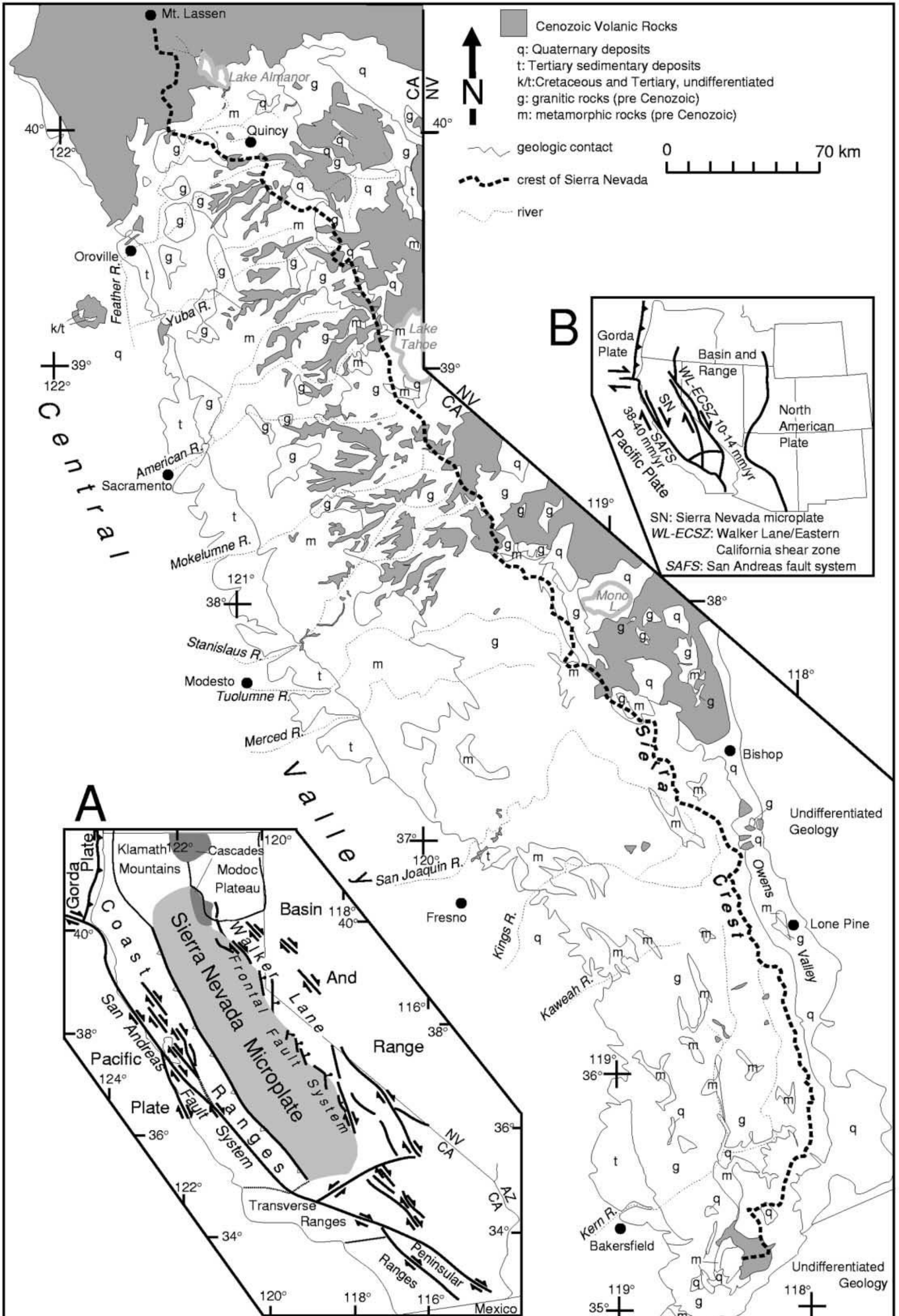
Stream Incision, Tectonics, Uplift, and Evolution of Topography of the Sierra Nevada, California

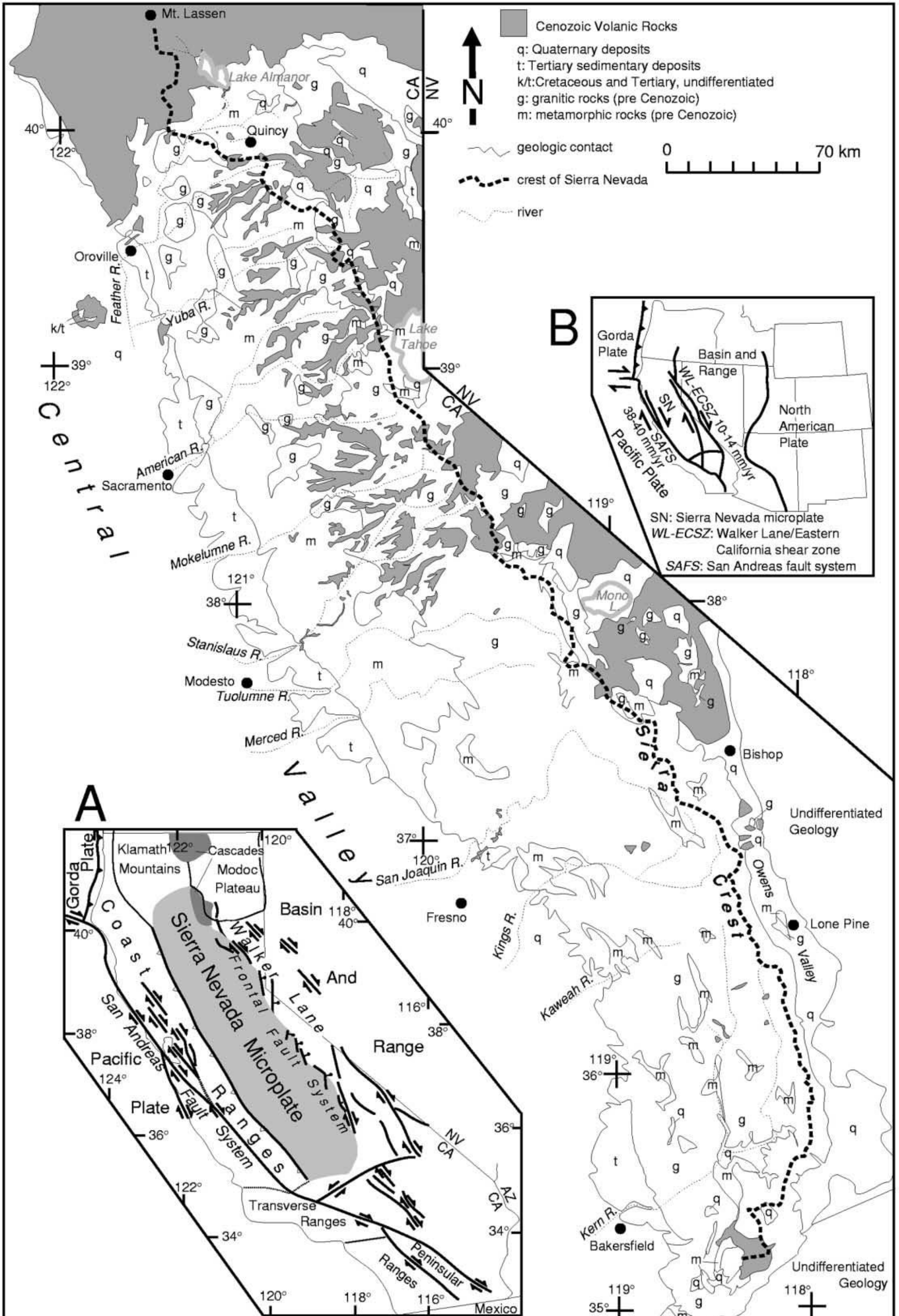
John Wakabayashi and Thomas L. Sawyer

The Journal of Geology, 2001



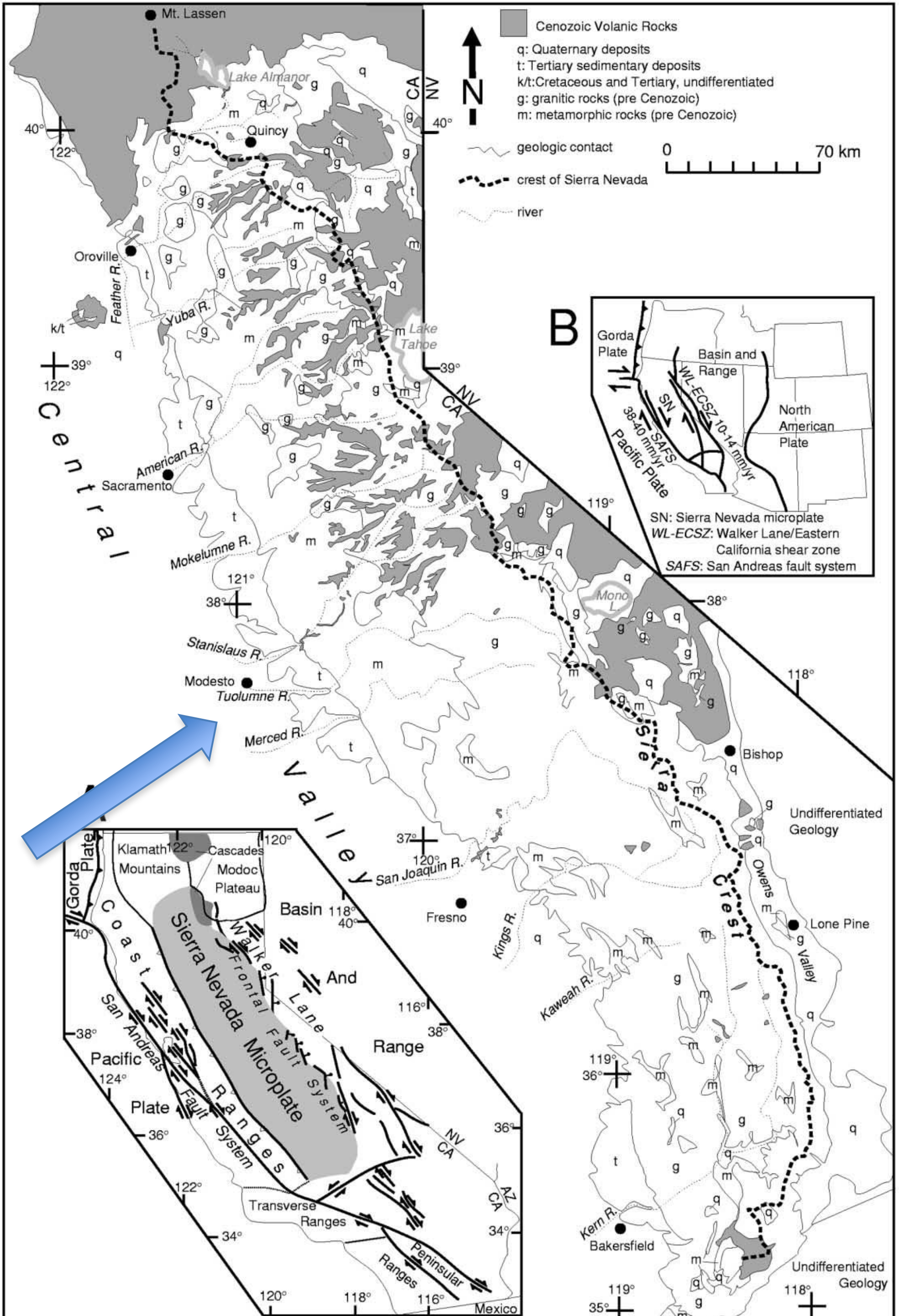
background

- Sierra Nevada microplate



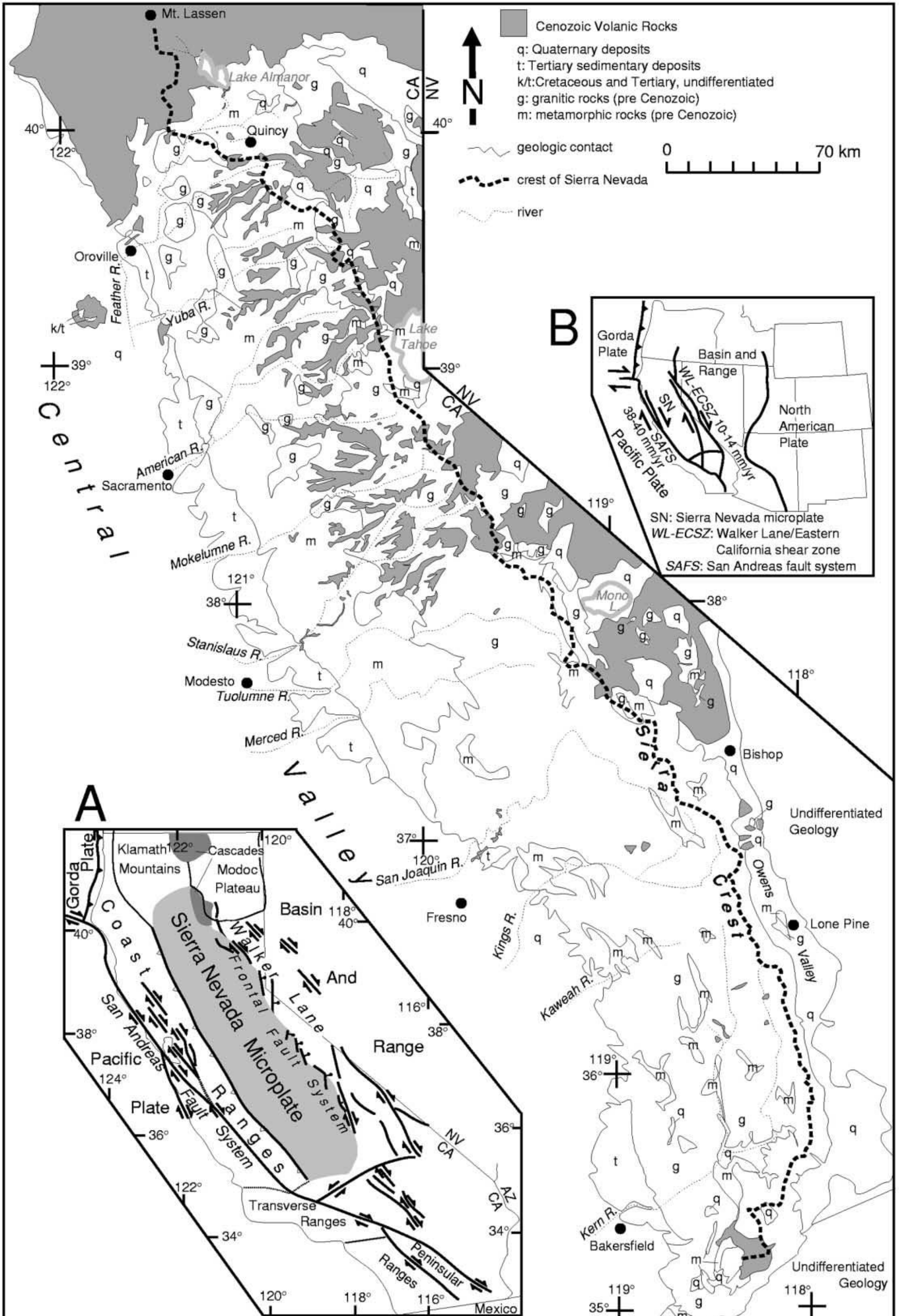
background

- Sierra Nevada microplate
- Cenozoic Volcanics



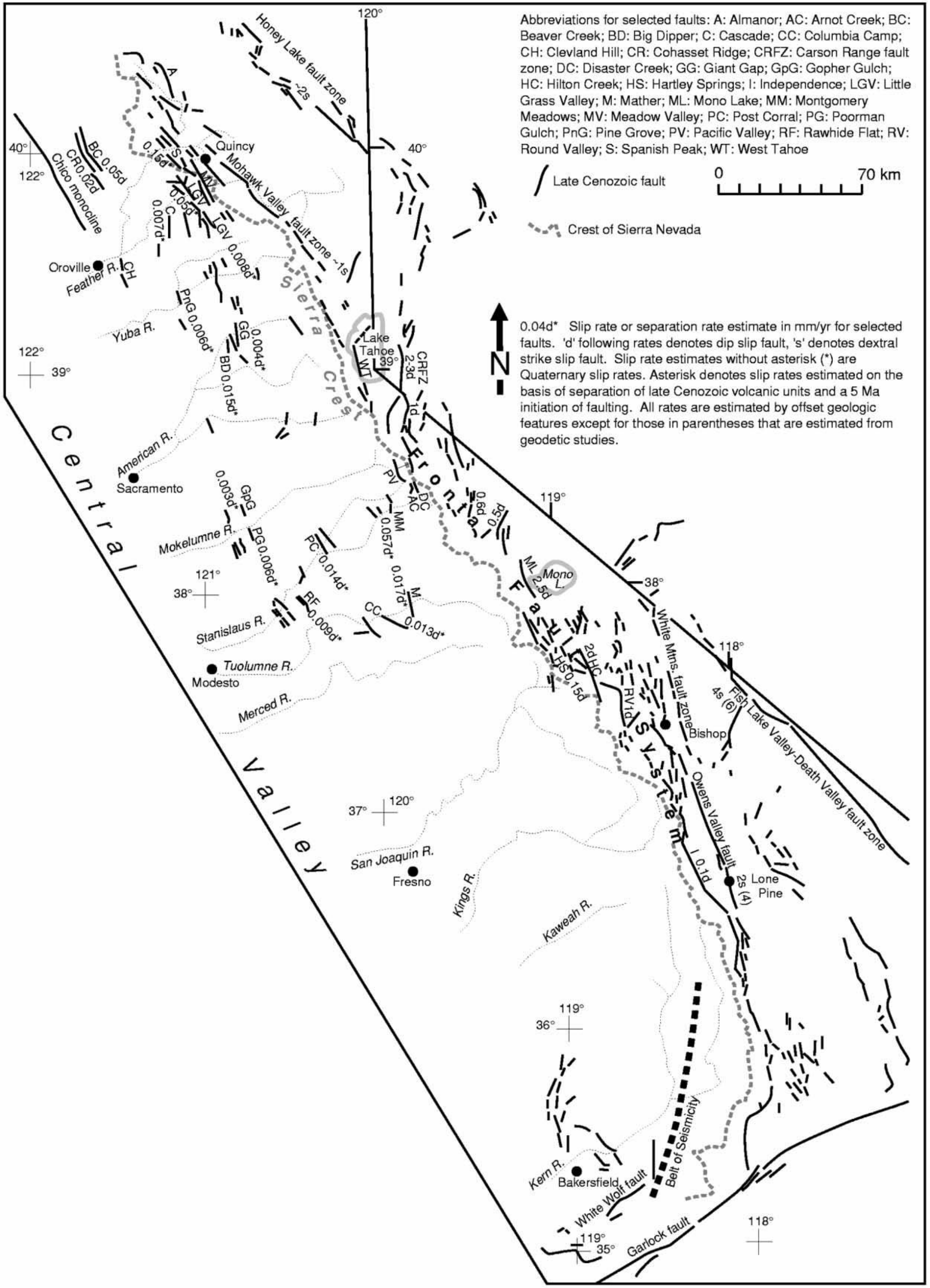
background

- Sierra Nevada microplate
- Cenozoic Volcanics
  - distribution?

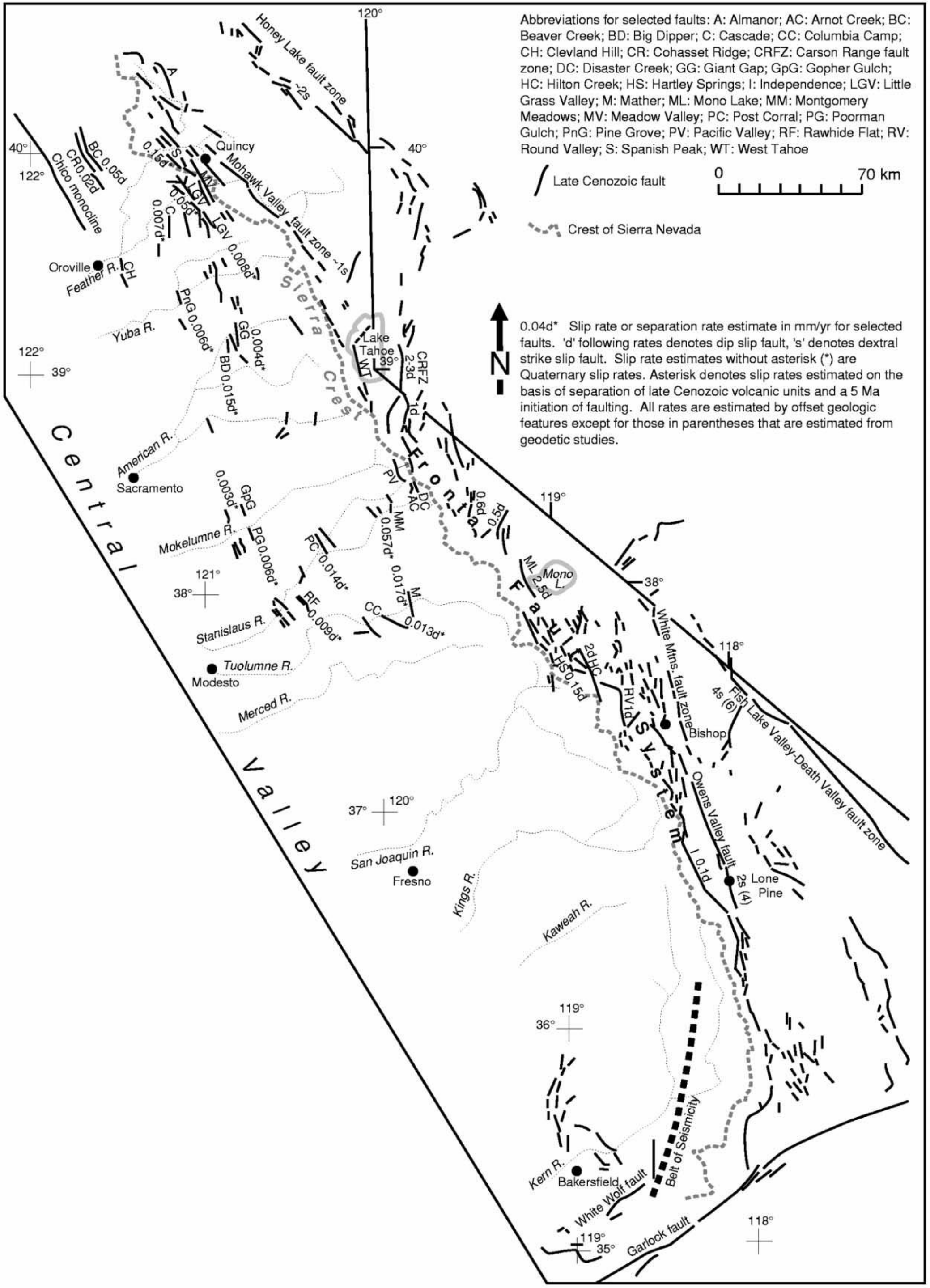


background

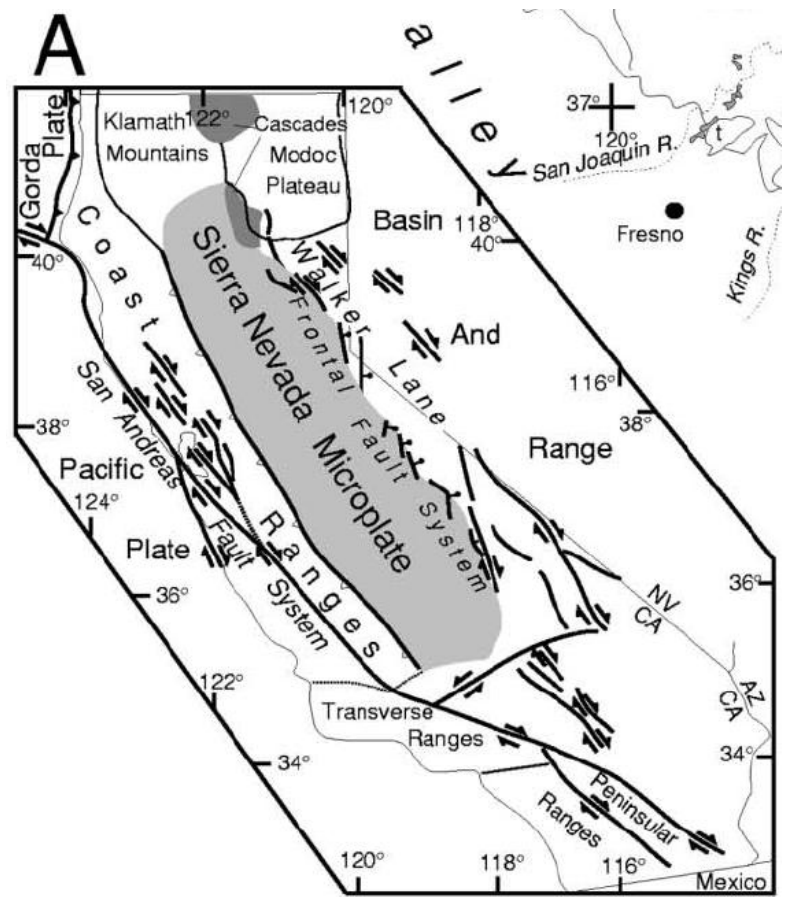
- Sierra Nevada microplate
- Cenozoic Volcanics
- important stratigraphy
  - Crystallization ages of plutons (110-85Ma)
  - Eocene (57-34Ma) auriferous gravels/Ione Formation
  - 34-20Ma rhyolites
  - 14-4Ma andesites & volcaniclastics: Mehrten Formation

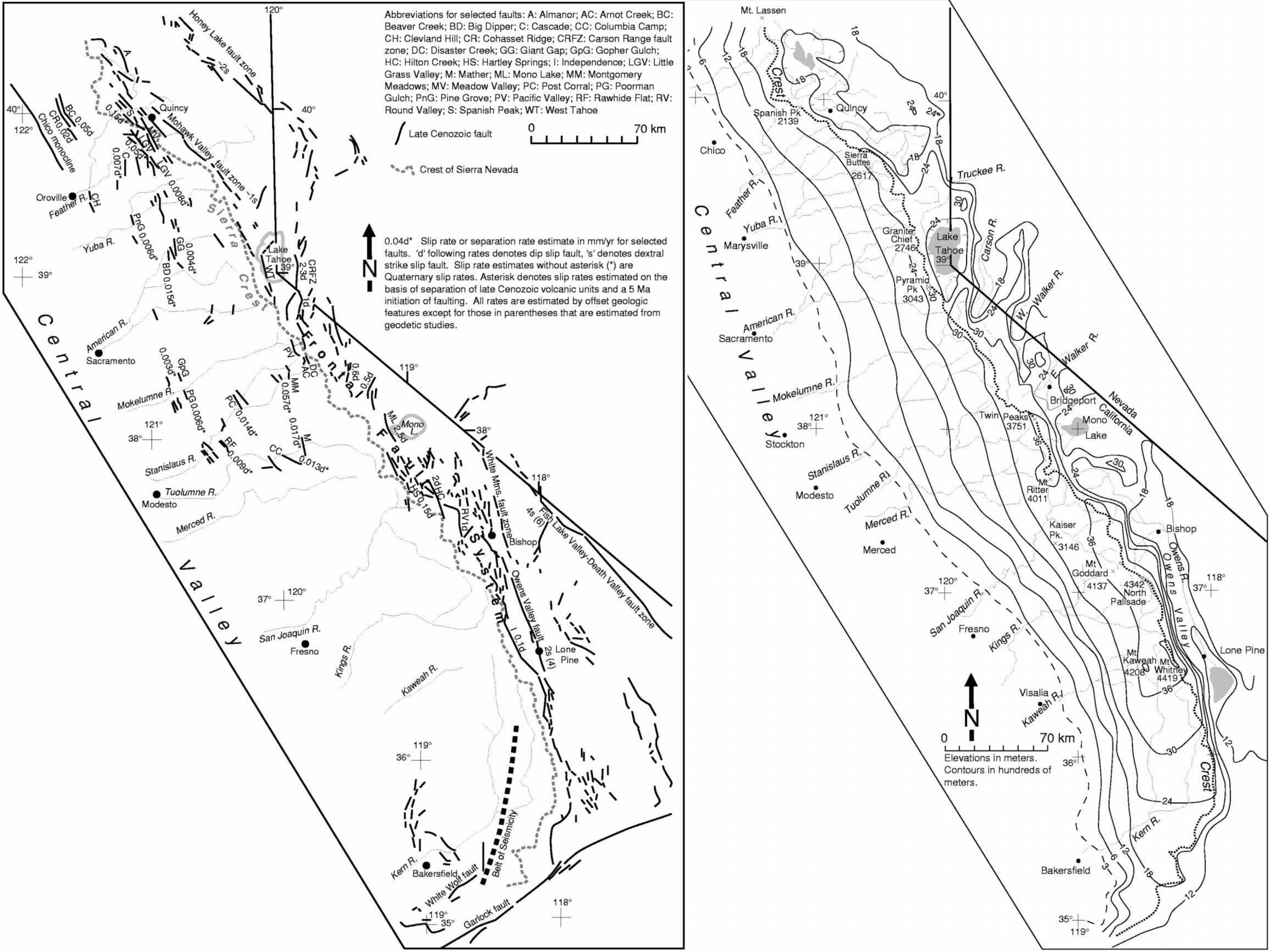


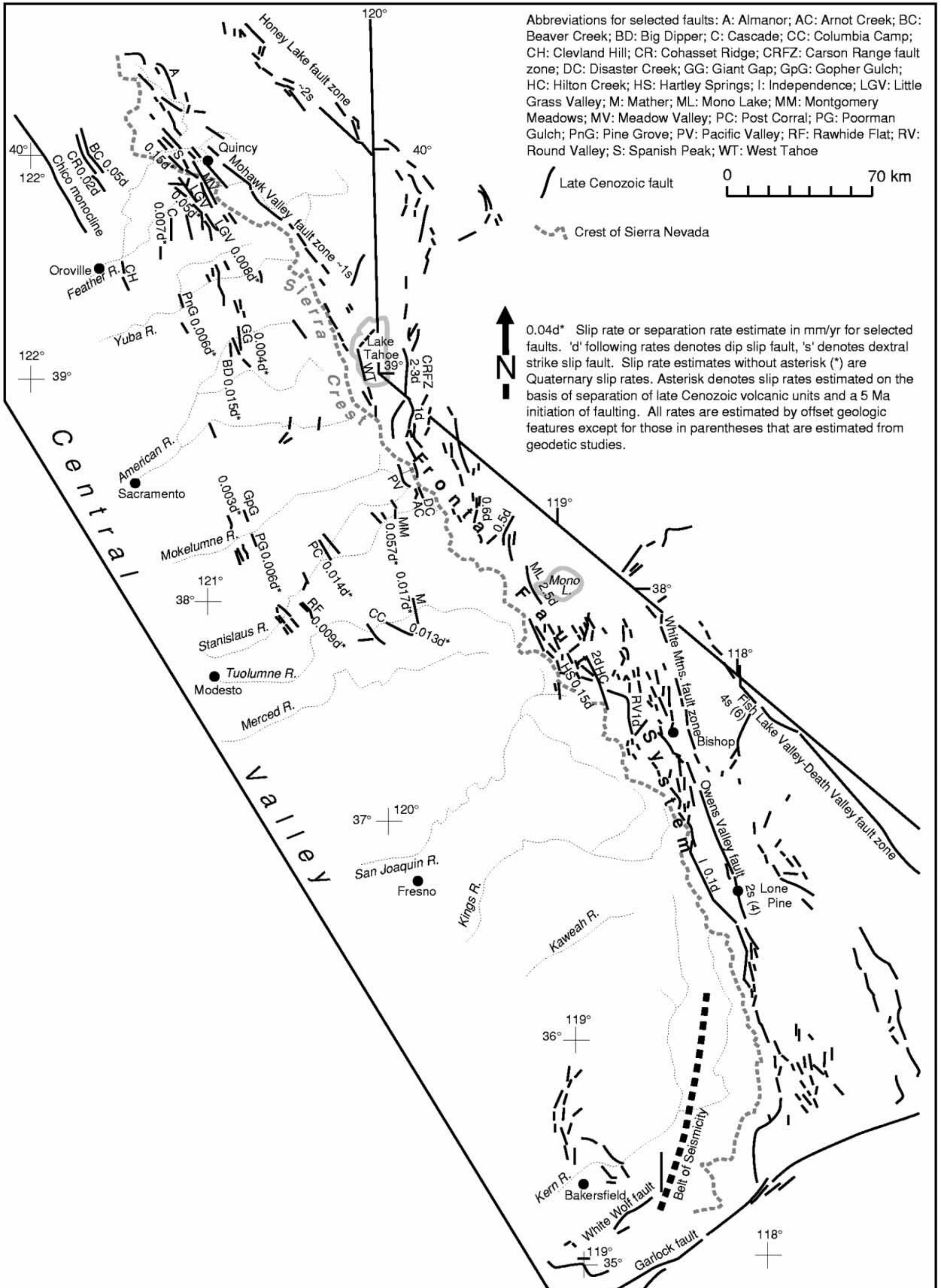
- Slip rates
  - ‘d’ = dip slip fault
  - ‘s’ = dextral strike slip fault
- Frontal fault system dextral “Walker Lane Belt”



- Frontal fault system

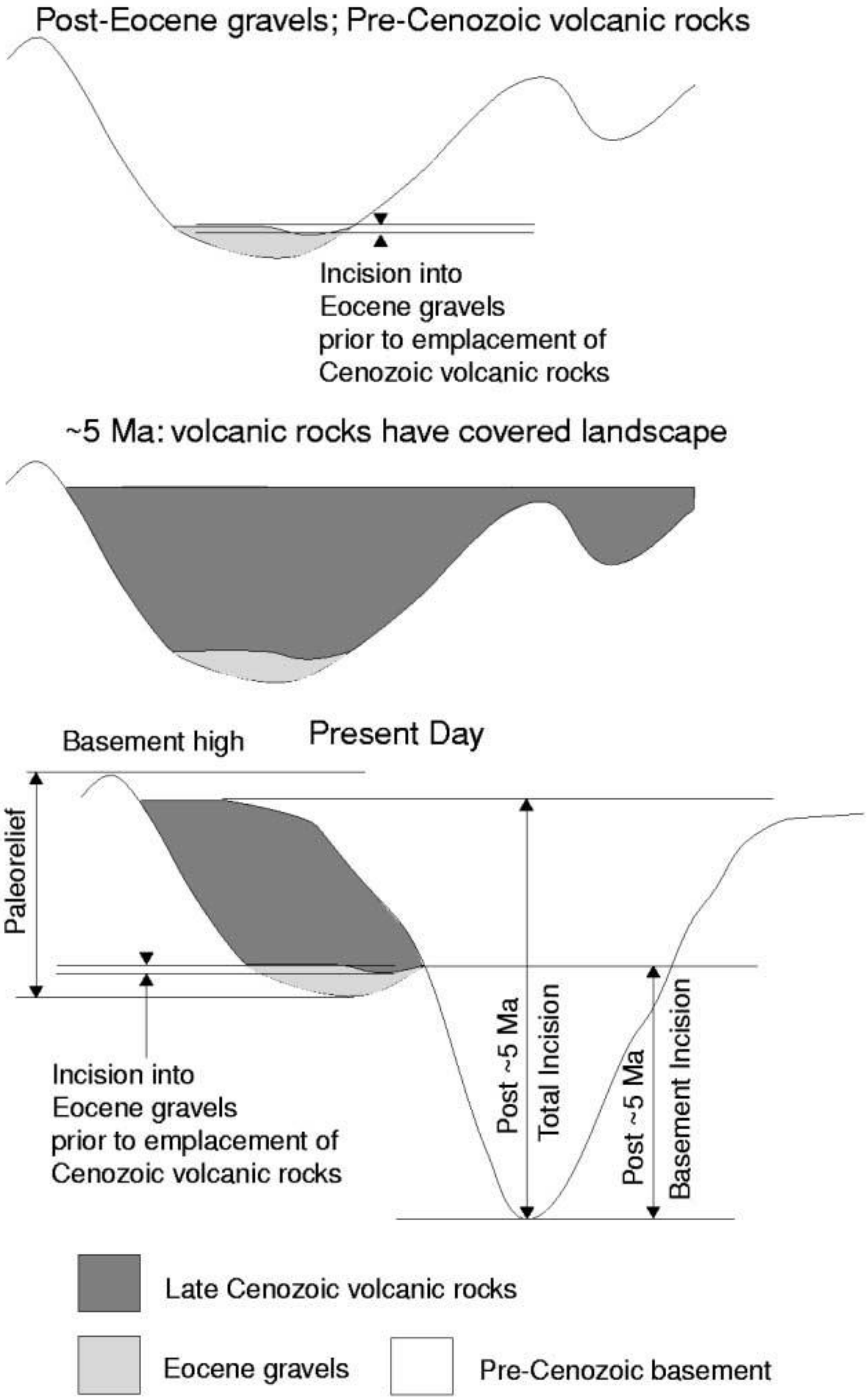



Abbreviations for selected faults: A: Almanor; AC: Arnot Creek; BC: Beaver Creek; BD: Big Dipper; C: Cascade; CC: Columbia Camp; CH: Clevland Hill; CR: Cohasset Ridge; CRFZ: Carson Range fault zone; DC: Disaster Creek; GG: Giant Gap; GpG: Gopher Gulch; HC: Hilton Creek; HS: Hartley Springs; I: Independence; LGV: Little Grass Valley; M: Mather; ML: Mono Lake; MM: Montgomery Meadows; MV: Meadow Valley; PC: Post Corral; PG: Poorman Gulch; PnG: Pine Grove; PV: Pacific Valley; RF: Rawhide Flat; RV: Round Valley; S: Spanish Peak; WT: West Tahoe
Late Cenozoic fault
0 70 km
Crest of Sierra Nevada
0.04d* Slip rate or separation rate estimate in mm/yr for selected faults. 'd' following rates denotes dip slip fault, 's' denotes dextral strike slip fault. Slip rate estimates without asterisk (*) are Quaternary slip rates. Asterisk denotes slip rates estimated on the basis of separation of late Cenozoic volcanic units and a 5 Ma initiation of faulting. All rates are estimated by offset geologic features except for those in parentheses that are estimated from geodetic studies.
N
Honey Lake fault zone
Mohawk Valley fault zone ~1s
Chico monocline
Sierra Crest
Frontal Fault System
White Mtns. fault zone
Fish Lake Valley-Death Valley fault zone
Owens Valley fault
Belt of Seismicity
White Wolf fault
Garlock fault
Central Valley
Quincy
Oroville
Sacramento
Modesto
Fresno
Bishop
Lone Pine
Bakersfield
Lake Tahoe
Mono L.
Feather R.
Yuba R.
American R.
Mokelumne R.
Stanislaus R.
Tuolumne R.
Merced R.
San Joaquin R.
Kings R.
Kaweah R.
Kern R.
Mt. Lassen
Spanish Pk 2139
Sierra Buttes 2617
Granite Chief 2746
Pyramid Pk 3043
Twin Peaks 3751
Mt Ritter 4011
Kaiser Pk. 3146
Mt Goddard 4137
4342 North Palisade
Mt Kaweah 4208
Mt Whitney 4419
Chico
Marysville
Stockton
Merced
Visalia
Truckee R.
Carson R.
W. Walker R.
E. Walker R.
Bridgeport
Mono Lake
Nevada
California
Owens R.
Owens Valley
Crest
Elevations in meters. Contours in hundreds of meters.



intro II

- Slip rates
  - ‘d’ = dip slip fault
  - ‘s’ = dextral strike slip fault
- Frontal fault system
- Internal deformation
  - “rigid block model”?



stream incision

- Terminology:
  - "total incision" vs "basement incision"
- How are incision rates determined?

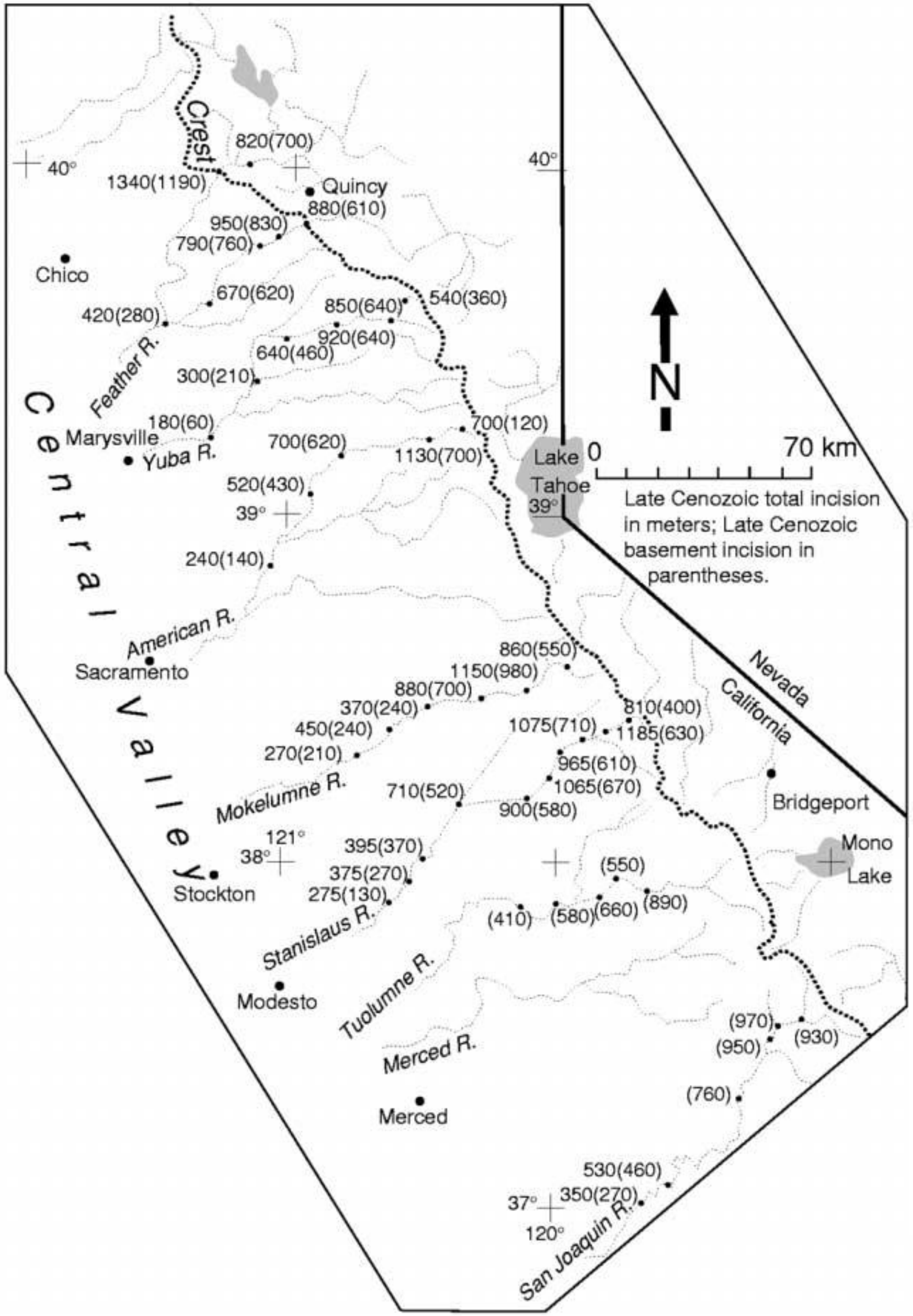


Figure 5. Late Cenozoic stream incision of the northern and central Sierra Nevada.

stream incision

#s represent: Total incision [m]
(basement incision [m])

Table 1. Deepest Cenozoic Incision and Corresponding Rates

	Minimum incision (m)[a]	Incision rate[b]	Time range
North Fork Feather River	1340 (1190)	.27 (.24)	5 Ma to present
Middle Fork Feather River	950 (830)	.19 (.17)	5 Ma to present
North Yuba River	915 (640)	.18 (.13)	5 Ma to present
North Fork American River	1130 (700)	.23 (.14)	5 Ma to present
North Fork Mokelumne River	1150 (980)	.23 (.20)	5 Ma to present
Stanislaus River	1075 (710)	.22 (.14)	5 Ma to present
Tuolumne River	(890)	(.18)	5 Ma to present
San Joaquin River	(580)	(.089)	10 to 3.5 Ma
	(390)	(.11)	3.5 Ma to present
Post-Eocene to Miocene Incision:[c]			
Yuba River drainage	≤60	<.003	...
American River drainage	150	<.007	...

[a] Incision below volcanic rocks in parentheses.
[b] Except where noted, minimum basement incision rate in parentheses.
[c] Averaged over 20 m.yr., the minimum age difference between the youngest Eocene gravels and oldest Mehrten Formation.

stream incision

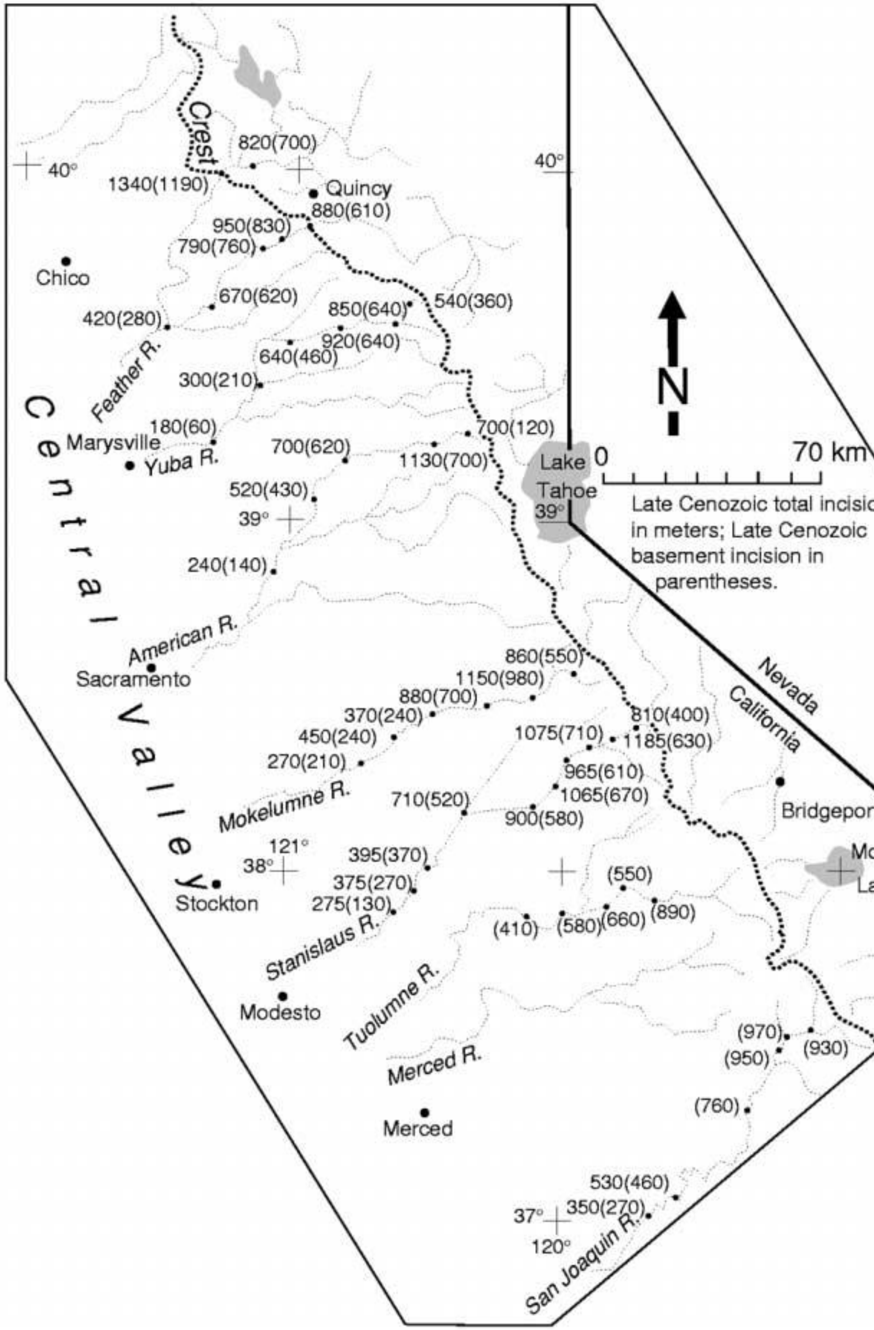
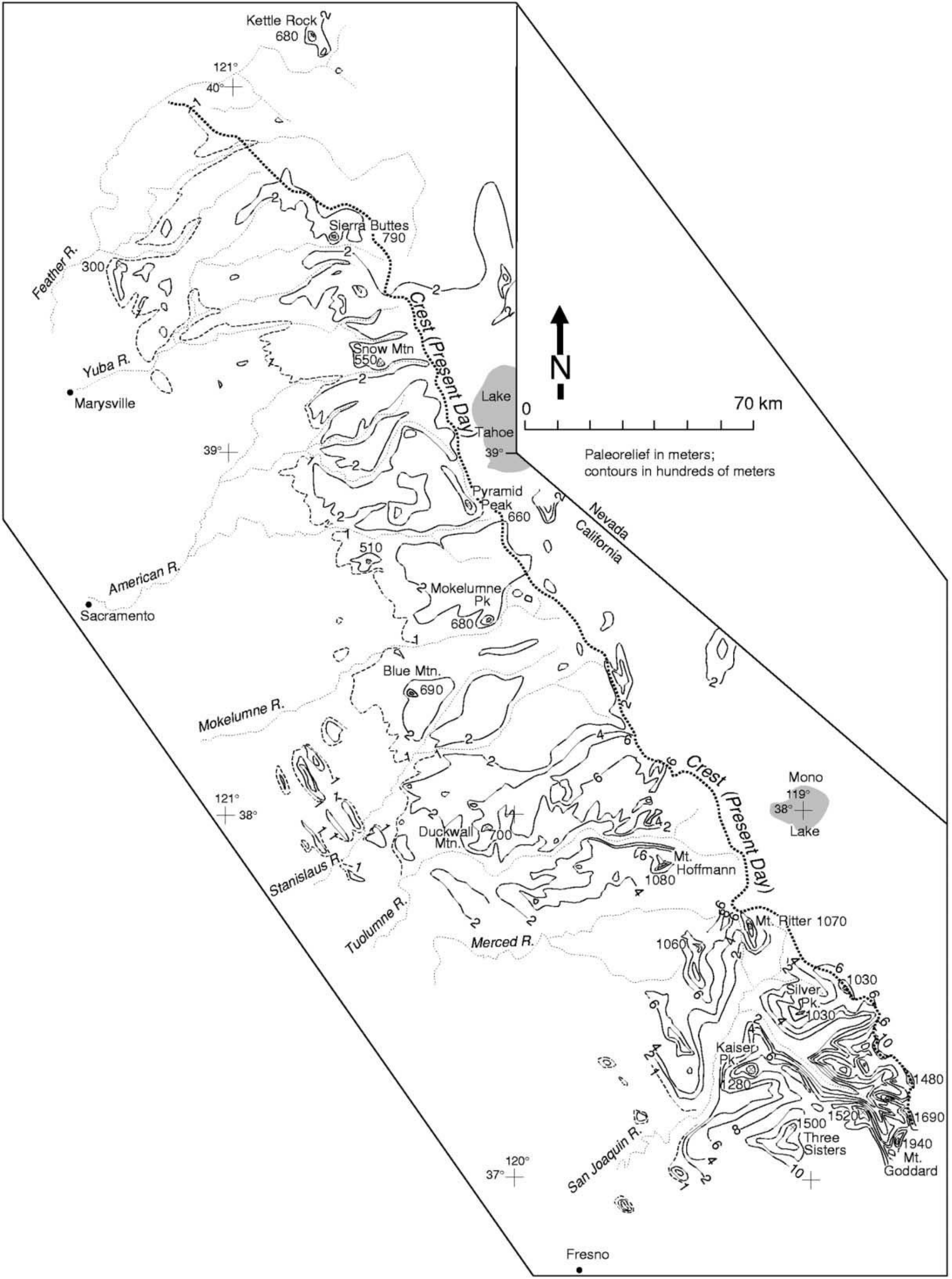


Figure 5. Late Cenozoic stream incision of the northe
and central Sierra Nevada.

Table 2. Incision Rate, North Fork Feather River, Lake Almanor to Confluence with East Branch North Fork Feather River

Fault block or reach of river	Total incision rate (mm/yr) with time interval[a]
Ohio Creek to Salmon Creek	.57–.73 Ma to present: .21–.26 (.096–.12); 1.11–1.20 Ma to present: .22–.24 (.16–0.17); 1.11–1.20 Ma to .57–.73 Ma: .31–.52 (.18–.31)
Davis Creek to Meeker Bar	.57–.73 Ma to present: .30–.38 (.10–.13); 1.11–1.20 Ma to present: .29–.31 (.24–.25); 1.11–1.20 Ma to .57–.73 Ma: .43–.71 (.33–.54); 2.05 Ma to 1.11–1.20 Ma: .13–.15 (.052–.058)
Butt Creek to Crablouse Ravine	.57–.73 Ma to present: .37–.48 (.15–.19); 1.11–1.20 Ma to .57–.73 Ma: .43–.72 (.31–.51); 1.11–1.20 Ma to present: .32–.34 (.25–.27)
Crablouse Ravine to Mosquito Creek	.57–.73 Ma to present: .28–.36 (.14–.18); 1.11–1.20 Ma to .57–.73 Ma: .32–.54 (.21–.35)
Mosquito Creek to Queen Lily	.57–.73 Ma to present: .29–.37 (.067–.086); 1.11–1.20 Ma to .57–.73 Ma: .39–.64 (.31–.51)
Waller Creek fault to East Branch confluence	.57–.73 Ma to present: .23–.29 (.12–.15); 1.11–1.20 Ma to .57–.73 Ma: 034–.57 (.24–.40); 2.81 Ma to 1.11–1.20 Ma: .14 (.082–.086); 2.81 Ma to present: .17 (.13)

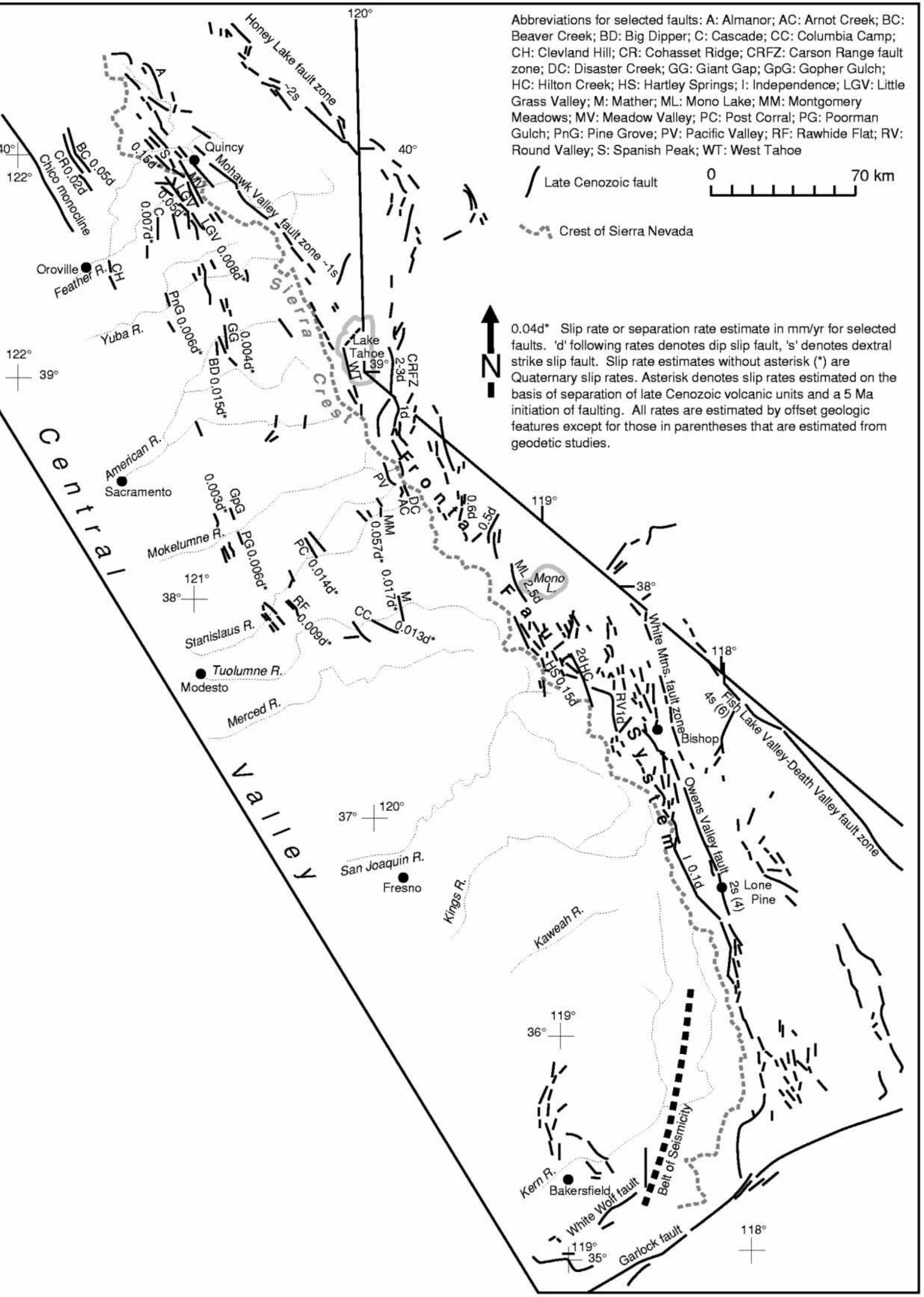
[a] Parentheses denote basement incision rate.



paleorelief

(i.e. relief predating Cenozoic deposits)

- how is this calculated?
- Differences between north/central and southern Sierra?



Late Cenozoic action on Frontal Fault System

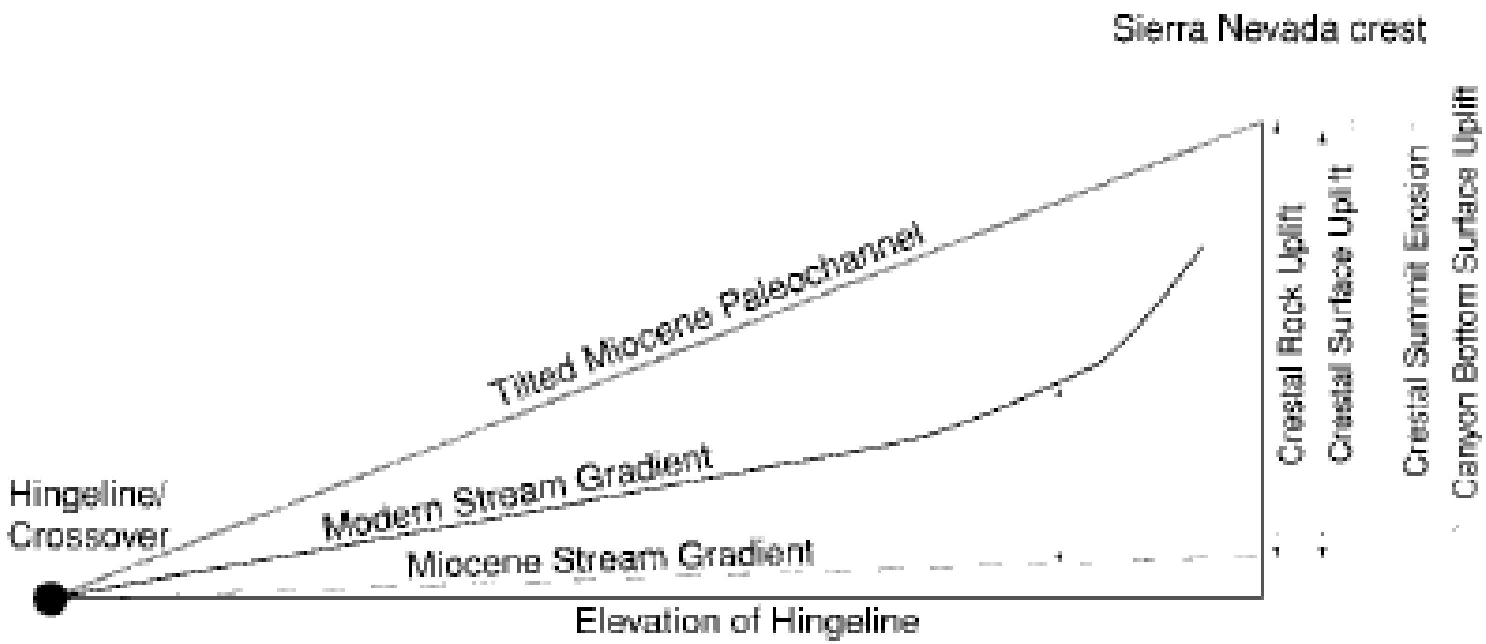
- Beheaded drainages and volcanic rocks provide timing/magnitude of vertical displacement on front
- westward encroachment of WLB

Internal deformation of 'rigid' Sierra block

- Rigid model appropriate?
- Why is it important?

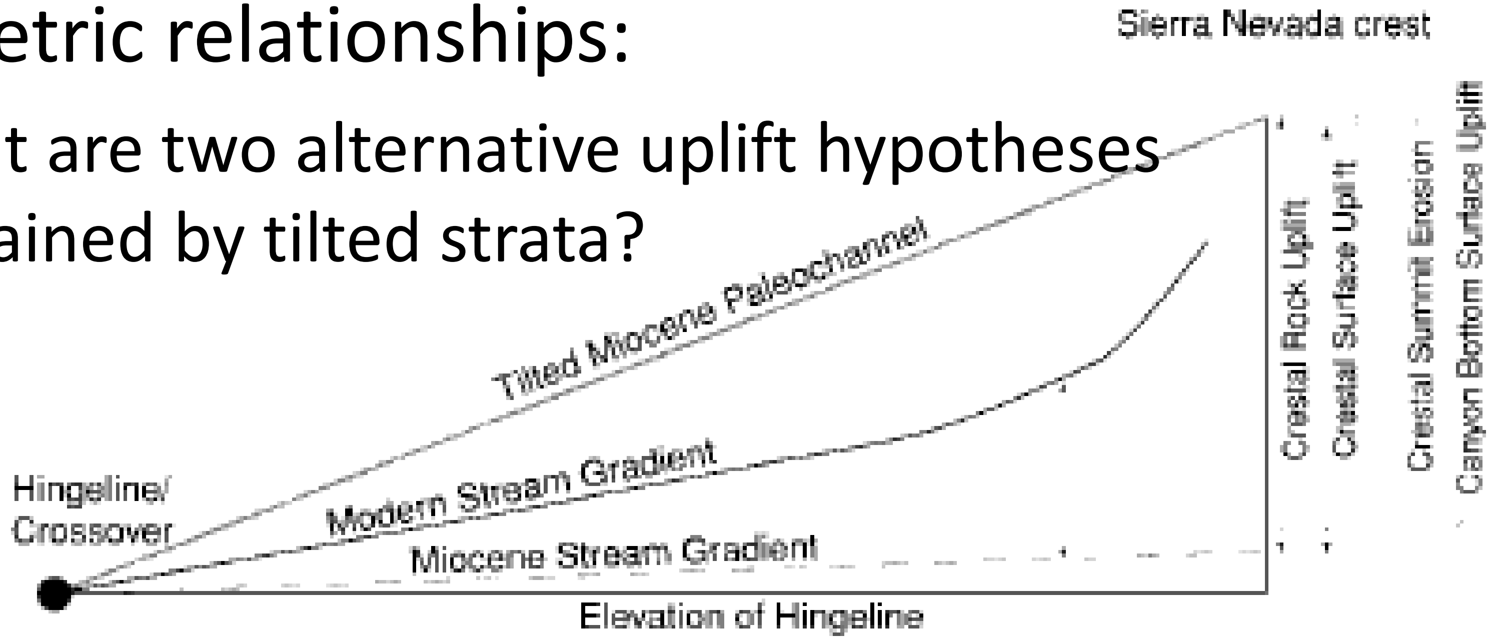
Uplift

- What are we talking about???
  - Surface uplift
  - Exhumation
  - Rock uplift

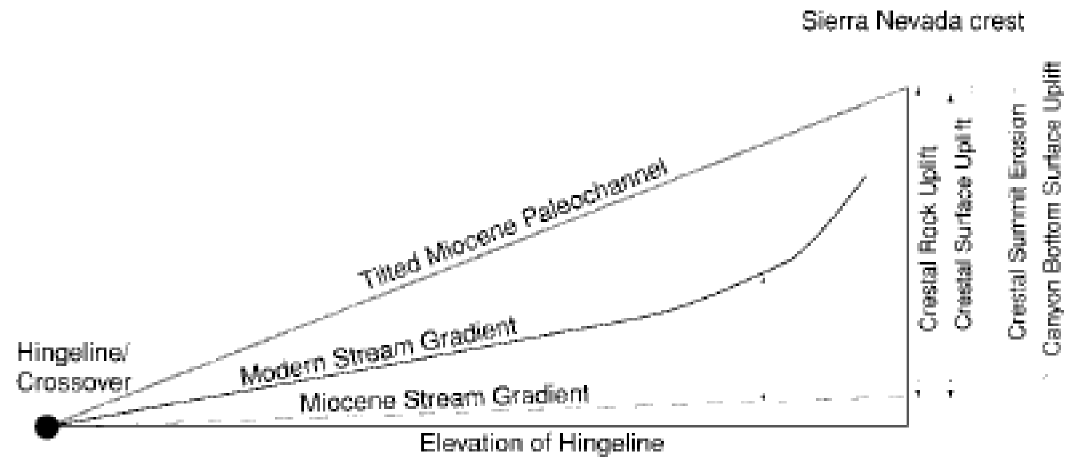


Uplift

- What are we talking about???
  - Surface uplift
  - Exhumation
  - Rock uplift
- Geometric relationships:
  - What are two alternative uplift hypotheses explained by tilted strata?

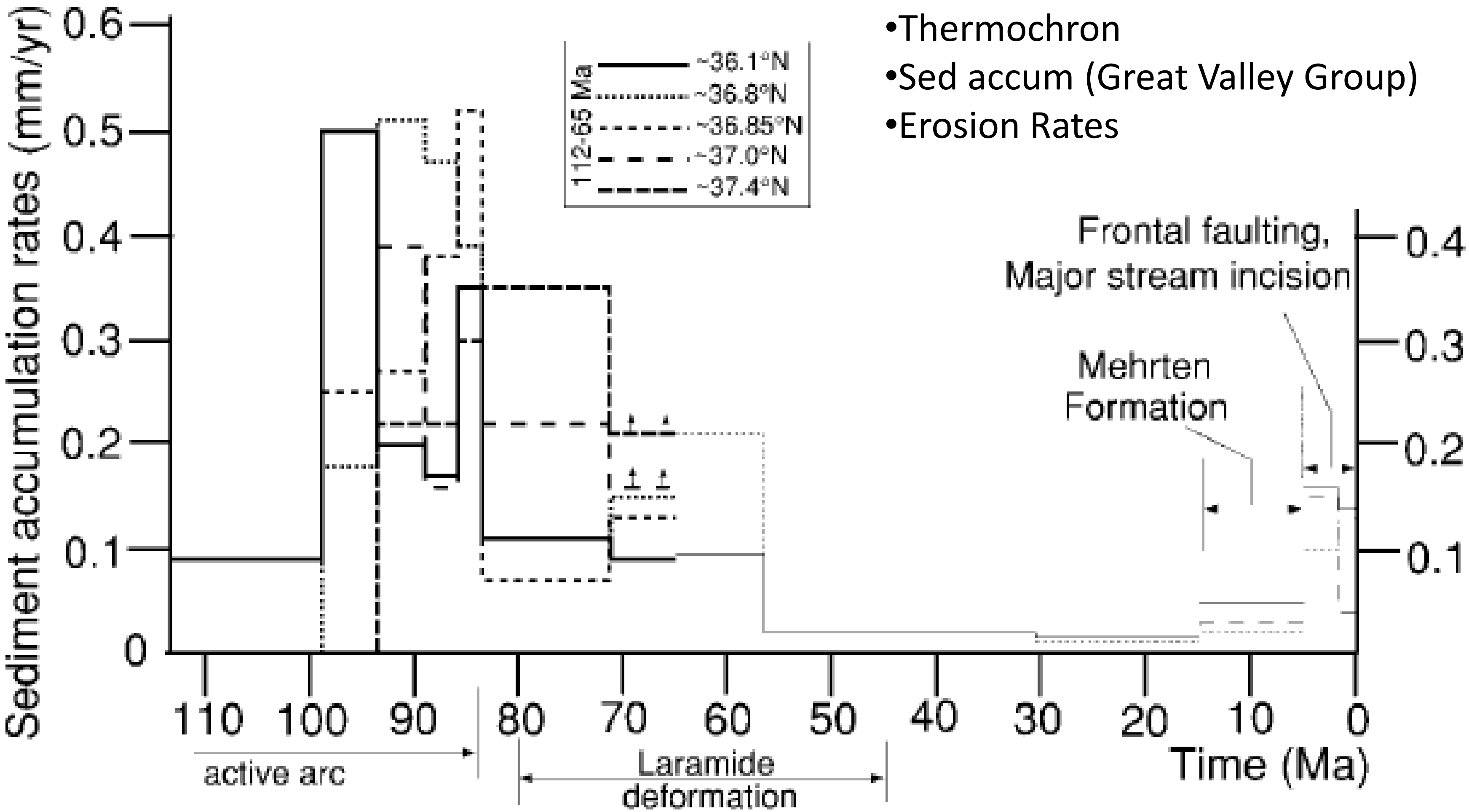


Uplift history

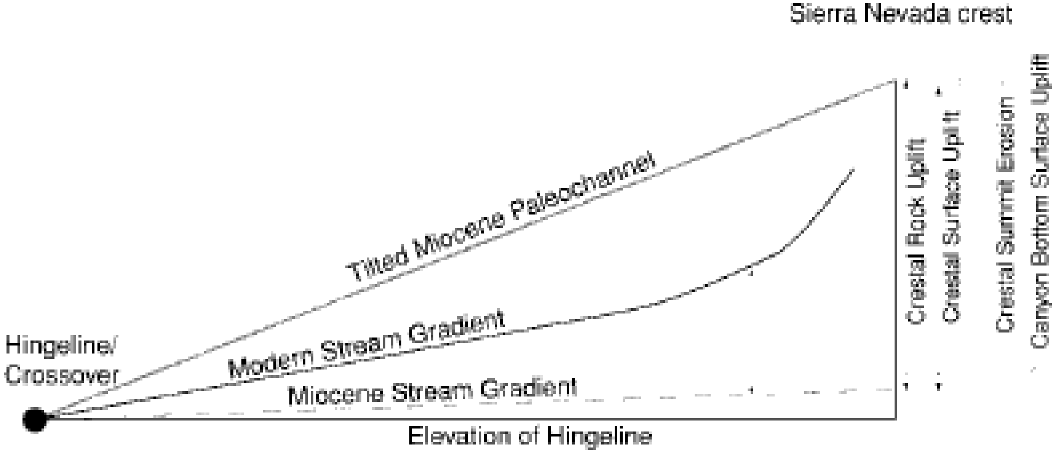


100-60Ma: early exhumation, erosion, and associated surface uplift

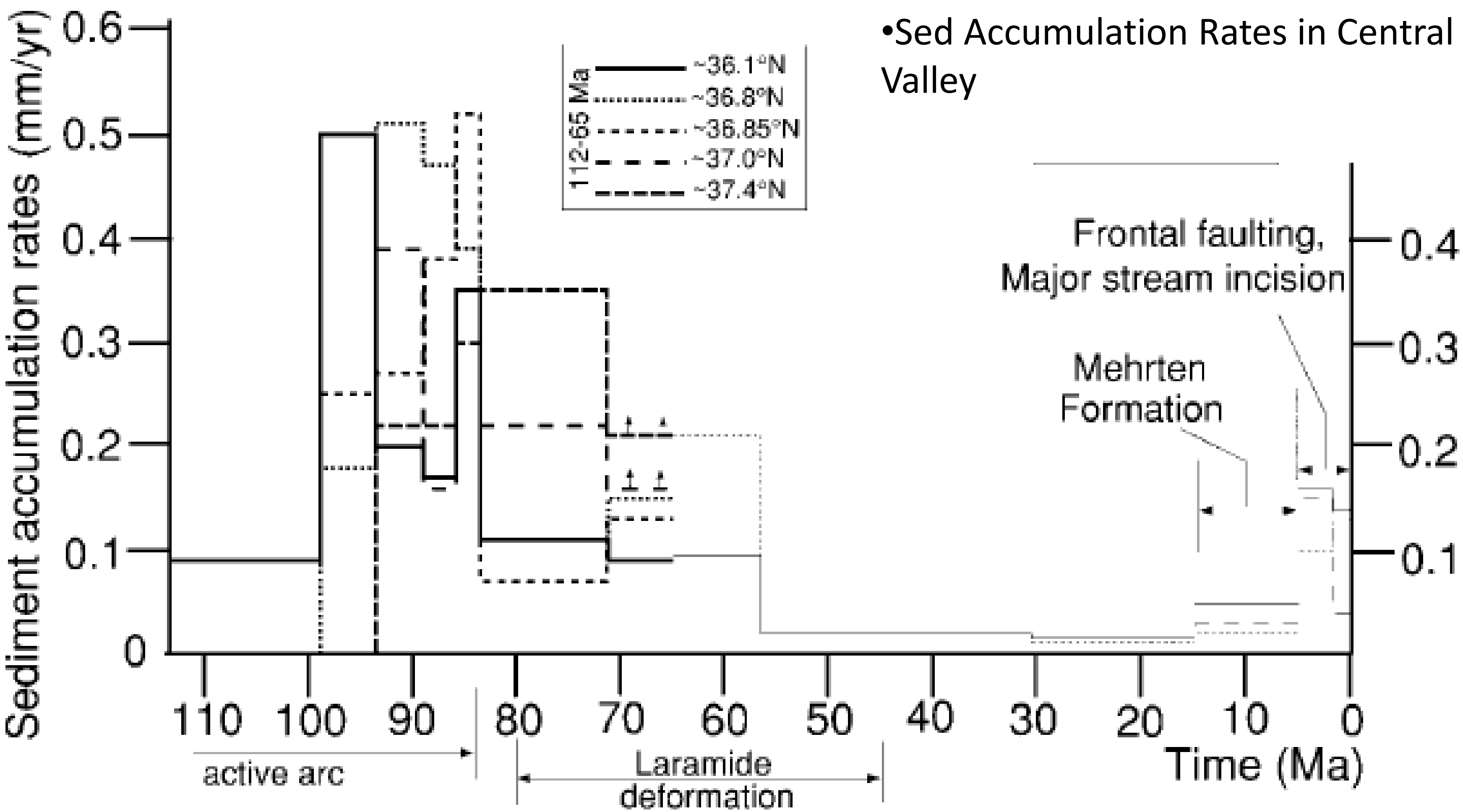
- Thermochron
- Sed accum (Great Valley Group)
- Erosion Rates



Uplift history

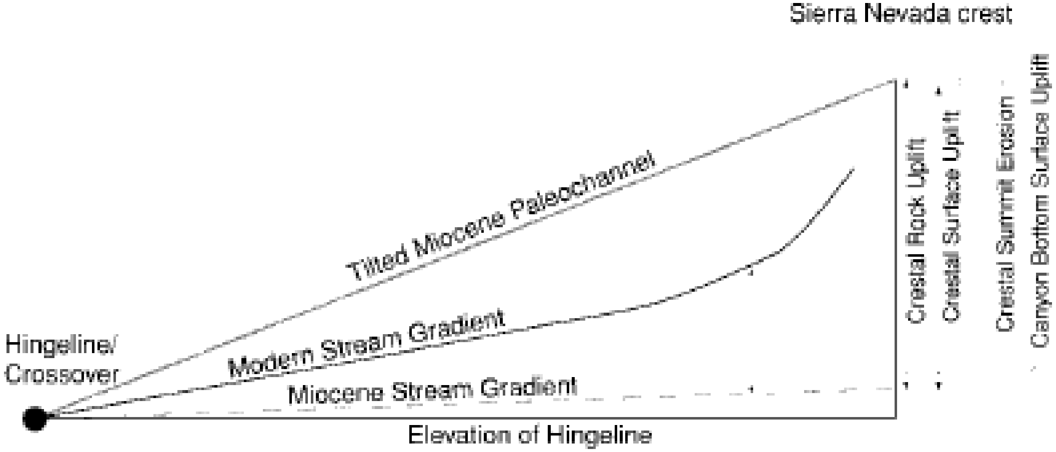


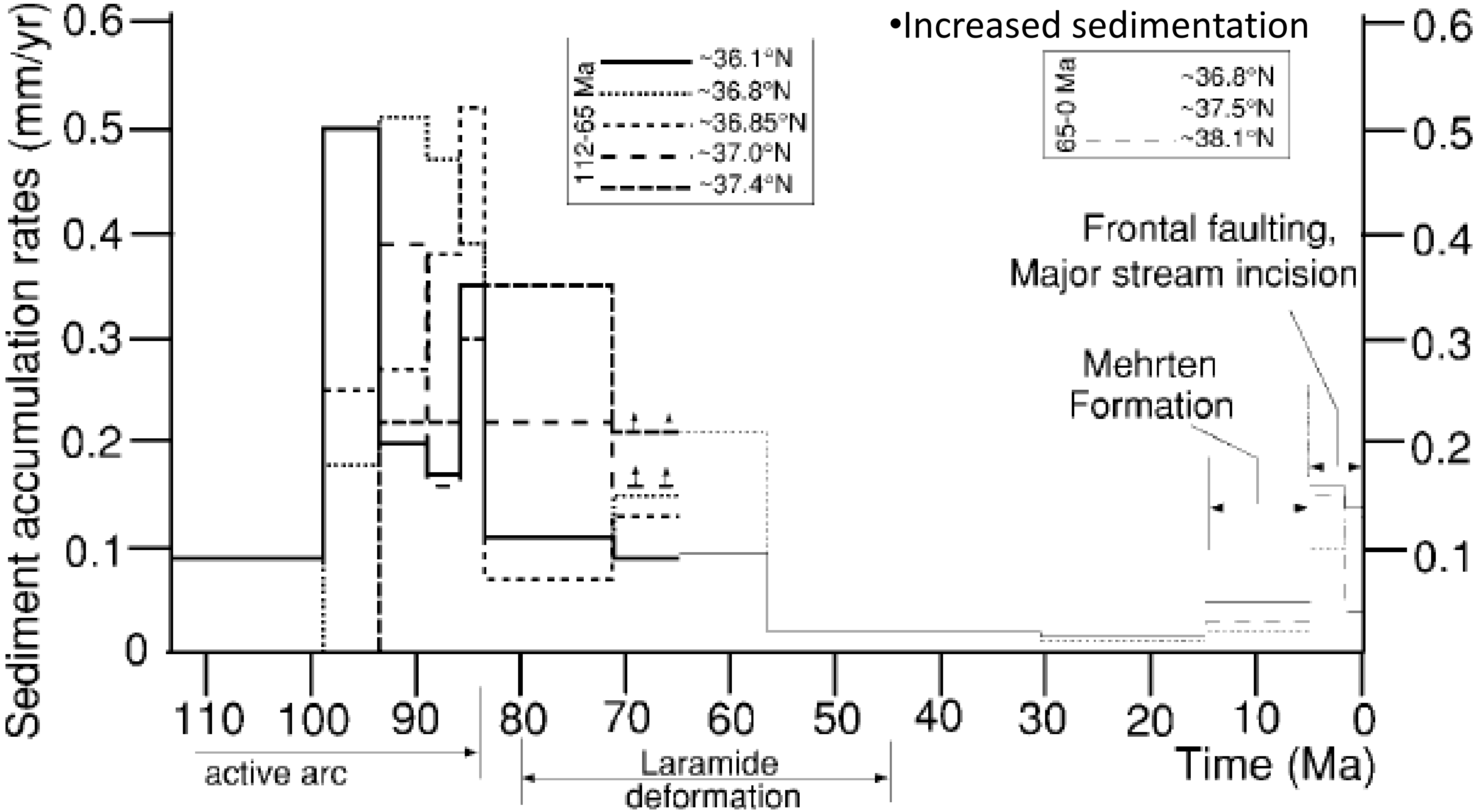
Eocene-Miocene: negligible uplift
- •Less tilt
- •Incision reduced
- •Sed Accumulation Rates in Central Valley

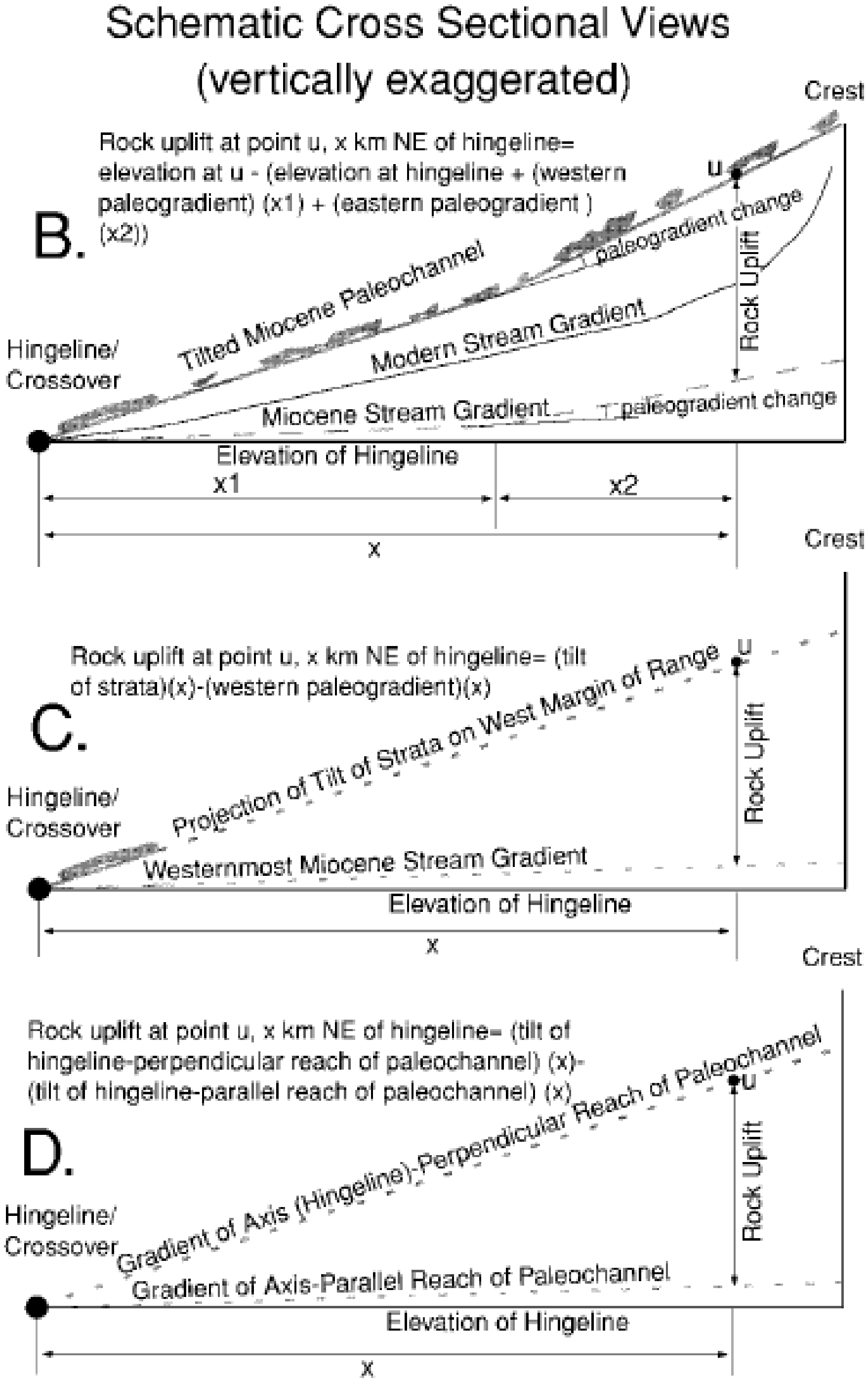


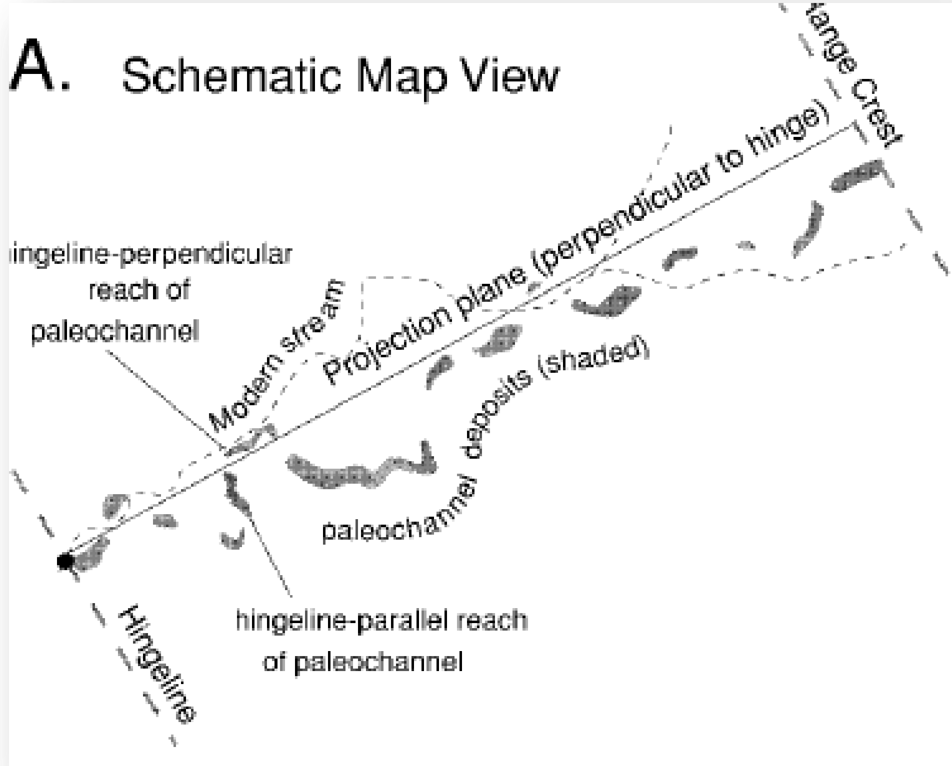
Uplift history

Late Cenozoic uplift
- Tilting
- Increased incision/relief
- Increased sedimentation

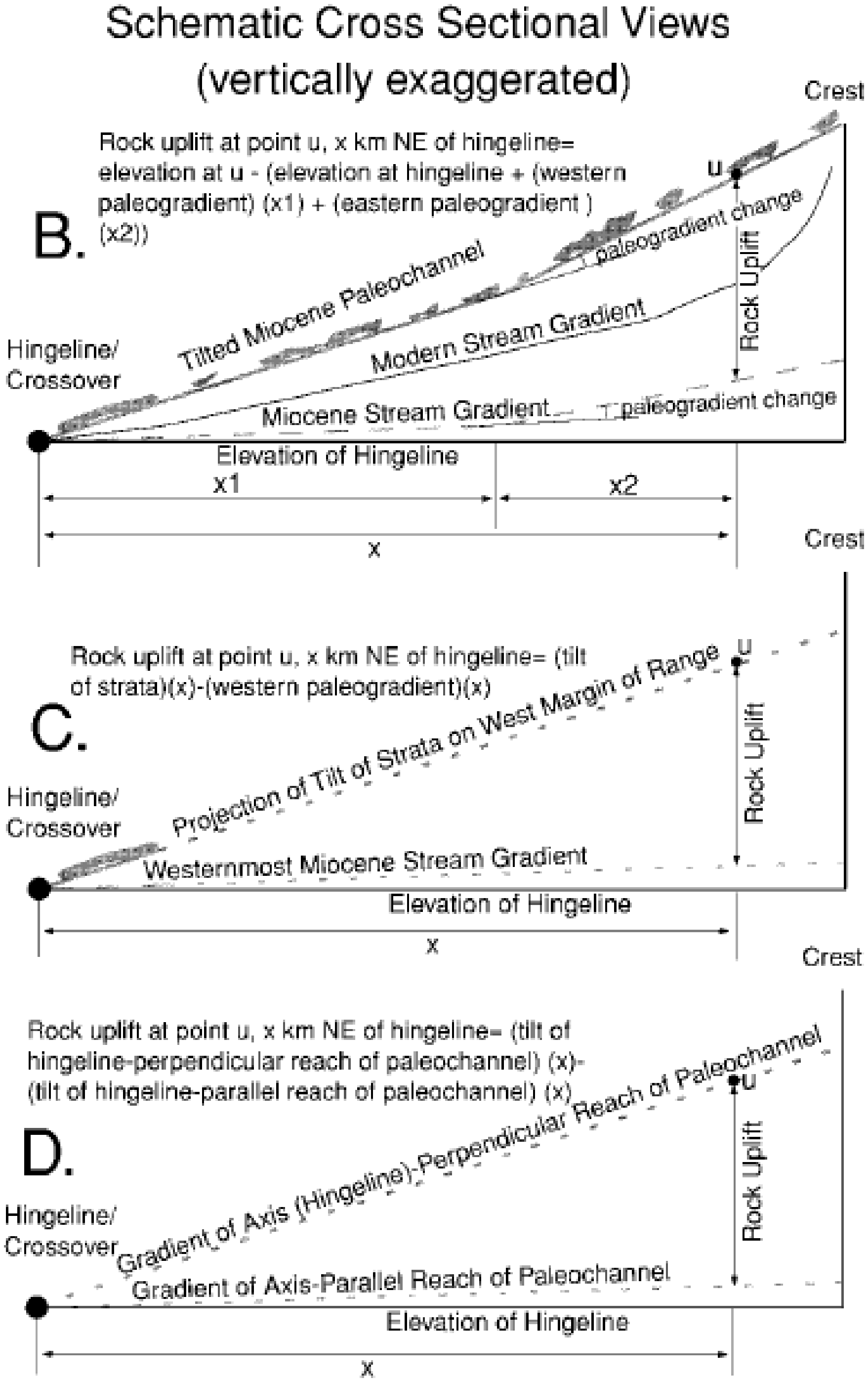








3 methods of estimating rock uplift from tilted Cenozoic strata



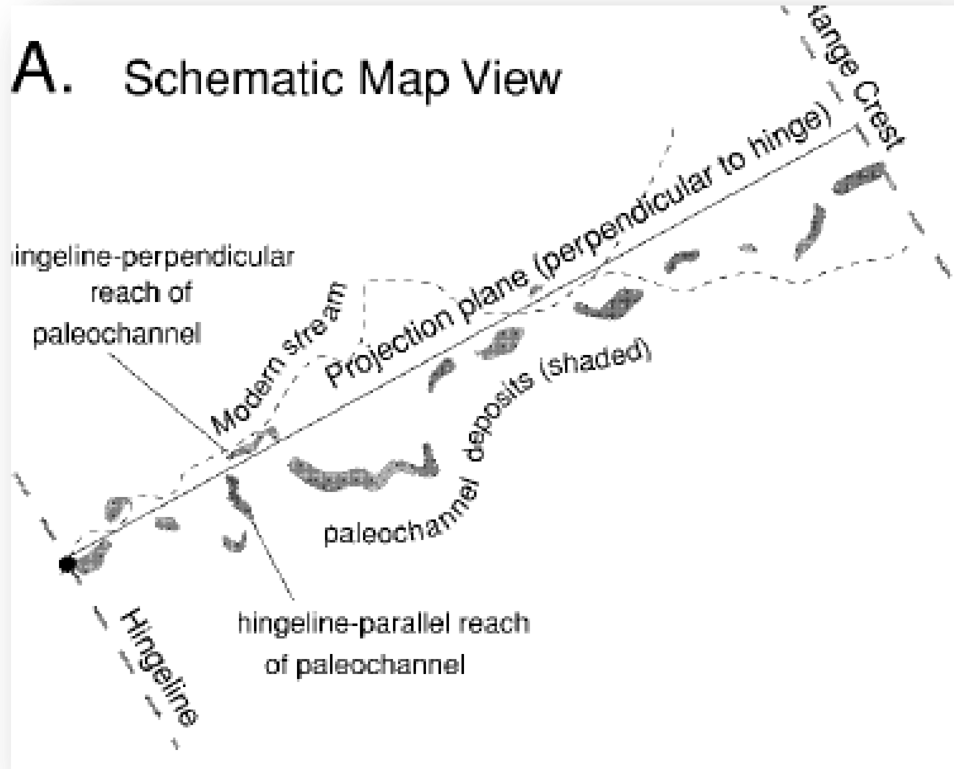
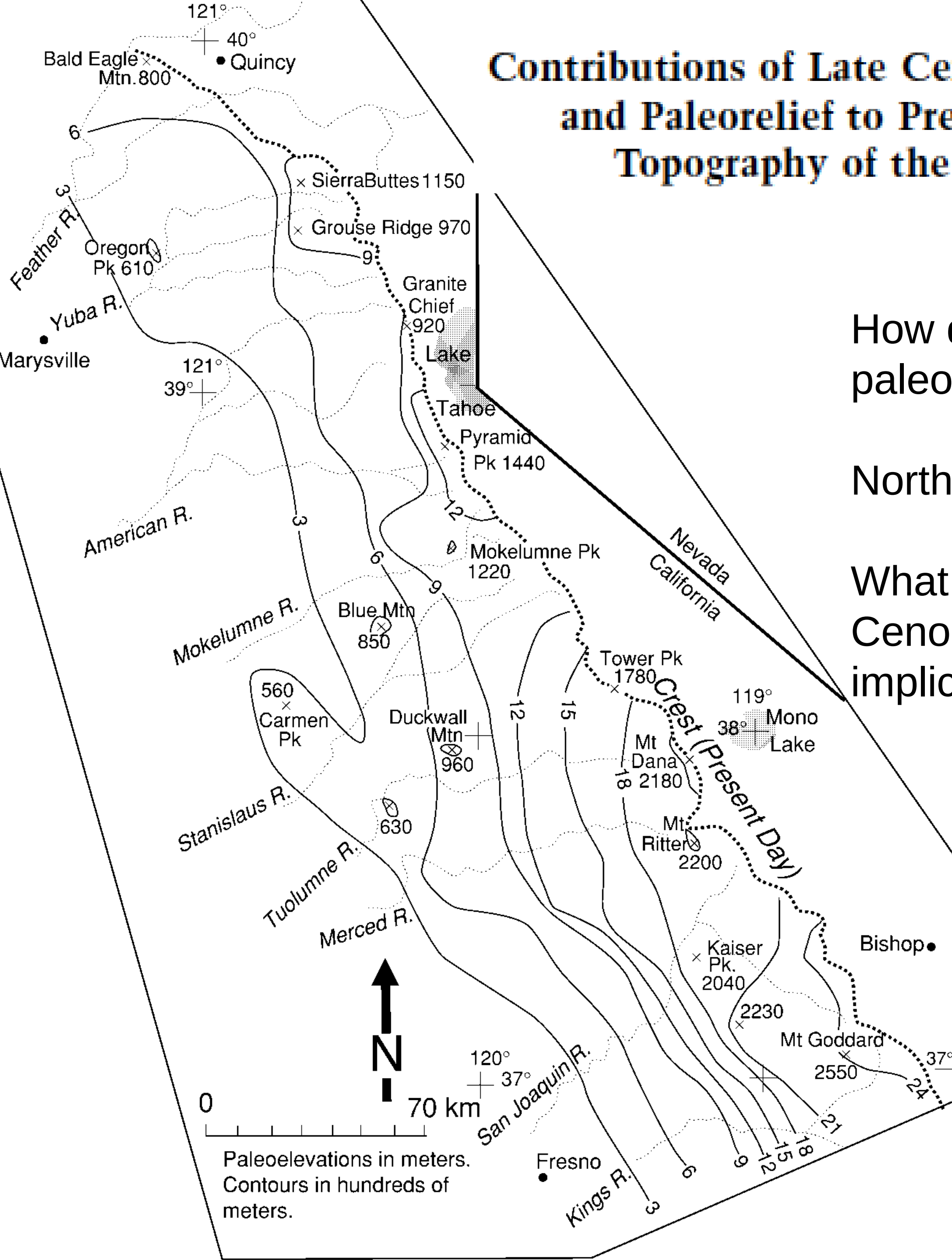


Table 3. Late Cenozoic Crestal Uplift Estimates

Basis of estimate	Width (km)[a]	Uplift (m)
Differential tilt of Late Cenozoic strata, easternmost Central Valley (Unruh 1991)	80, 100	1950, 2440
Reconstruction of Lovejoy Basalt (Wakabayashi and Sawyer 2000; this study)	70	1710–1860
Reconstruction of ancestral South Fork American channel (this study)	100	1440–1940
Paleobotany, Carson Pass (Axelrod 1997)	NA	2500
Reconstruction of ancestral Mokelumne River channel (this study)	95	1520–1690
Reconstruction of Stanislaus Table Mountain Latite and related rocks (Wakabayashi and Sawyer 2000; this study)	90	1790–1930
Reconstruction of ancestral Tuolumne River channel (Huber 1990)	97	>1480
Paleobotany, headwaters of San Joaquin (Axelrod and Ting 1960)	100	2000
As above, adjusted by Huber (1981)	100	1000
Reconstruction of ancestral San Joaquin River base level (Huber 1981)	100	2150

Note. NA, not applicable.
[a] The distance between the hingeline and the point of highest uplift measured perpendicular to the tilt axis.

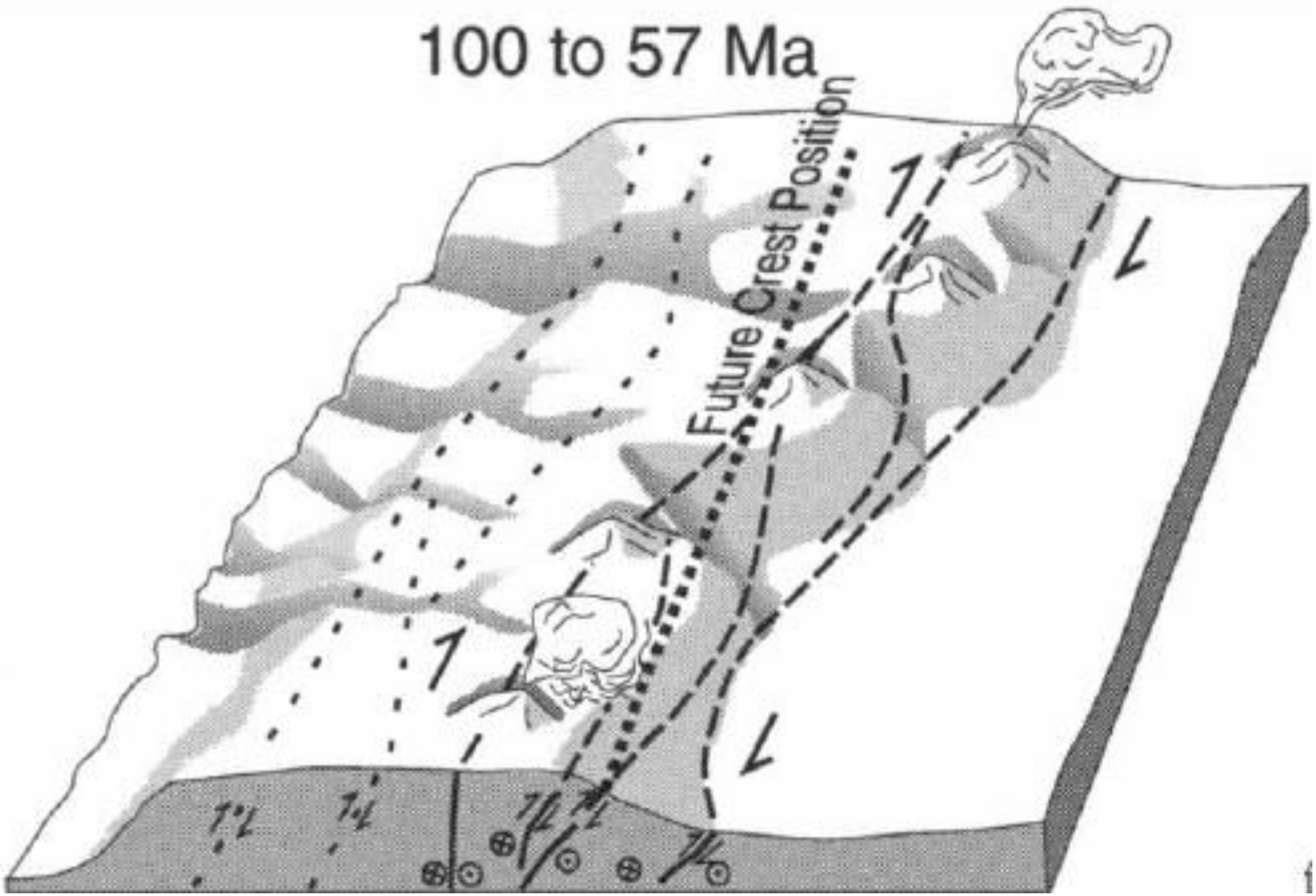
Contributions of Late Cenozoic Uplift and Paleorelief to Present-Day Topography of the Sierra



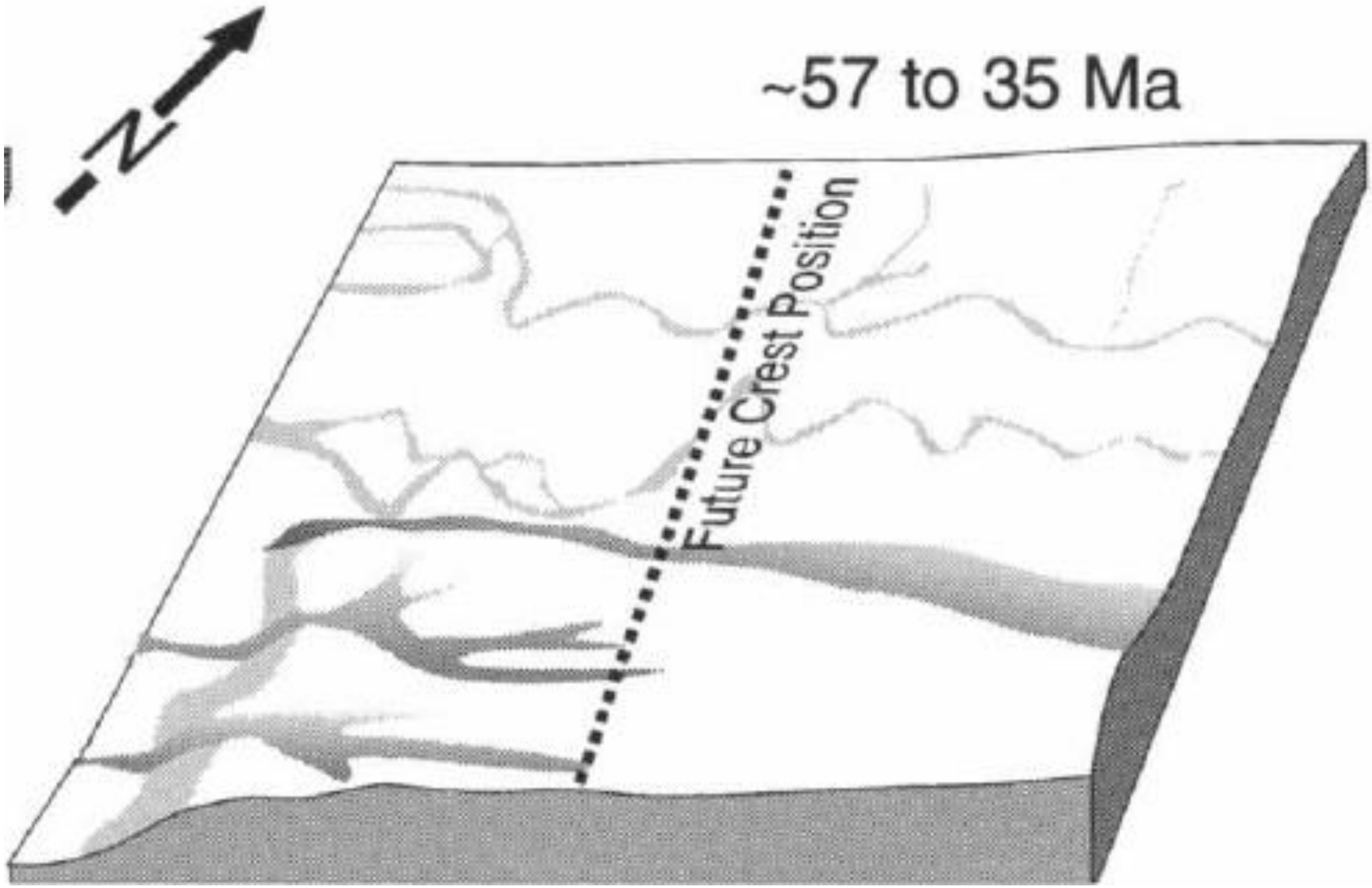
How did they construct this paleotopography?

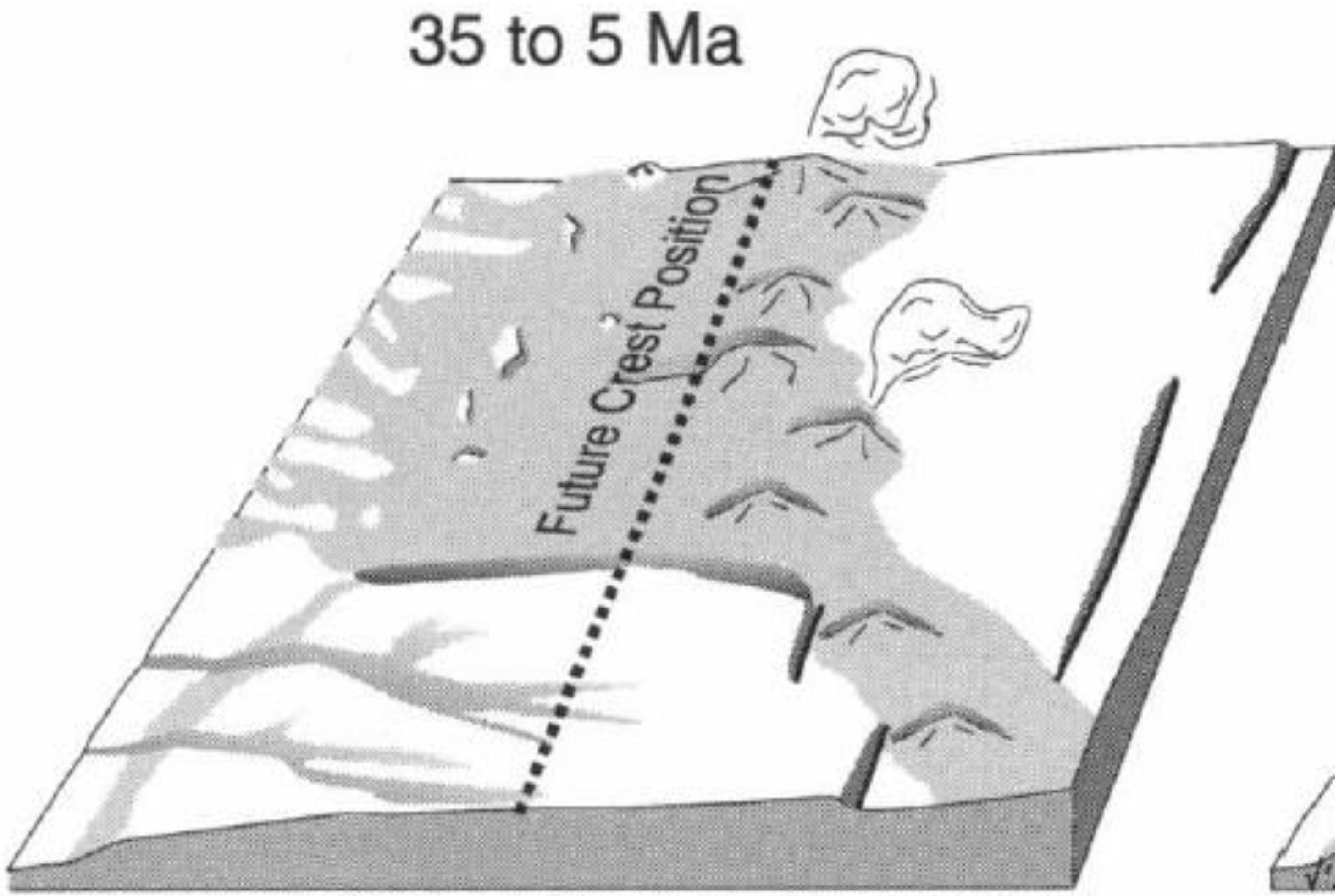
North/Central vs. South

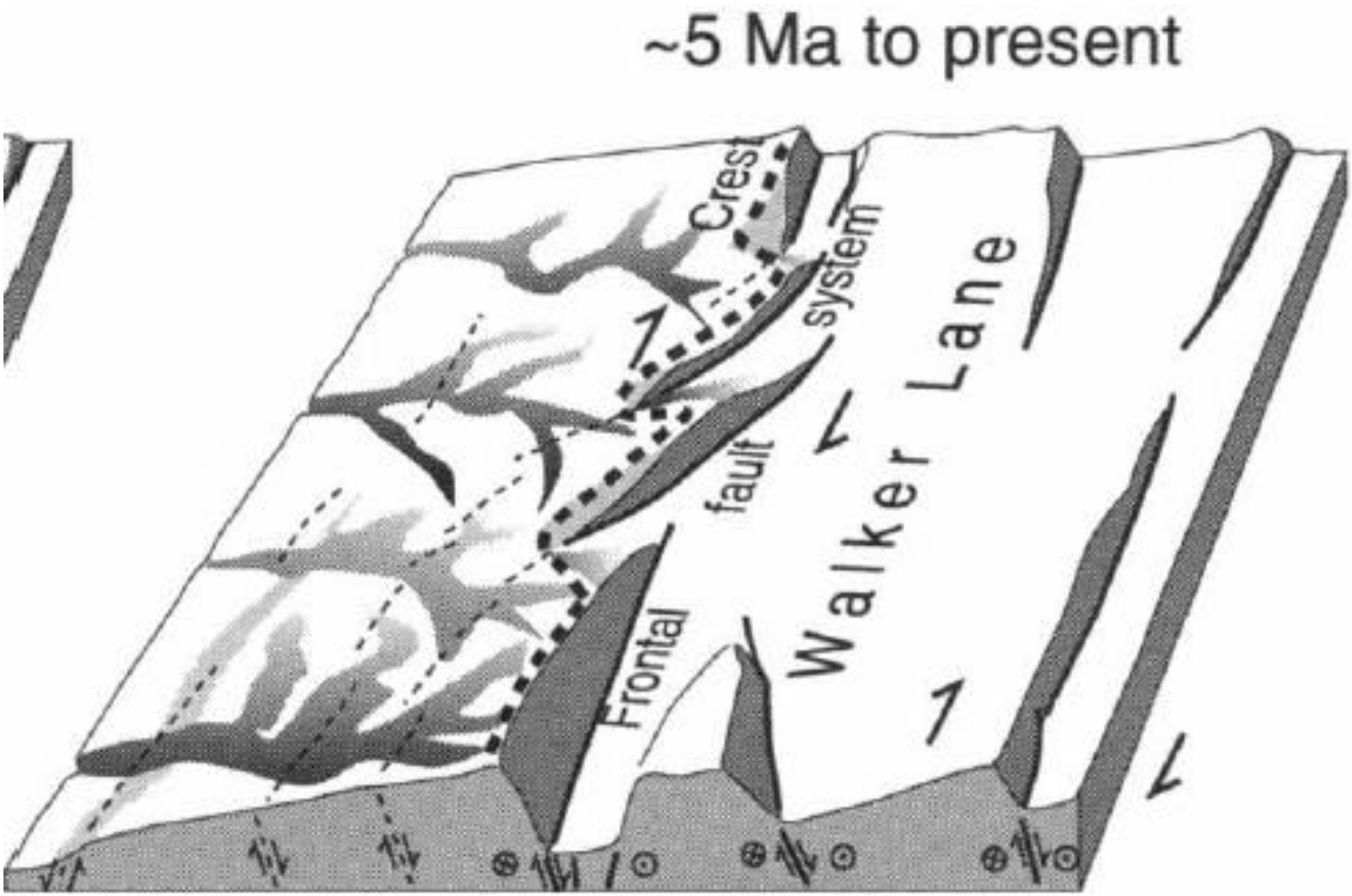
What do you think about the pre-Cenozoic paleoelevation/paleorelief implications of this map?



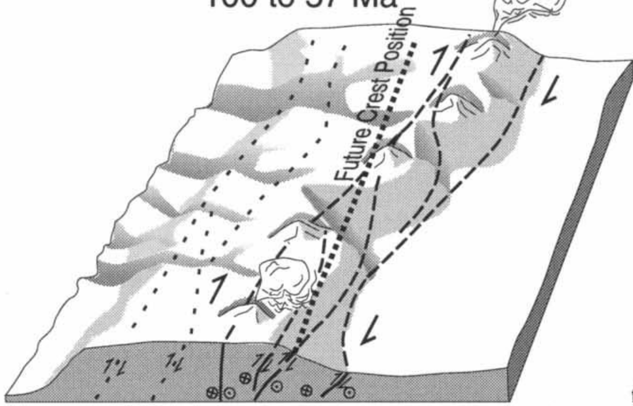
100 to 57 Ma
Future Crest Position


N
~57 to 35 Ma
Future Crest Position


35 to 5 Ma
Future Crest Position

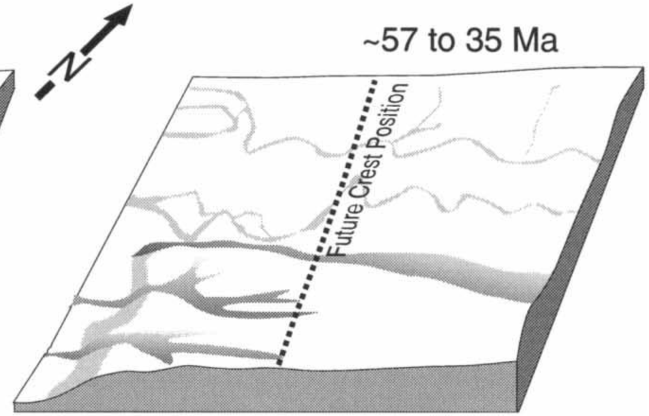

~5 Ma to present
Crest
system
fault
Frontal
Walker Lane

100 to 57 Ma



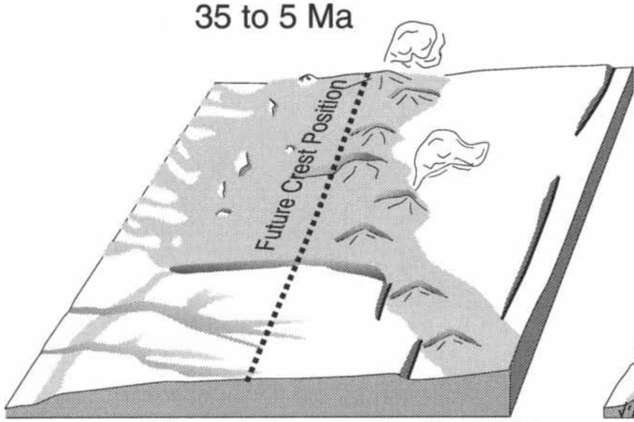
During the last 15 Ma of arc activity, from 100 to 85 Ma, activity along transpressional fault zones causes major exhumation and erosion. Faulting migrates eastward within the arc as does magmatism. As a result, the most deeply exhumed rocks are in the west. The late Cretaceous arc, and associated shear zones, are well east of the present day Sierran block in the northern part of the range. Fault activity and erosion continues after magmatism ceases. High erosion rates persist for about 25 Ma after cessation of magmatism. Reduction of elevation and relief occur during the latter part of the 100-57 Ma period; lowering of elevation may coincide with eclogitic recrystallization of the root of the batholith following cessation of arc magmatism.

~57 to 35 Ma



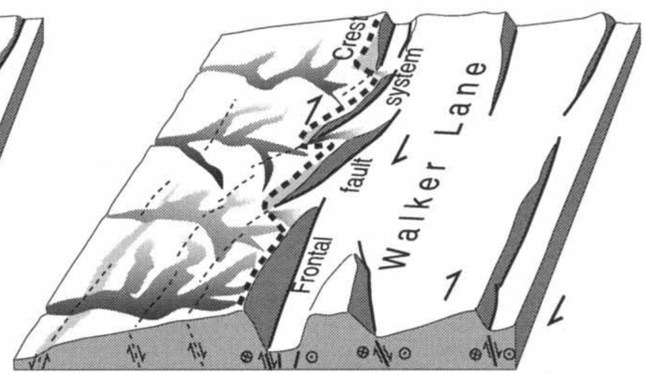
Relief and elevations have been reduced, especially in the northern part of the range. Erosion and incision rates are low in the Sierra. Laramide uplift has resulted in a regional westward slope from highlands east of the present Sierra Nevada. Large river systems flow down this slope, depositing the Eocene gold bearing gravels. The southern part of the range (and, possibly other ranges to the east) presents a topographic barrier and the Eocene streams do not cross it.

35 to 5 Ma



Renewed arc activity. In what is now the Sierra Nevada block, volcanic activity is confined to the northern and central parts, and covers the entire landscape in this region except for isolated basement highs. Although Basin and Range extension begins to the east, and extensional faulting encroaches progressively westward, no significant tilting or stream incision occurs in the Sierra during this time. The subducting plate margin is converted to a transform margin, thus ending arc volcanism south of the Feather River drainage.

~5 Ma to present

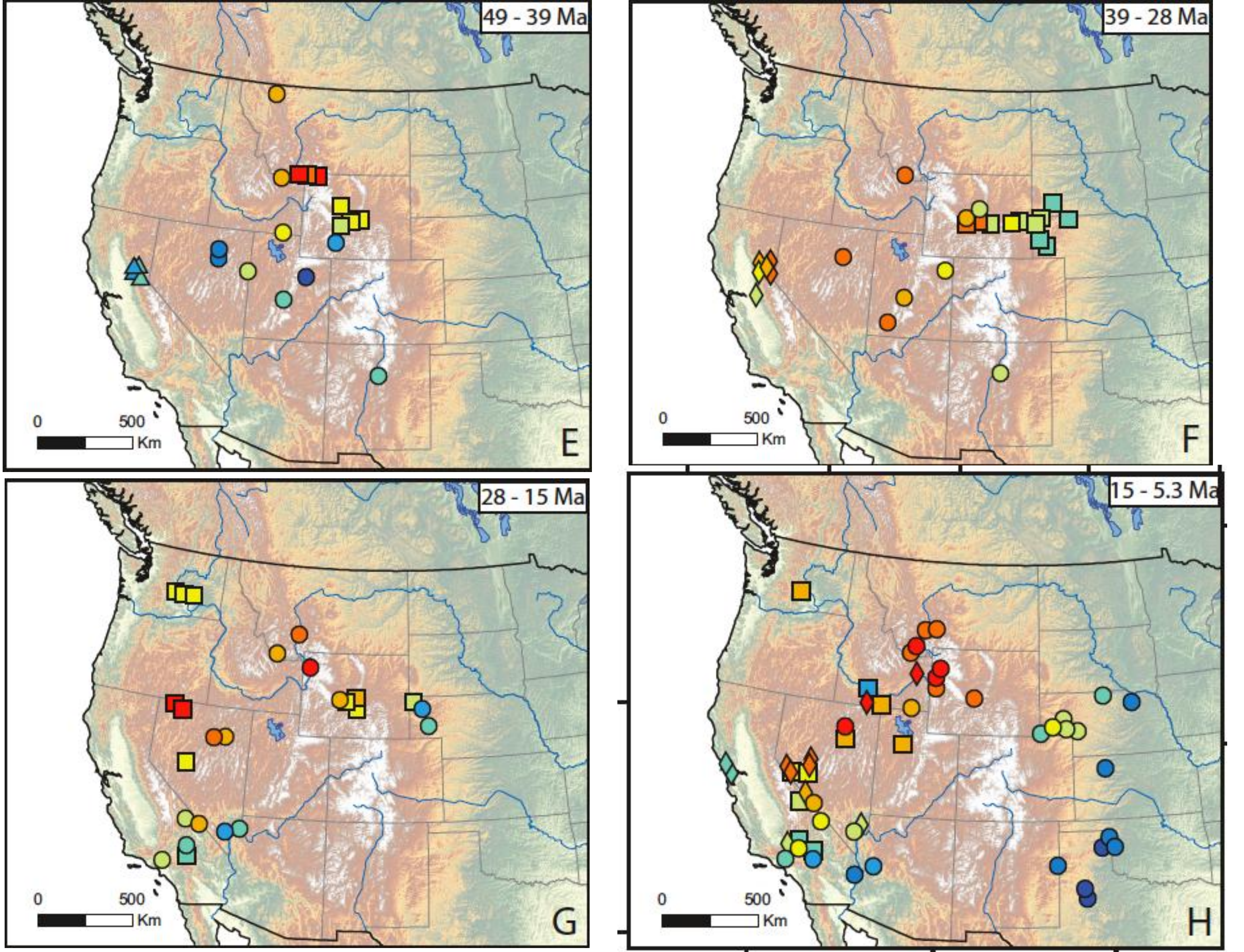


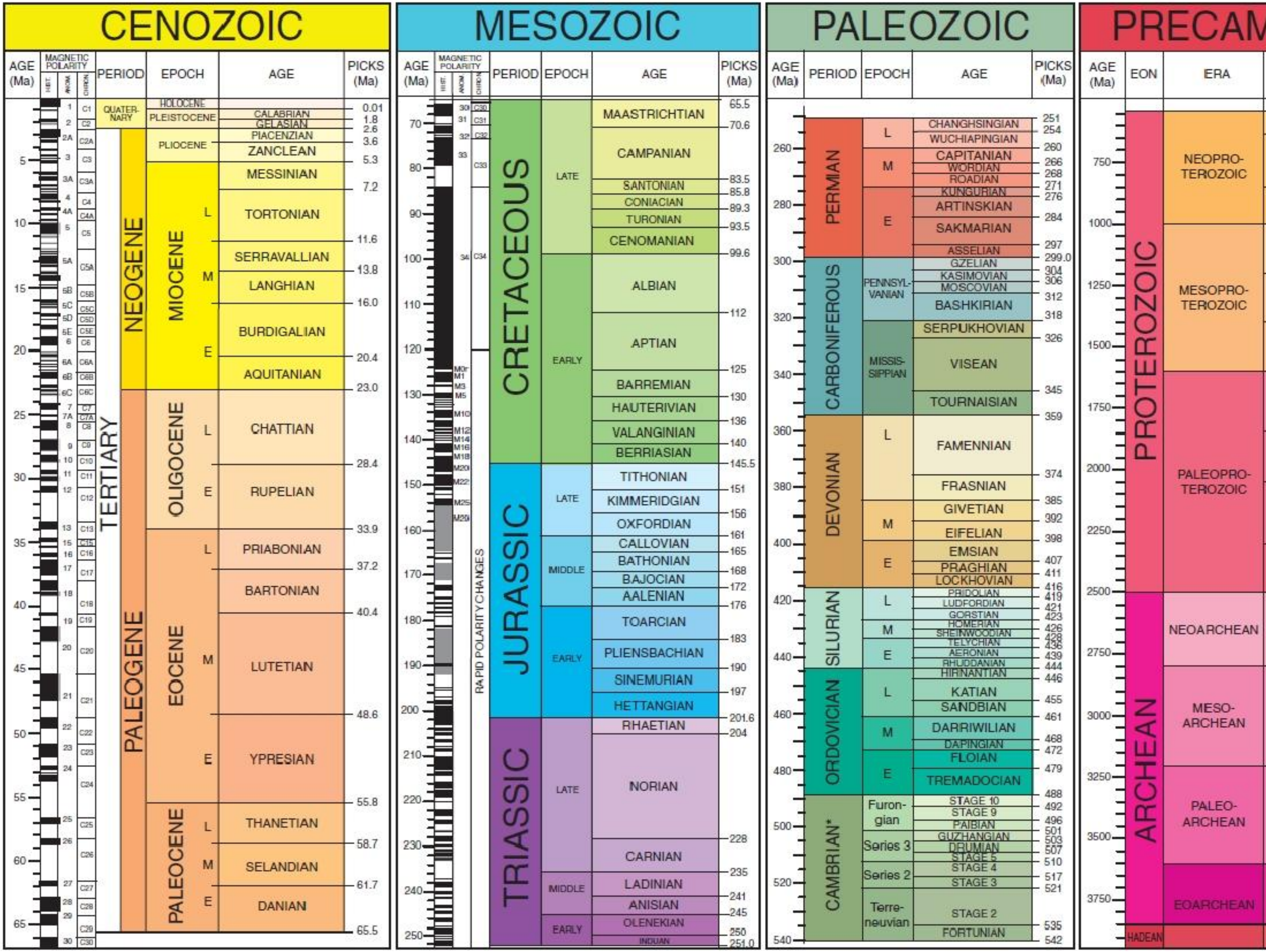
The Walker Lane shear zone has encroached westward. Uplift begins and is associated with westward tilting of the range and east-down and dextral faulting. Uplift may be triggered by the foundering of an eclogitic root beneath the eastern Sierra. Rivers incise rapidly. In the southern Sierra, incision results in the deepening of older canyons, whereas in the northern Sierra, little relief is present before incision begins. Westward encroachment of the Frontal fault system continues, beheading many drainages in the central and northern Sierra Nevada. The greater amount of paleotopography in the southern part of the range contributes to higher elevations in that region.

All tectonic uplift?

What about:

- Isostatic response to Sierra erosion/Central Valley deposition
- Climatic considerations?


49 - 39 Ma
0
500
Km
E
39 - 28 Ma
0
500
Km
F
28 - 15 Ma
0
500
Km
G
15 - 5.3 Ma
0
500
Km
H


CENOZOIC
AGE (Ma)
MAGNETIC POLARITY
PERIOD
EPOCH
AGE
PICKS (Ma)
QUATERNARY
TERTIARY
NEOGENE
PALEOGENE
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CALABRIAN
GELASIAN
PIACENZIAN
ZANCLEAN
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
THANETIAN
SELANDIAN
DANIAN
0.01
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2.6
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5.3
7.2
11.6
13.8
16.0
20.4
23.0
28.4
33.9
37.2
40.4
48.6
55.8
58.7
61.7
65.5
MESOZOIC
CRETACEOUS
JURASSIC
TRIASSIC
LATE
EARLY
MIDDLE
RAPID POLARITY CHANGES
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
TITHONIAN
KIMMERIDGIAN
OXFORDIAN
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
RHAETIAN
NORIAN
CARNIAN
LADINIAN
ANISIAN
OLENEKIAN
INDUAN
65.5
70.6
83.5
85.8
89.3
93.5
99.6
112
125
130
136
140
145.5
151
156
161
165
168
172
176
183
190
197
201.6
204
228
235
241
245
250
251.0
PALEOZOIC
PERMIAN
CARBONIFEROUS
PENNSYL-VANIAN
MISSIS-SIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN*
Furon-gian
Series 3
Series 2
Terre-neuvian
CHANGHSINGIAN
WUCHIAPINGIAN
CAPITANIAN
WORDIAN
ROADIAN
KUNGURIAN
ARTINSKIAN
SAKMARIAN
ASSELIAN
GZELIAN
KASIMOVIAN
MOSCOVIAN
BASHKIRIAN
SERPUKHOVIAN
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GIVETIAN
EIFELIAN
EMSIAN
PRAGHIAN
LOCKHOVIAN
PRIDOLIAN
LUDFORDIAN
GORSTIAN
HOMERIAN
SHEINWOODIAN
TELYCHIAN
AERONIAN
RHUDDANIAN
HIRNANTIAN
KATIAN
SANDBIAN
DARRIWILIAN
DAPINGIAN
FLOIAN
TREMADOCIAN
STAGE 10
STAGE 9
PAIBIAN
GUZHANGIAN
DRUMIAN
STAGE 5
STAGE 4
STAGE 3
STAGE 2
FORTUNIAN
251
254
260
266
268
271
276
284
297
299.0
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312
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345
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374
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392
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PRECAM
EON
ERA
PROTEROZOIC
ARCHEAN
HADEAN
NEOPRO-TEROZOIC
MESOPRO-TEROZOIC
PALEOPRO-TEROZOIC
NEOARCHEAN
MESO-ARCHEAN
PALEO-ARCHEAN
EOARCHEAN
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750