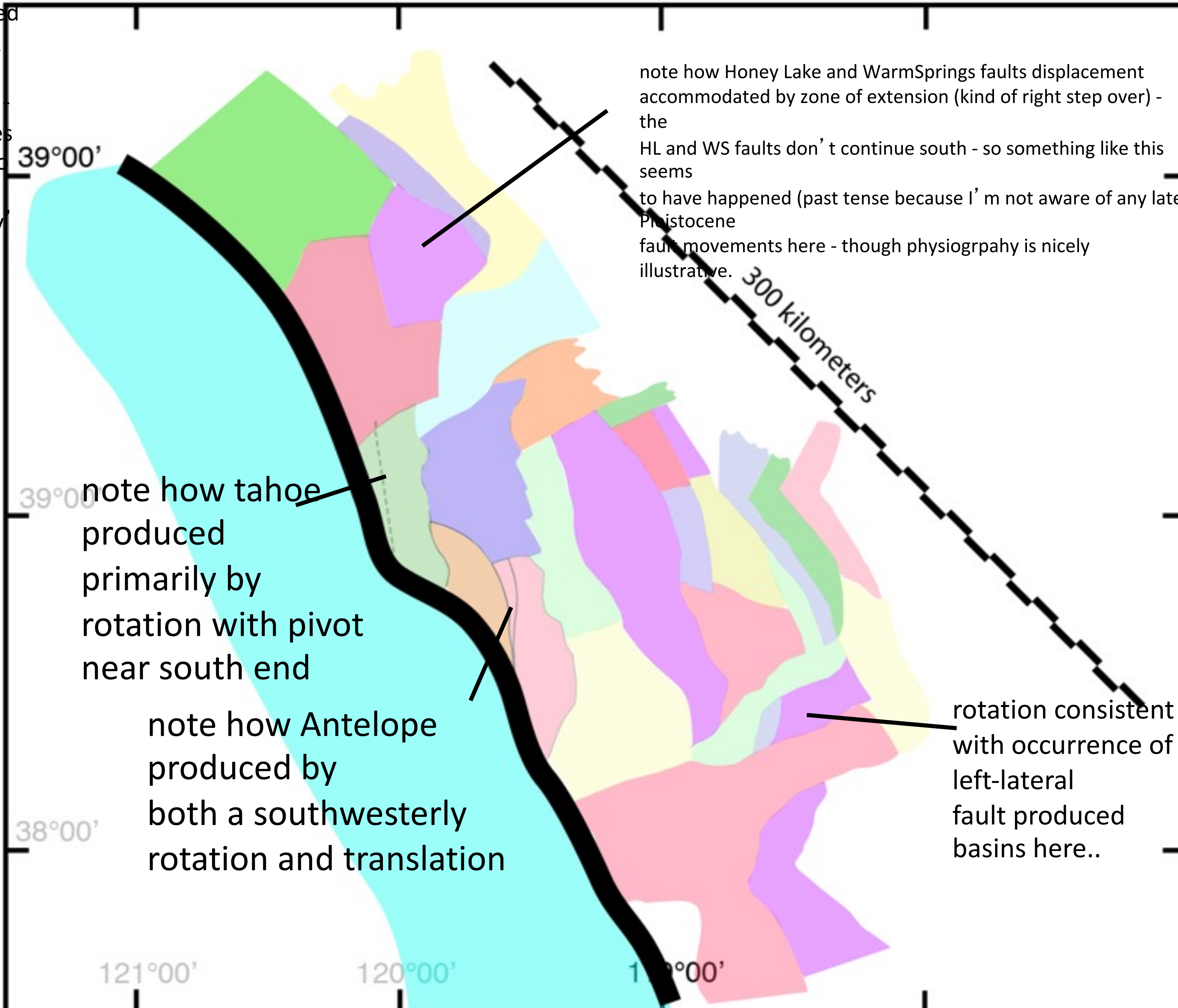
faults
removed



02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

and blocks placed back together....

why this is here - because it makes convenient to go toggle between ‘today’ (next slide) and ‘original’ view (this slide).



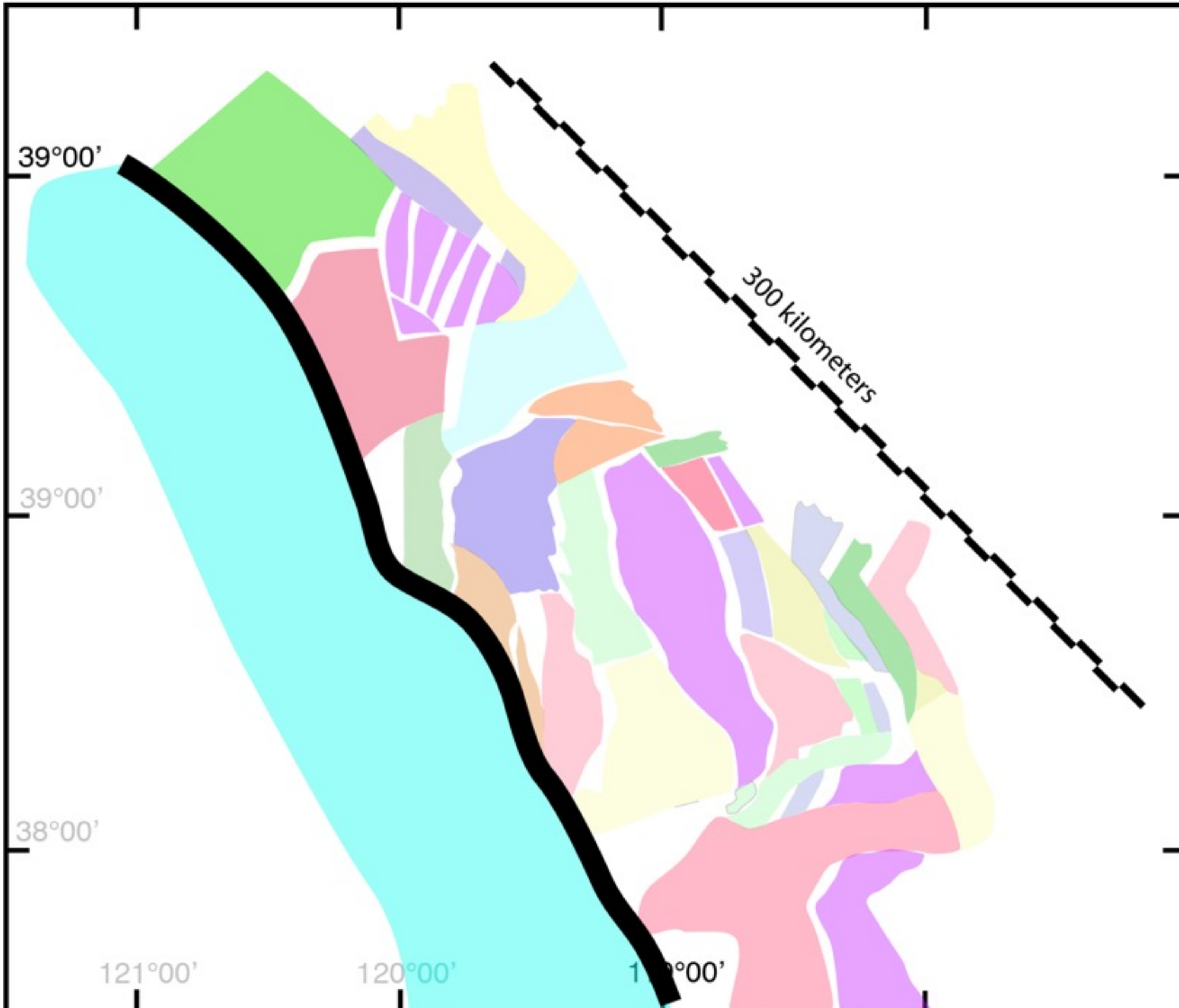
note how Honey Lake and WarmSprings faults displacement accommodated by zone of extension (kind of right step over) - the
HL and WS faults don’t continue south - so something like this seems
to have happened (past tense because I’m not aware of any late Pleistocene
fault movements here - though physiogrpahy is nicely illustrative.

note how tahoe produced primarily by rotation with pivot near south end

note how Antelope produced by both a southwesterly rotation and translation

rotation consistent with occurrence of left-lateral fault produced basins here..

'today'
view



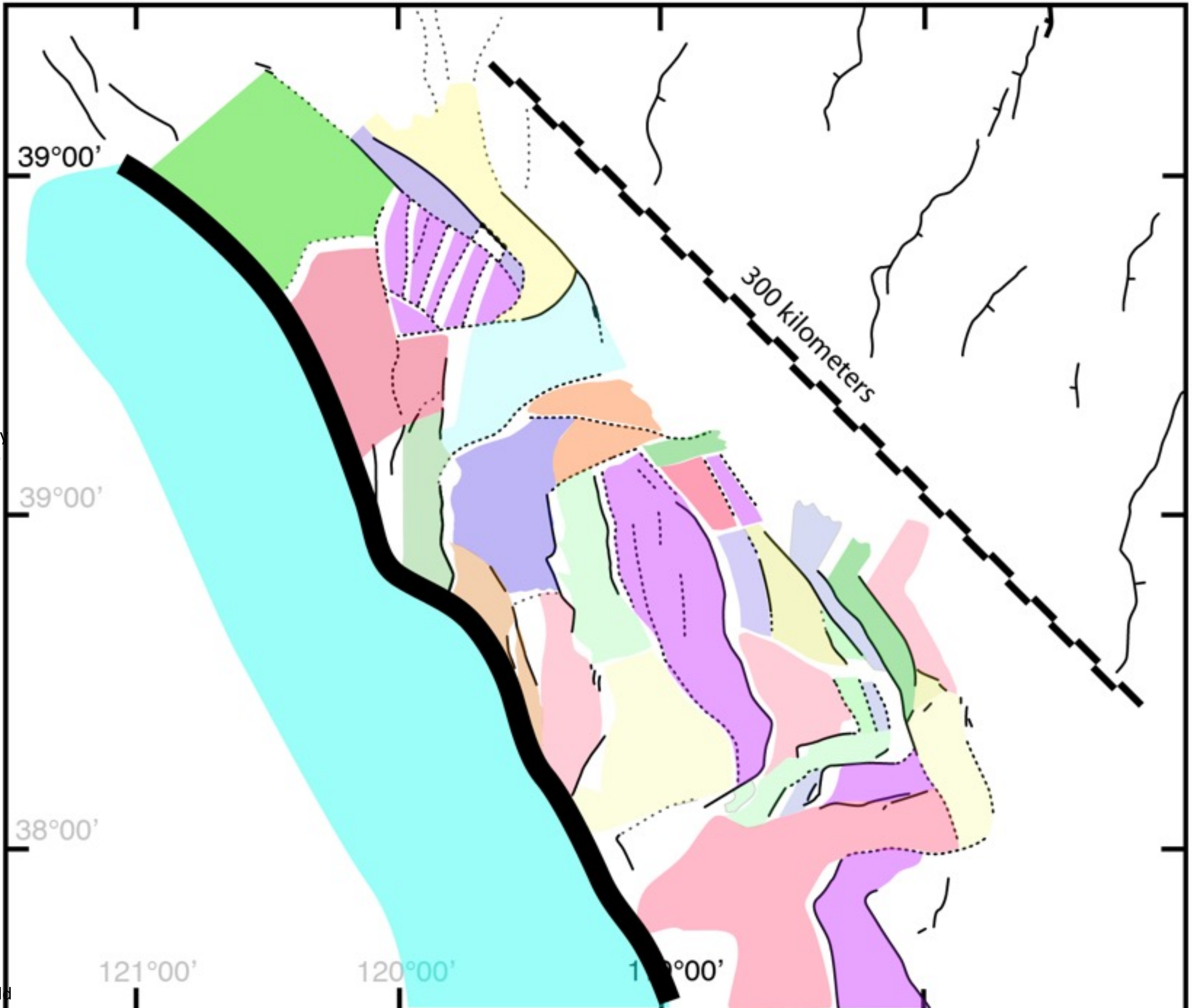
02-ModelFig03vers2-3x-300-45-36dpi-3.75%.ai @ 300% (RGB/Preview)

‘today’ view again but with faults this time

in sum seems quite hard or next to impossible to get cumulative deformation field to share directional characteristics of geodetic field without requiring some oblique slip on the major range bounding normal faults....

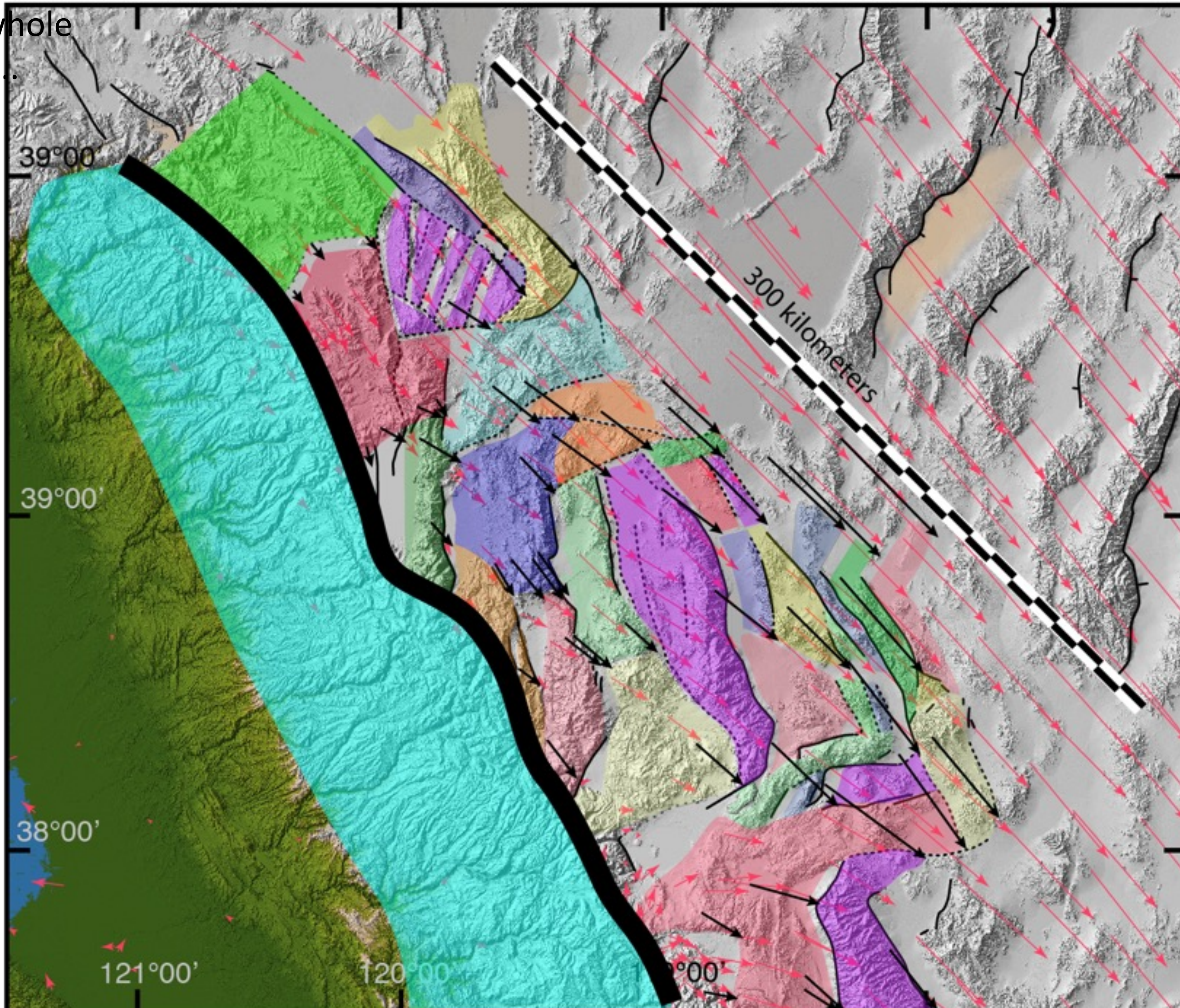
so we are missing it in the morphology and trenches of the faults or it is being accommodated by distributed deformation or something out in the basins --- the 1954 Fairview Peak earthquake showed 50-50 strike-slip but it would not be recognized but for the earthquake itself (though bedrock mapping suggests so) -

Nonetheless, I think the previous idea that a transect across the Lane cannot account for the geodetic field by faulting alone -

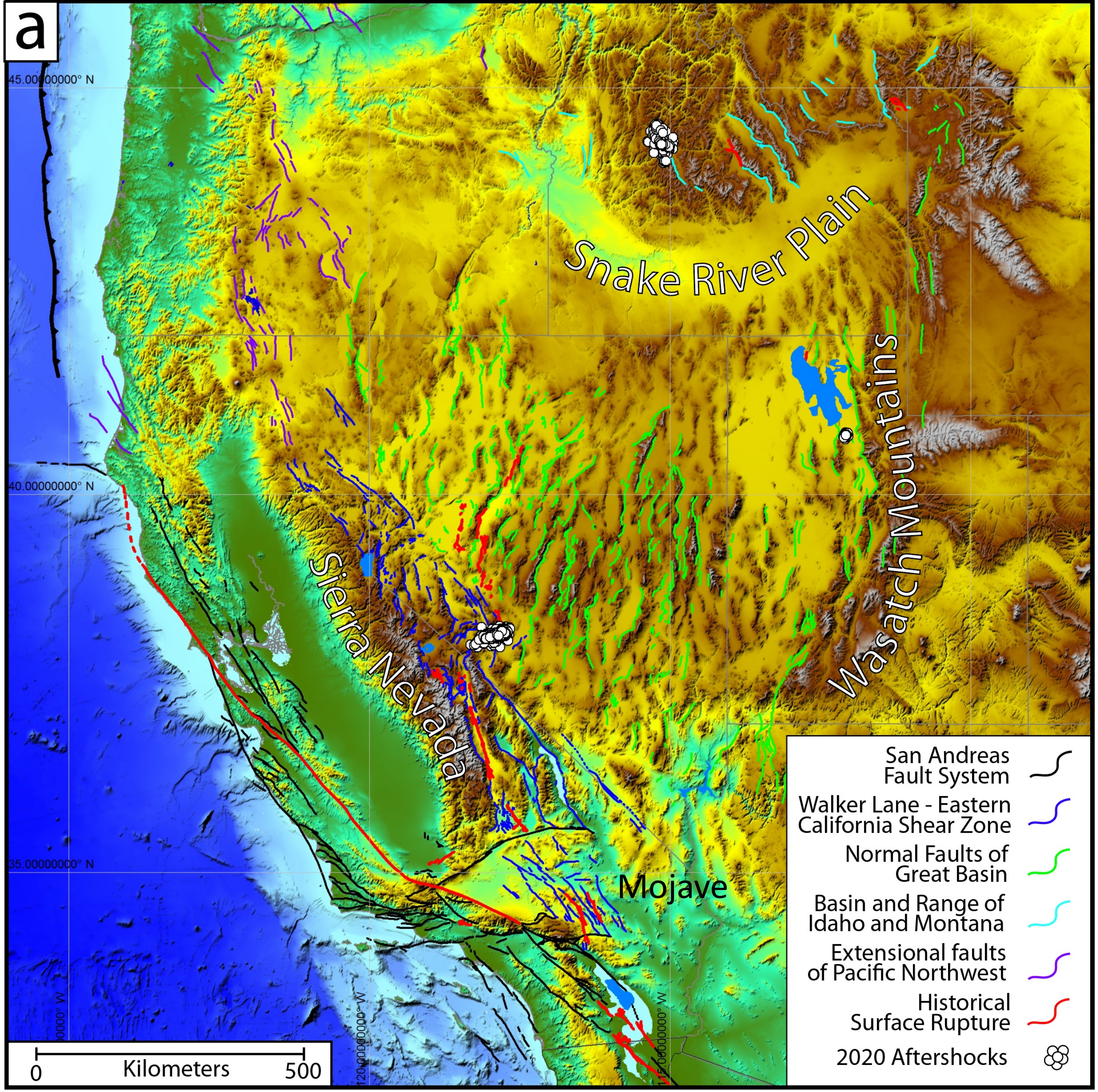


the ‘stretching and

and the whole enchilada..



all based on phsiography and faults - not checking geology someone should.



So now, how did it get this way and when

With a brief stop to consider glaciations