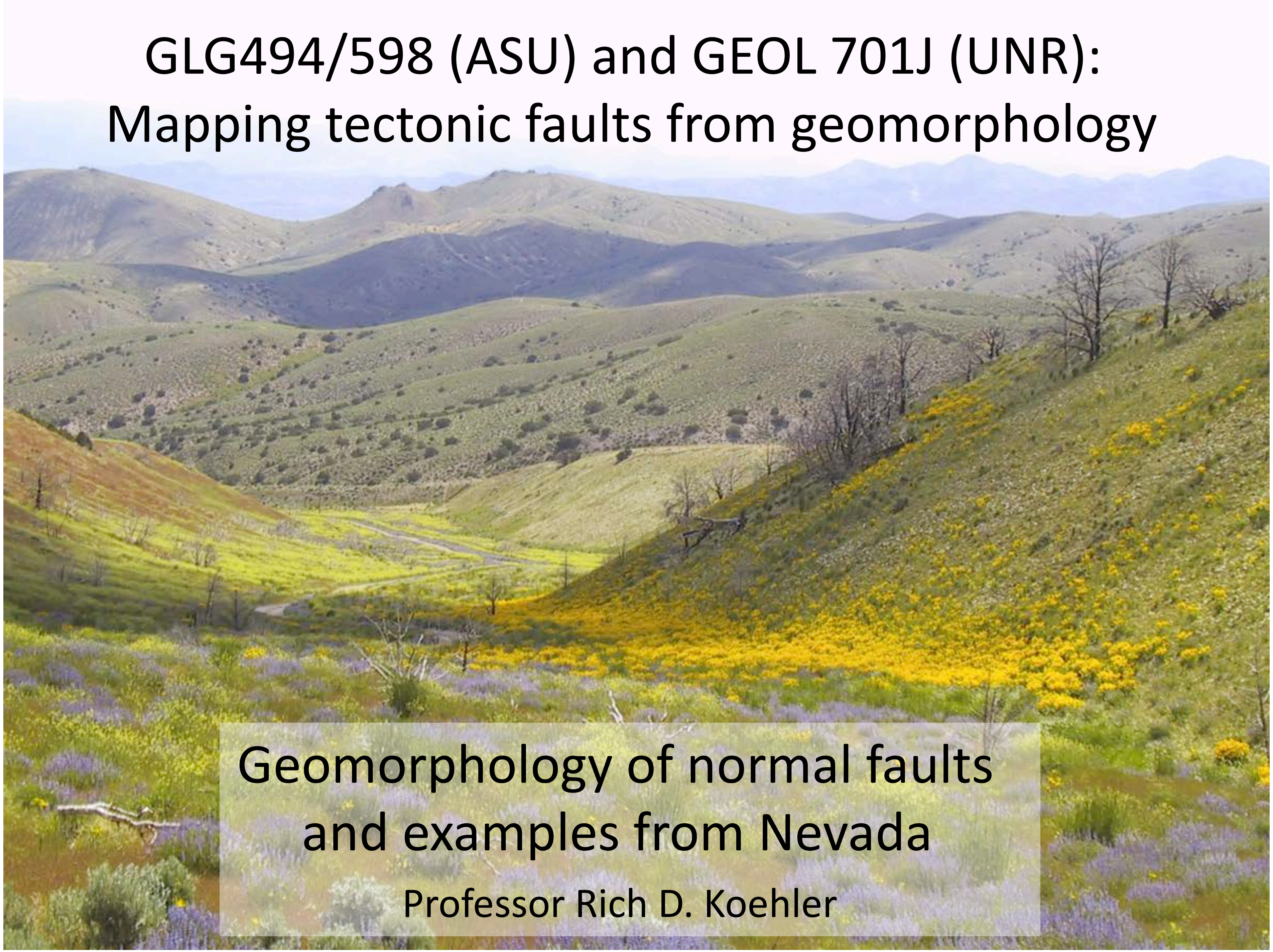
GLG494/598 (ASU) and GEOL 701J (UNR): Mapping tectonic faults from geomorphology



Geomorphology of normal faults and examples from Nevada

Professor Rich D. Koehler

Outline of topics

- Normal faulting environments
- Basin and Range Province
- Geomorphic features along active normal faults
- Historical ruptures: surface map expression
- Examples of mapping normal faults

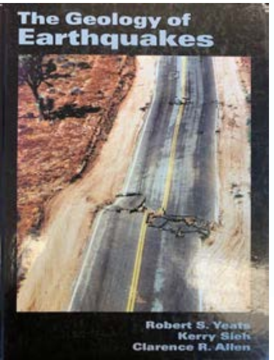


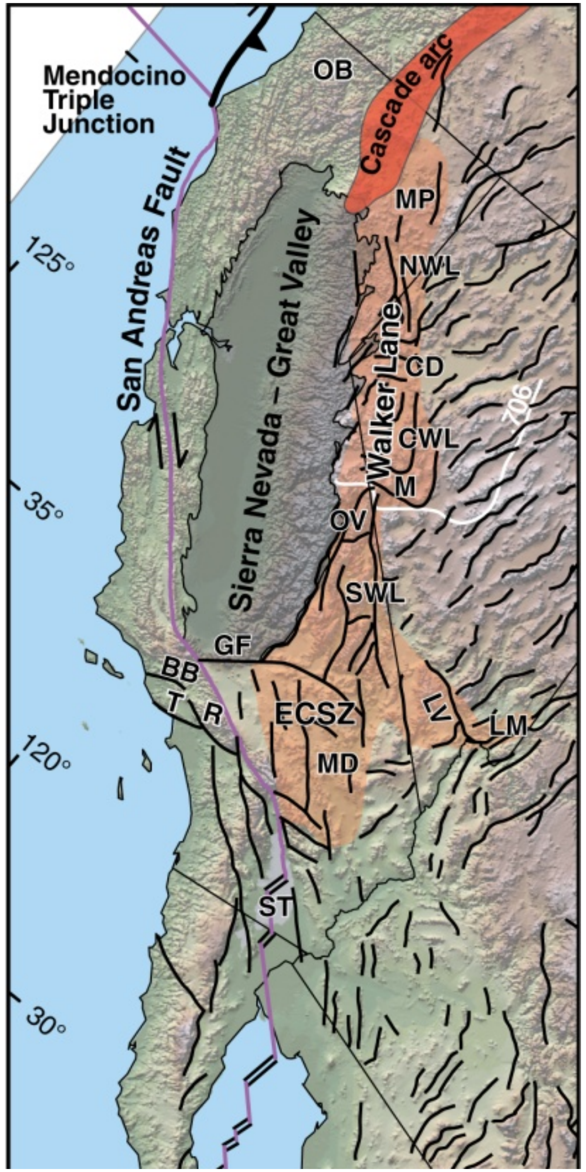
Figure 9–1. Locations of major active onshore normal-fault systems: 1. Hawaii; 2. Sierra foothills; 3. Basin and Range; 4. Rio Grande Rift; 5. Gulf of Guayaquil; 6. Altiplano; 7. Mejillones Peninsula; 8. Iceland; 9. Apennines; 10. Greece; 11. Bulgaria; 12. Western Anatolia; 13. North Yemen; 14. Afar Triangle; 15. East African rift valleys; 16. Southern Tibet; 17. Ordos; 18. Baikal rift system; 19. Taupo Volcanic Zone.

- Origin due to crustal extension.
- Maximum compressive stress is vertical.
- Commonly in areas with high heat flow and relatively low velocity upper mantle.

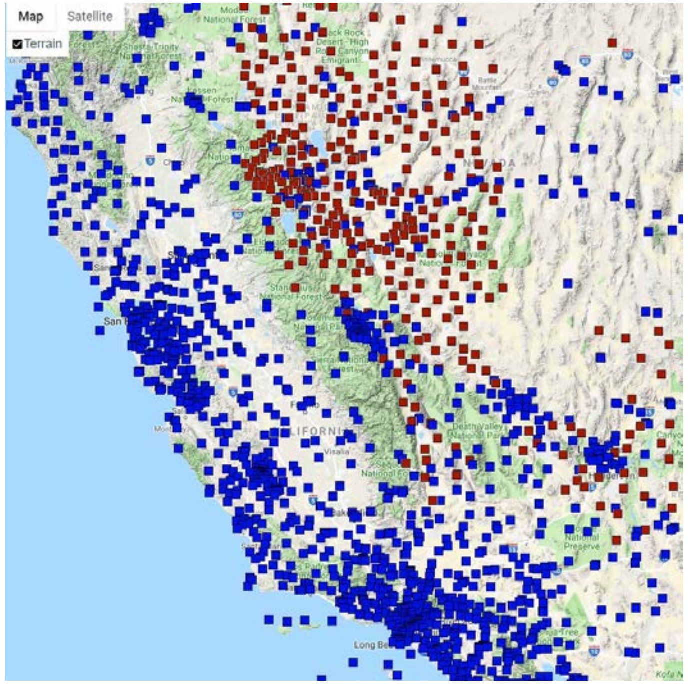
Geologic environments include:

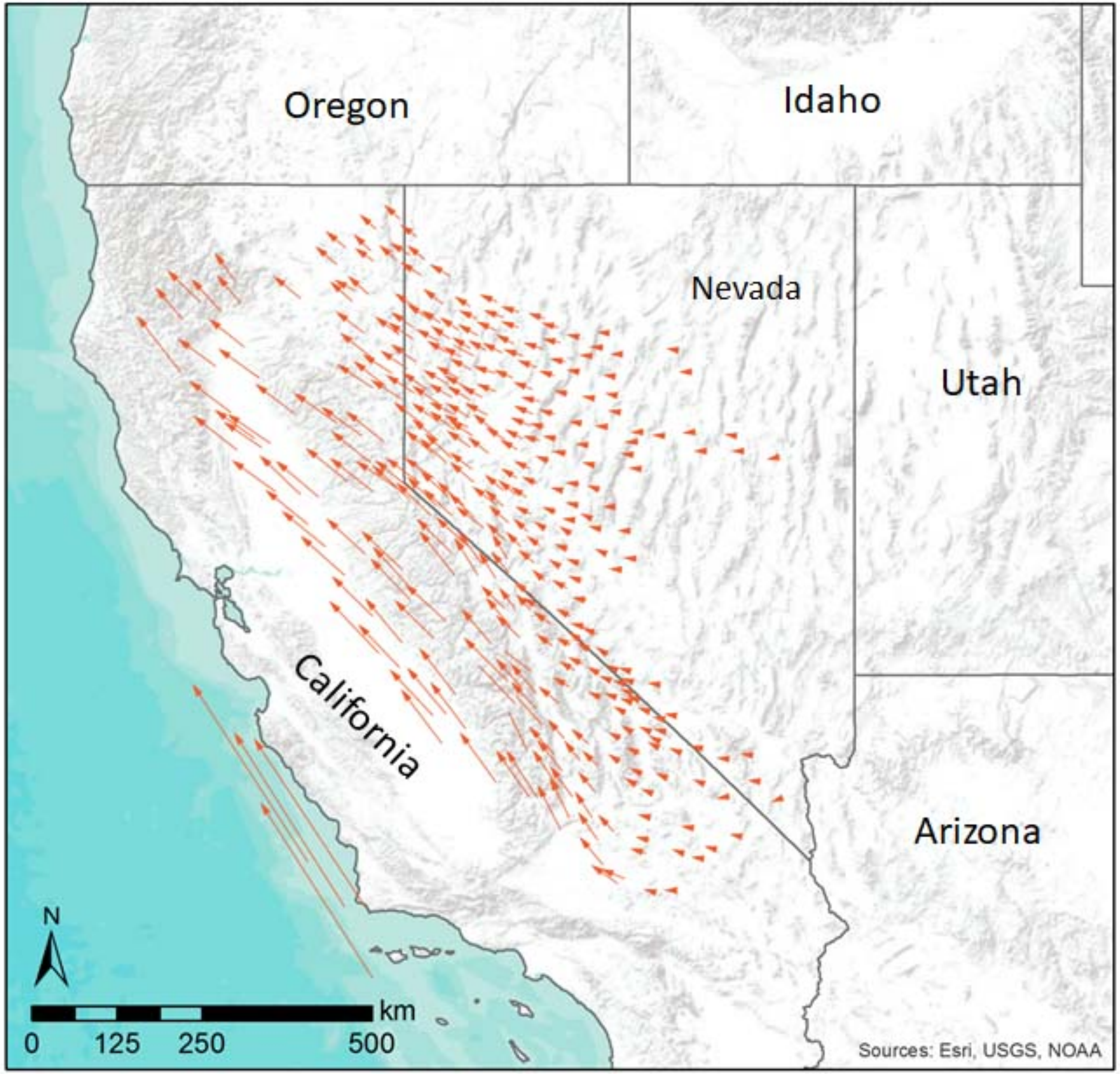
- Spreading centers
- Back arc basins
- Intracontinental rift systems
- Areas inboard of continent/continent collision.
- Subduction zones (due to flexing and horizontal compression)

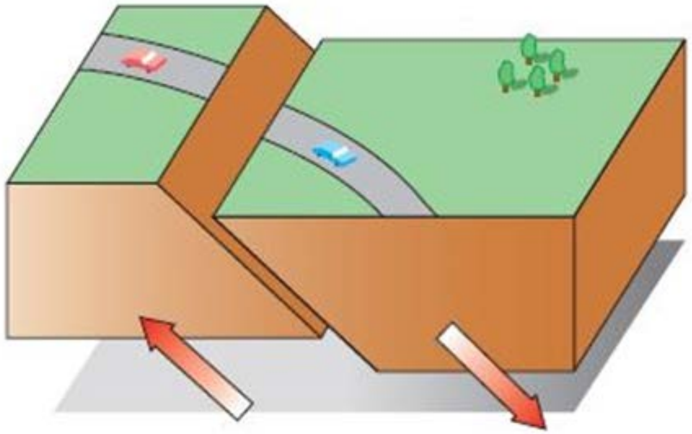
Basin and Range Province

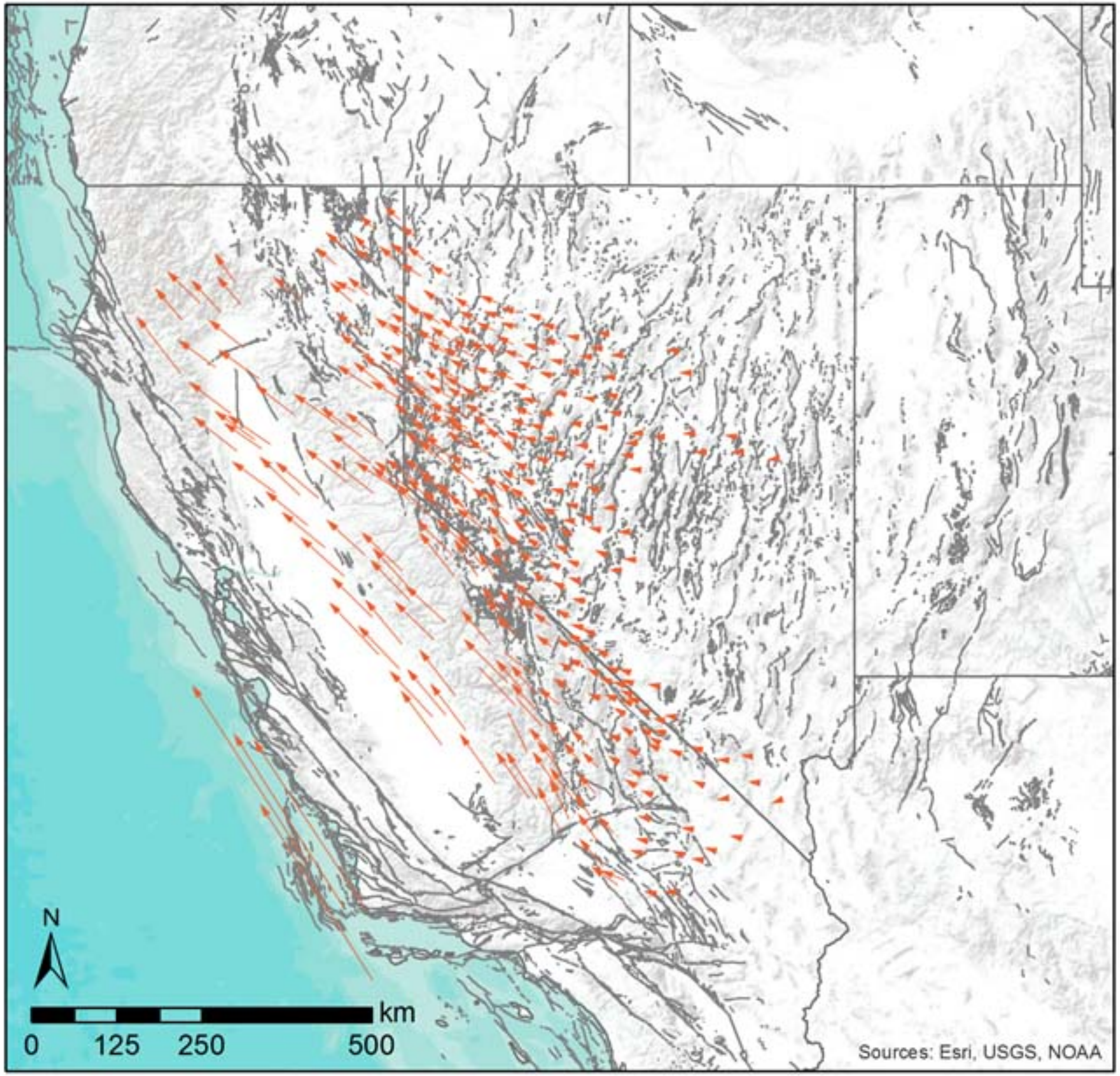


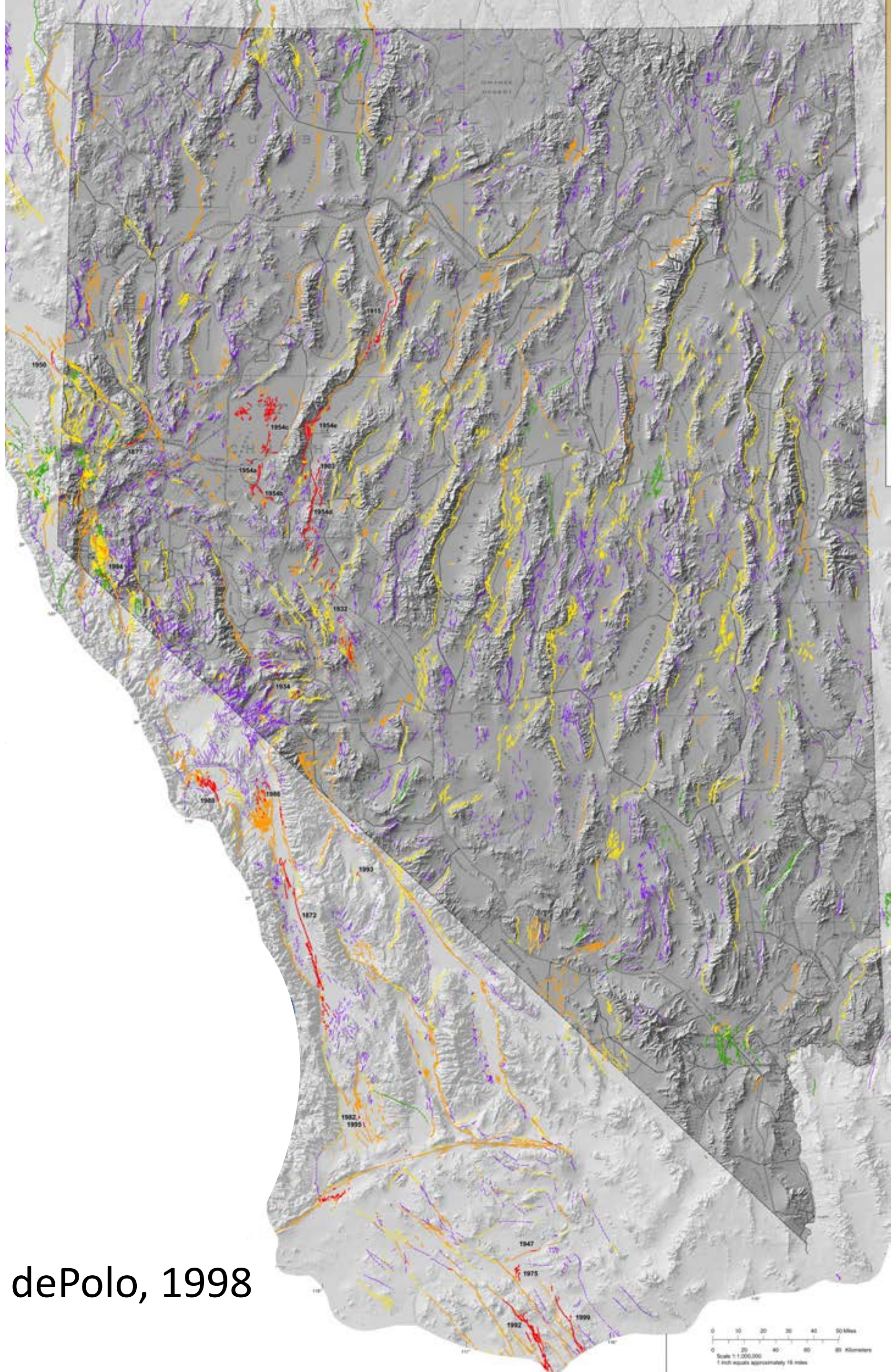
Mountain and basin topography is the result of
Progressive extension and normal fault displacement


Map
Satellite
Terrain


Oregon
Idaho
Nevada
Utah
California
Arizona
N
km
0
125
250
500
Sources: Esri, USGS, NOAA




N
km
0
125
250
500
Sources: Esri, USGS, NOAA



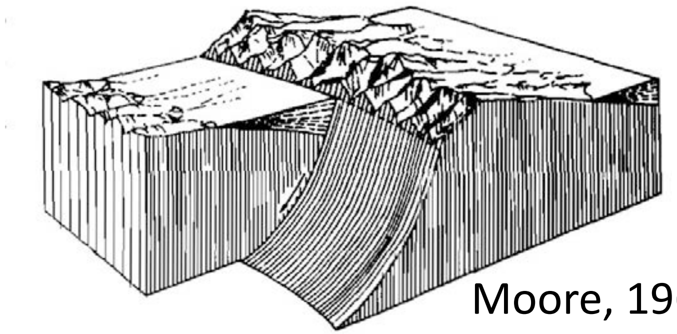
dePolo, 1998

Quaternary fault map of Nevada

- Purple – Quaternary <1.8 ma
- Green – mid Quaternary <750 ka
- Yellow- latest Quaternary <130 ka
- Orange – latest Pleistocene-Holocene <15 ka
- Red - Historic

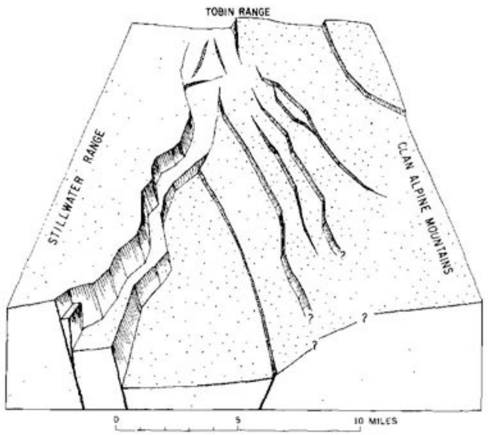
Models of Basin and Range faulting

Tilted block model



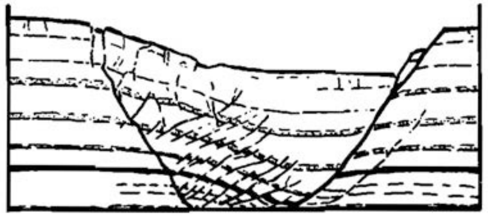
Moore, 1960

Tilted block model
With basin sediment removed

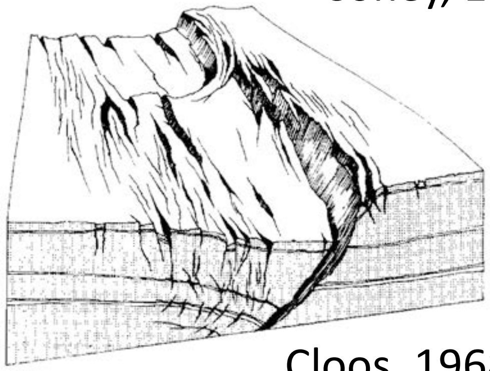


Burke, 1967

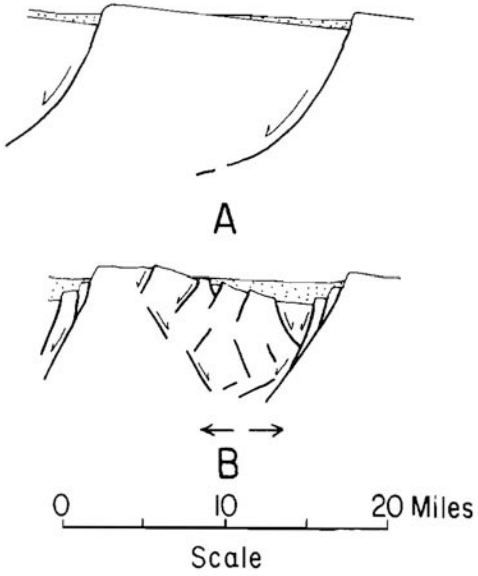
Clay models



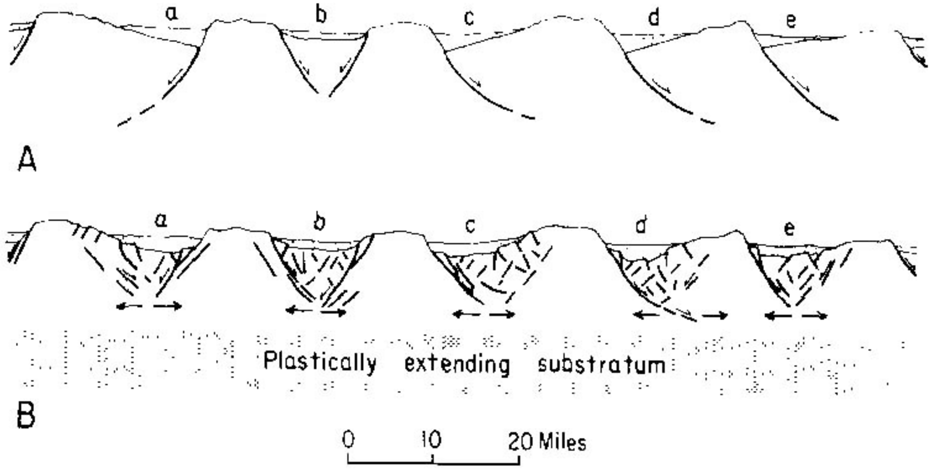
Coney, 1969



Cloos, 1968

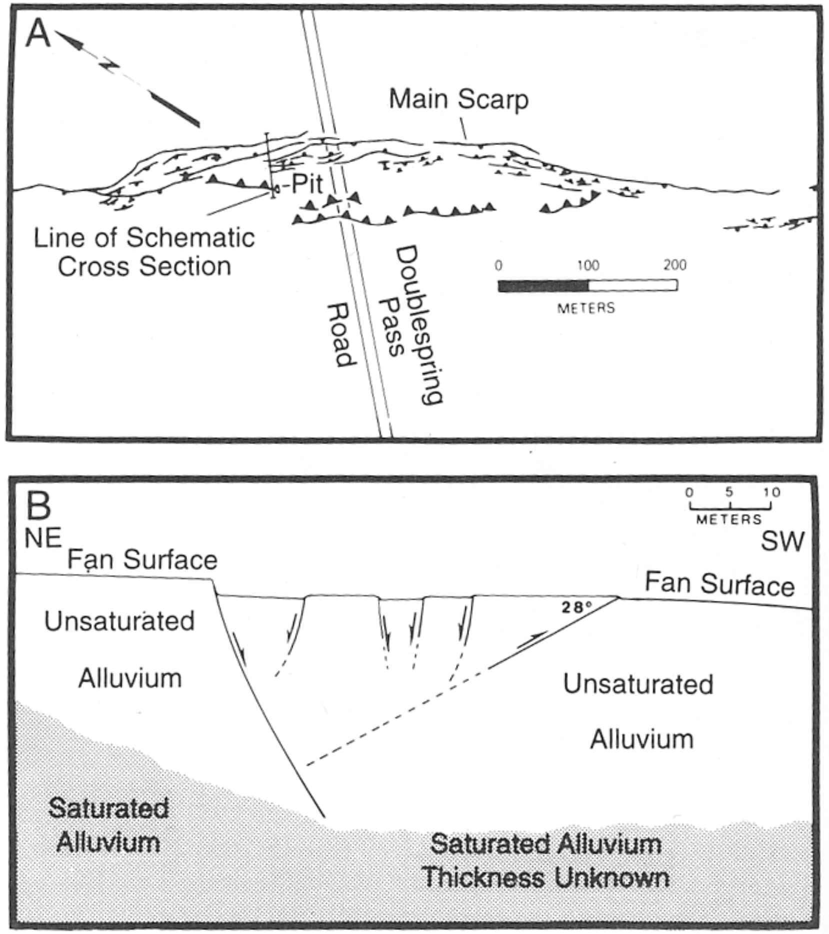


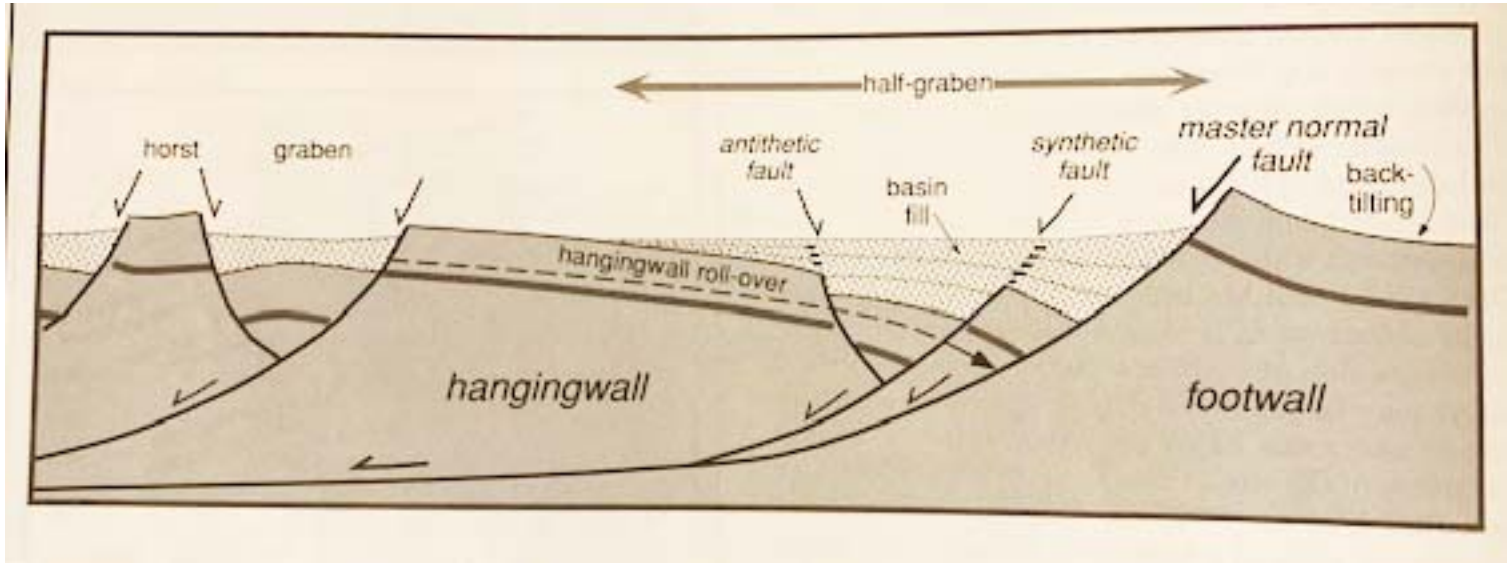
Asymmetrical graben



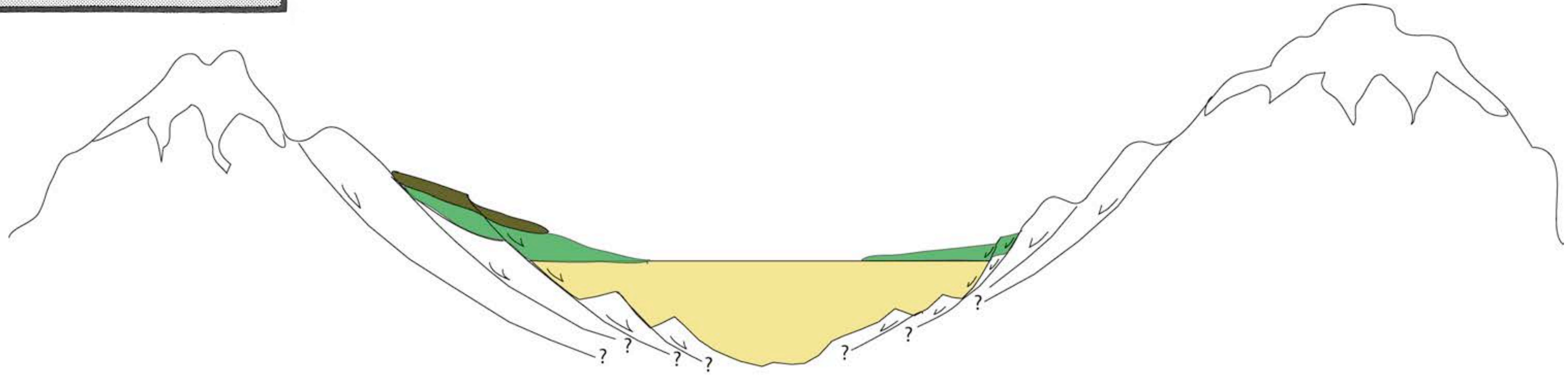
Stewart, 1971

Basin and Range structure some combination of tilted blocks and horst and graben formation.

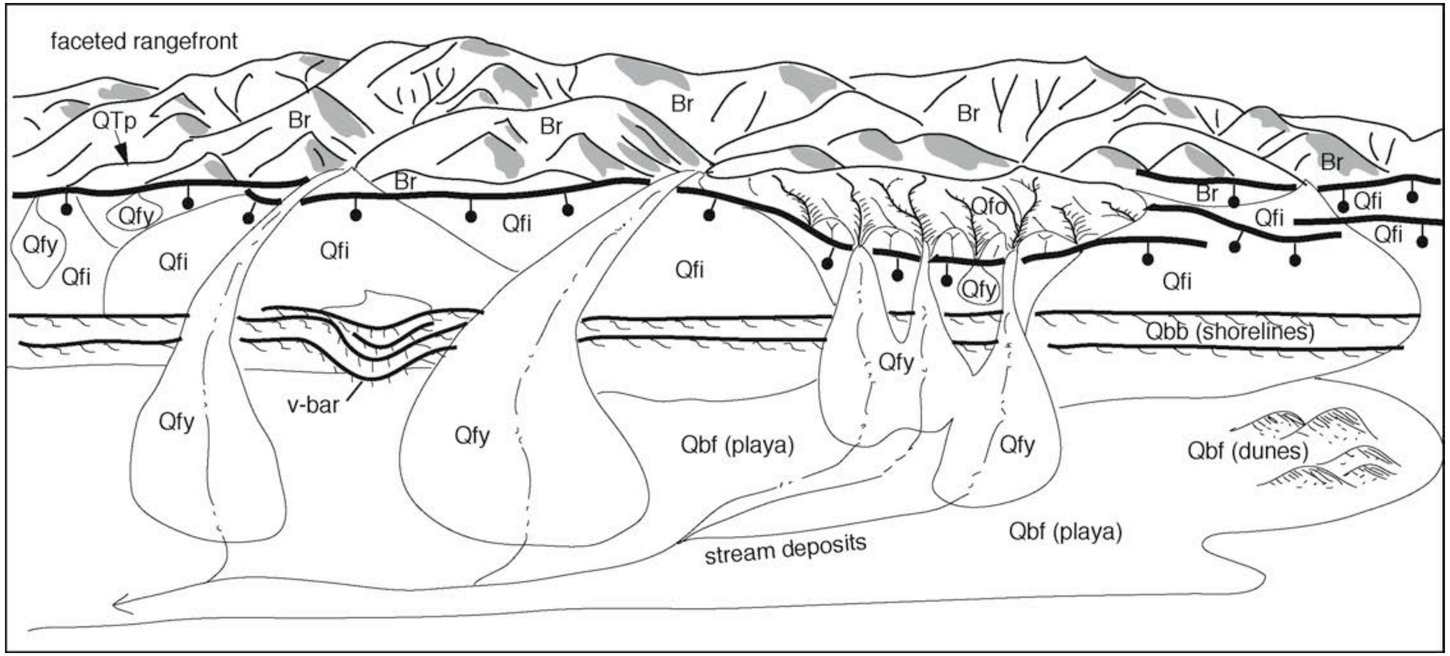




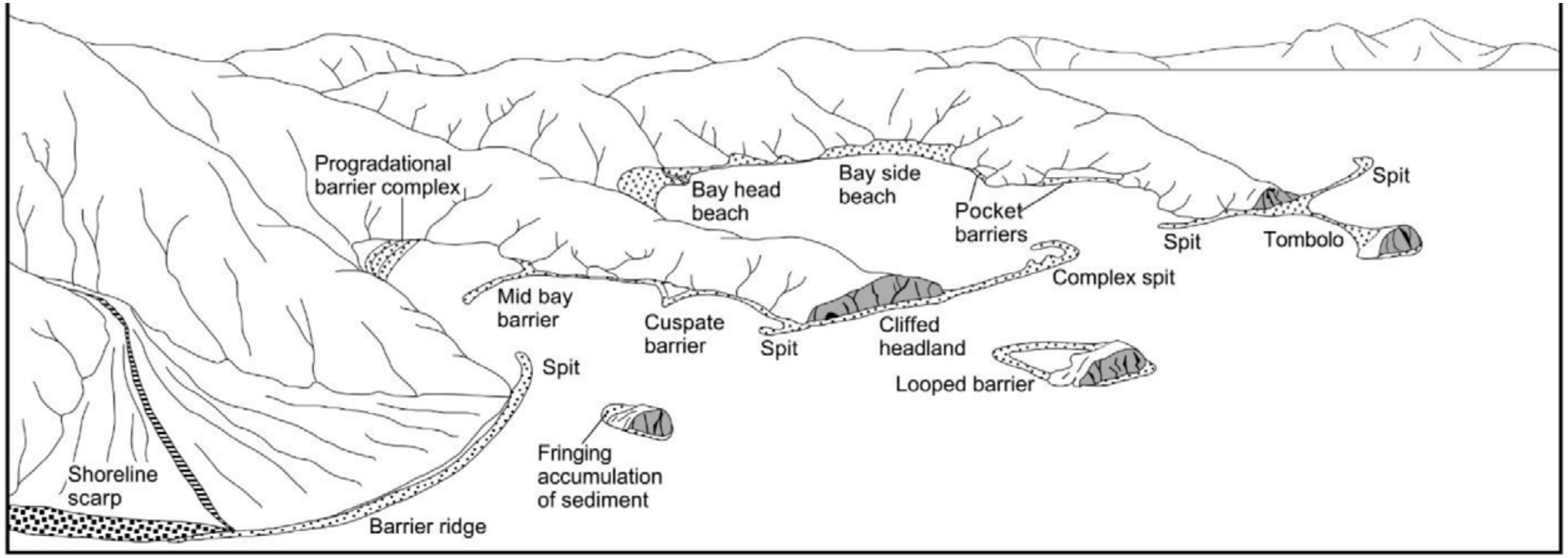
Burbank and Anderson, 2001



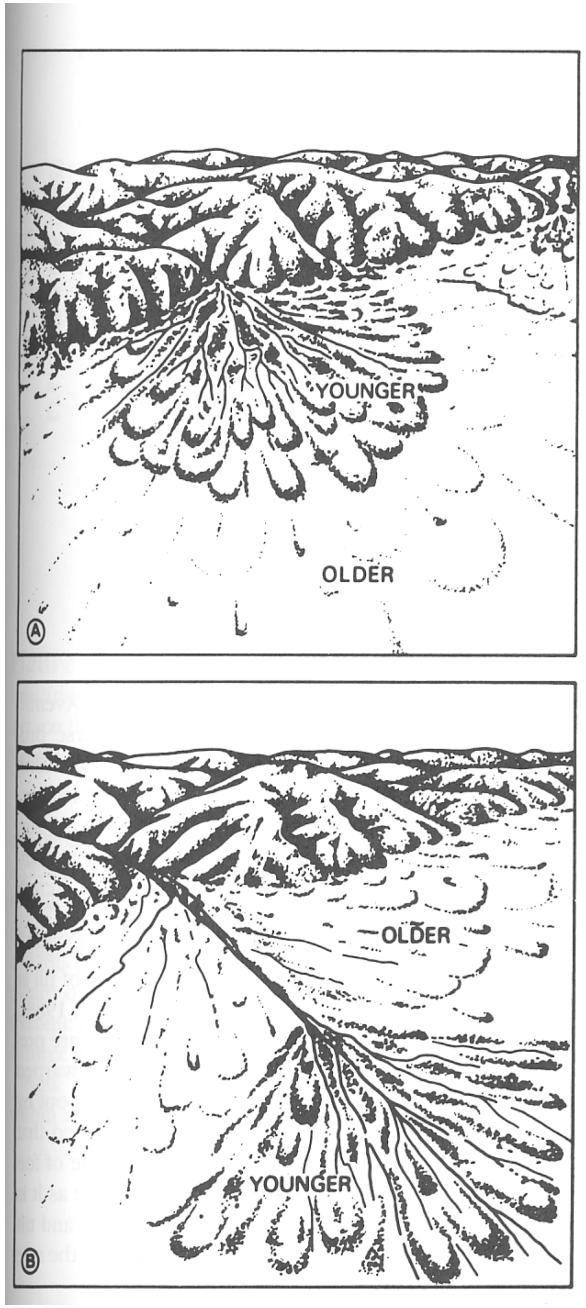
Geomorphic features along normal faults



Alluvial fan and
Lacustrine stratigraphy



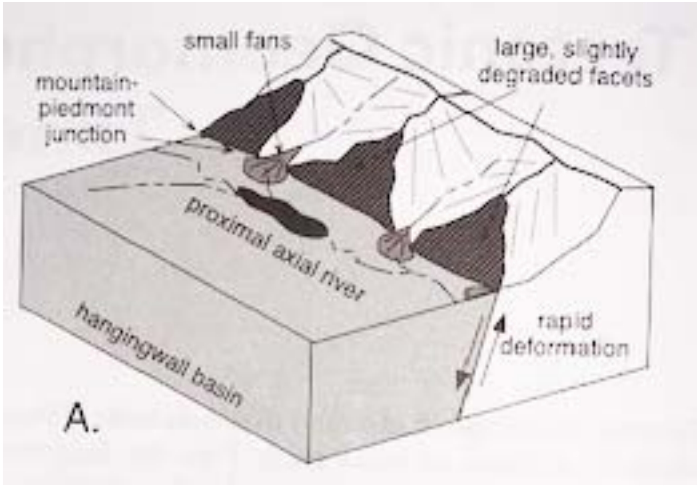
Variable rates of deformation



Bull, 1964

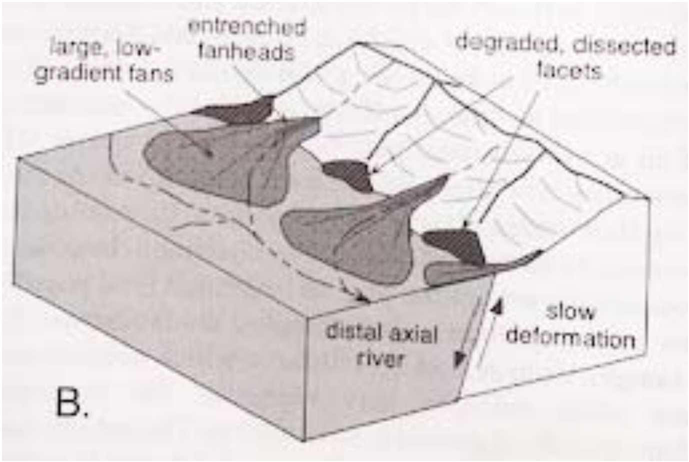
Relatively fast Uplift

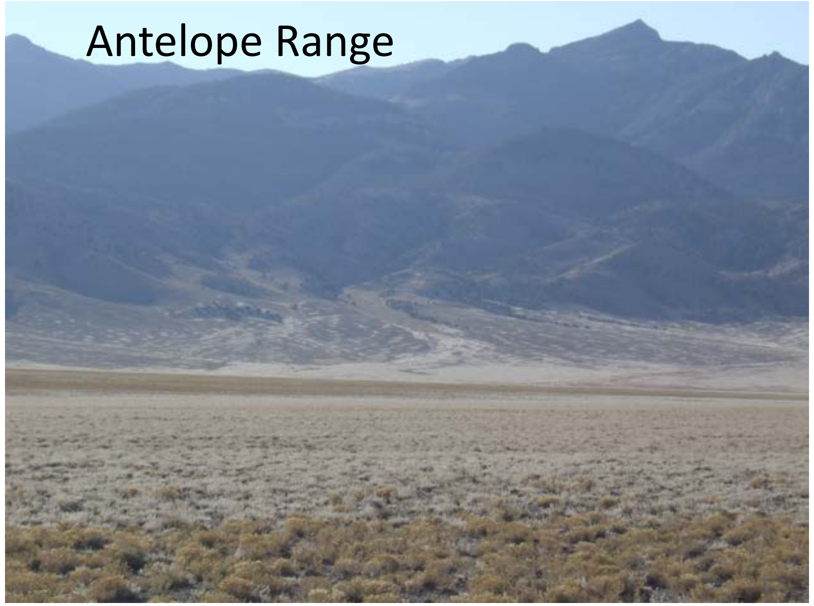
Steep young fans at mt. front, large Facets, proximal axial river, linear range front.



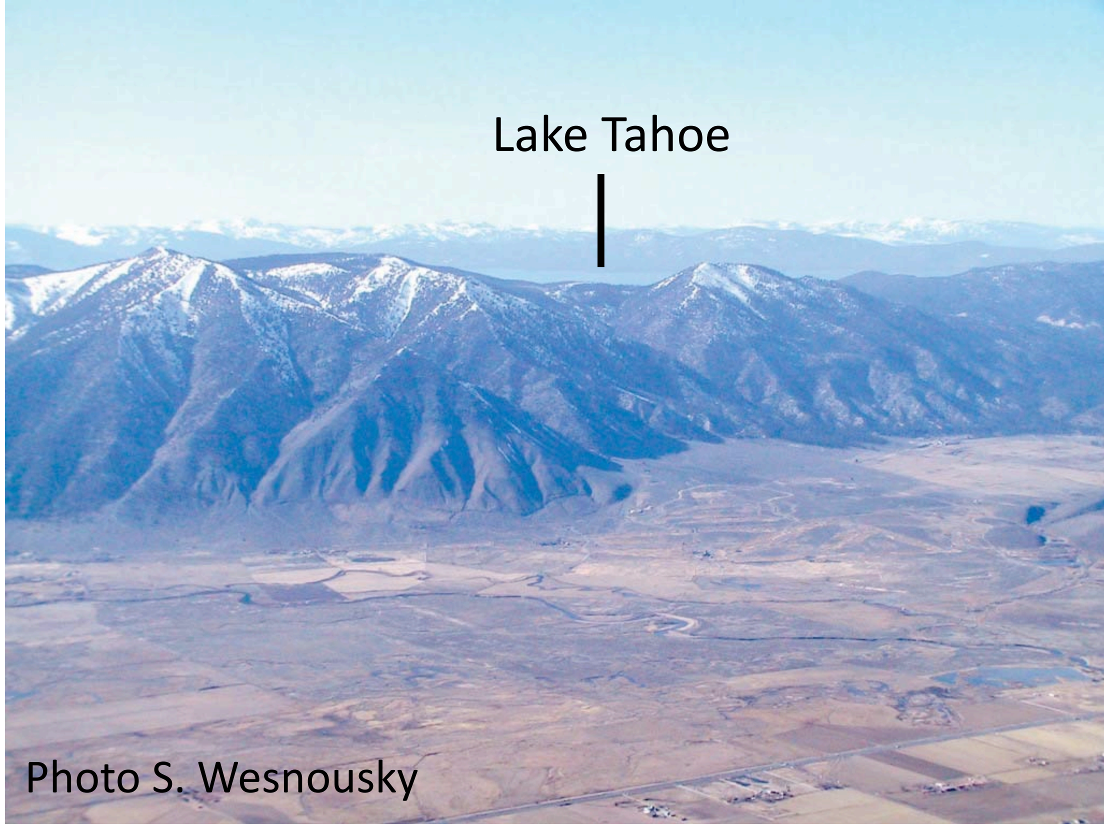
Relatively slow Uplift

Shallow young fans away from Mt front, small facets, distal axial river, sinuous range front.



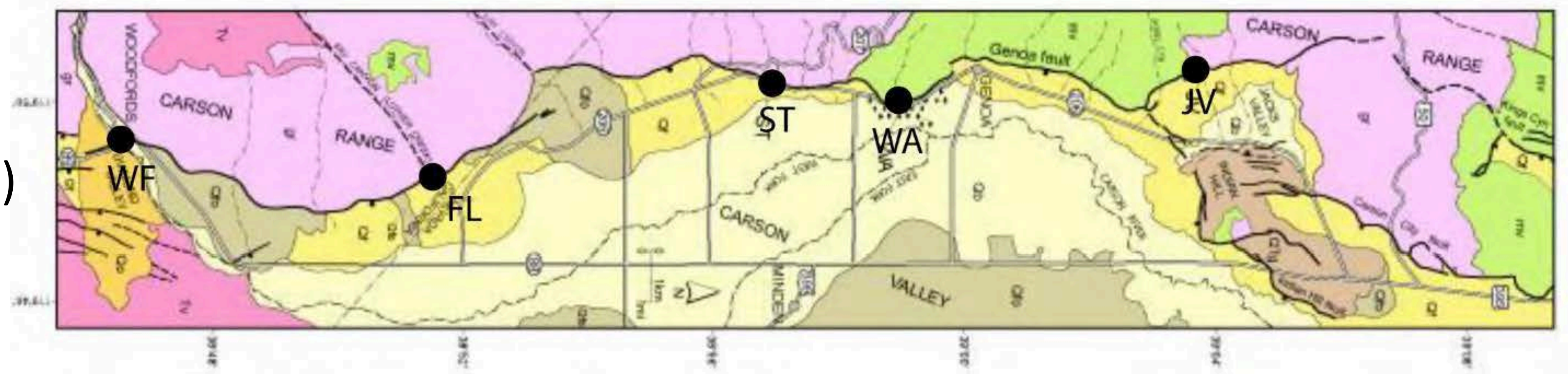


Genoa fault, Sierra Range front

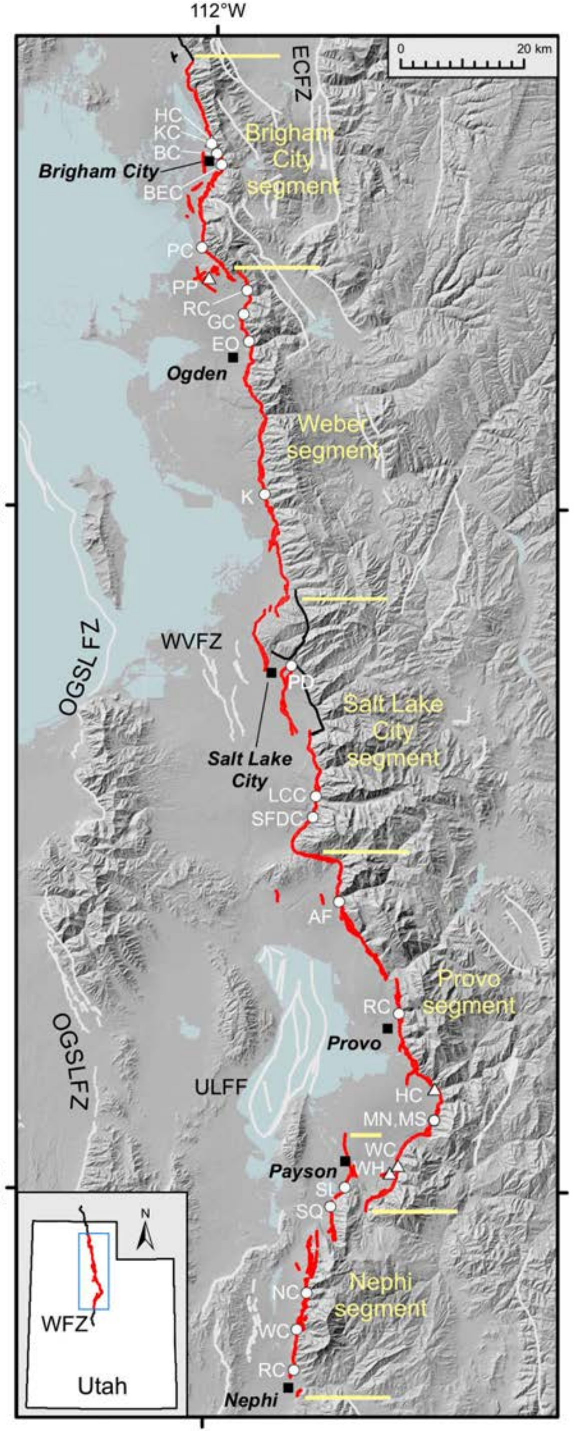


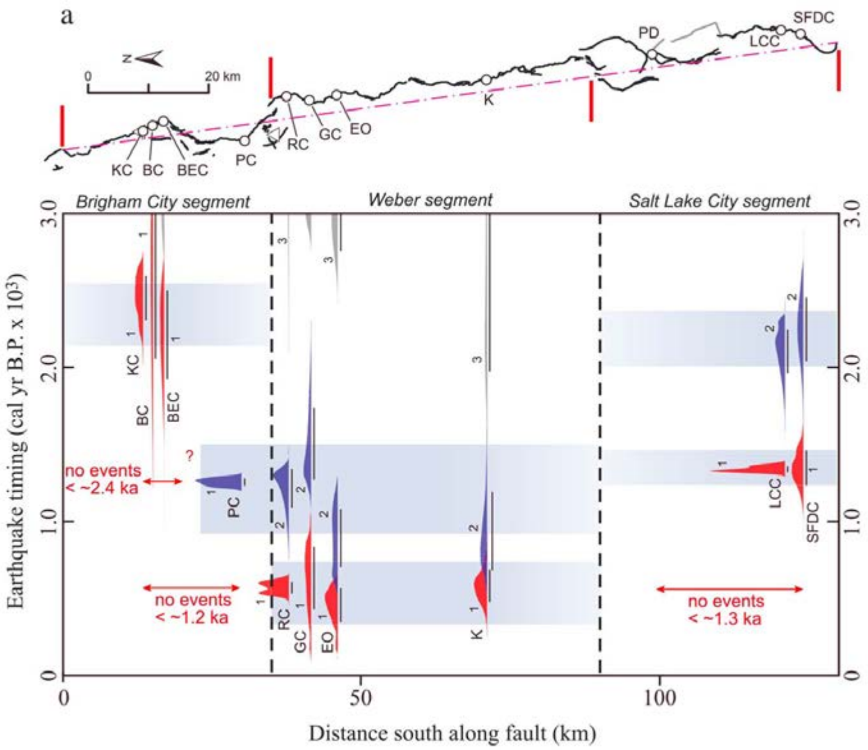
Ramelli et al., 1999

- Triangular facets
- Wineglass canyons
- Young scarp (~500 yr)



Wasatch fault, Utah





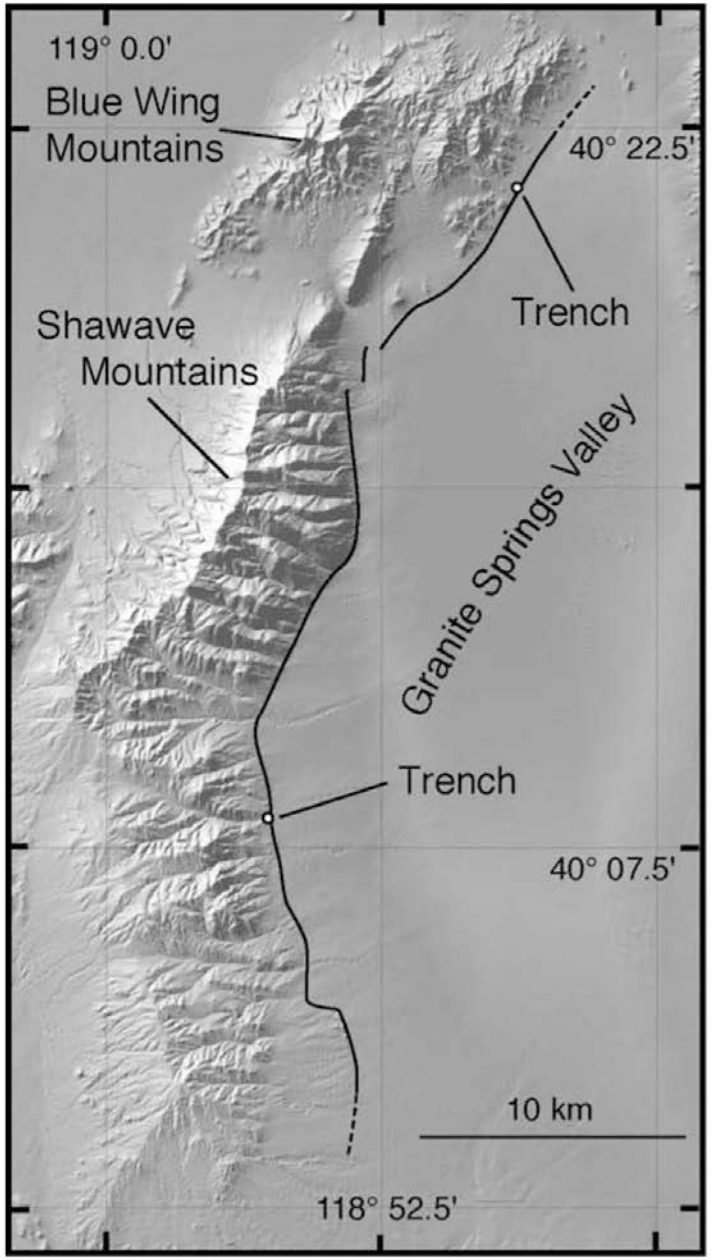
DuRoss et al., 2015


Cortez Range

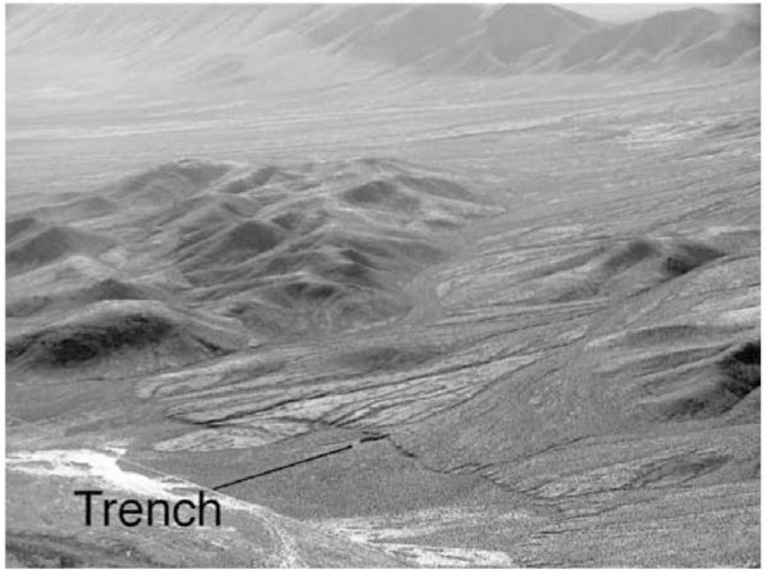

Basin facing scarps

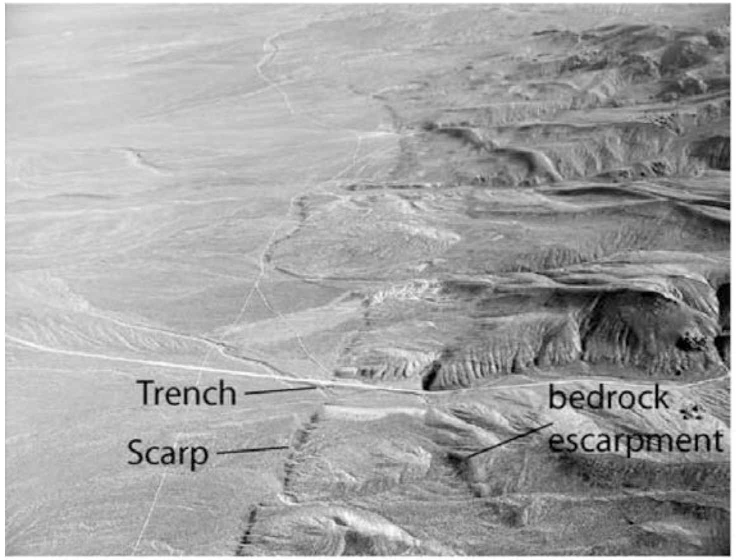
Simpson Park Mountains

Schell Creek Range

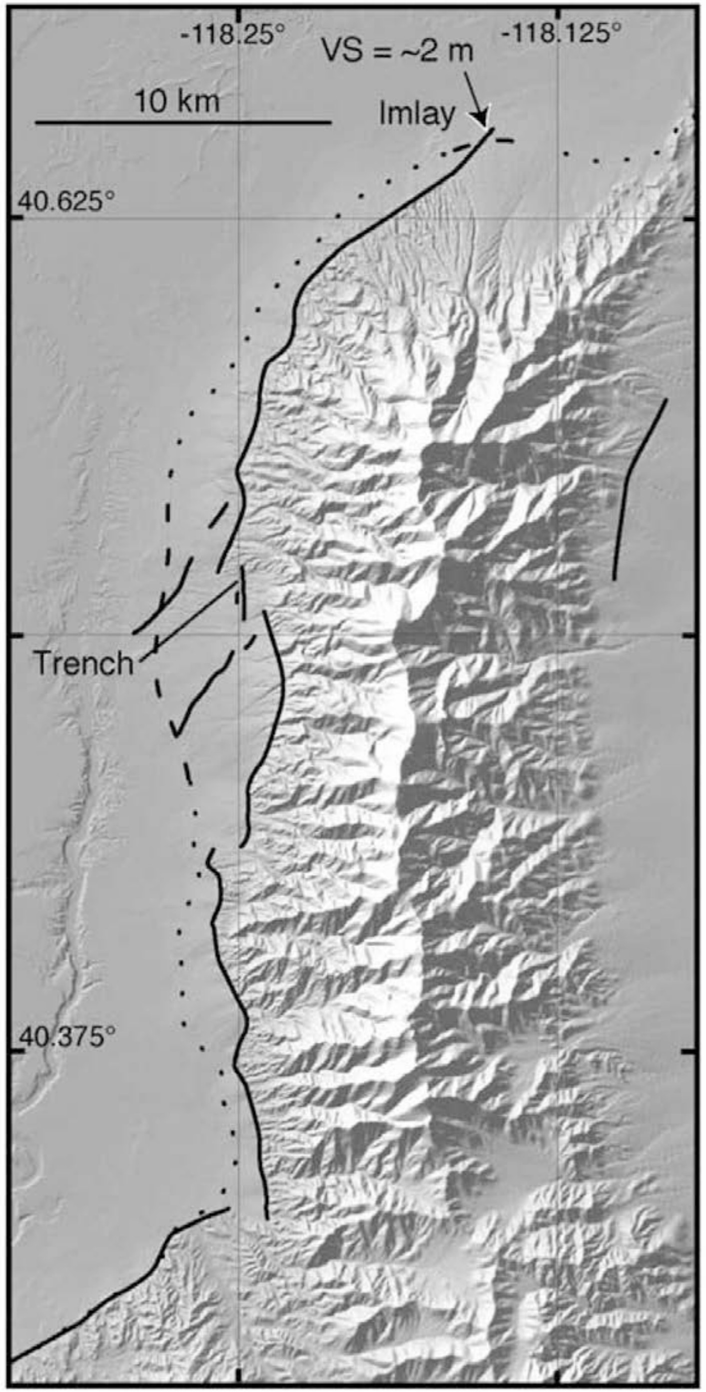


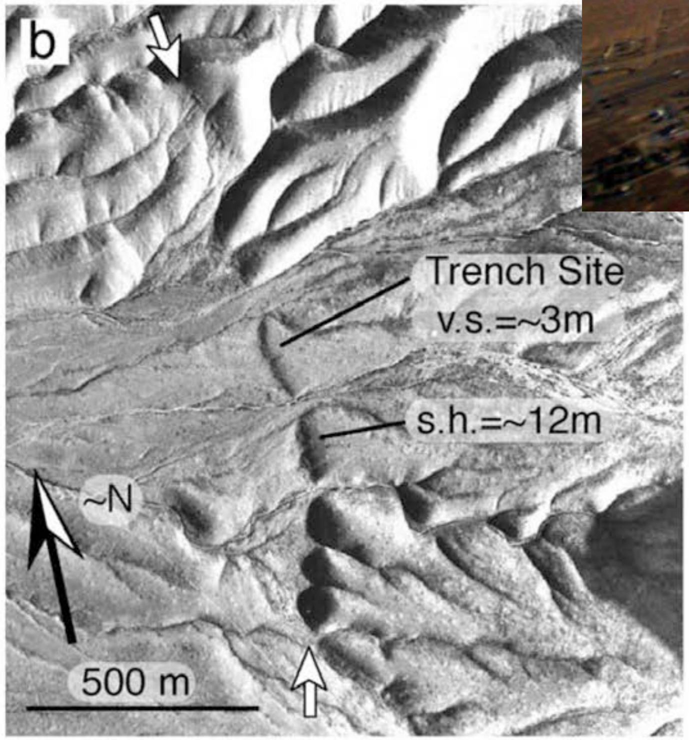
Wesnousky et al., 2005





Humboldt Range

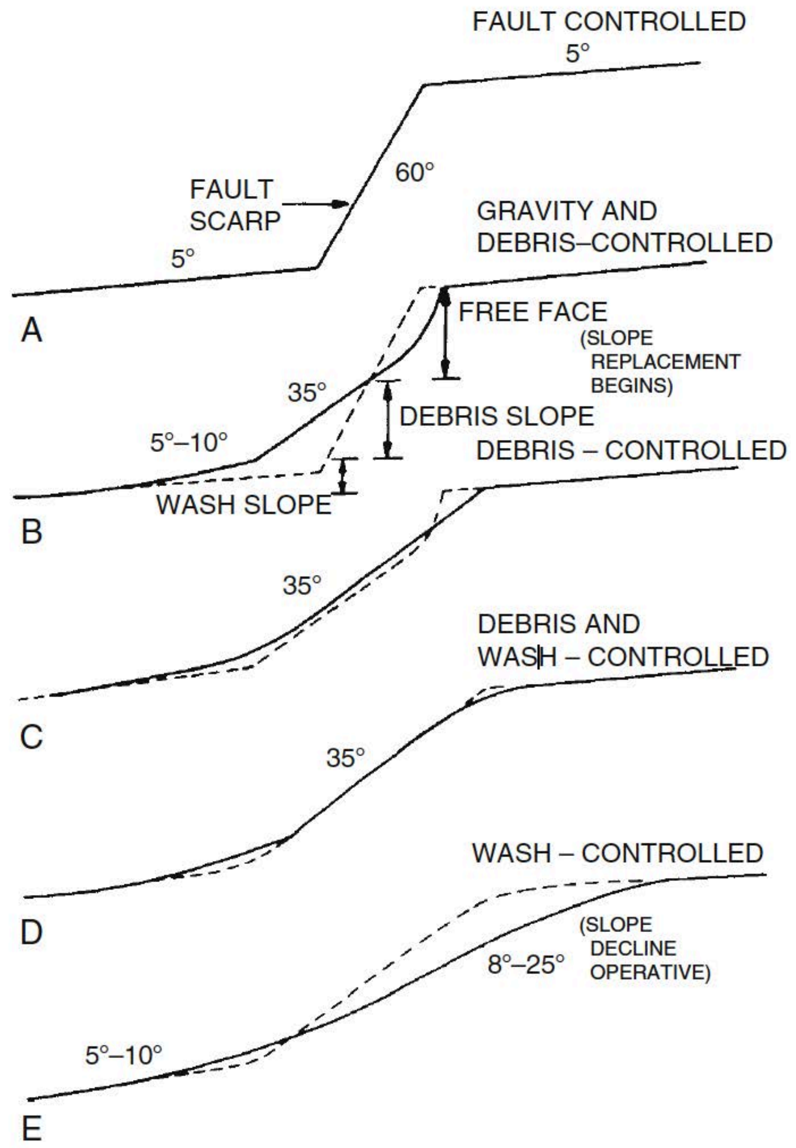




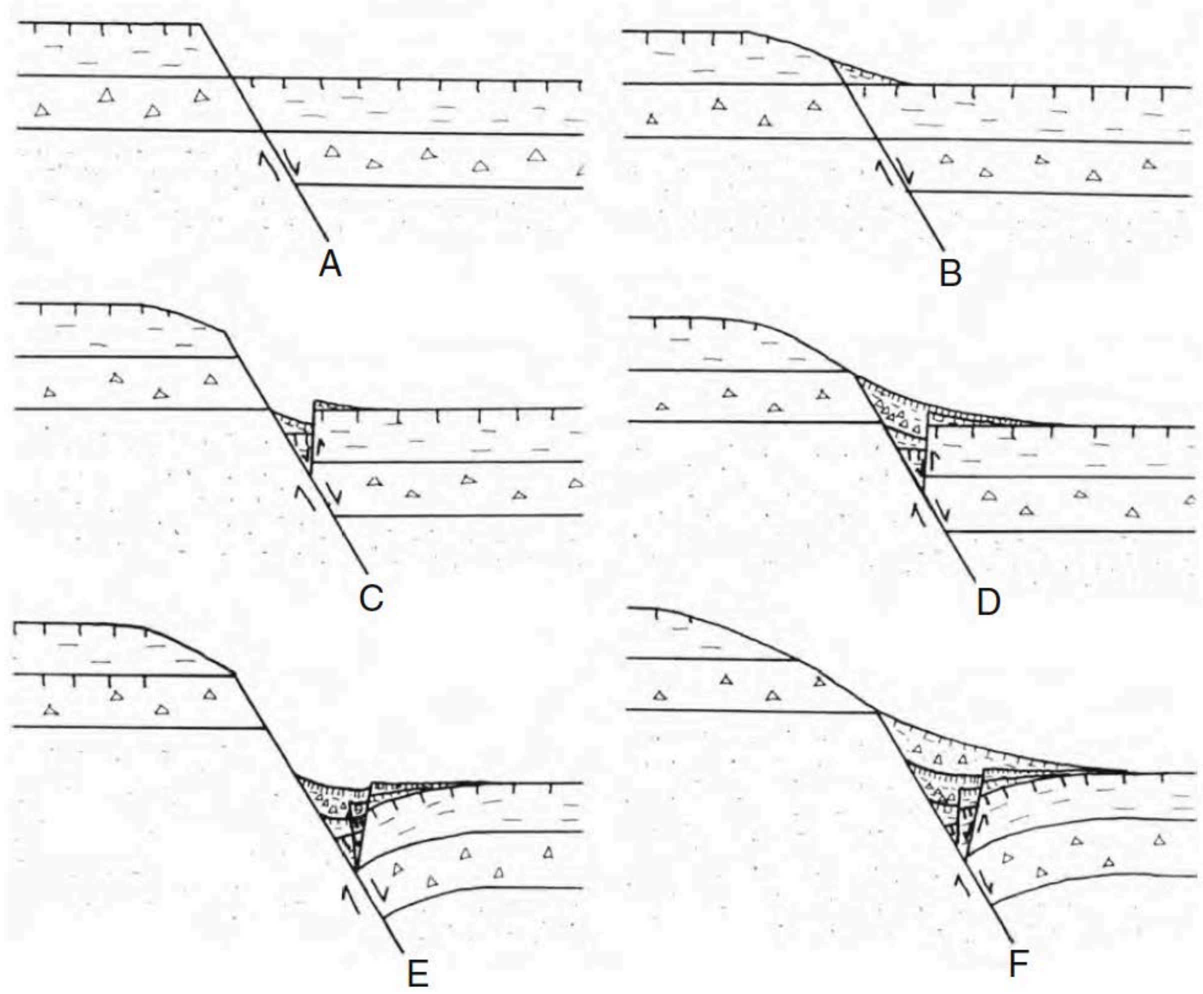
2 events 4600 and 1900 years ago
Must be careful separating shorelines and fault scarps.

Wesnousky et al., 2005

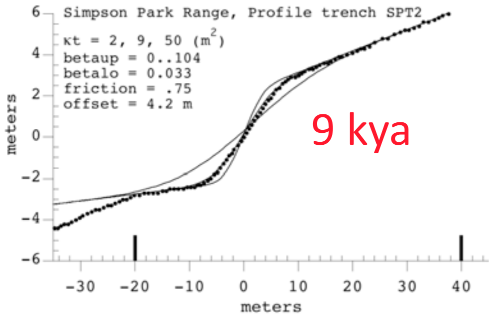
Colluvial facies related to scarp degradation

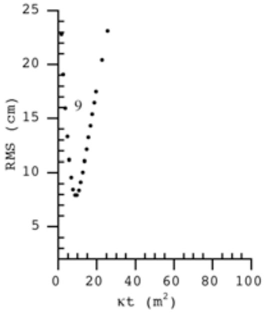


Subsurface colluvial stratigraphy

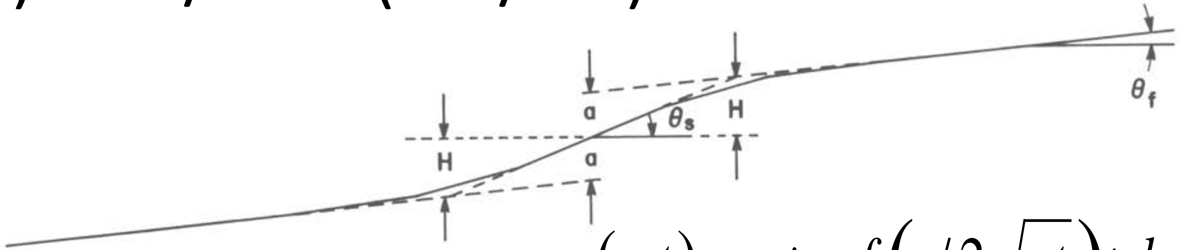


Diffusion Analyses of Scarp Profiles

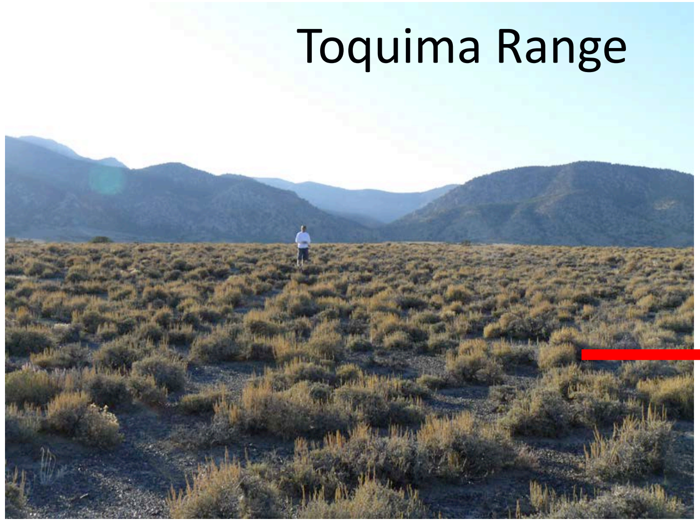


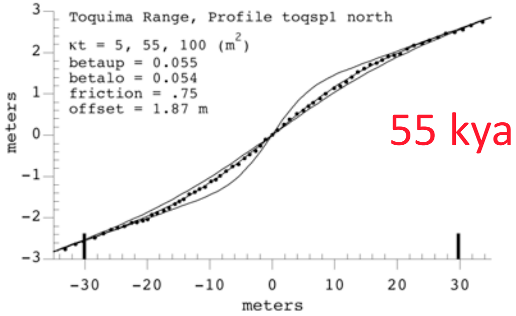


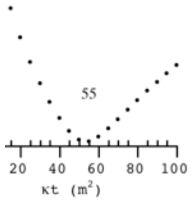
$$u(x,t) = du/dt - \kappa(d^2u/dx^2) = 0$$



$$u(x,t) = a * erf\left(x / 2\sqrt{\kappa t}\right) + bx$$



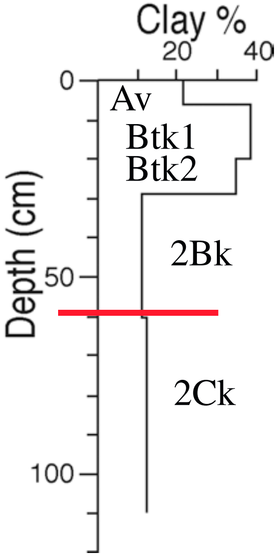




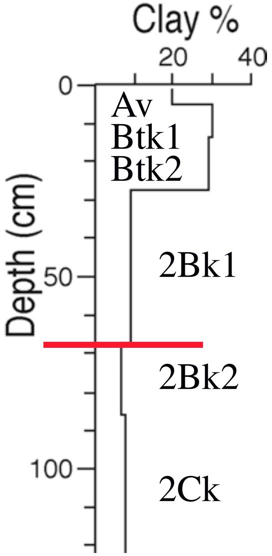
Knowing slopes, offsets, and
estimate of mass diffusivity (m2/time)
Age of scarp can be estimated

Soil pit exposures and clay % depth profiles
Used to correlate map units and better understand the age of faulted deposits

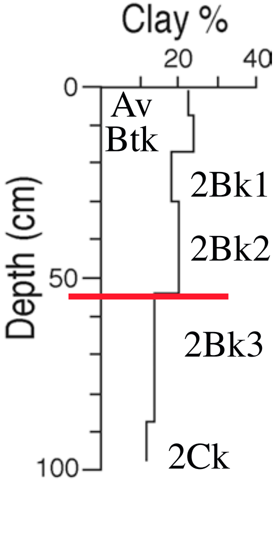
Desatoya



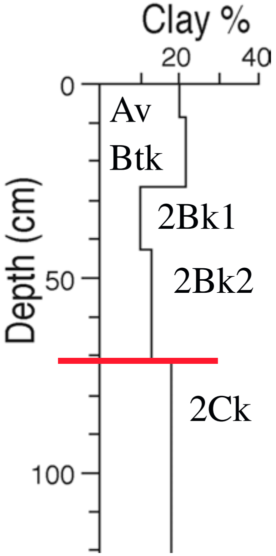
Toiyabe



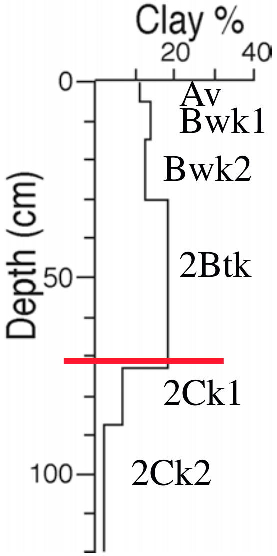
Butte



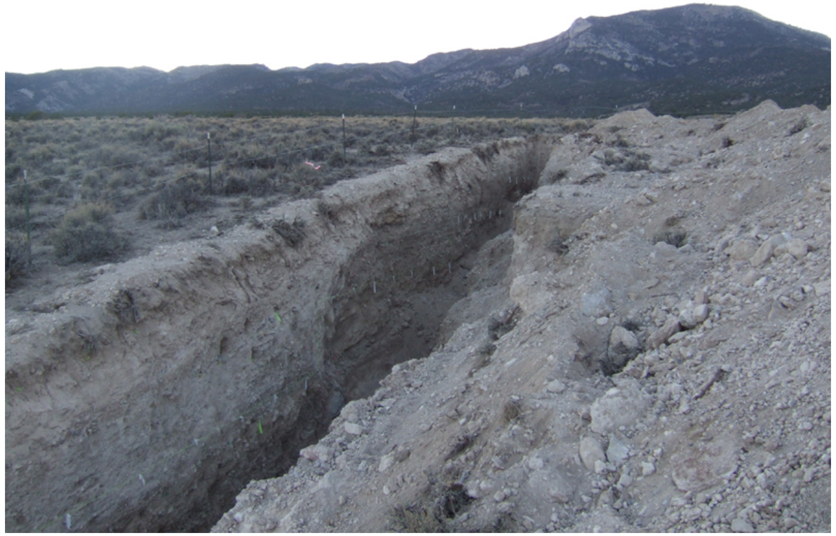
Egan

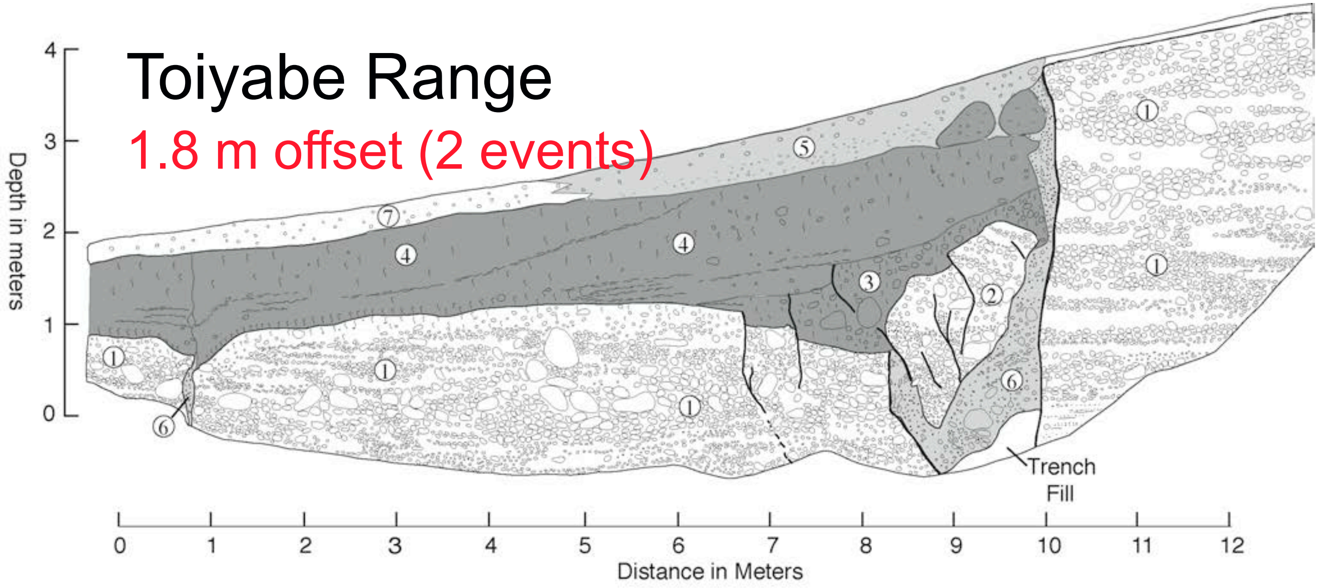


Schell Creek



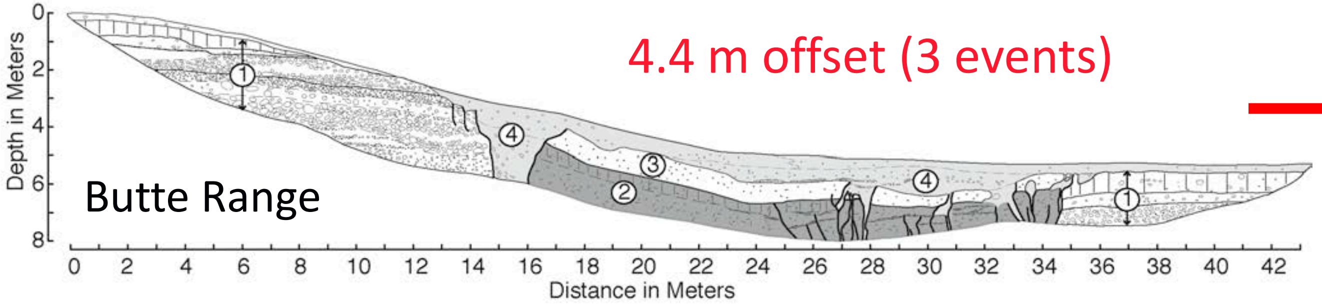
Trenching



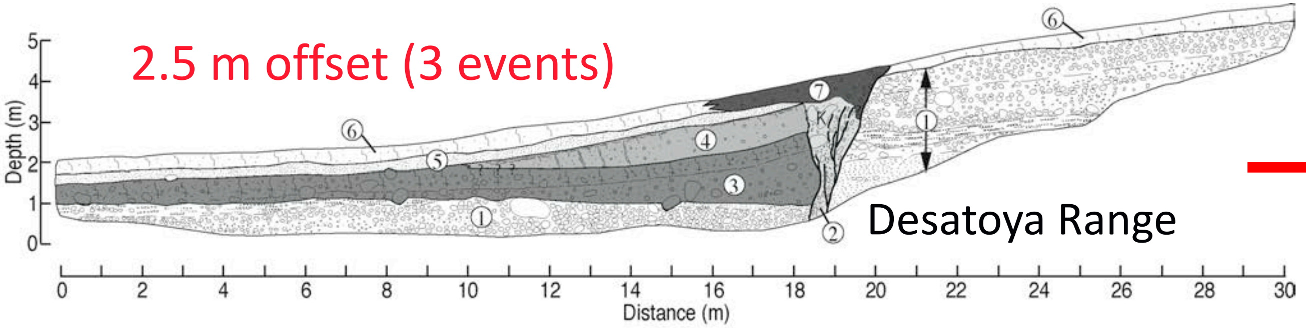

Toiyabe Range
1.8 m offset (2 events)
Depth in meters
0
1
2
3
4
Distance in Meters
0
1
2
3
4
5
6
7
8
9
10
11
12
Trench Fill
1
2
3
4
5
6
7

Trench Exposures

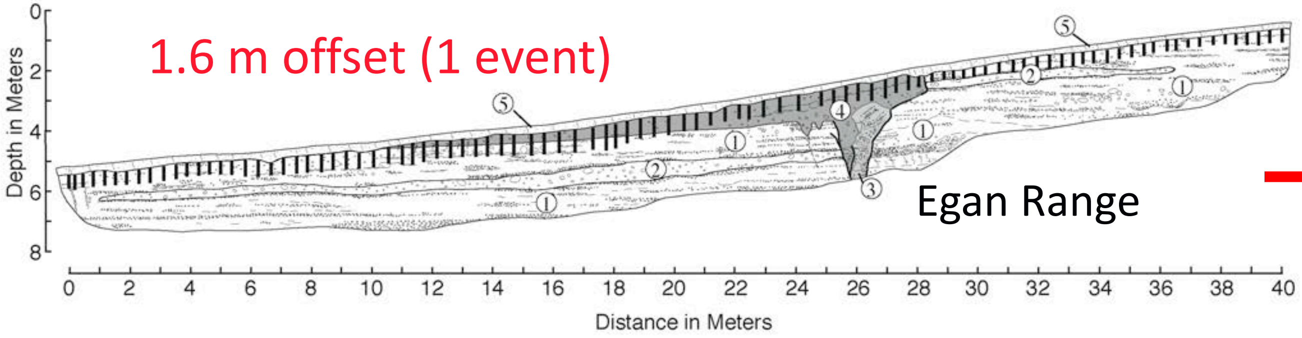
4.4 m offset (3 events)



2.5 m offset (3 events)



1.6 m offset (1 event)



Abbreviations for geomorphic features for use in mapping faults

strike-sip faults

Table 1. Geomorphic Symbol Codes used in Map Compilation

Geomorphic Feature	Symbol
Scarp (northeast facing)	s (NE)
Scarp (southwest facing)	s (SW)
Pond	p
Swampy depression	ds
Dry linear depression or swale	d
Saddle	sa
Spring	sp
Linear valley	lv
Linear drainage	ld
Swale	sw
Linear break in slope	bs
Bench	b
Tectonic ridge	r
Stream knickpoint	kp
Vegetation lineament	v
Drainage divide	dd
Offset stream channel	os
Beheaded or abandoned stream channel	bs
Deflected stream	ds
Pirated channel	pc

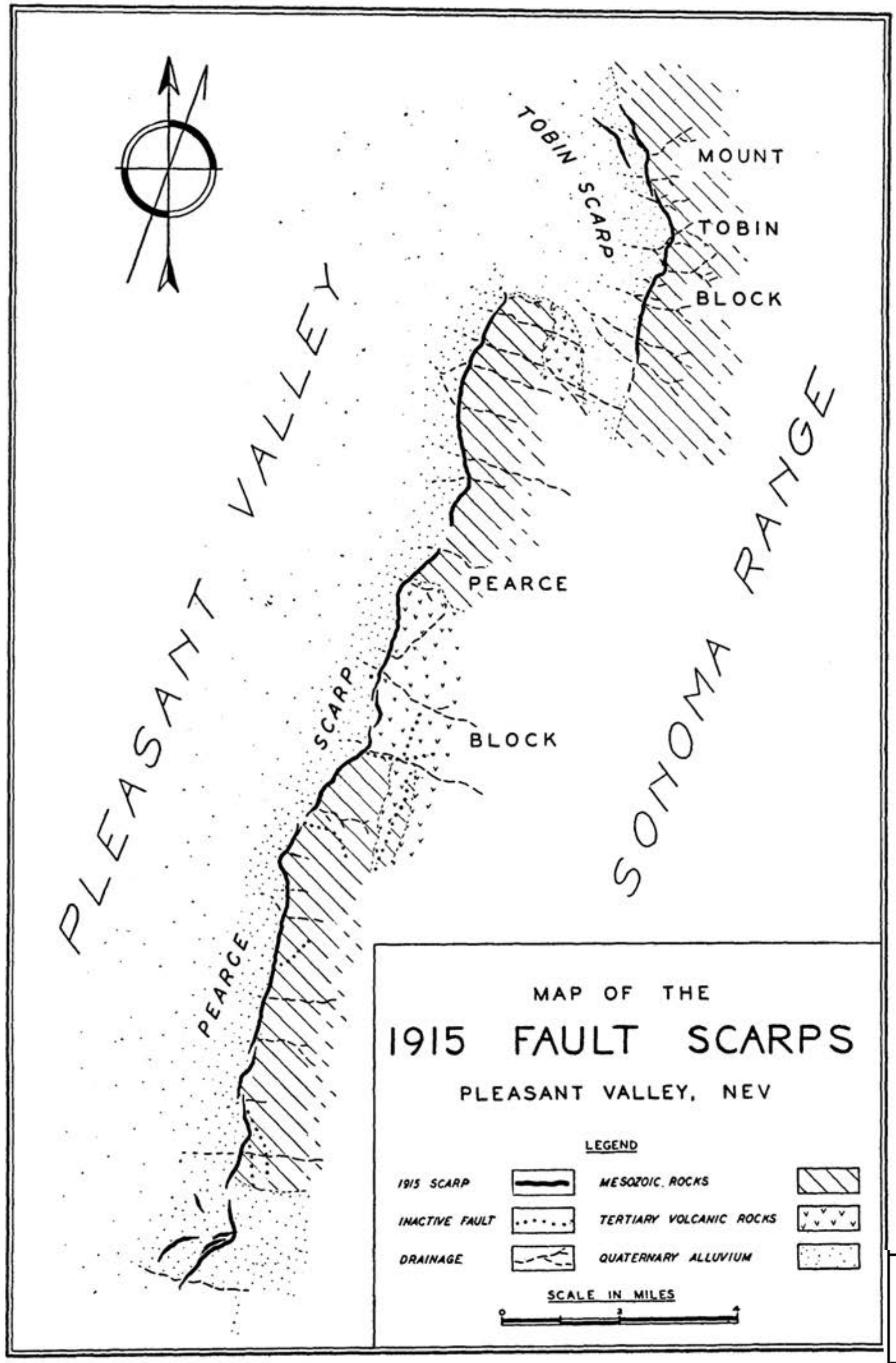
normal faults

Geomorphic feature	Symbol
triangular facet	tf
graben	g
scarp	s
Over-steepened rangefront	or
wineglass canyon	wc
beveled scarp	bs
Distributed fracturing	df

Other data

Vertical separation (v.s.)
Scarp height (s.h.)

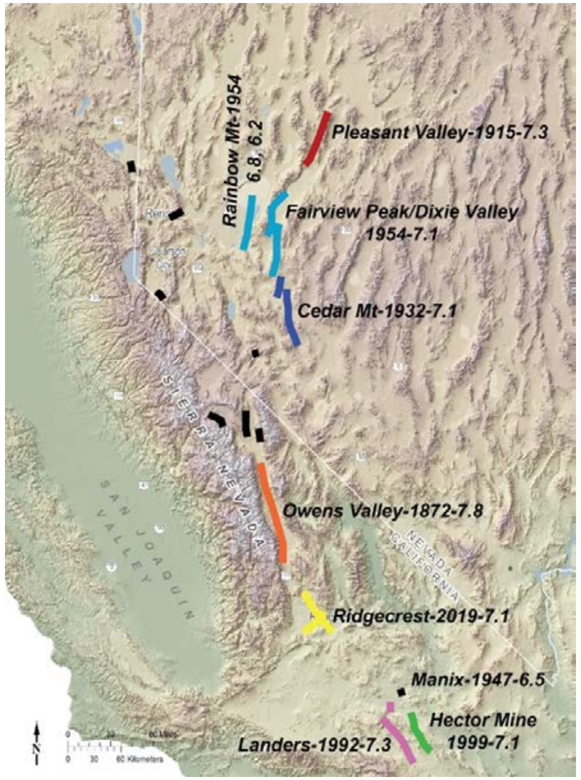
can be measured in the field or using profile tools in ArcGIS or QGIS

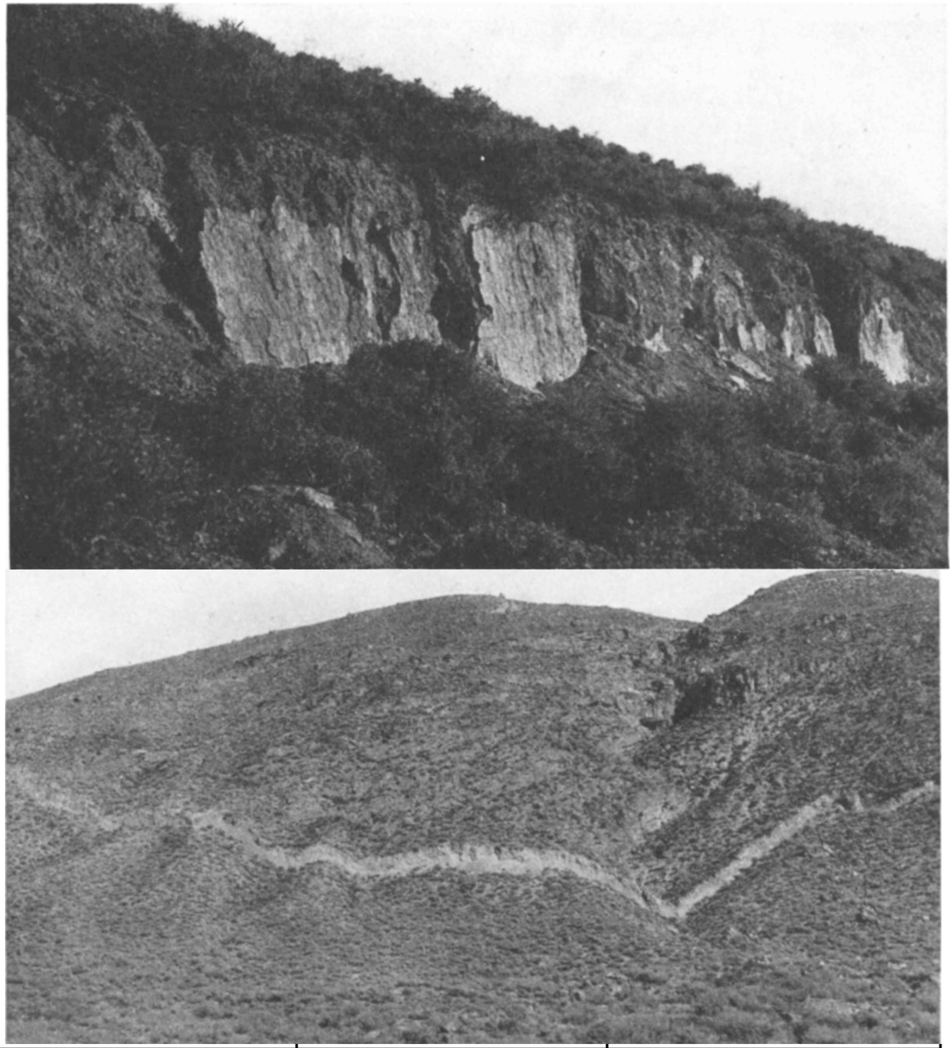


Page, 1935 Fig. 3.—Map of the 1915 fault scarps

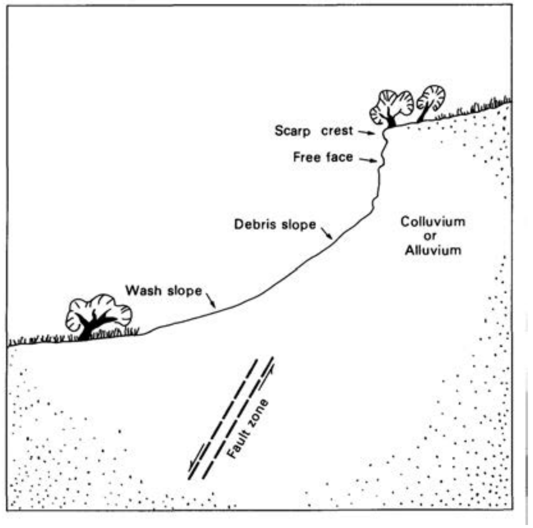
Historical surface rupture examples

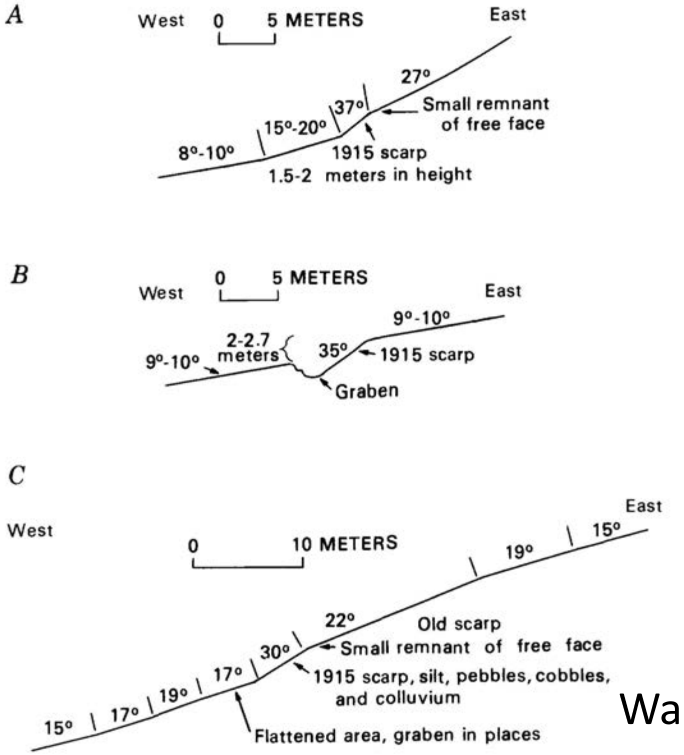
1915 Pleasant Valley earthquake



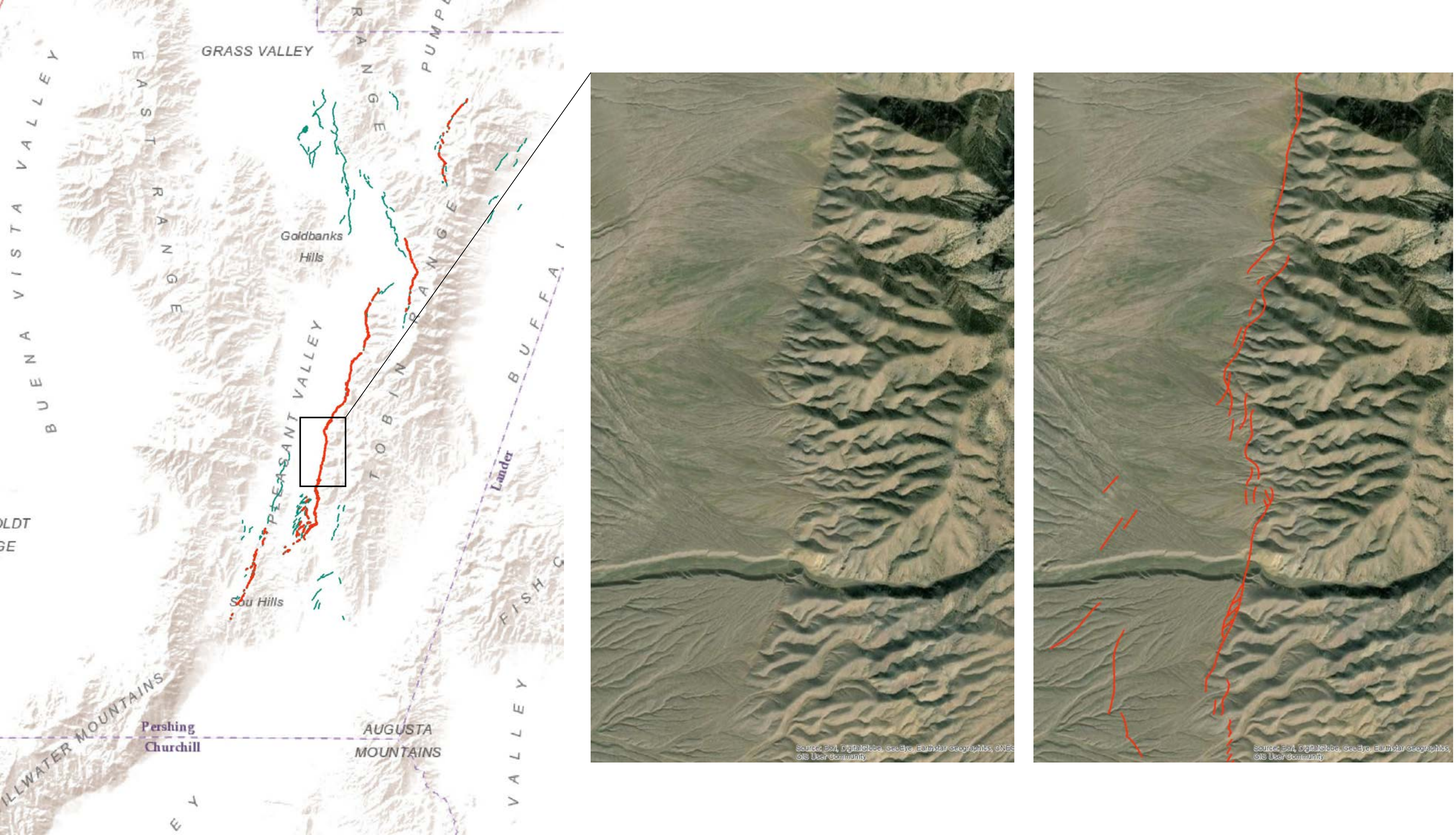


1915, M_s 7.6	Pleasant Valley, Nevada	5.8 m displ.	59 Km length	Wallace (1984)

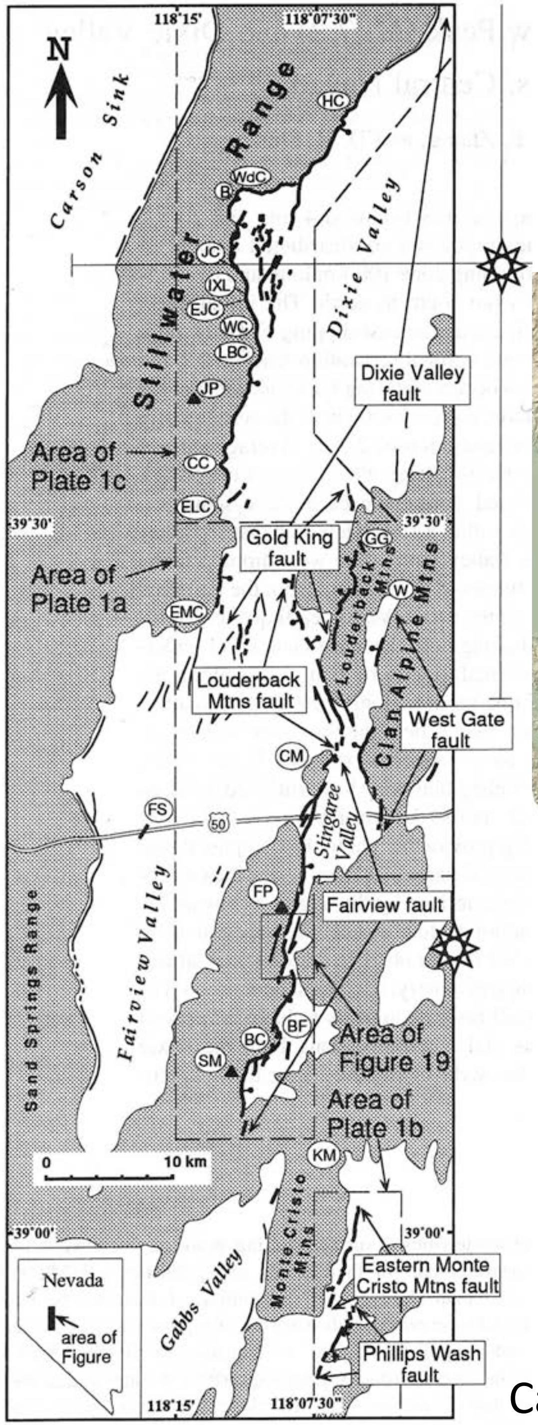




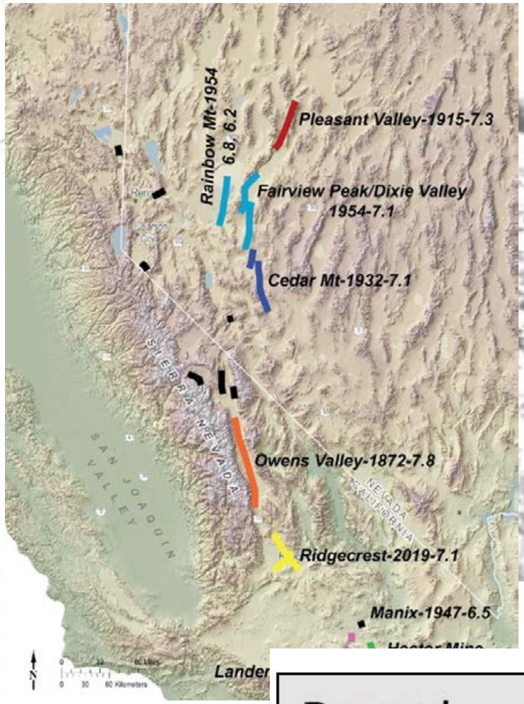
Wallace, 1984


GRASS VALLEY
EAST RANGE
BUENA VISTA VALLEY
Goldbanks Hills
PLEASANT VALLEY
TOBIN RANGE
Sou Hills
Lander
Pershing
Churchill
AUGUSTA MOUNTAINS
ILLWATER MOUNTAINS
VALLEY
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES
GIS User Community

Historical surface rupture examples

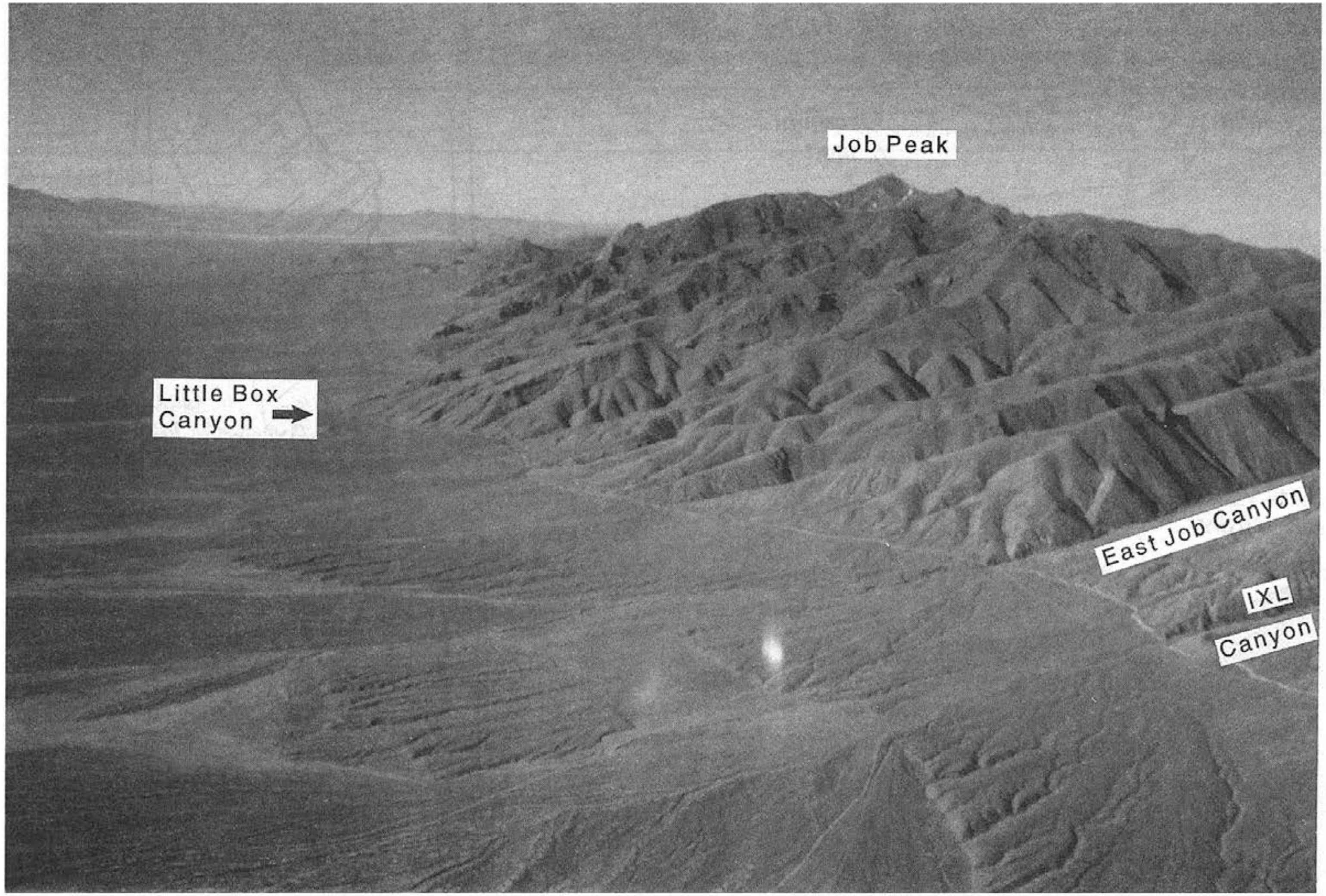


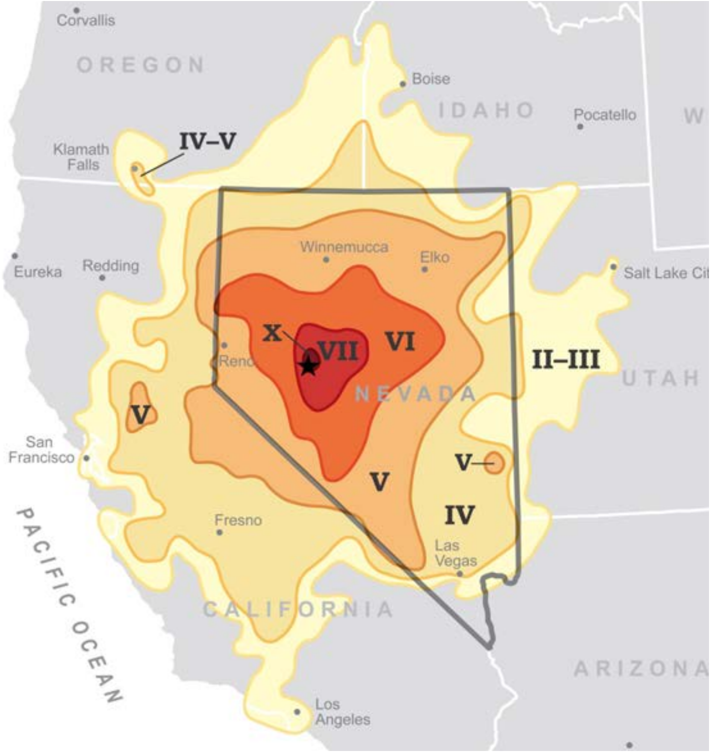
1954 Fairview Peak and Dixie Valley earthquakes



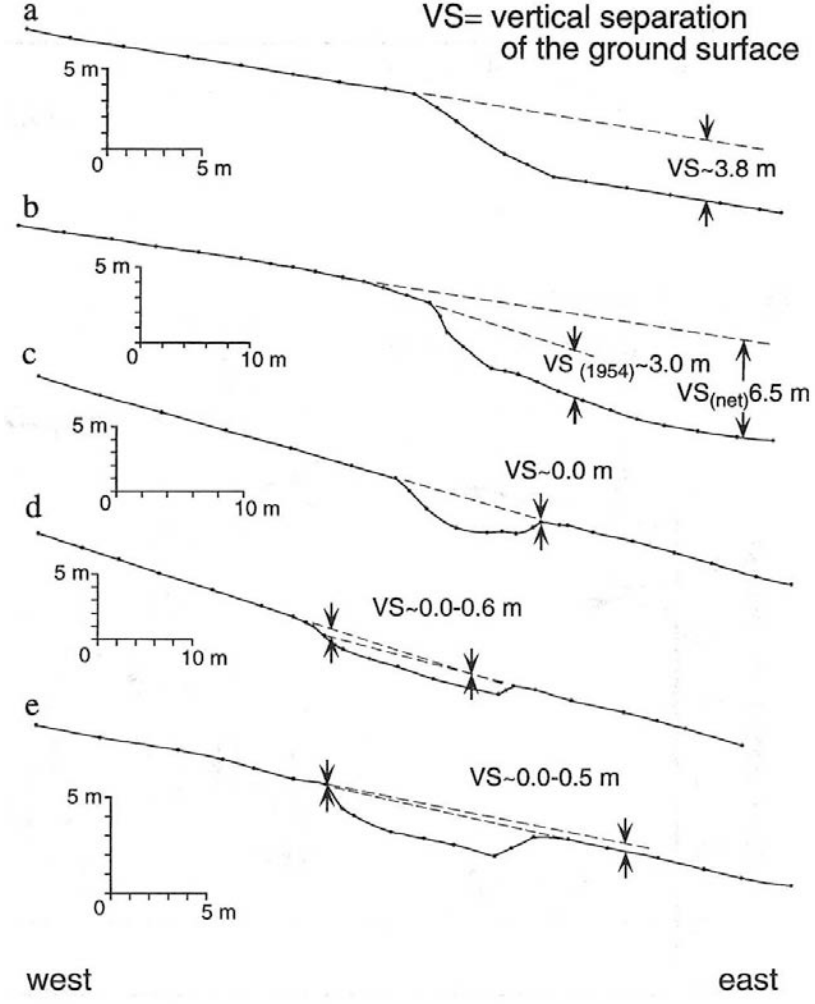
Date and magnitude	Area/fault	Maximum displacement[a] (m)	Length of rupture[a] (km)	References
a. Ruptures studied immediately after the earthquake				
1954, M_s 6.8	Dixie Valley, Nevada	3.8	45	Slemmons (1957)
1954, M_s 7.2	Fairview Peak, Nevada	4.8	67	Slemmons (1957)

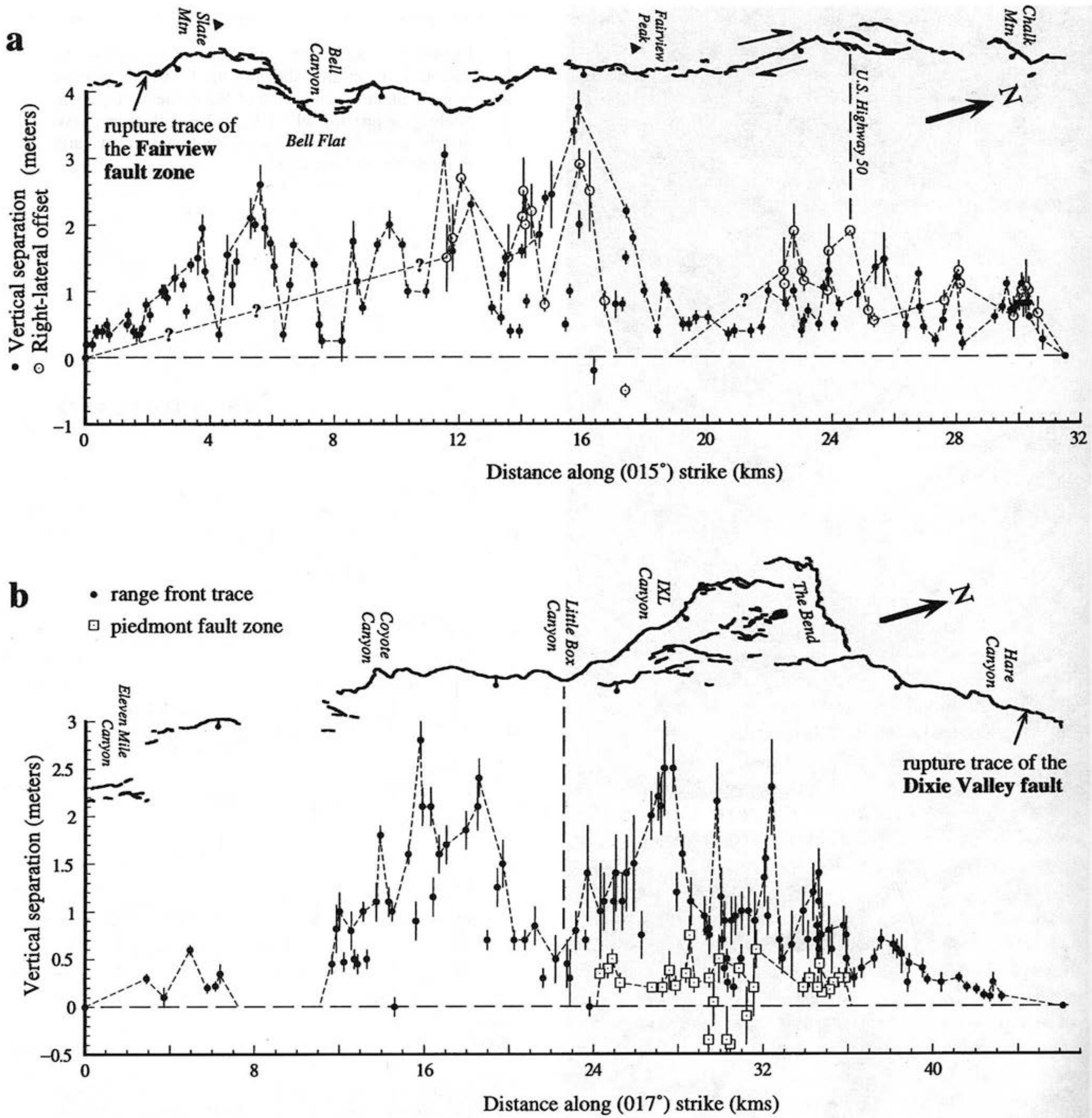
Caskey et al., 1996



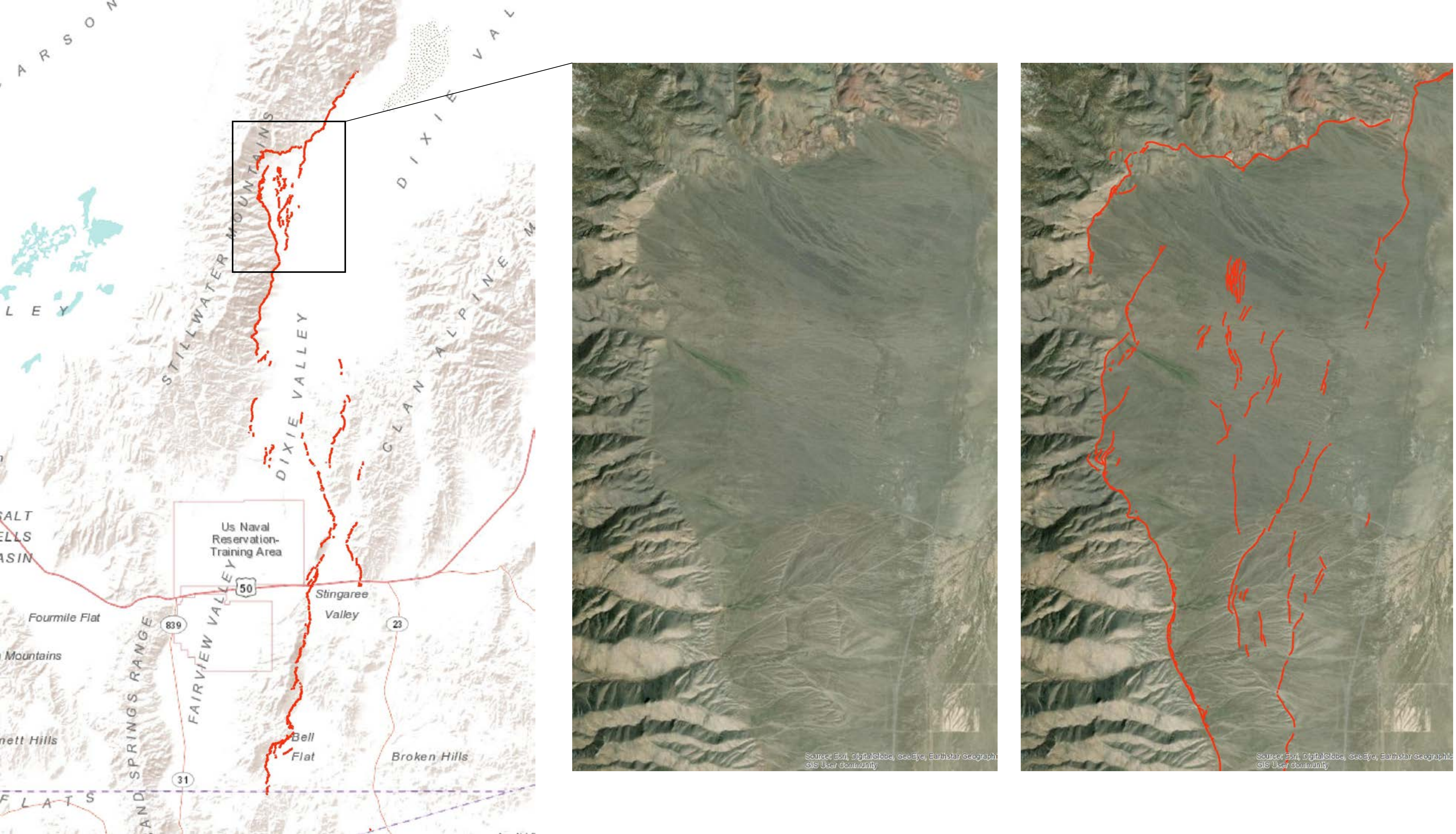


Caskey et al., 1996



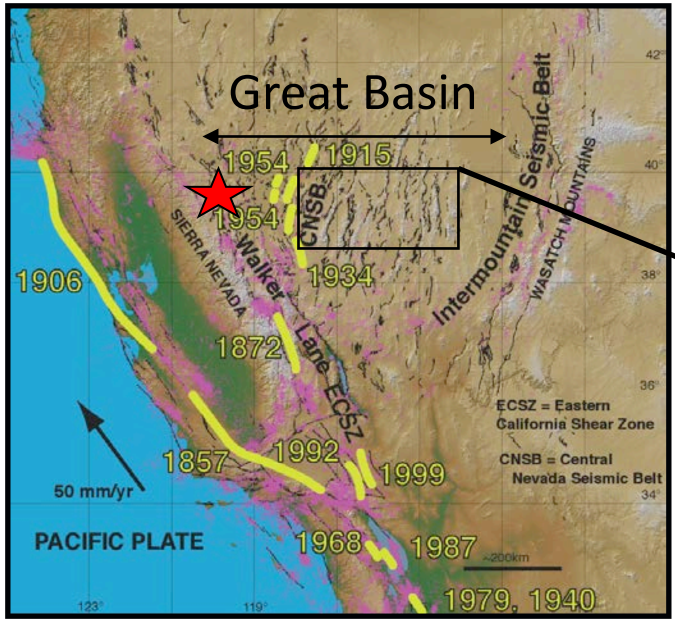


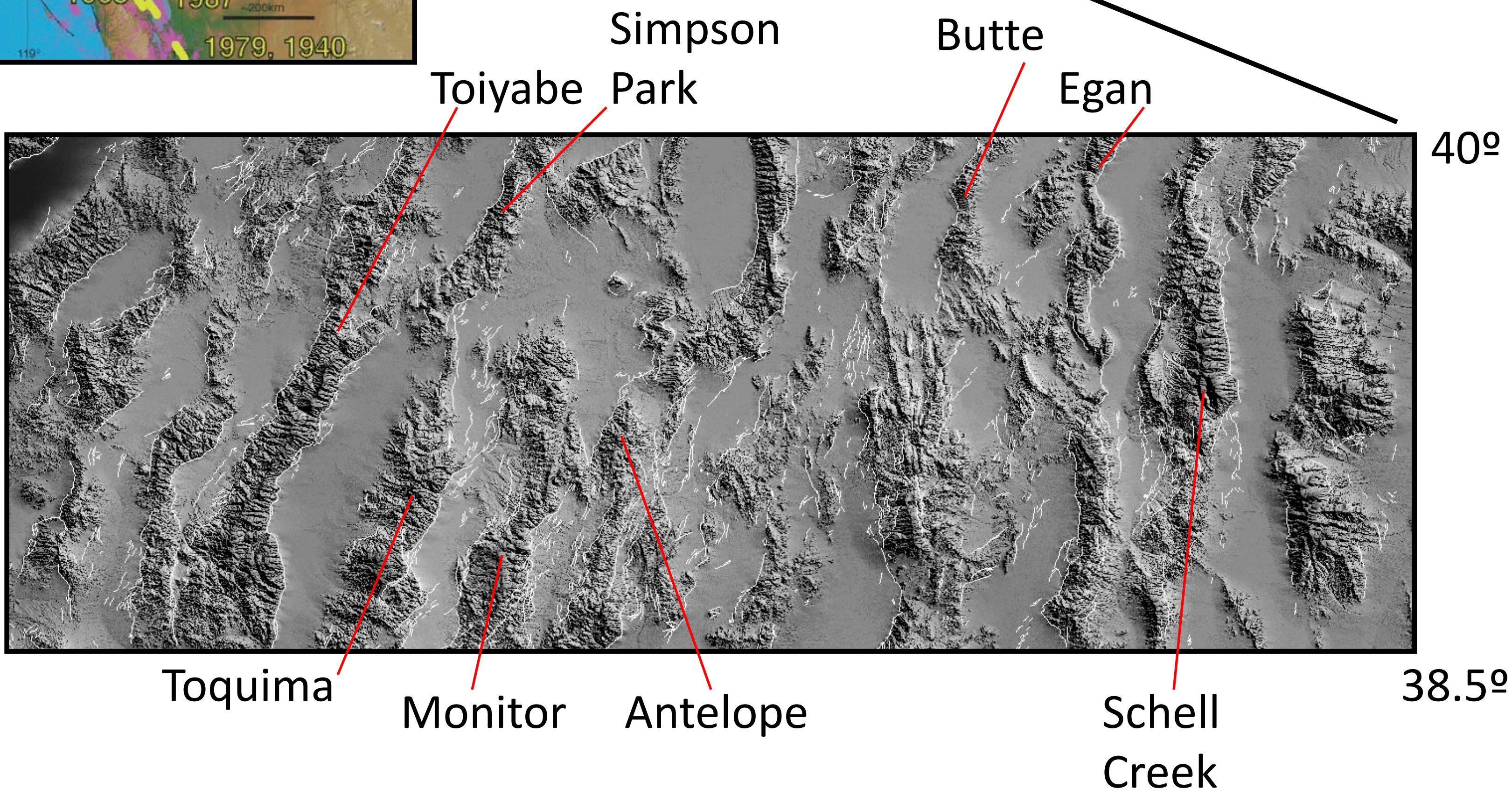
Caskey et al., 1996



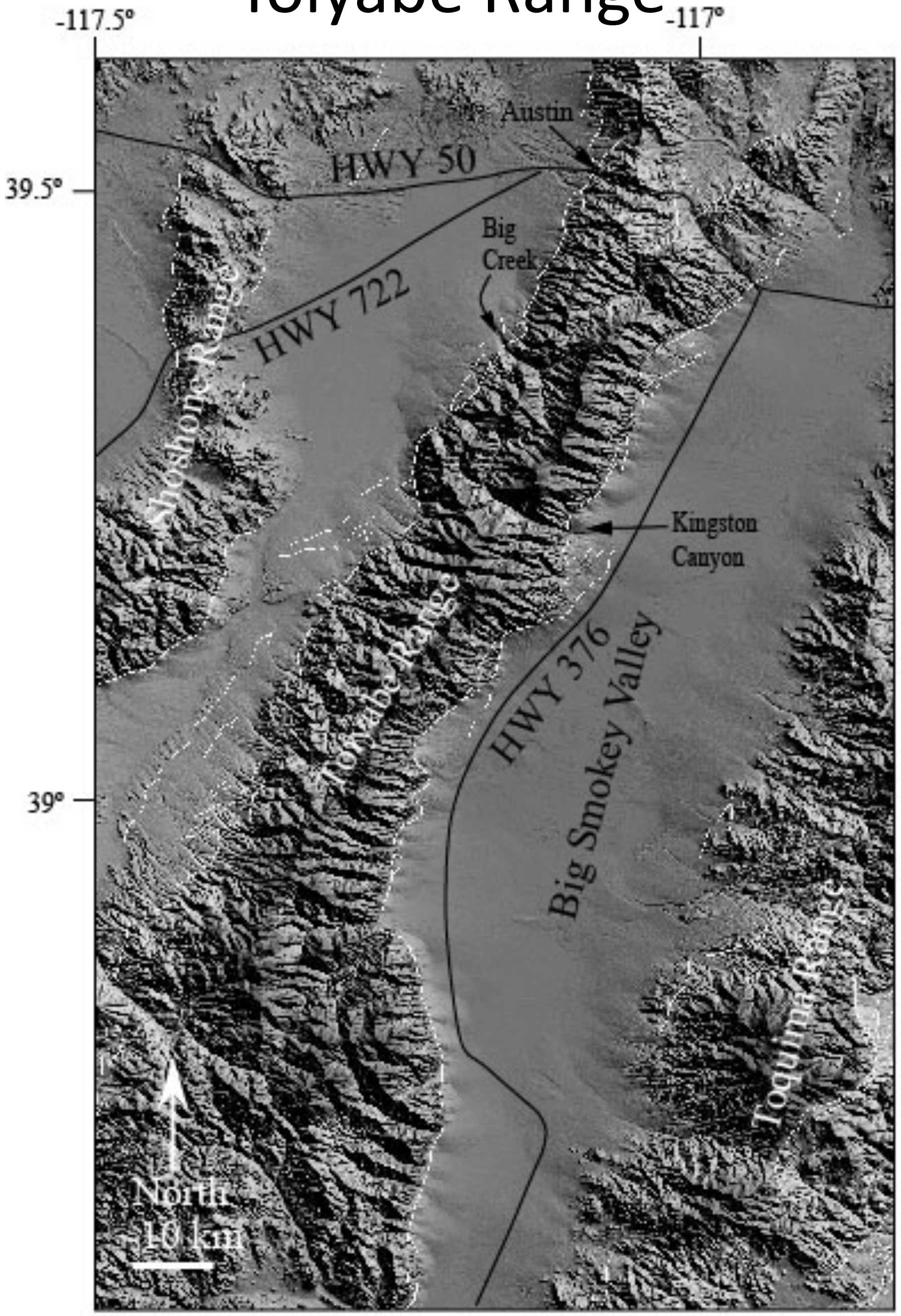
STILLWATER MOUNTAINS
DIXIE VALLEY
CLAN ALPINE
Us Naval Reservation-Training Area
50
Stingaree Valley
23
839
Fourmile Flat
FAIRVIEW VALLEY
SPRINGS RANGE
Bell Flat
Broken Hills
31
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, GIS User Community

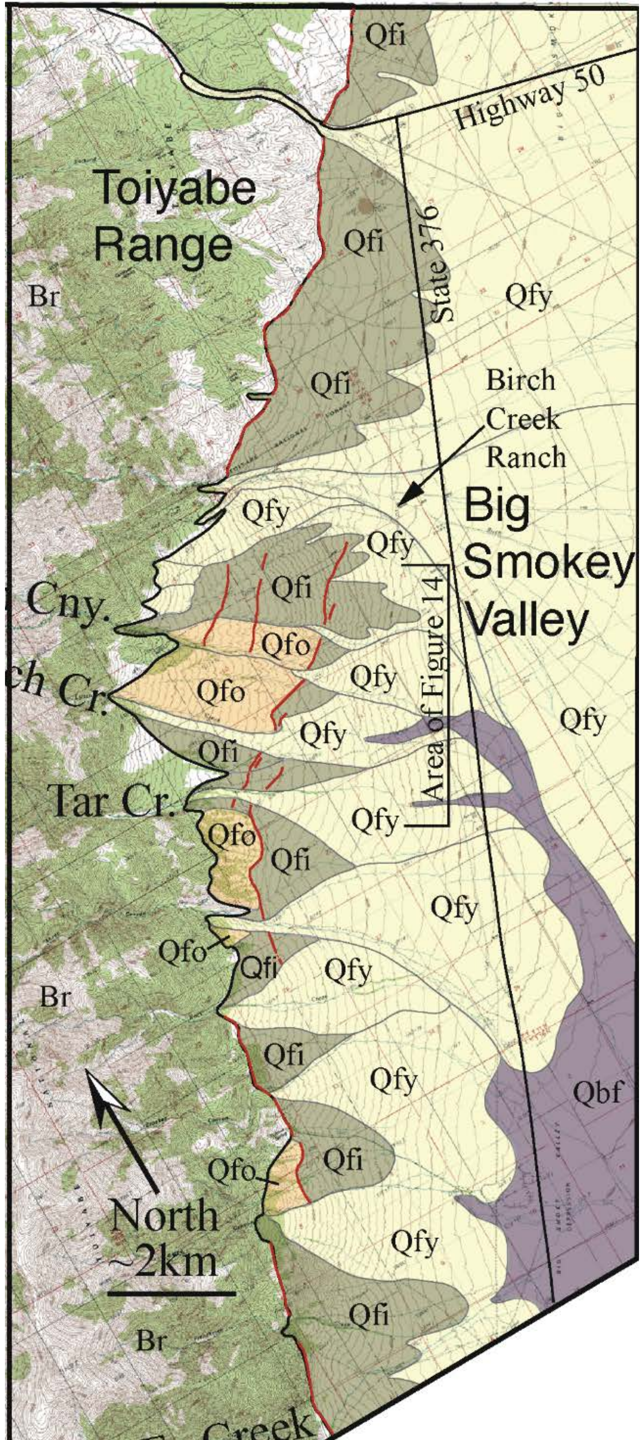
Fault mapping across US HWY 50 central Basin and Range



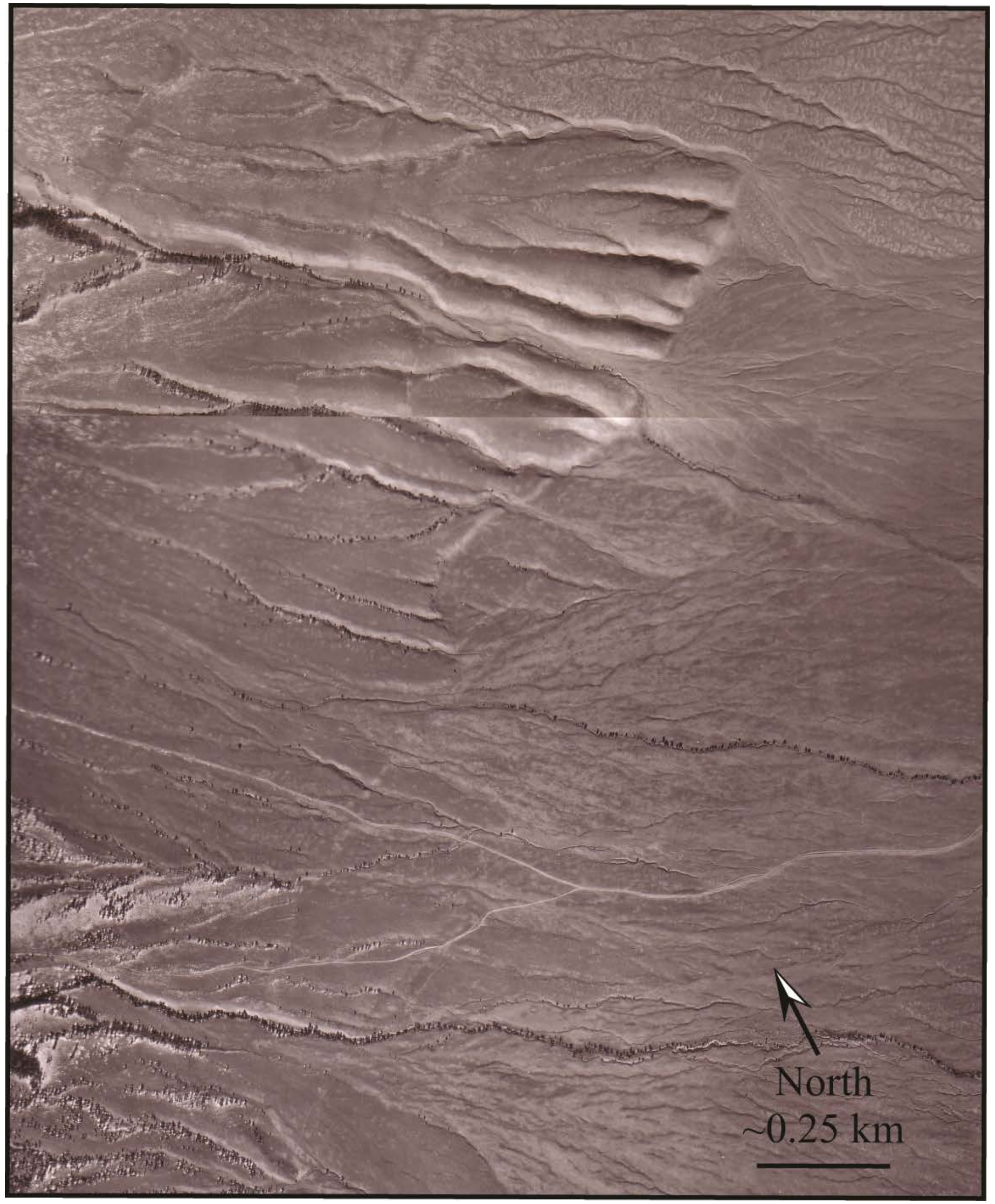


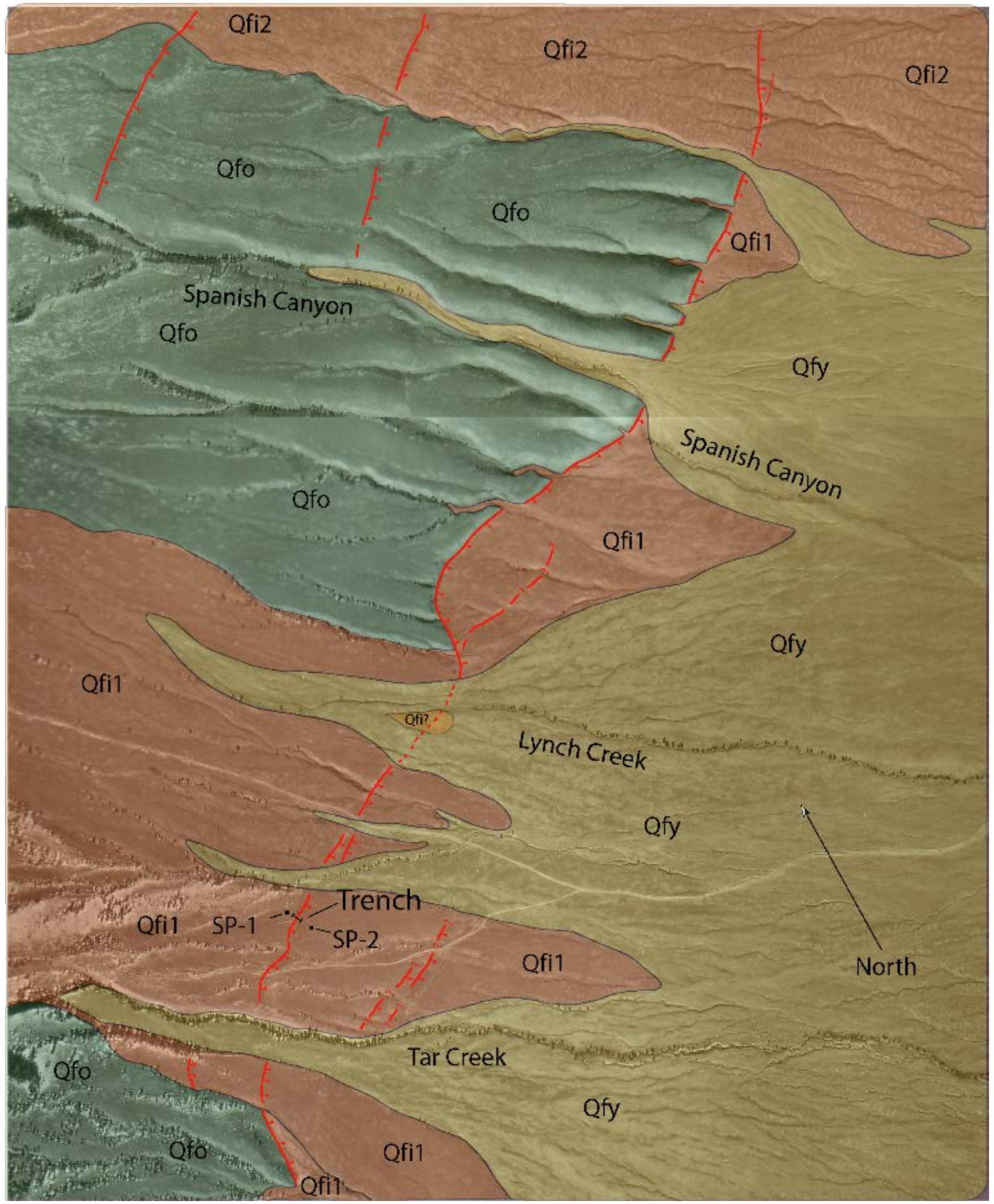
Toiyabe Range



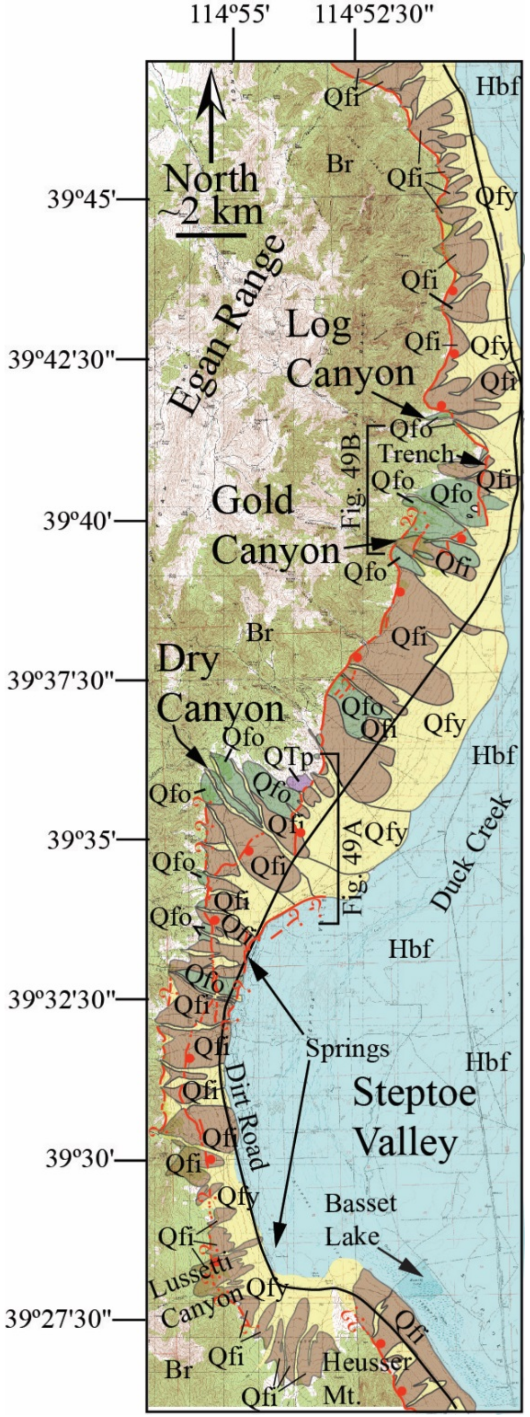


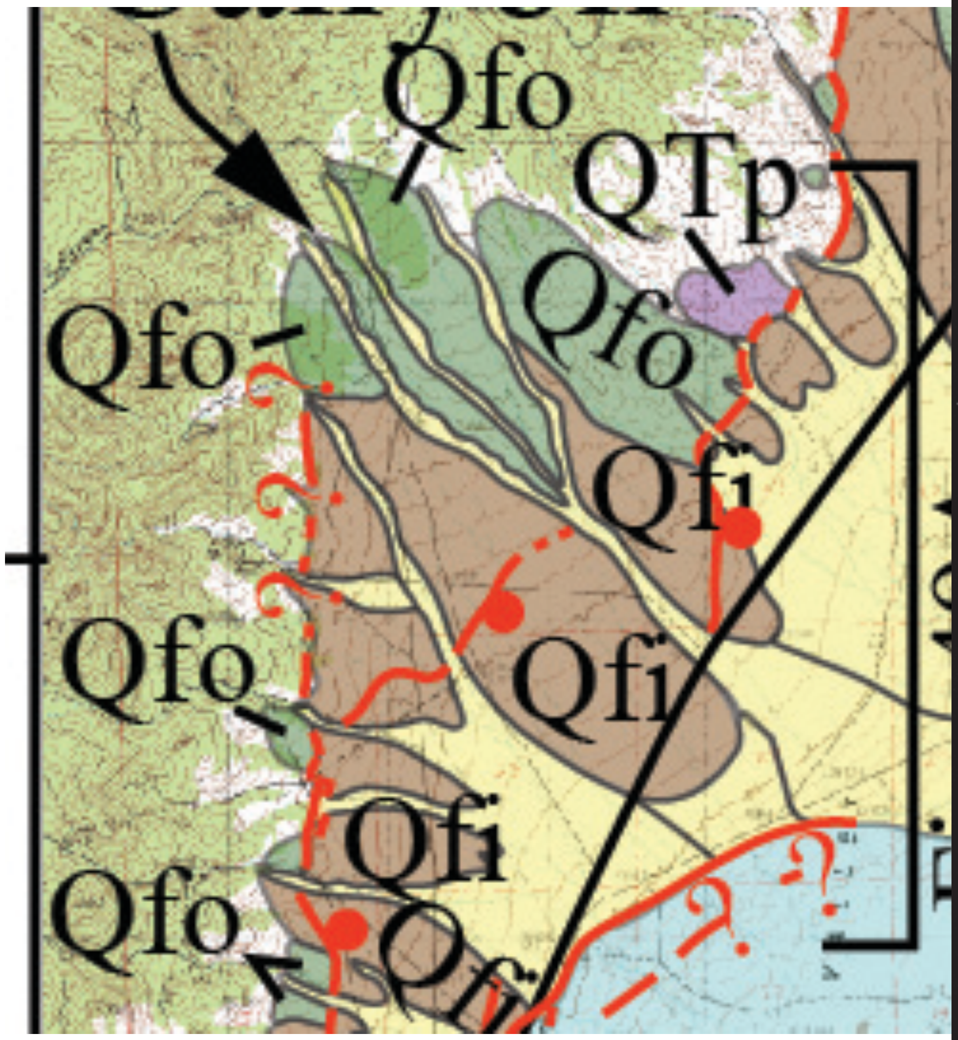
Toiyabe Range

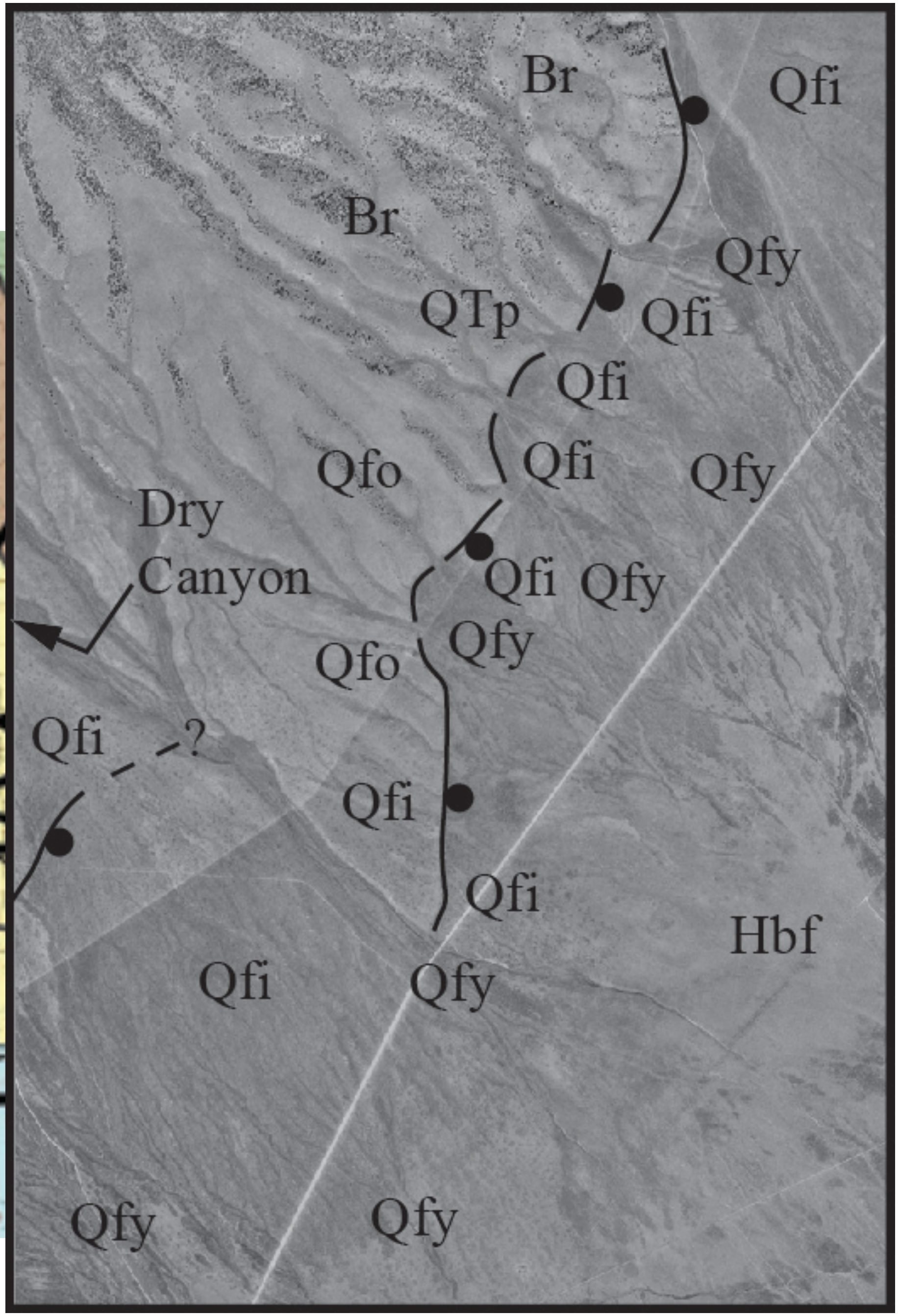




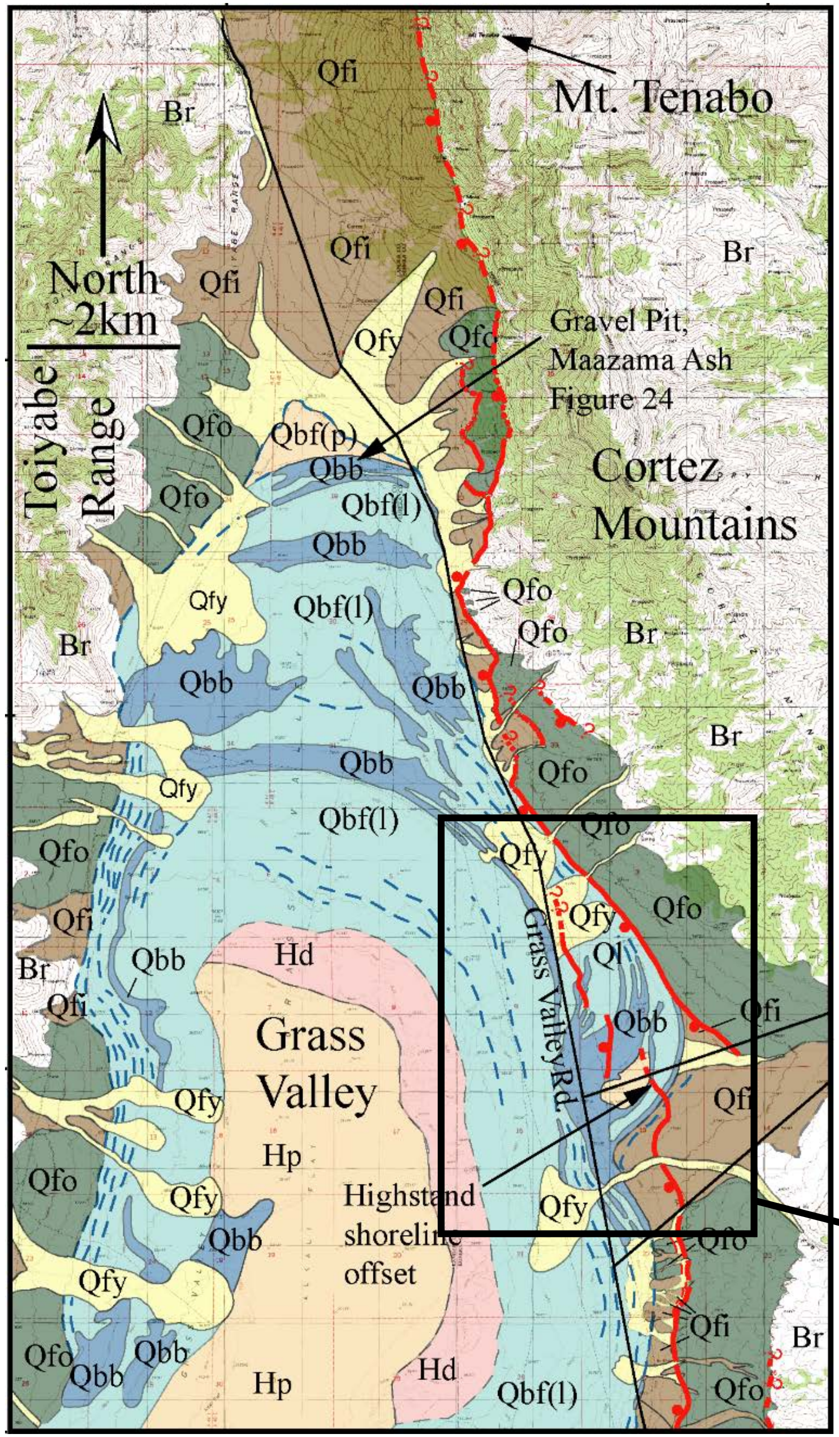
Eagan Range

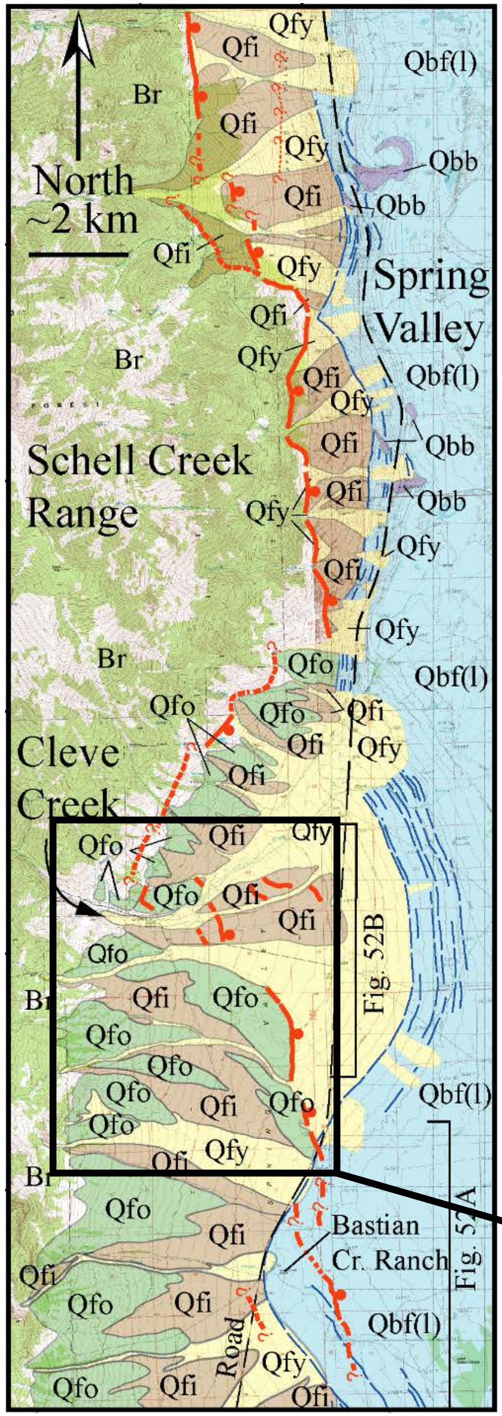

114°55'
114°52'30"
North
~2 km
39°45'
39°42'30"
39°40'
39°37'30"
39°35'
39°32'30"
39°30'
39°27'30"
Egan Range
Log Canyon
Gold Canyon
Dry Canyon
Lussetti Canyon
Trench
Fig. 49B
Fig. 49A
Springs
Dirt Road
Steptoe Valley
Duck Creek
Basset Lake
Heusser Mt.
Br
Hbf
Qfi
Qfy
Qfo
QTp


Qfo
QTp
Qfi

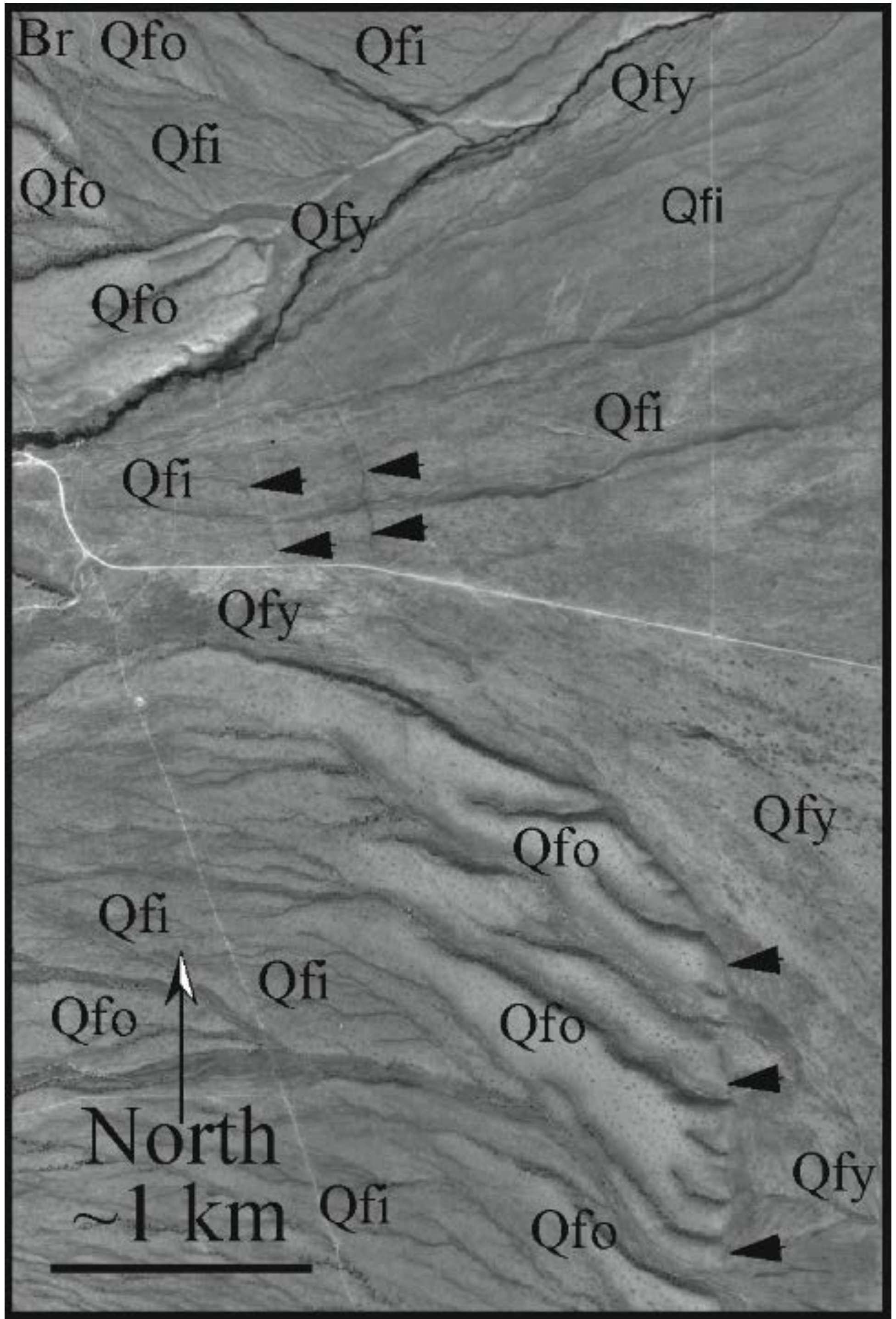

Br
Qfi
Qfy
QTp
Qfo
Dry Canyon
?
Hbf

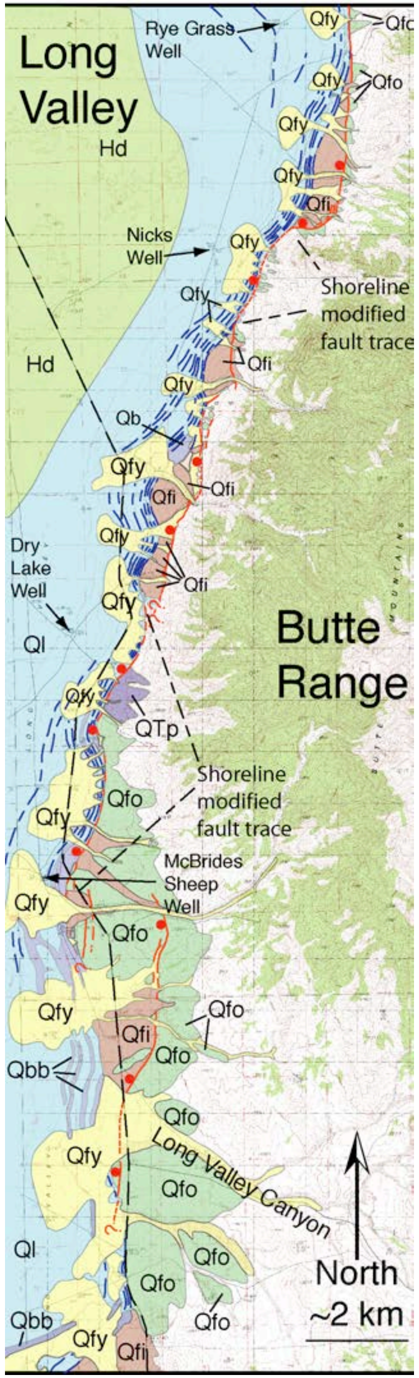
Simpson Park Range

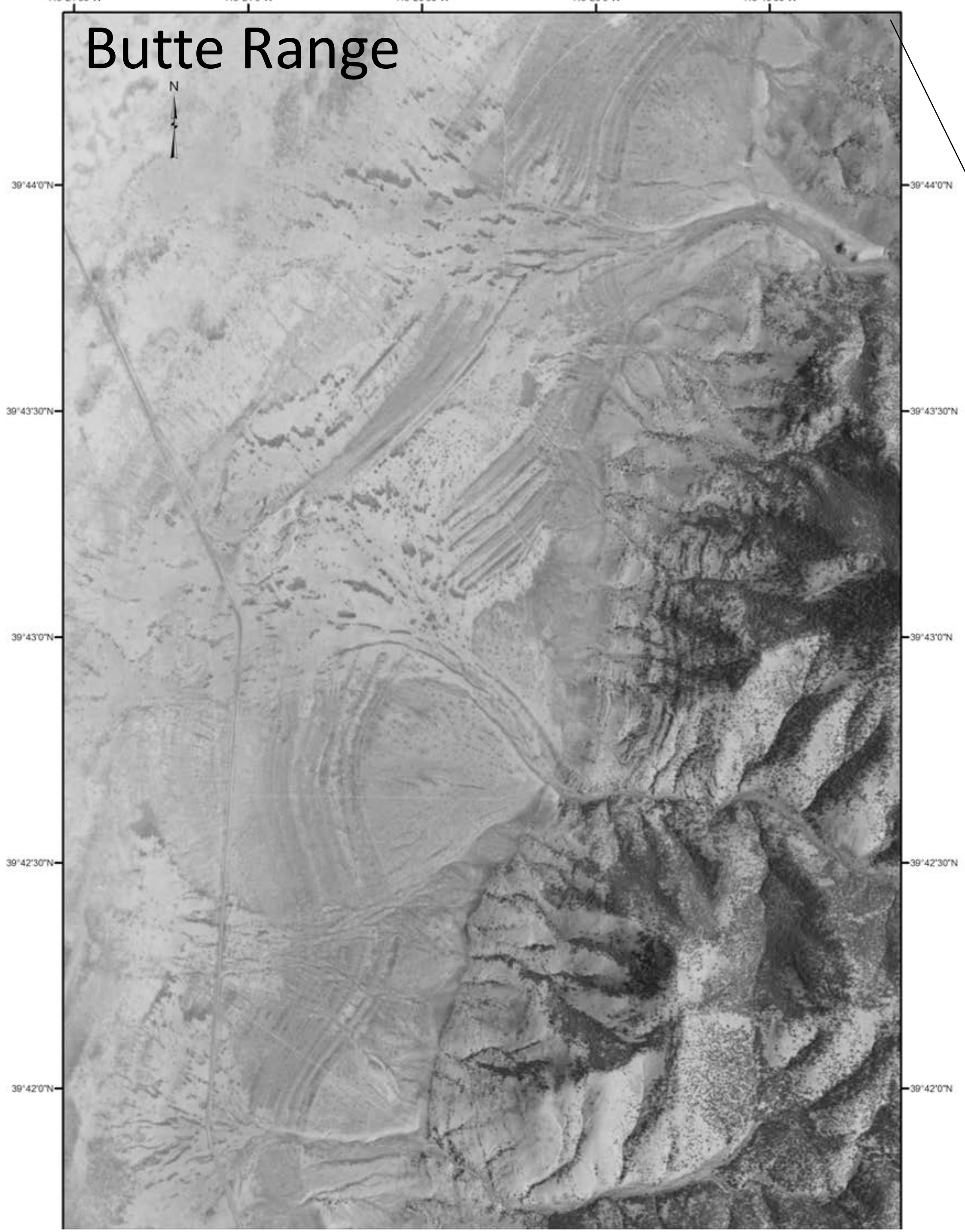


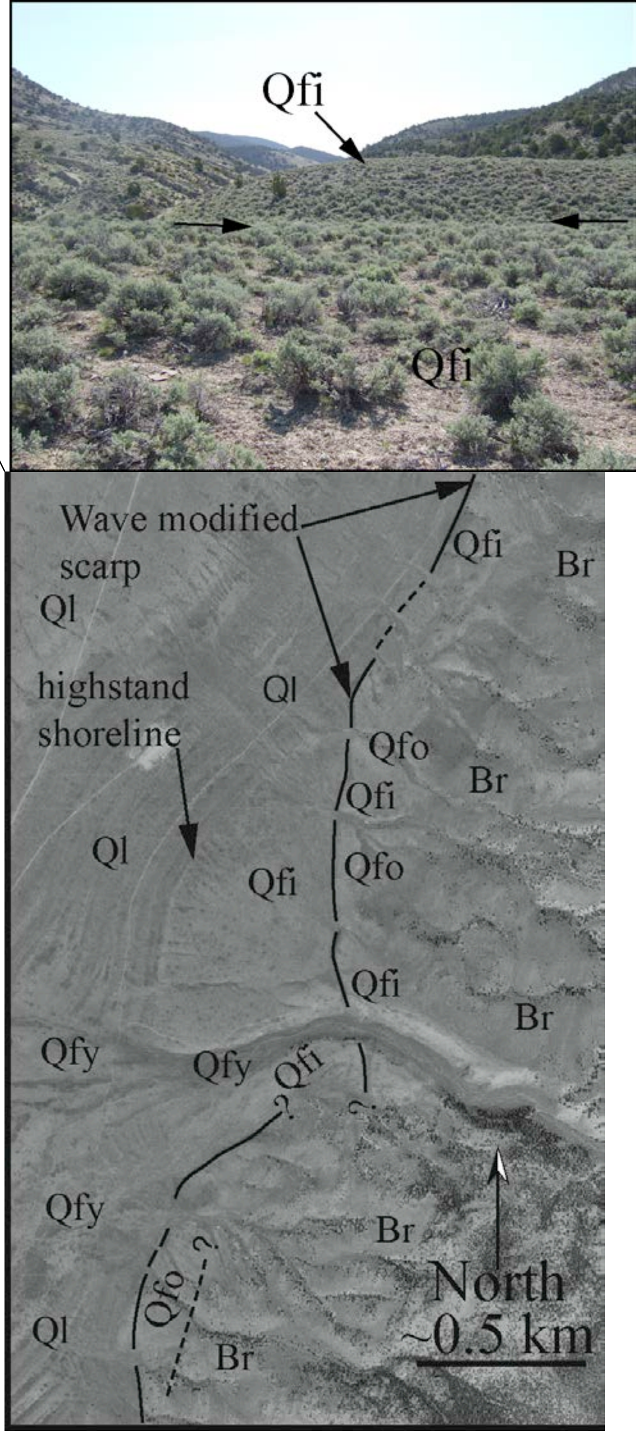


Schell Creek Range

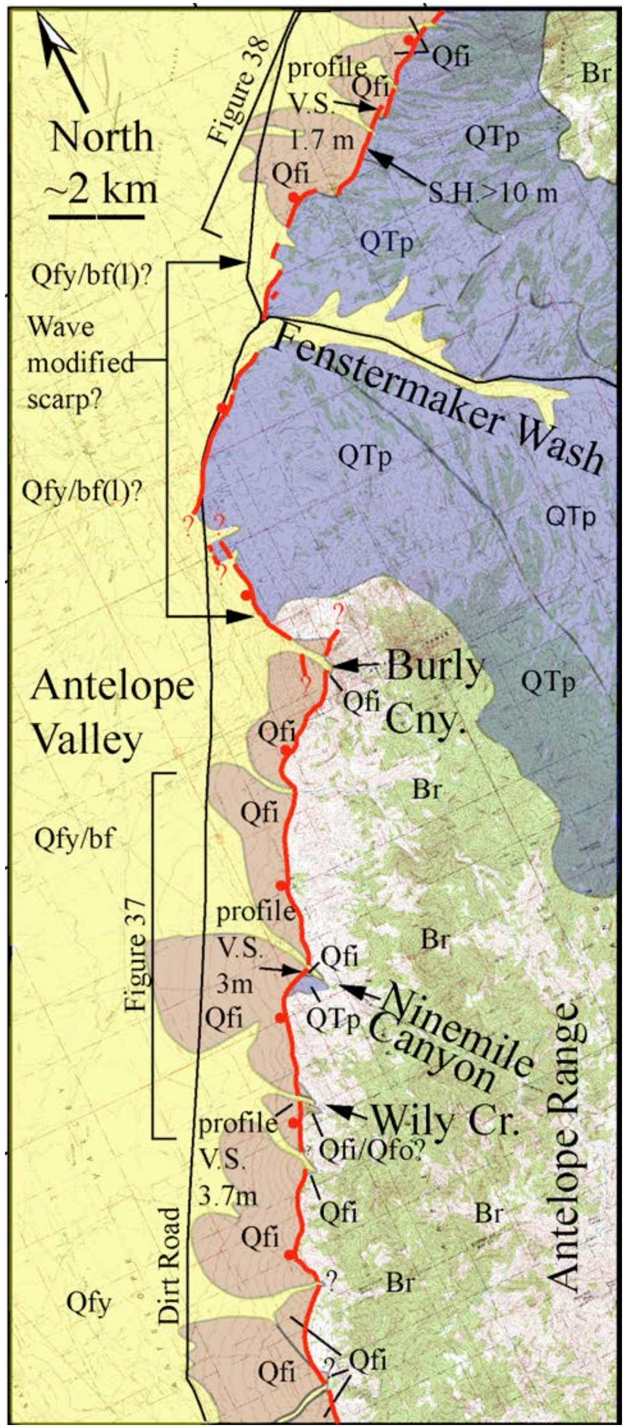


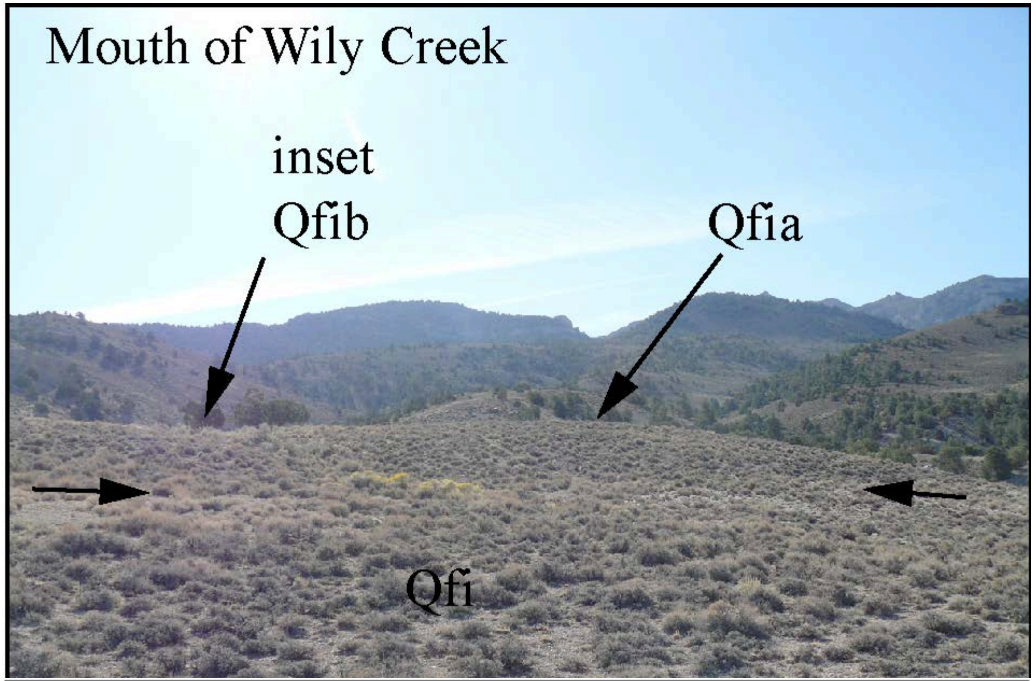

Long Valley
Rye Grass Well
Nicks Well
Shoreline modified fault trace
Dry Lake Well
Butte Range
Shoreline modified fault trace
McBrides Sheep Well
Long Valley Canyon
Hd
Ql
Qb
Qbb
QTp
Qfy
Qfi
Qfo
North
~2 km

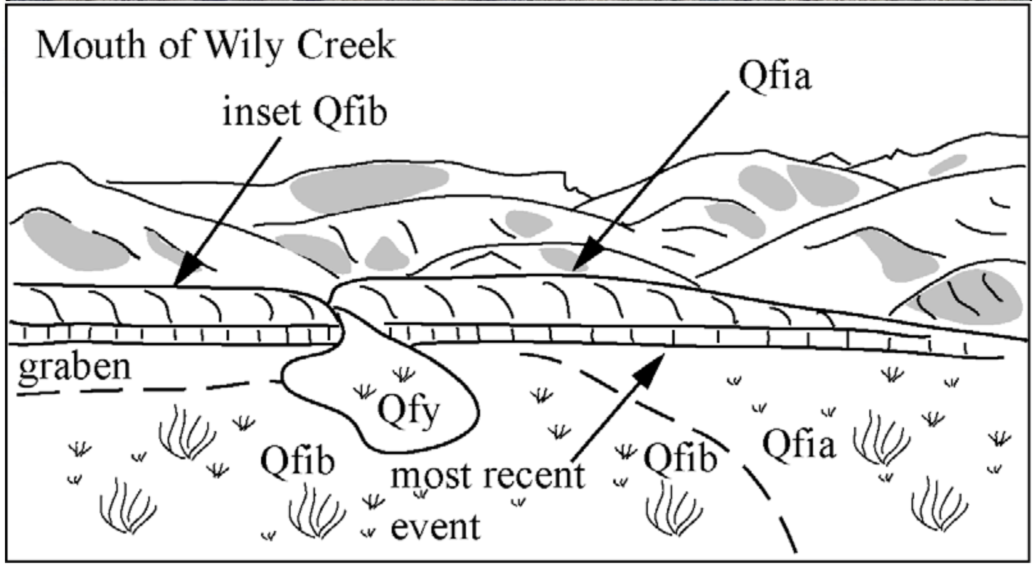

Butte Range
N
39°44'0"N
39°43'30"N
39°43'0"N
39°42'30"N
39°42'0"N


Qfi
Qfi
Wave modified scarp
highstand shoreline
Ql
Qfi
Qfo
Qfy
Br
North
~0.5 km

Antelope Range

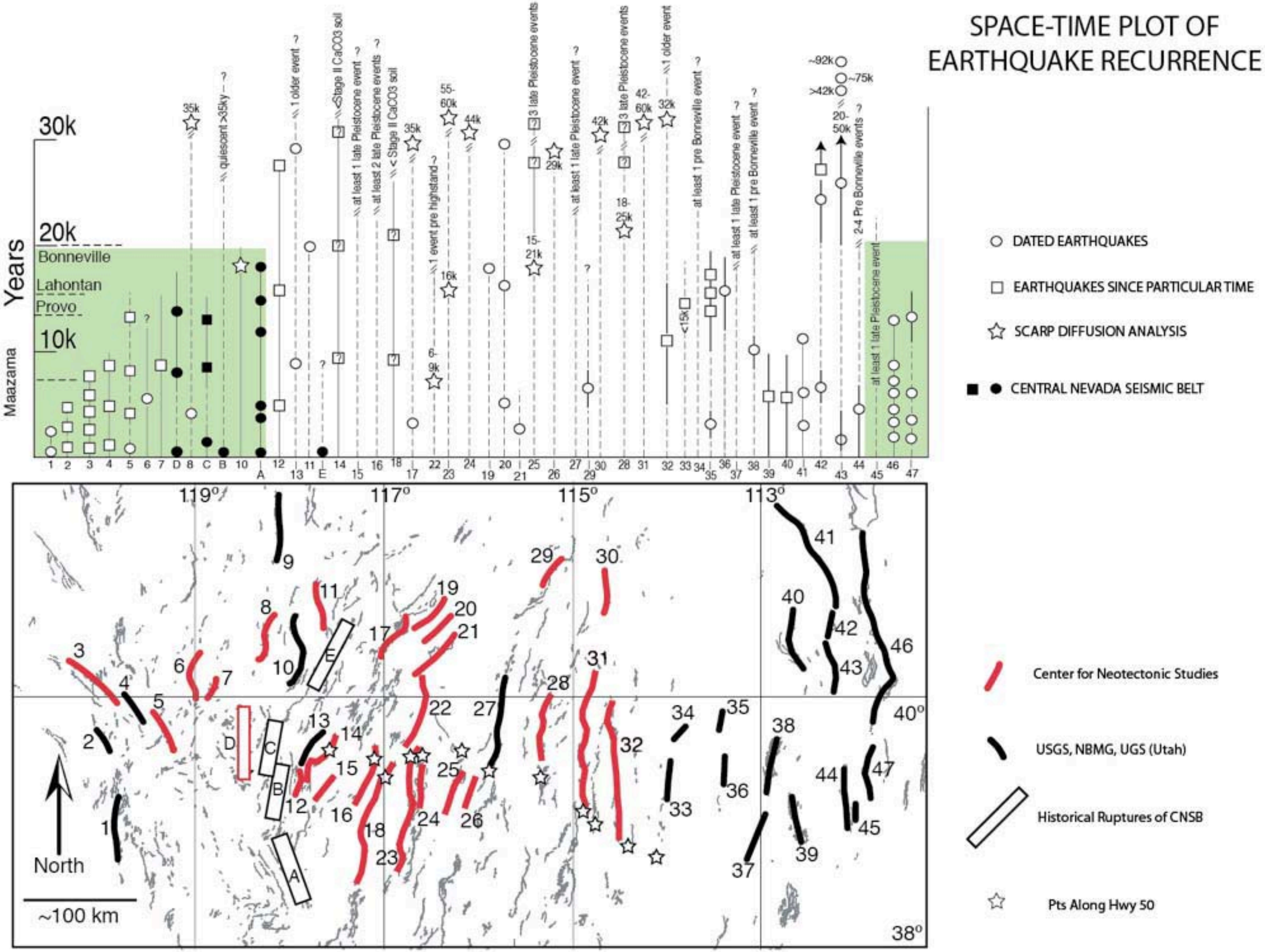




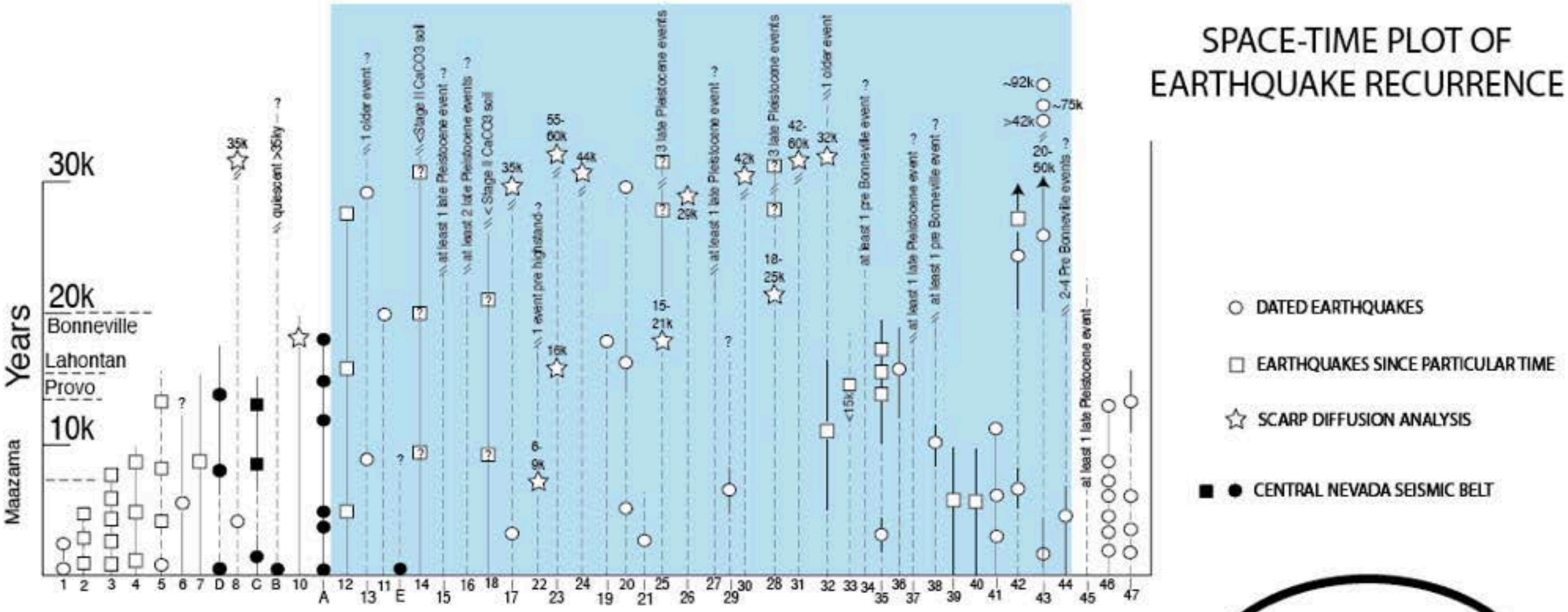


3 events recorded in scarp.

SPACE-TIME PLOT OF EARTHQUAKE RECURRENCE



SPACE-TIME PLOT OF EARTHQUAKE RECURRENCE

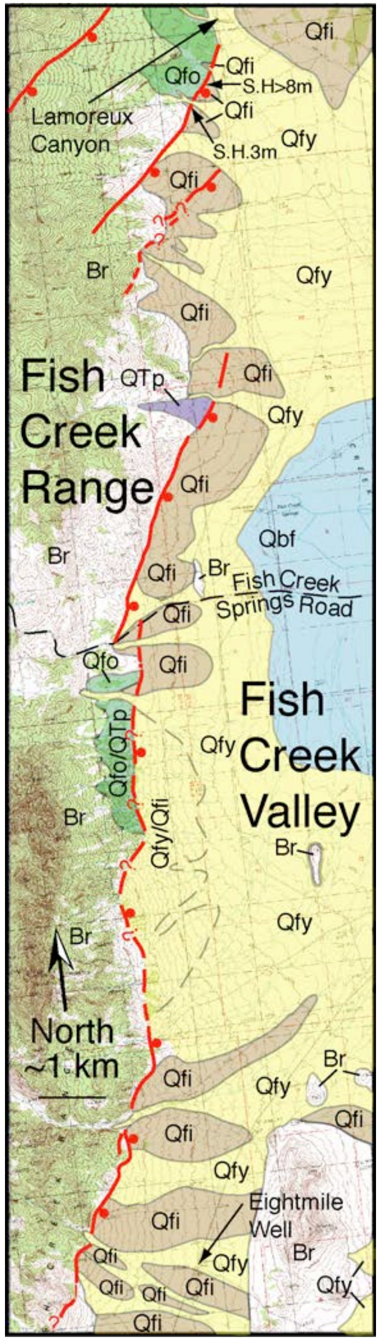


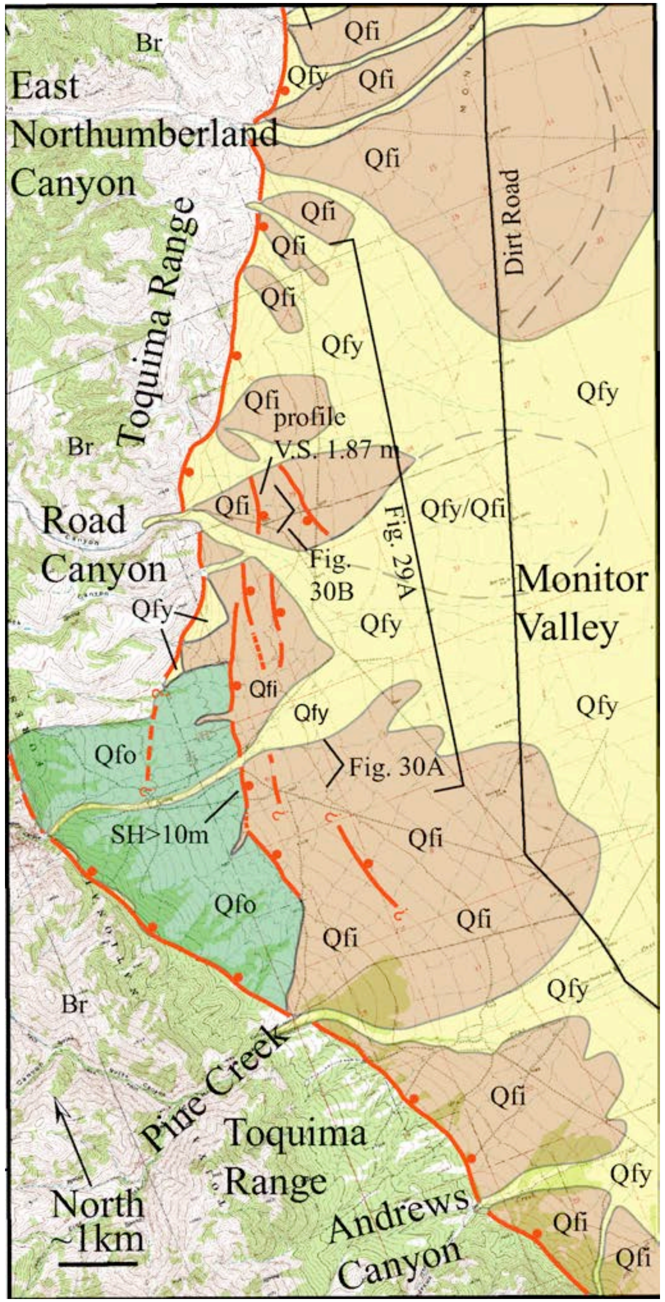
Fault	Vertical Separation (60 ky)	Extension	Strike	E-W Component of Extension
13. Clan Alpine	6 m	3.5 m	27°	3.1 m
.	.	.	.	.
.	.	.	.	.
SUM	91.3 m	58.5 m		48.4 m

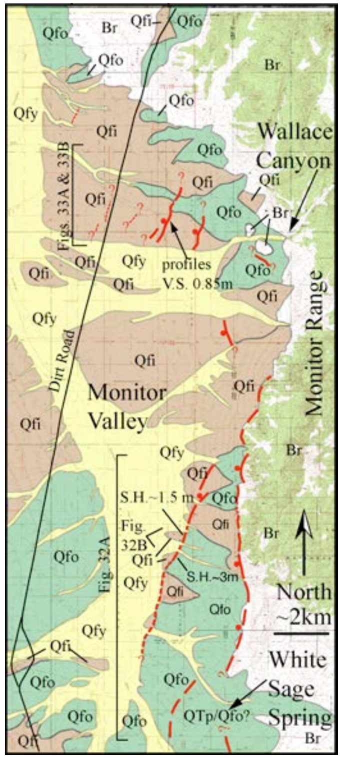
48. 4 m / 60 ky = 0.8 mm/yr

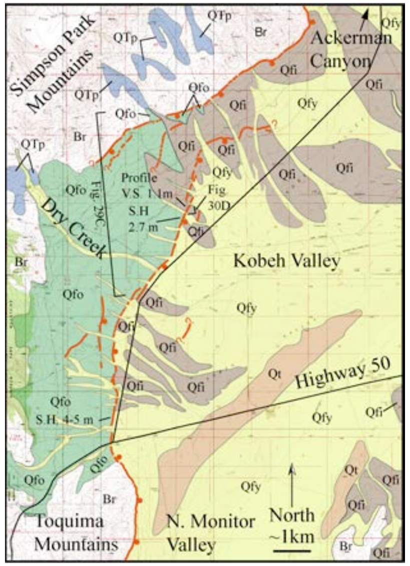
Fault	Vertical Separation (20 ky)	Extension	Strike	E-W Component of Extension
13. Clan Alpine	1.2 m	0.7 m	27°	0.6 m
.	.	.	.	.
.	.	.	.	.
SUM	35.4 m	24.5 m		19.3 m

19.3 m / 60 ky = 1.0 mm/yr


Lamoreux
Canyon
S.H.>8m
S.H.3m
Fish
Creek
Range
QTp
Qbf
Fish Creek
Springs Road
Fish
Creek
Valley
Qfo/QTp
Qfy/Qfi
North
~1 km
Eightmile
Well
Qfi
Qfo
Qfy
Br


East
Northumberland
Canyon
Toquima Range
Dirt Road
profile
V.S. 1.87 m
Road
Canyon
Fig.
30B
Fig. 29A
Qfy/Qfi
Monitor
Valley
Fig. 30A
SH>10m
Pine Creek
Toquima
Range
Andrews
Canyon
North
~1km
Qfi
Qfo
Qfy
Br


Wallace
Canyon
Figs. 33A & 33B
profiles
V.S. 0.85m
Dirt Road
Monitor
Valley
Monitor Range
S.H.~1.5 m
Fig
32B
Fig. 32A
S.H.~3m
North
~2km
White
Sage
Spring
QTp/Qfo?
Qfi
Qfo
Qfy
Br


Simpson Park
Mountains
Ackerman
Canyon
QTp
Profile
V.S. 1.1m
S.H
2.7 m
Fig.
30D
Fig. 29C
Dry Creek
Kobeh Valley
Highway 50
S.H. 4-5 m
Toquima
Mountains
N. Monitor
Valley
North
~1km
Qfi
Qfo
Qfy
Qt
Br