$^{40}Ar/^{39}Ar$ K-feldspar thermochronology of the Harcuvar core complex, western Arizona:

New insights into the timing of extension and degree of footwall tilt

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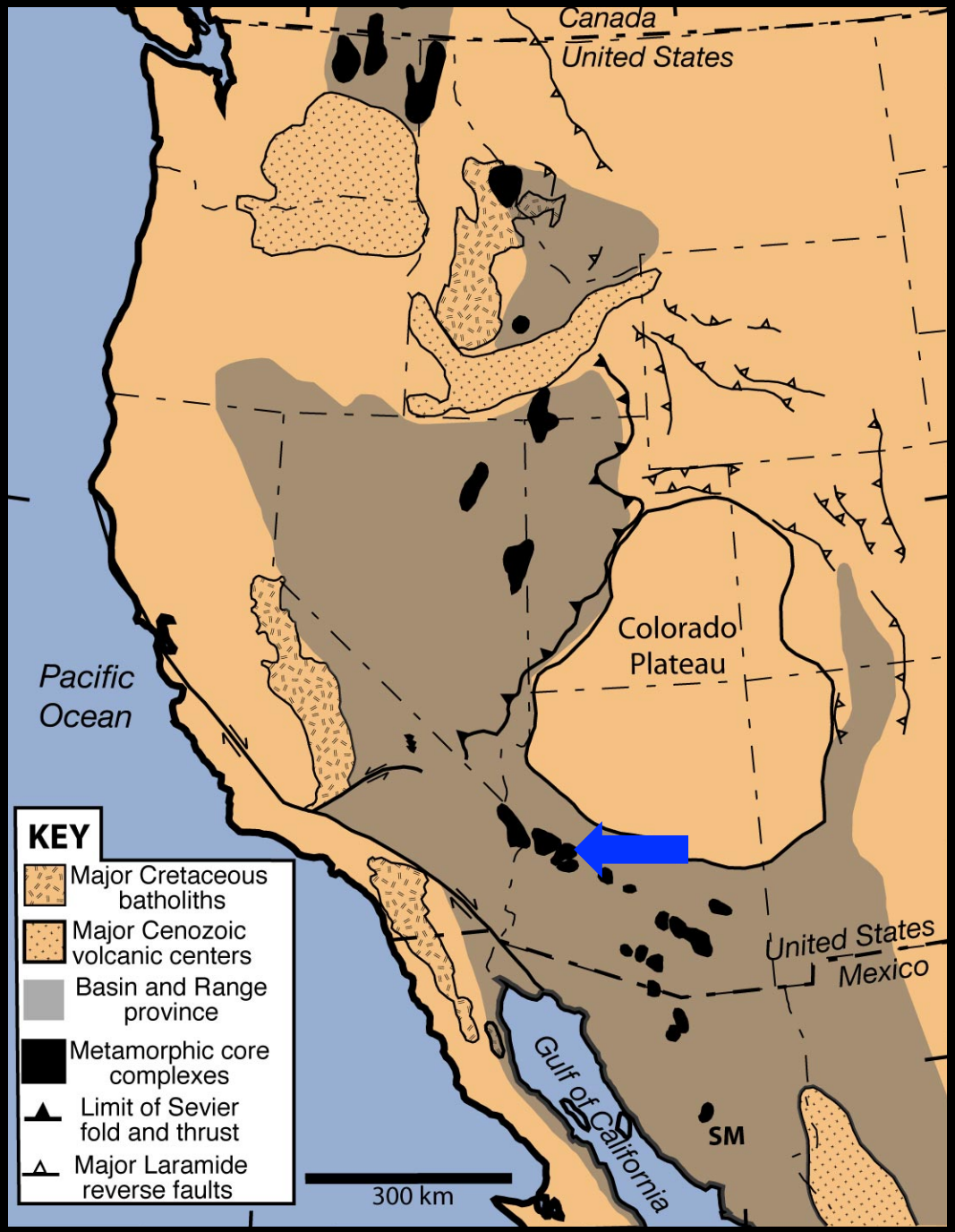
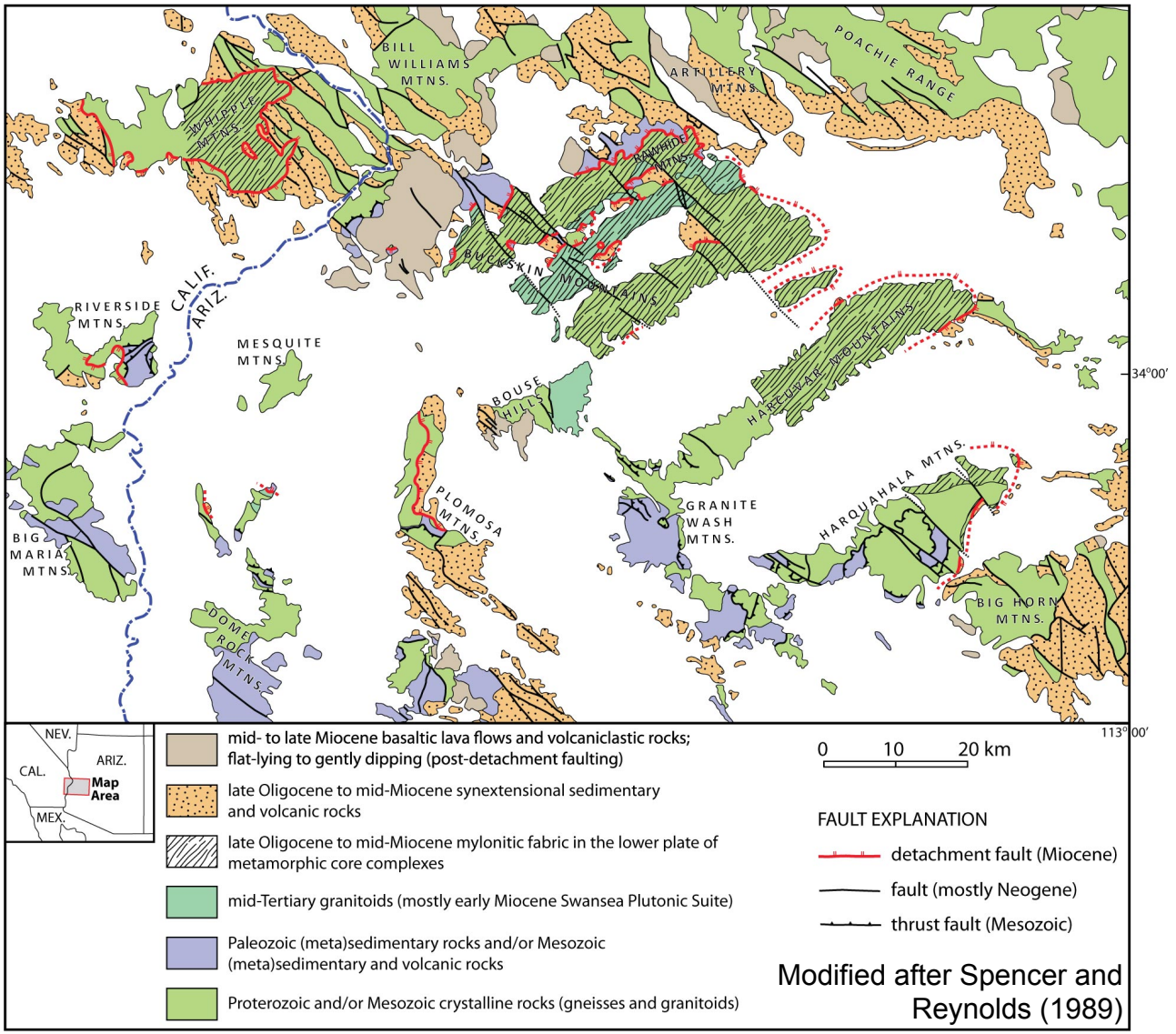


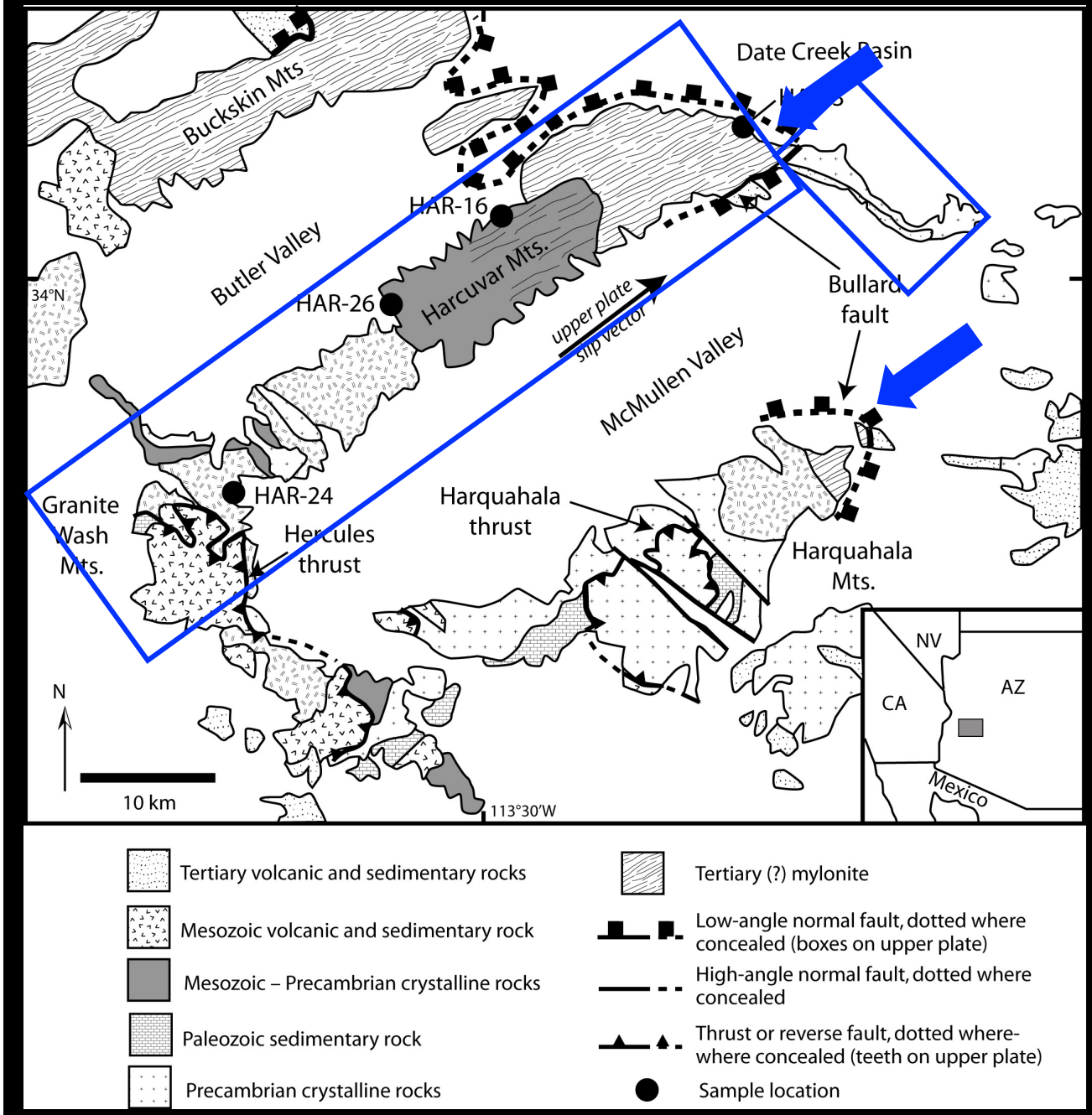
The Harcuvar metamorphic core complex

Located within the Colorado River extensional corridor in western AZ



- Proximal to the Whipple and Rawhide-Buckskin core complexes
- Unroofed by the same or related low-angle normal fault system

Figure courtesy J. Singleton



Geologic overview

Footwall

- Precambrian gneiss and Cretaceous granite
- Gently dipping foliation (variable)
- NE lineation
- Top-NE sense of shear

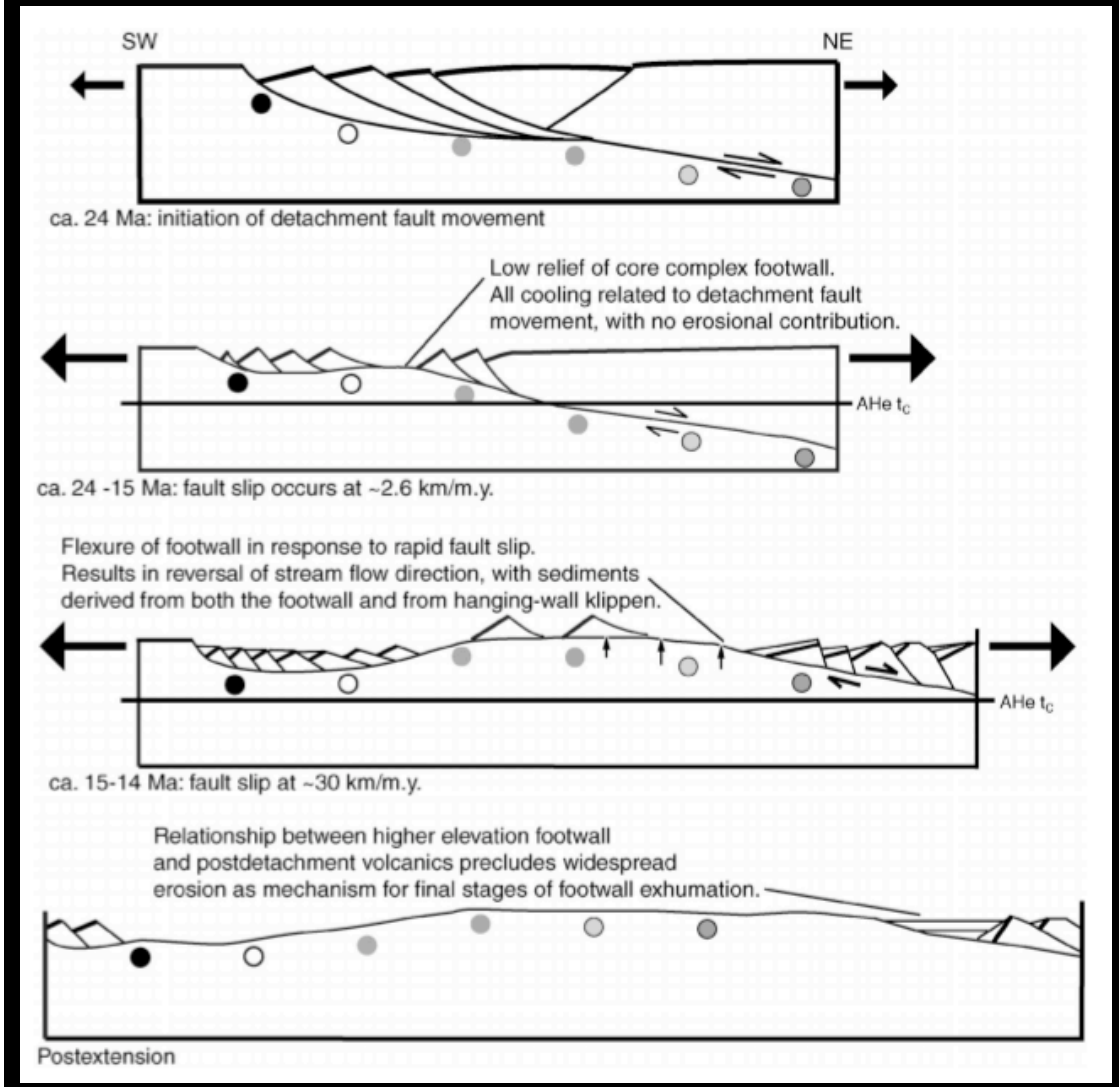
Hanging wall

- Basement and Tertiary volcanic and sedimentary rocks
- Dip 40-60°SW

Rawhide/Bullard fault

- Dips 10-20° NE
- Top-NE slip
- Prominent corrugations

Previous work



From Carter et al. (2004)

<u>Start of extension</u>

- 27 Ma based on sedimentary deposits in the Buckskin HW (Curtis, 1994)
- ca. 24 Ma based on FT and (U-Th)/He thermochronology (Foster et al., 1993; Carter et al., 2004)

<u>End of slip</u>

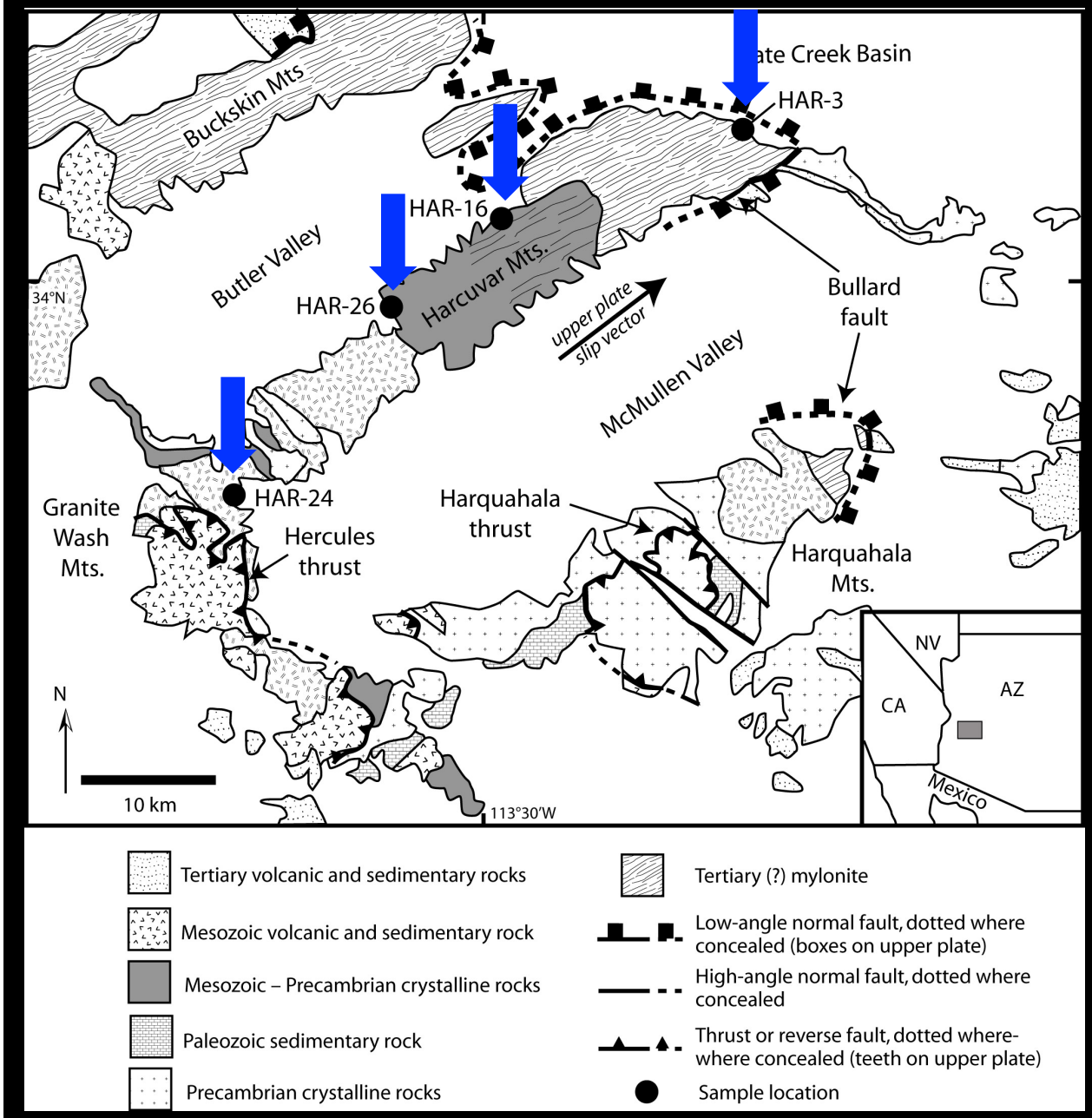
- (U-Th)/He ages as young as 14 Ma (Carter et al., 2004)
- Gently dipping basalt flows are ca. 10-9 Ma (Shackelford, 1980)

<u>Slip magnitude and rate</u>

- 50-60 km of slip (Reynolds and Spencer, 1985)
- Slip rates of 3-7 mm/yr (FT-dating; Foster et al., 1993)
- Increase to 30 mm/yr at ca. 15 Ma? (U-Th/He dating; Carter et al., 2004)

- Models assume a low-angle fault

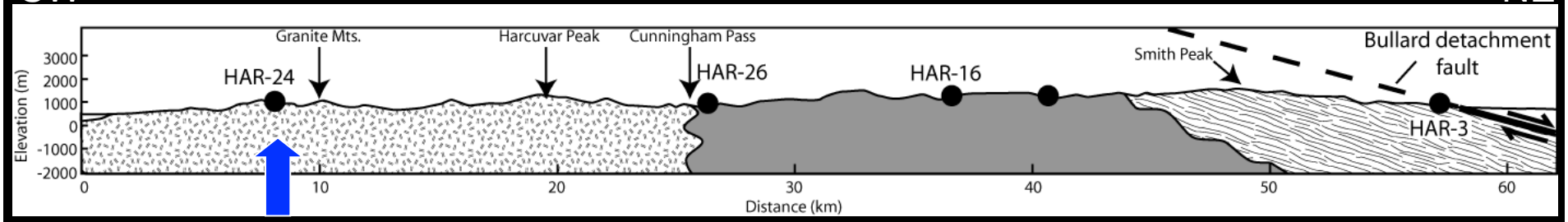
Ar/Ar thermochronologic transect

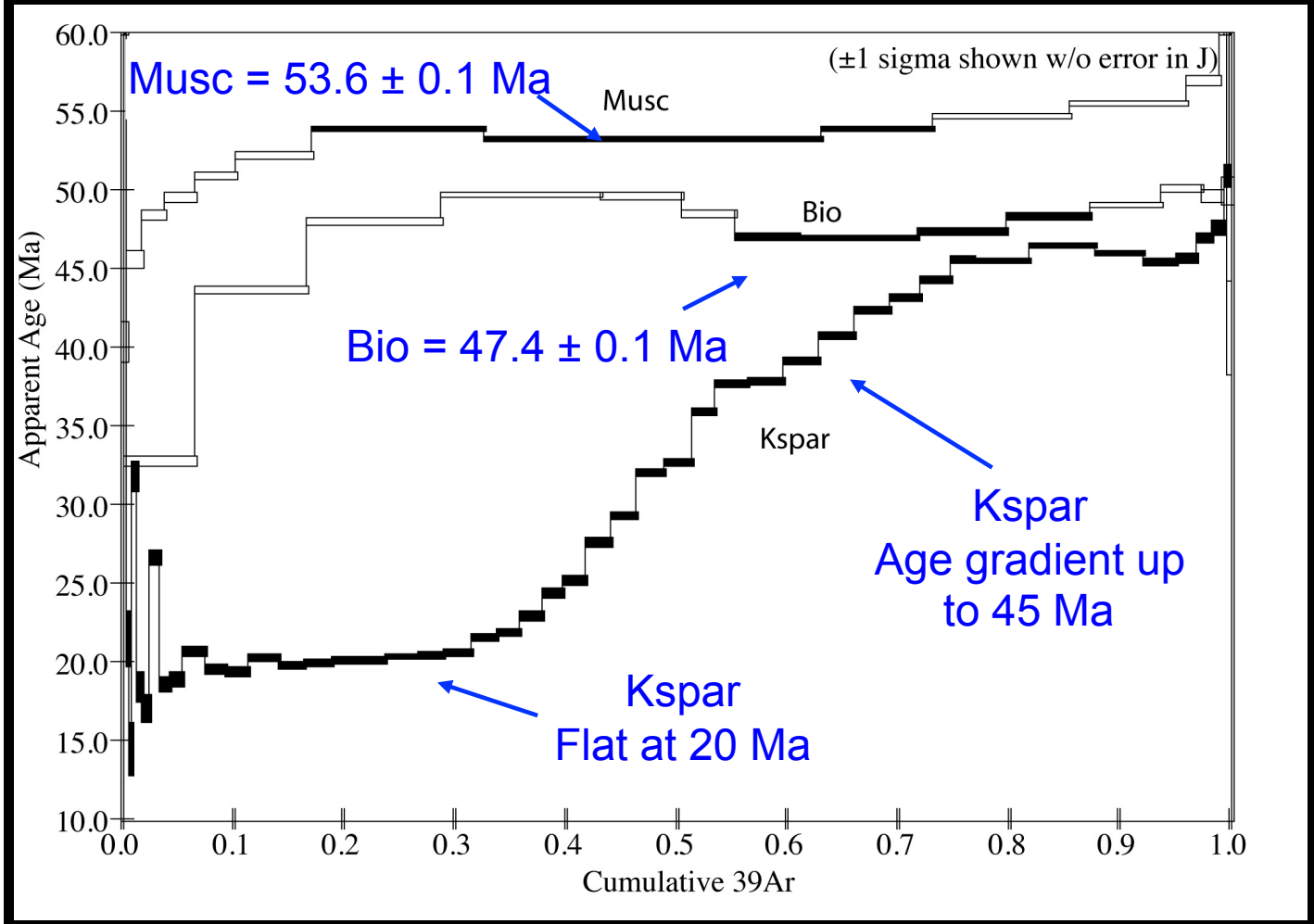


Goals

- Inception and duration of extension
- Fault slip rate
- Degree of footwall tilting and initial detachment fault dip

SW NE

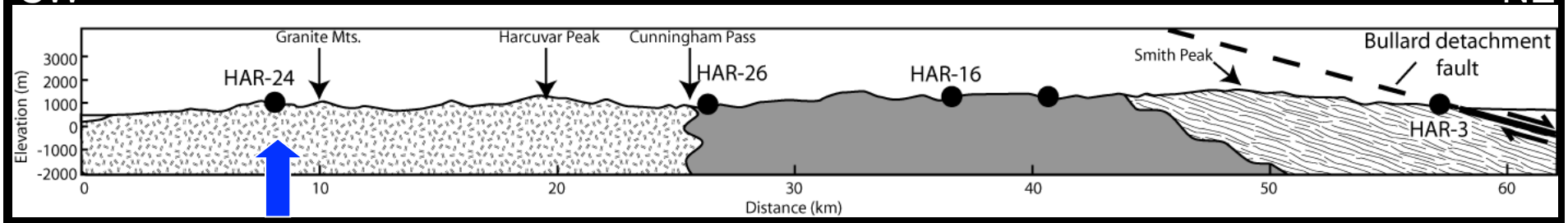


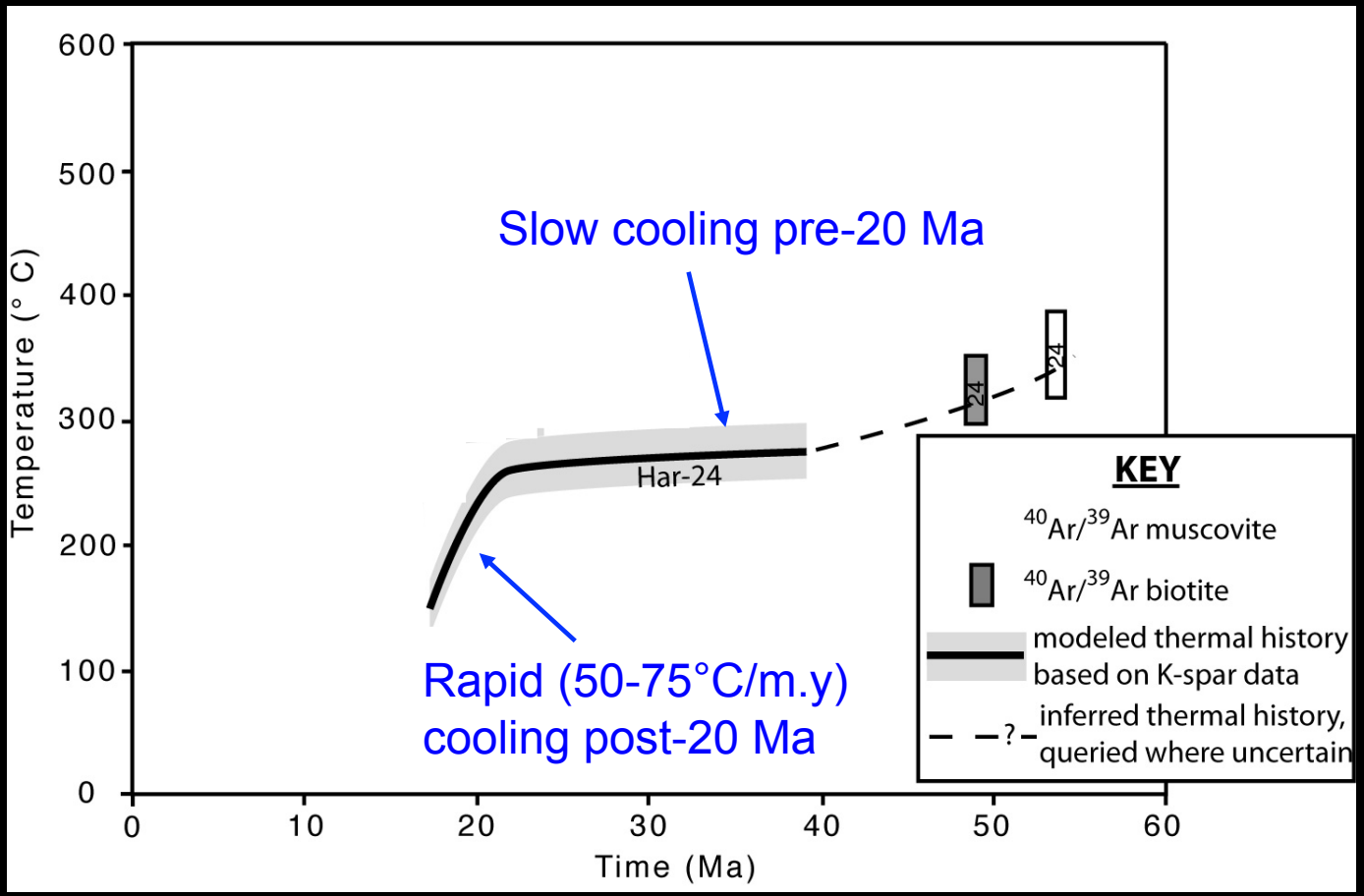


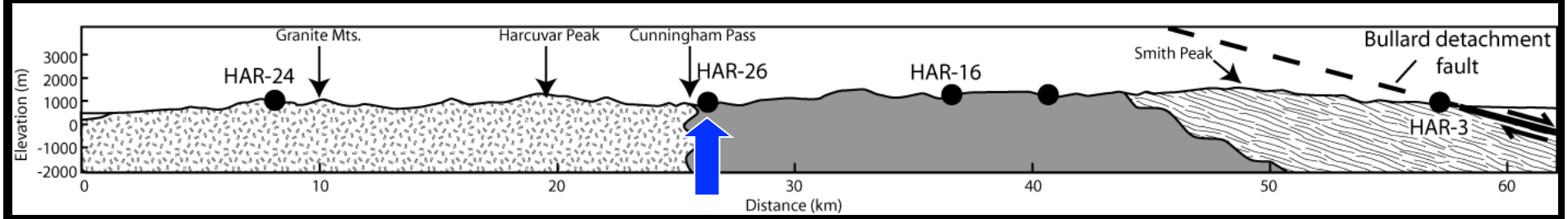
Har -24
SW footwall

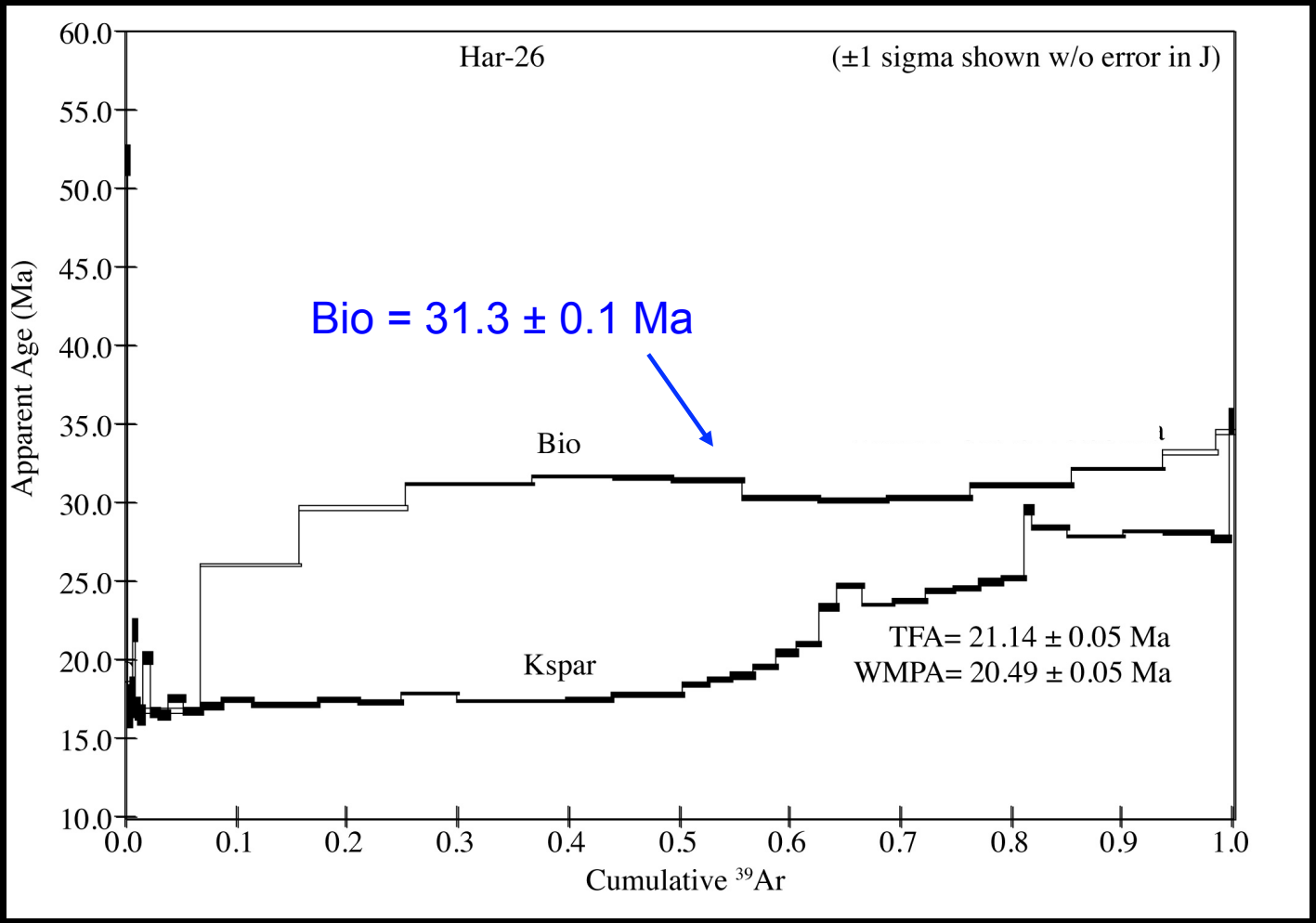
Oldest ages for all mineral systems

SW NE


Granite Mts.
Harcuvar Peak
Cunningham Pass
Smith Peak
Bullard detachment fault
HAR-24
HAR-26
HAR-16
HAR-3
Elevation (m)
3000
2000
1000
0
-1000
-2000
0
10
20
30
40
50
60
Distance (km)


Slow cooling pre-20 Ma
Har-24
Rapid (50-75°C/m.y) cooling post-20 Ma
KEY
40Ar/39Ar muscovite
40Ar/39Ar biotite
modeled thermal history based on K-spar data
inferred thermal history, queried where uncertain
Temperature (° C)
600
500
400
300
200
100
0
0
10
20
30
40
50
60
Time (Ma)

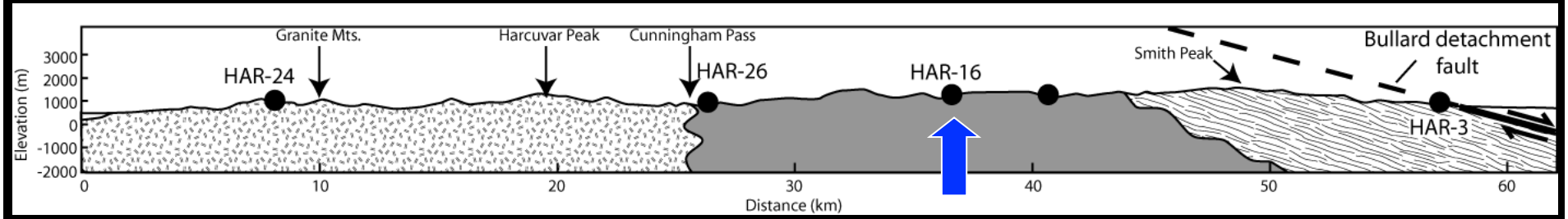


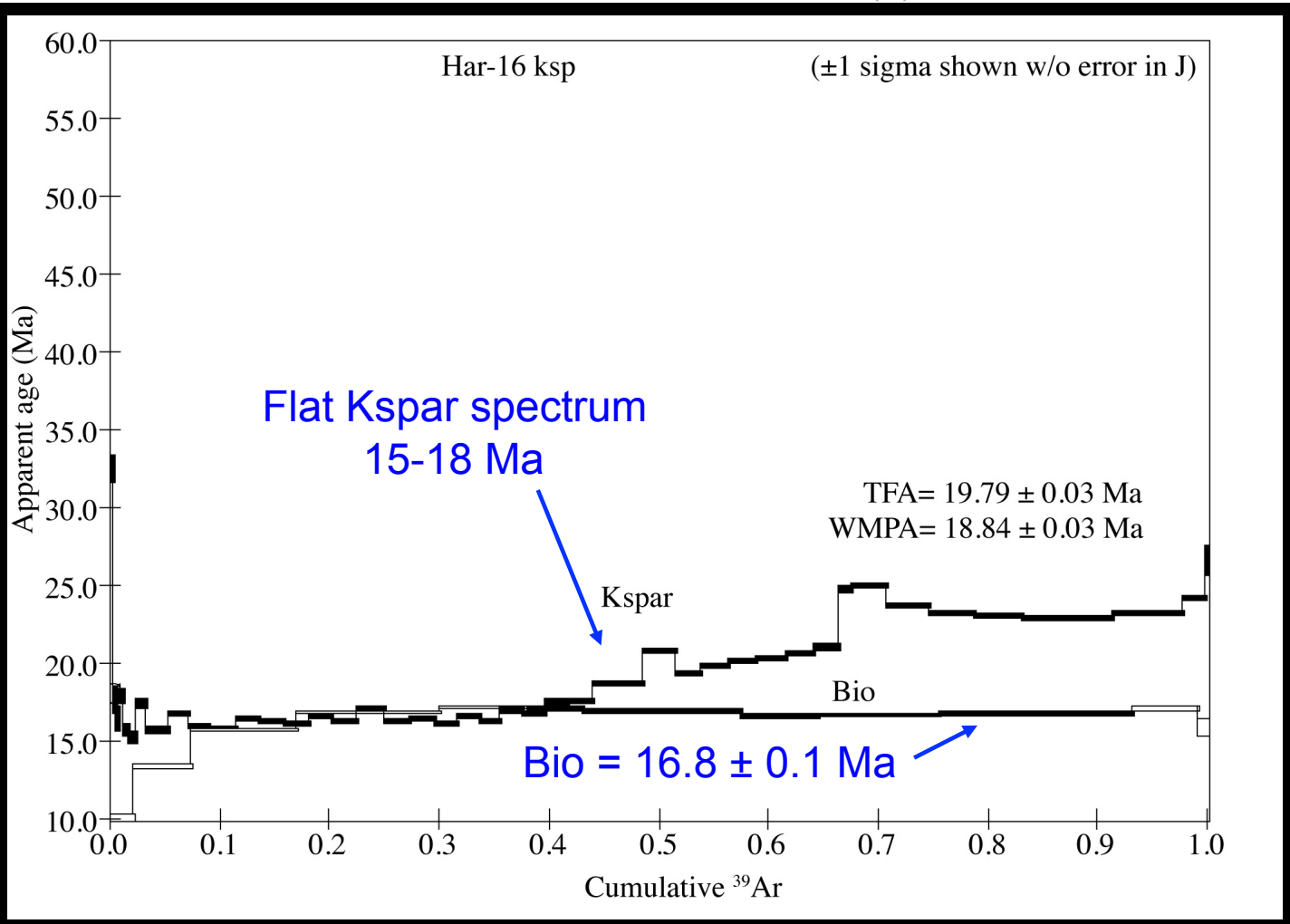


Har -26
Central footwall

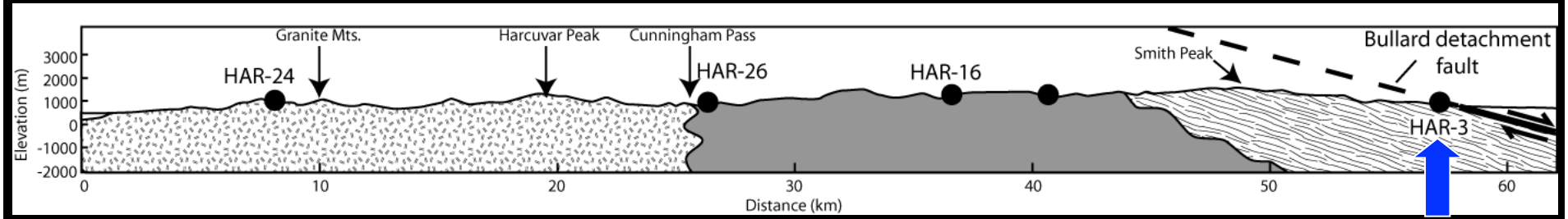
Younger biotite age

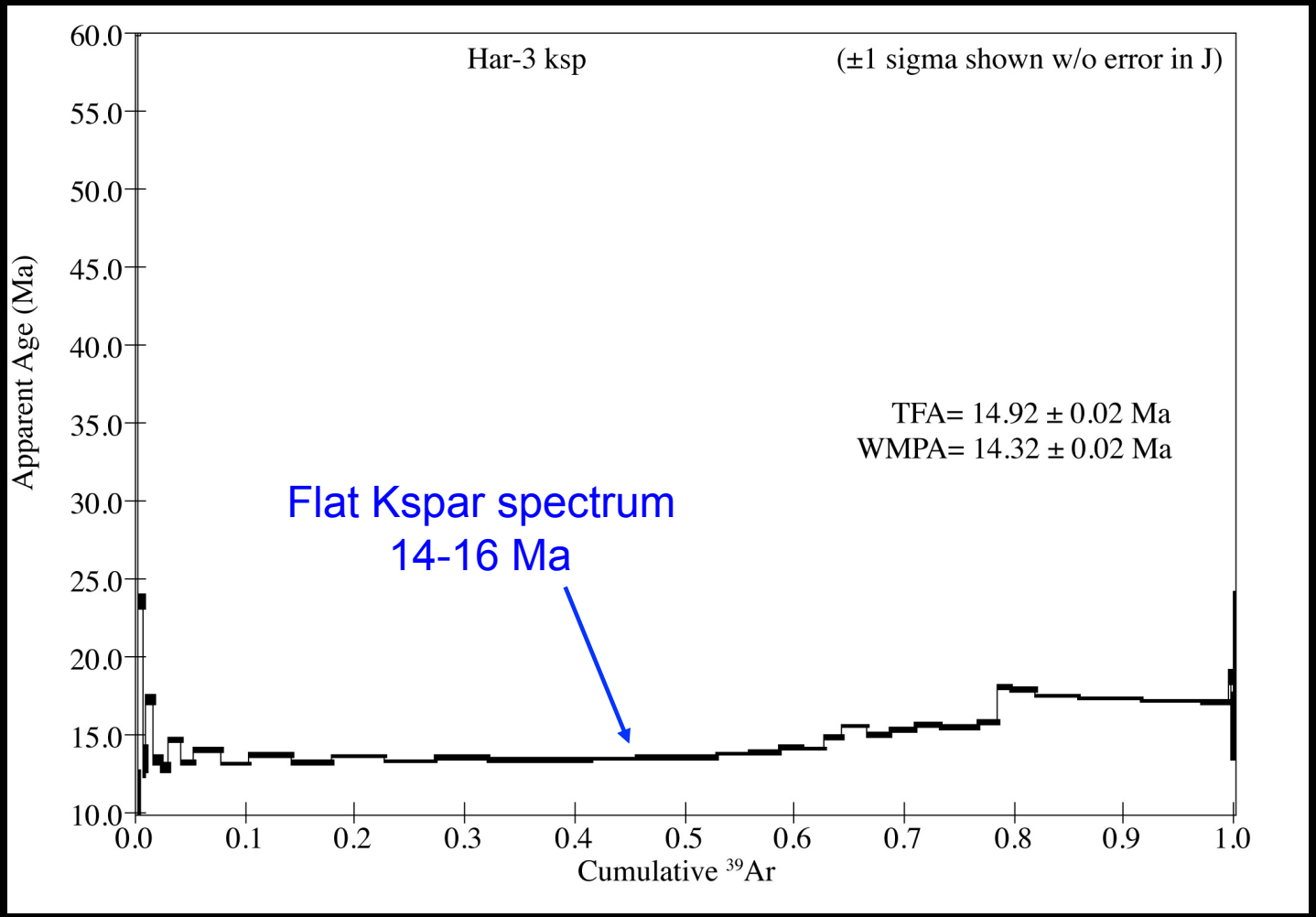
Kspar age spectrum is flatter (rapid cooling) at ca. 18 Ma





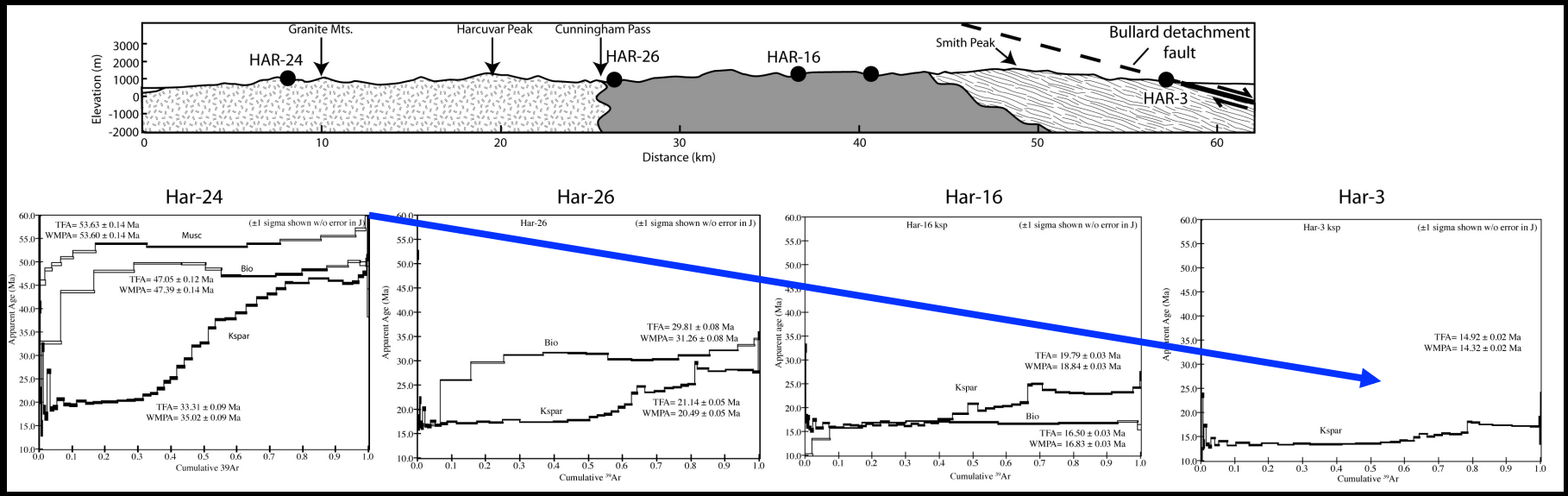
Har -16
NE-central
footwall





Har -3
NE-most
footwall

Thermochronology summary



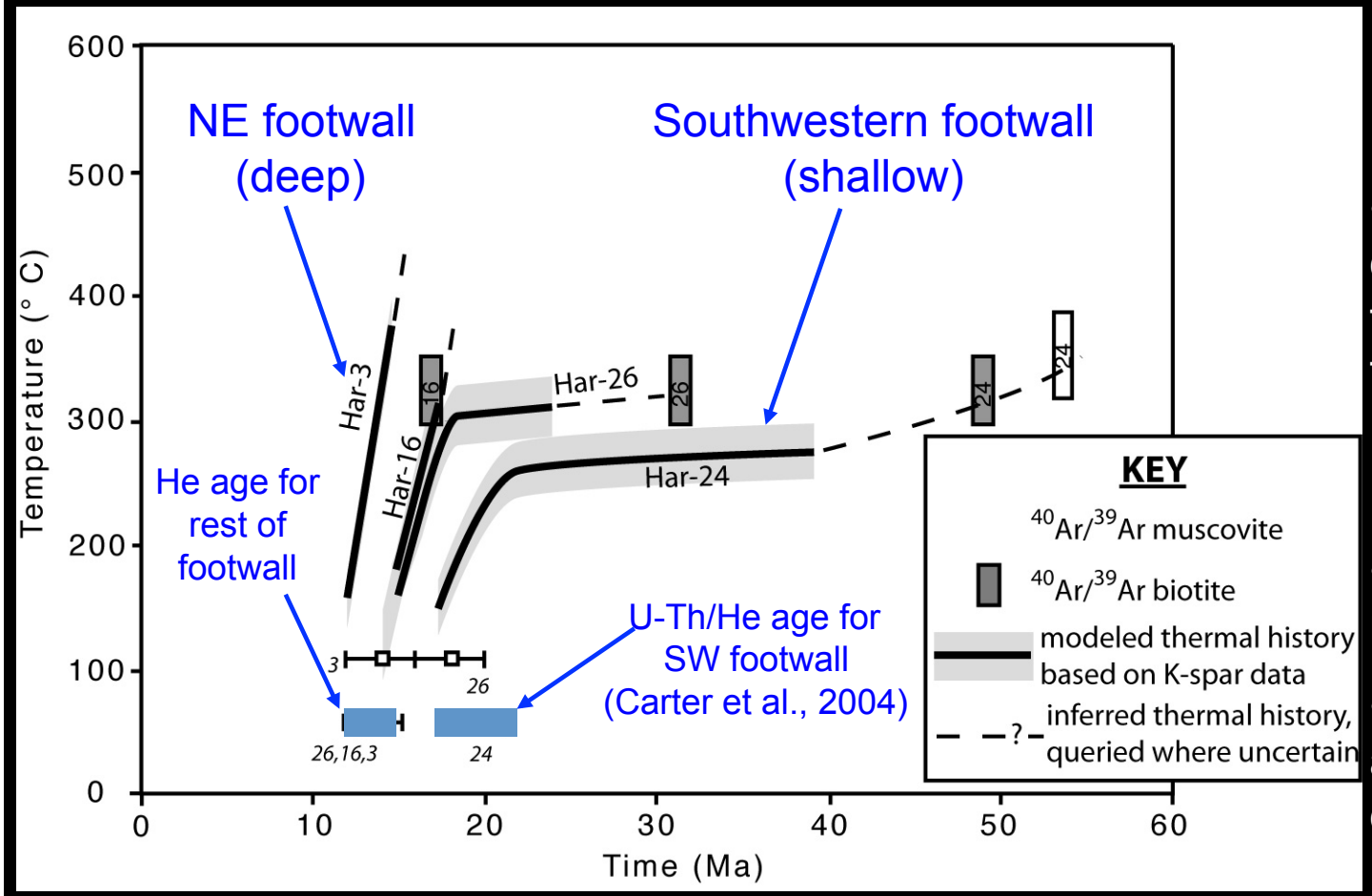
Consistently younger ages towards the northeastern (deepest) footwall

Significant footwall age gradient

K-spar age spectra get younger and flatter towards the northeast

Ar/Ar derived footwall thermal history and comparison to prior thermochronology

Based on mica and MDD thermal modeling of K-feldspar data



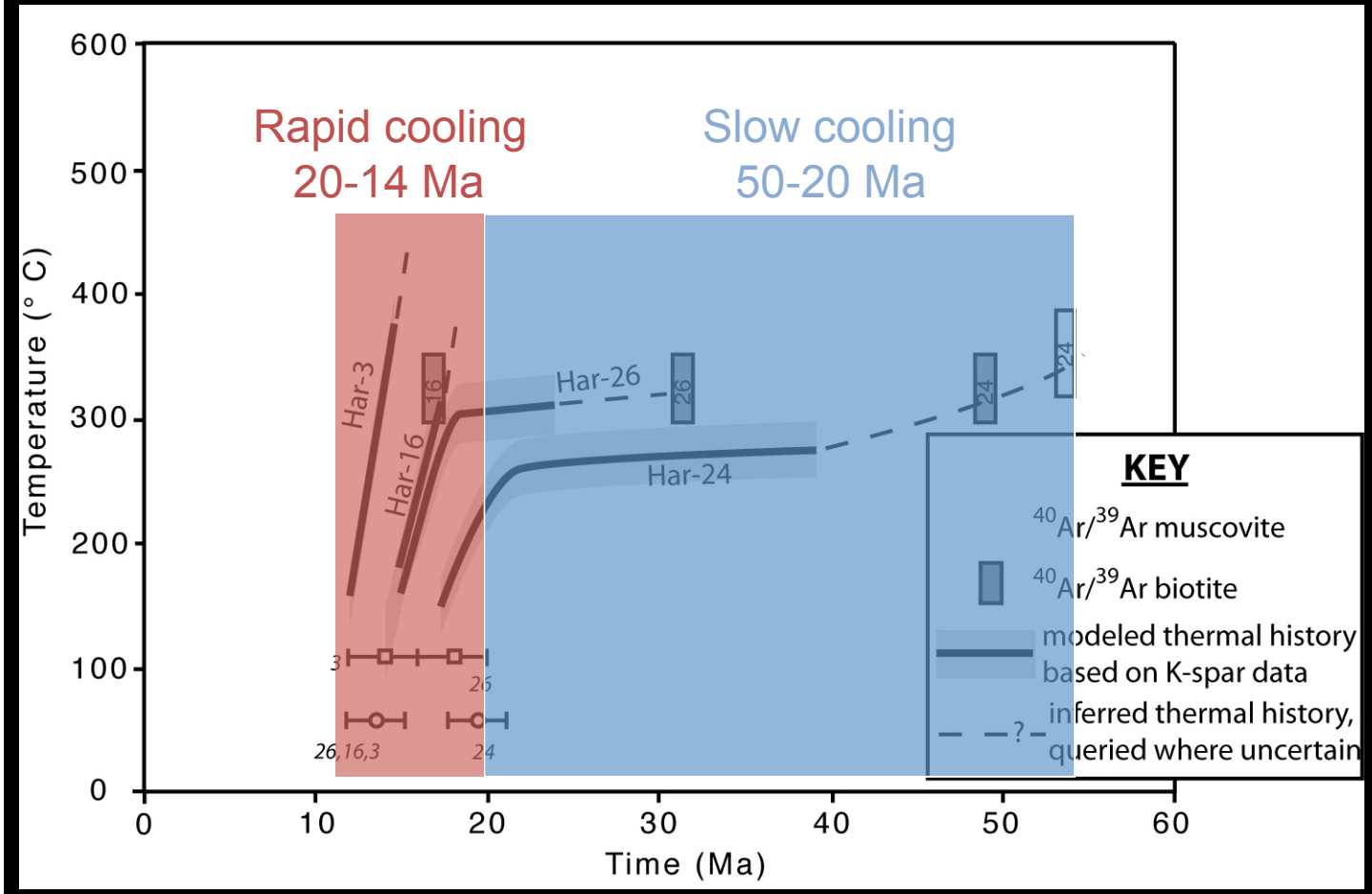
SW footwall

- (U-Th)/He age too old (20 Ma) relative to MDD K-spar thermal model

NE footwall

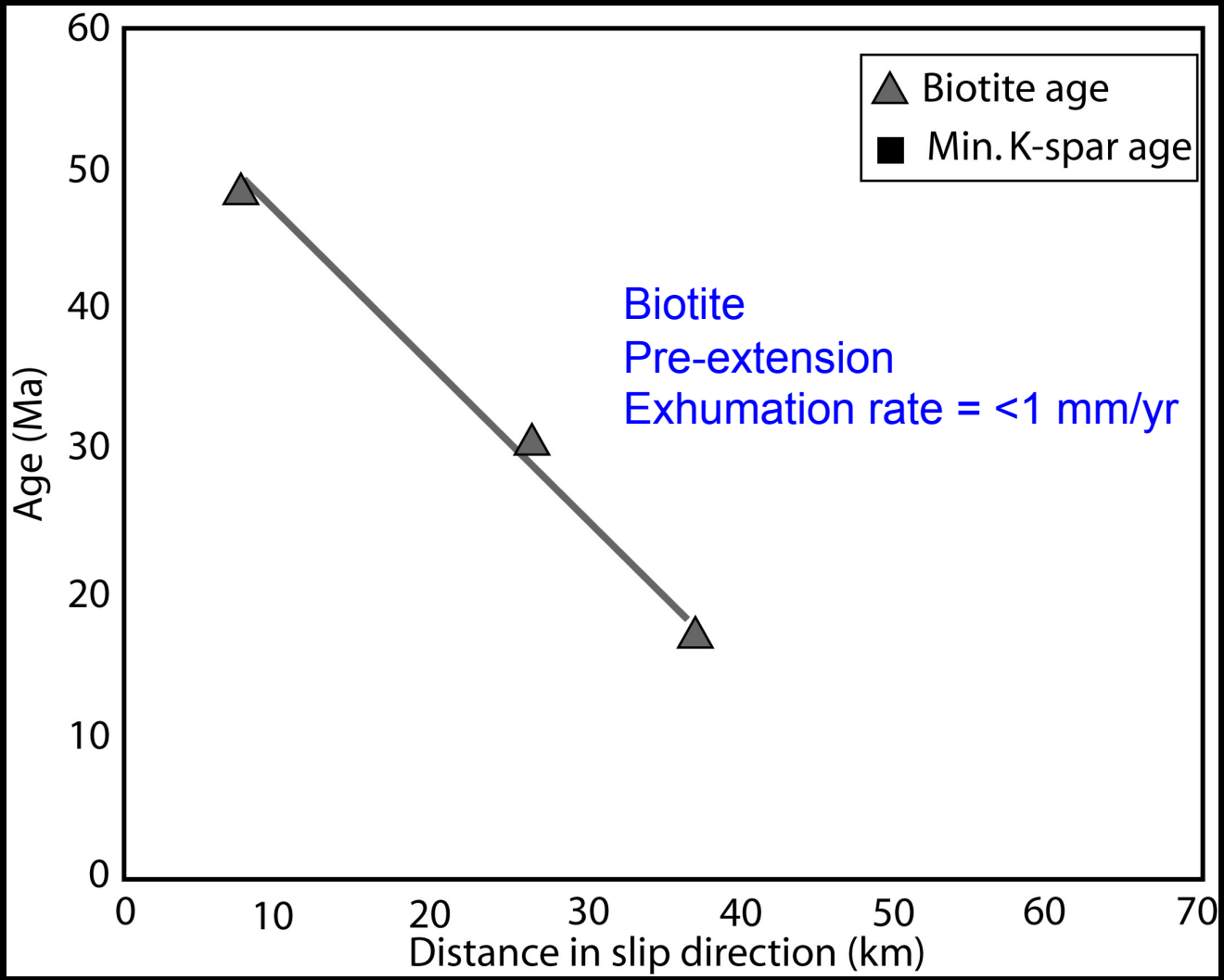
- He ages generally match well
- He ages don't show age gradient that Ar data does

Implications of footwall thermal history: Timing of slip

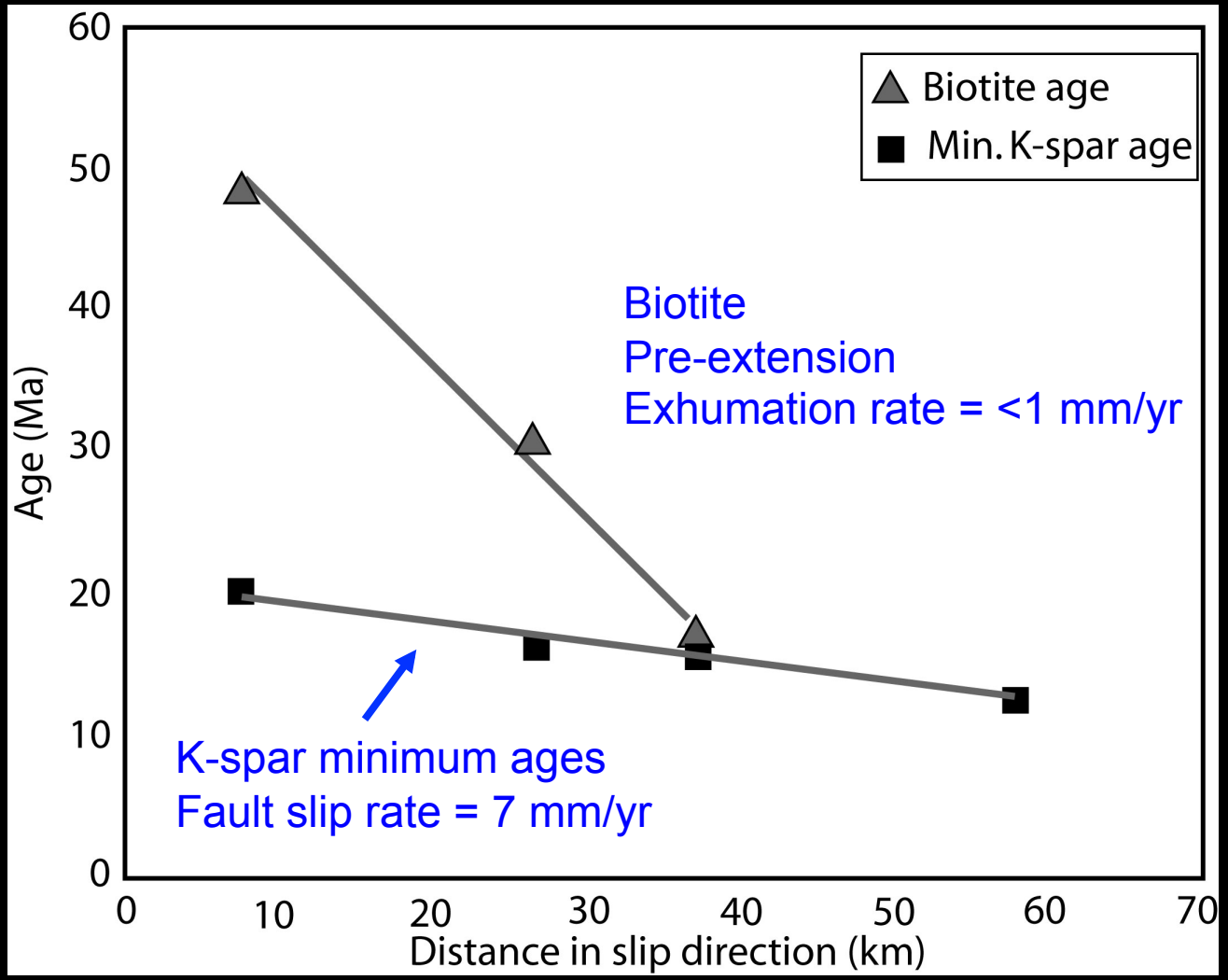


- Rapid cooling at ca. 20-19 Ma marks the inception of rapid slip
- No evidence for 27 Ma event as suggested by hanging wall sediments in the Rawhide HW
- Either not a significant event, only occurred in the Rawhide area, or it did not occur
- Extension continued until at least 14 Ma

Fault slip estimates

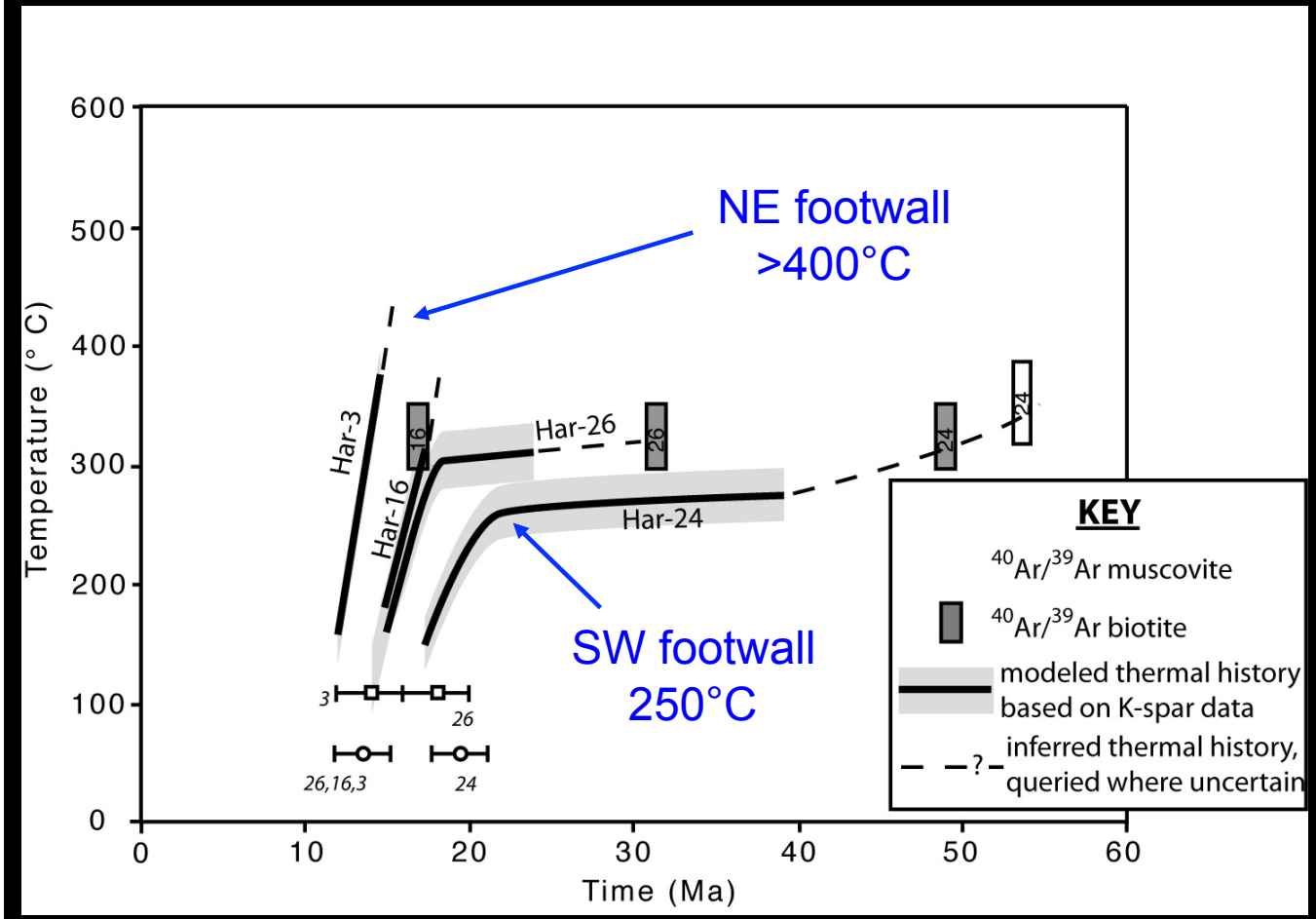


Fault slip estimates



- Matches with FT results (Foster et al., 1993) and pre-15 Ma slip rate from U-Th/He ages (Carter et al., 2004)
- Does not match post-15 Ma 30 mm/yr slip rate (Carter et al., 2004)

Footwall tilt estimates



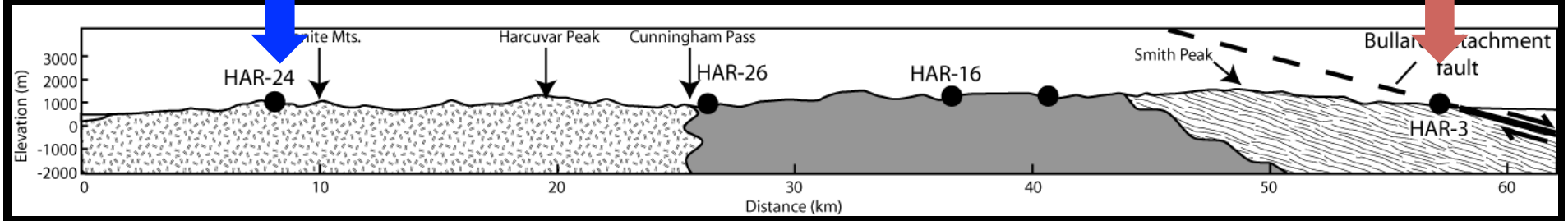
Significant footwall thermal gradient

At 20 Ma, SW footwall at ~ 250°C

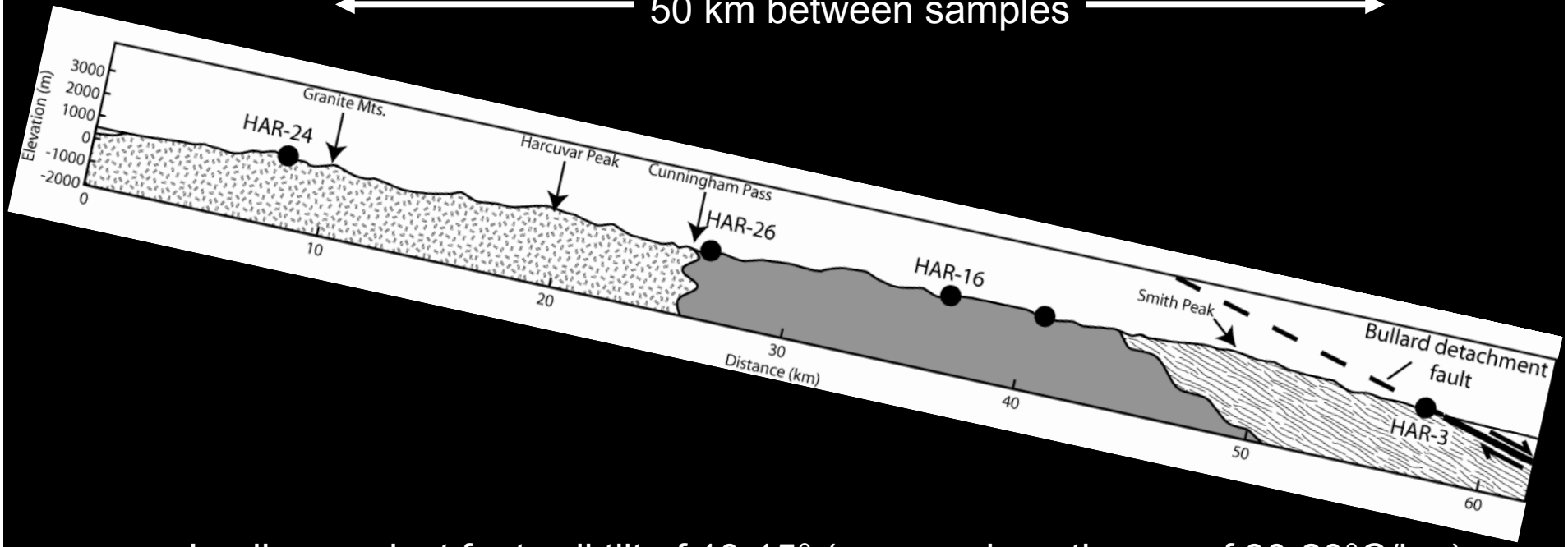
NE footwall at >400°C, likely 450-500°C

~250°C

~450-500°C



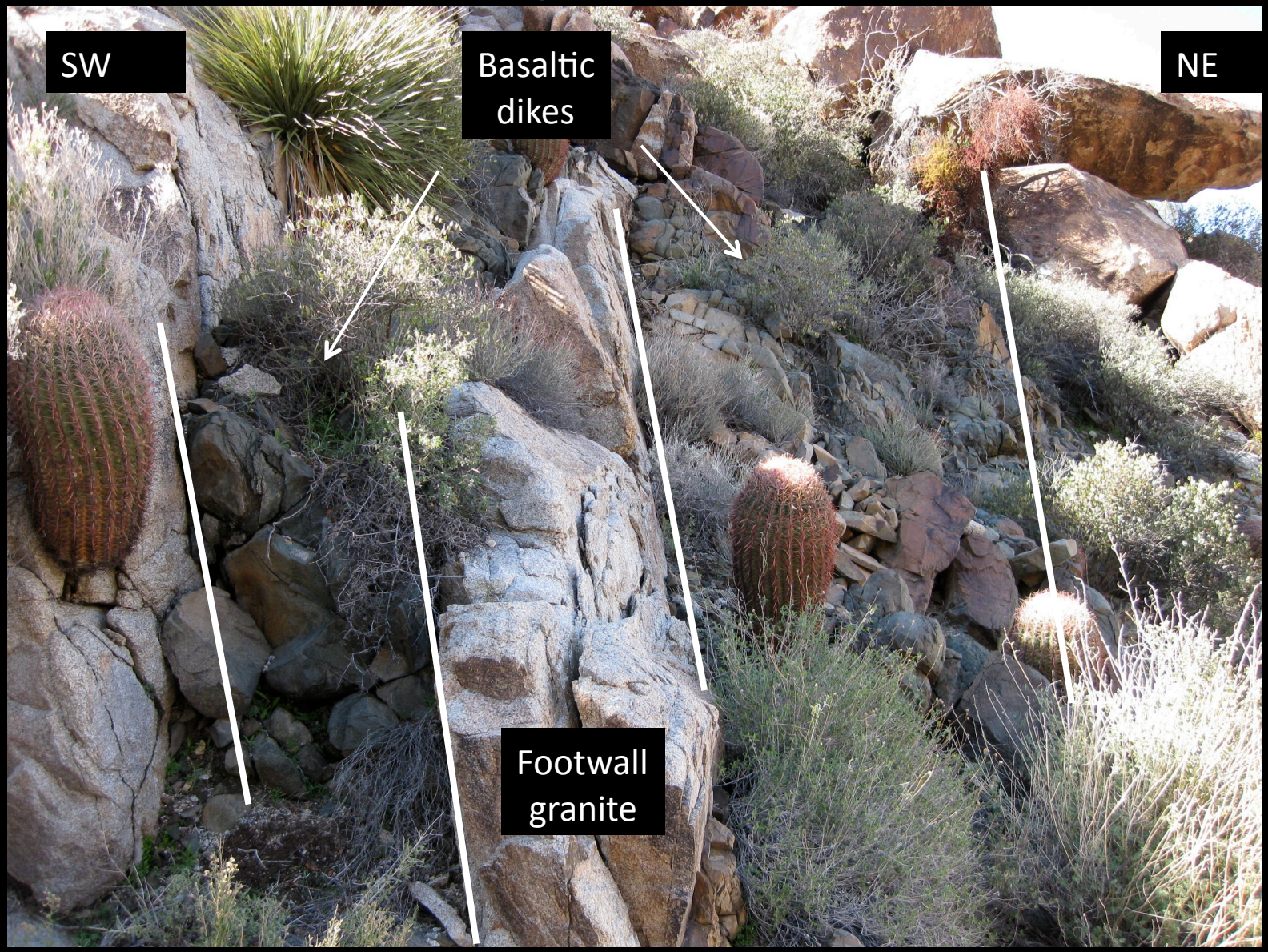
50 km between samples



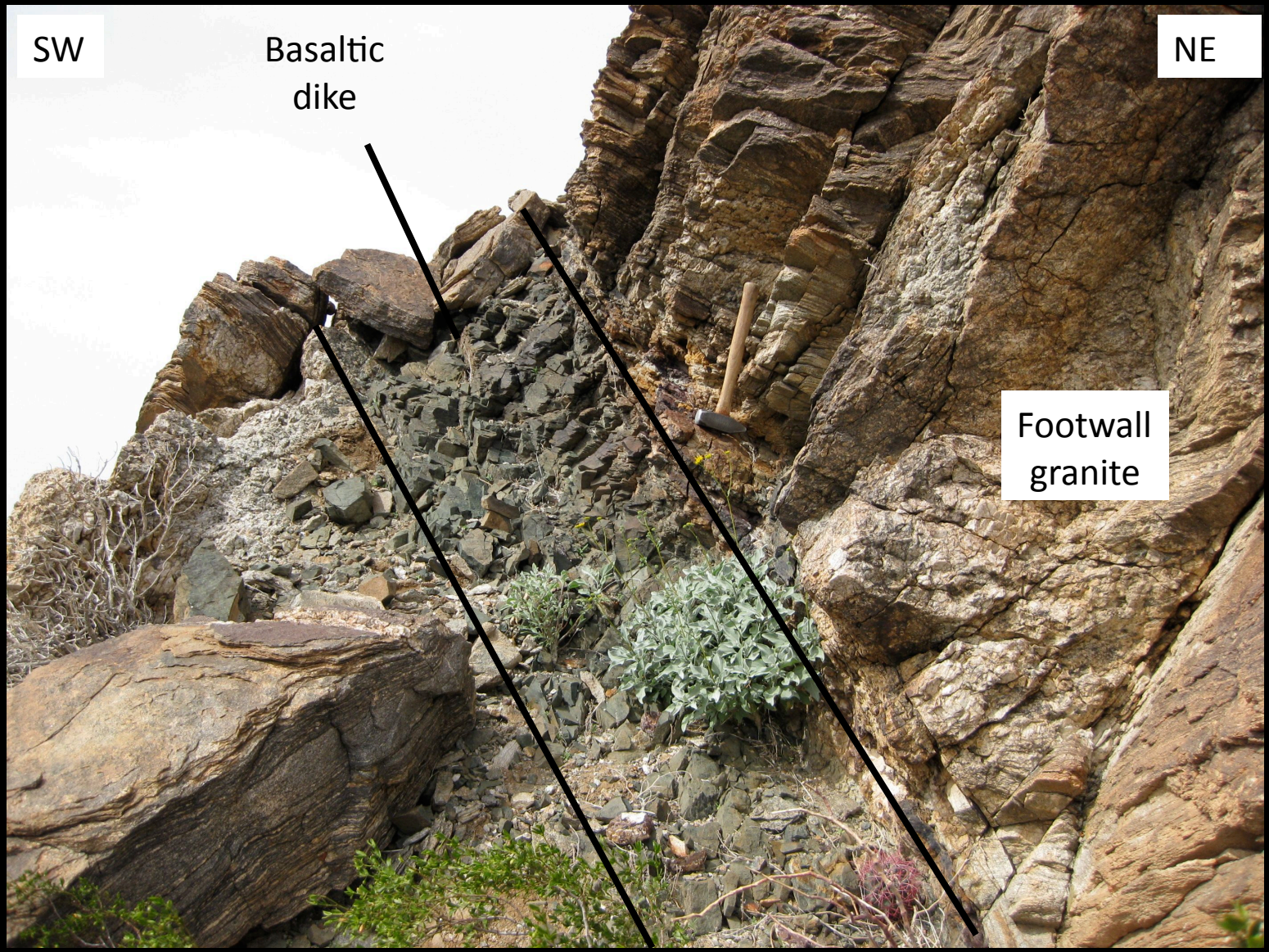
Implies modest footwall tilt of 10-15° (assumed geotherms of 30-20°C/km)

Would restore the initial detachment fault to ~ 30-35°

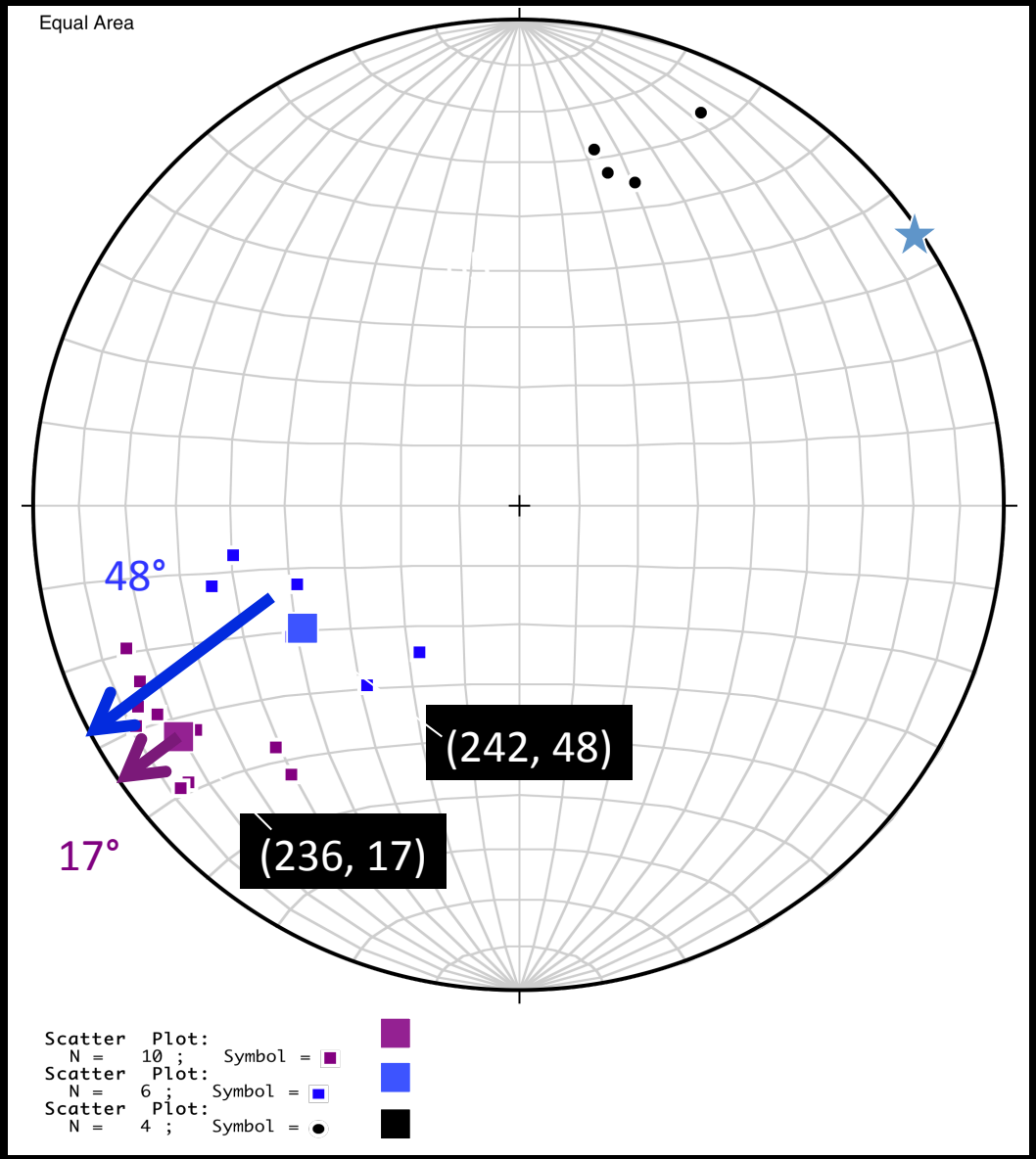
Other evidence for footwall tilting:
70-80° NE dipping dikes in the SW footwall



Other evidence for footwall tilting:
45° NE dipping dikes in the central footwall



How tilted is the Harcuvar footwall?

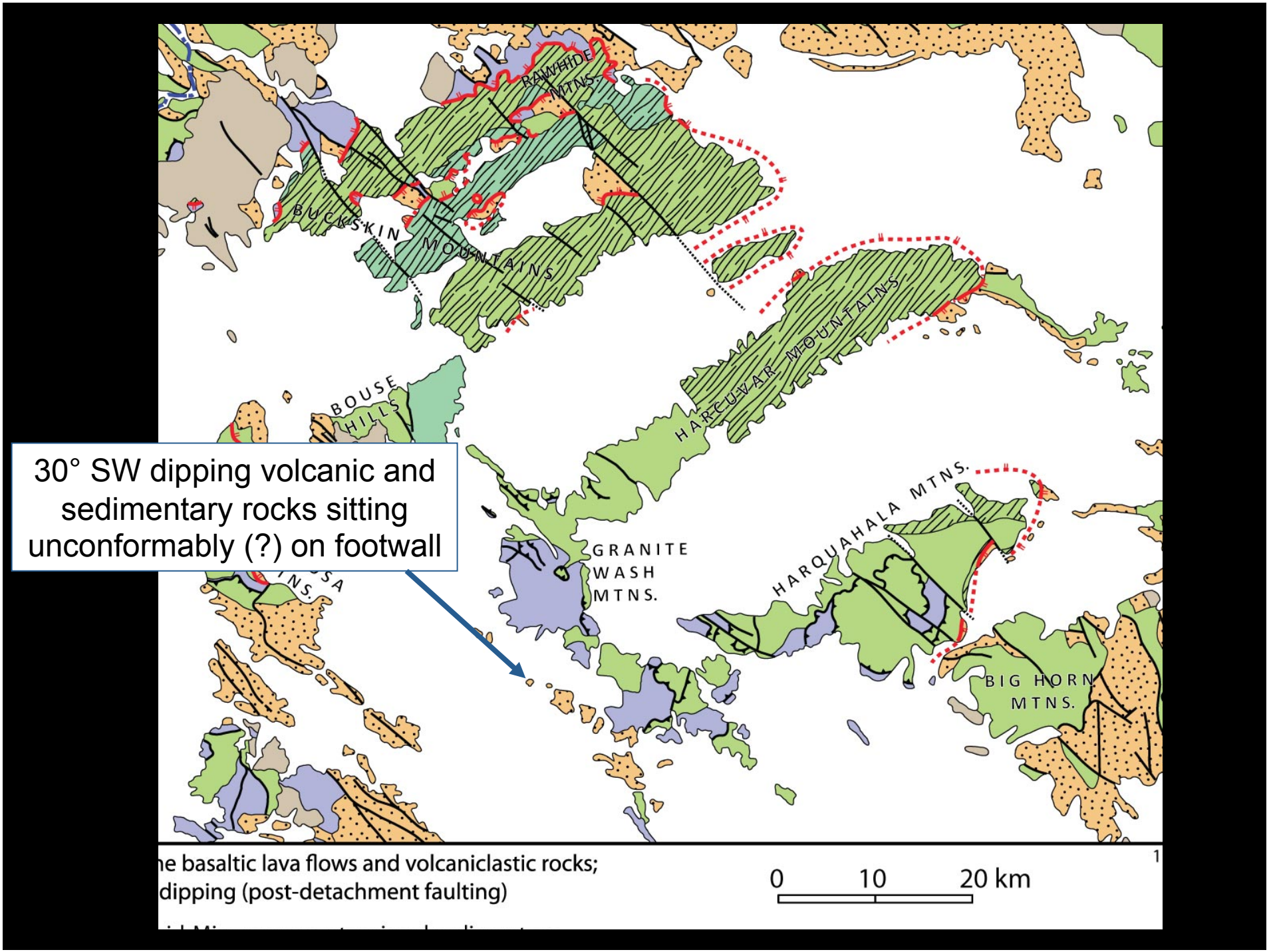


Assuming dikes were emplaced as Mode I vertical fractures during extension:

<u>Steep dikes</u>
17° of SW footwall tilt

<u>Moderately dipping dikes (older?)</u>
48° of SW footwall tilt

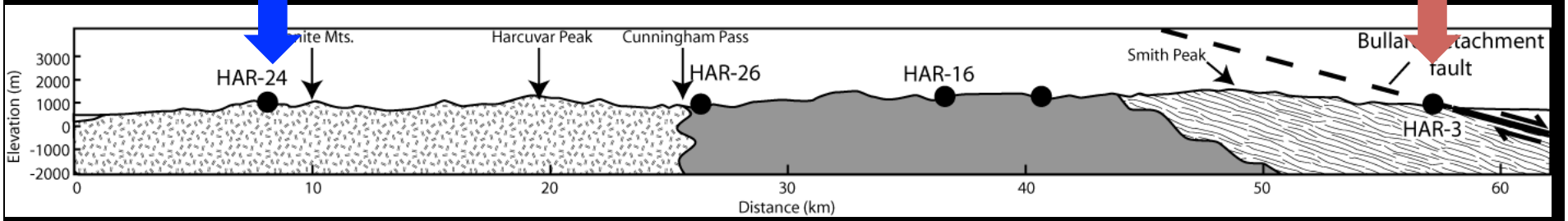
Footwall may be substantially tilted (45°)
Footwall and hanging wall equally tilted?
This would restore the detachment fault to 45-65°


30° SW dipping volcanic and sedimentary rocks sitting unconformably (?) on footwall
RAWHIDE MTNS.
BUCKSKIN MOUNTAINS
HARCUVAR MOUNTAINS
BOUSE HILLS
HARQUAHALA MTNS.
GRANITE WASH MTNS.
BIG HORN MTNS.
ne basaltic lava flows and volcaniclastic rocks;
dipping (post-detachment faulting)
0
10
20 km

Why do the thermochronologic and geologic data suggest different amounts of footwall tilt?

~250°C

~450-500°C



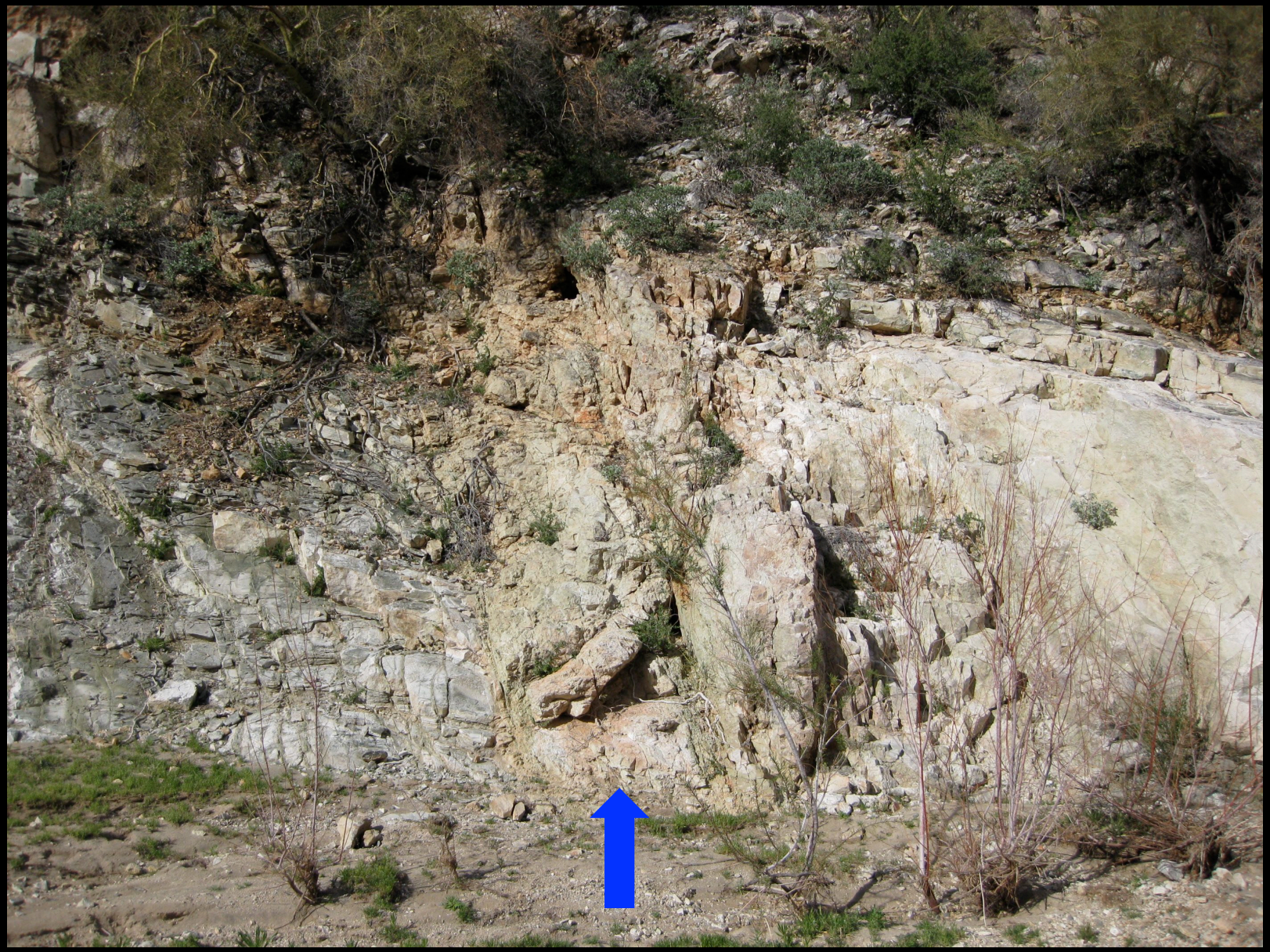
50 km between samples

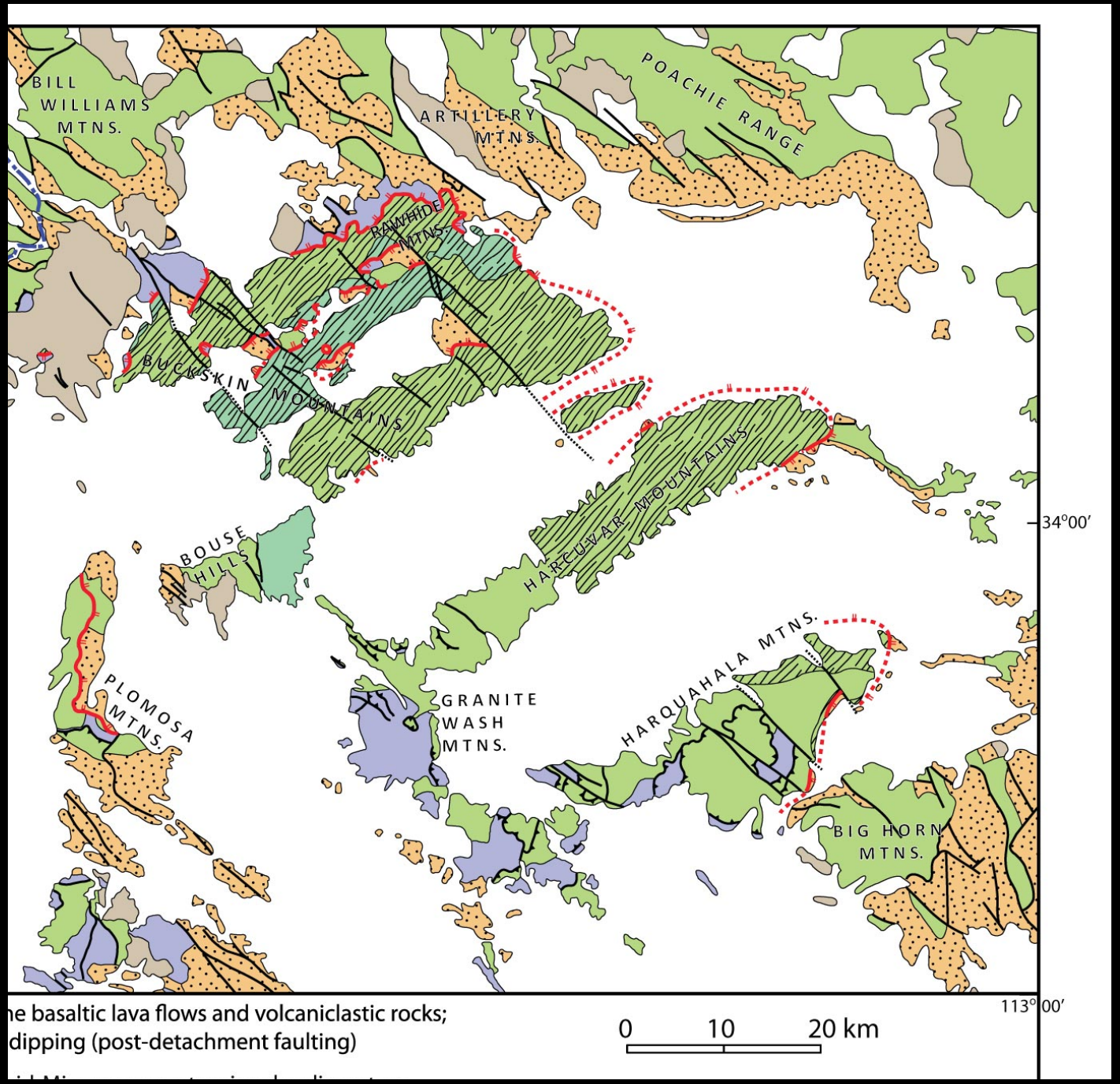
Is the footwall an intact block?

Is the Harcuvar footwall intact?

Small-scale (cm offset) normal faults

Fault zone of unknown displacement



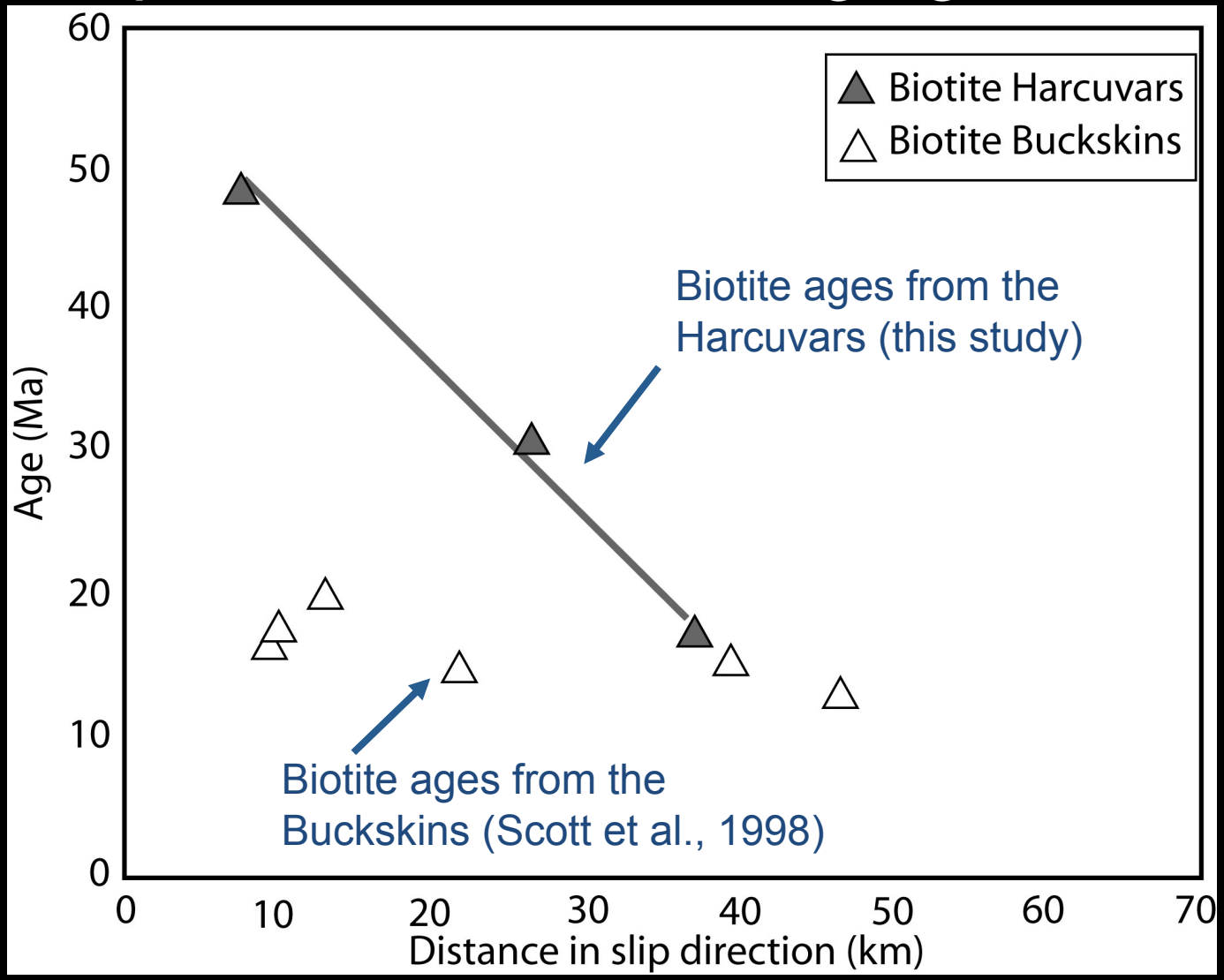


Do faults from the adjacent ranges project into the Harcuvar footwall?

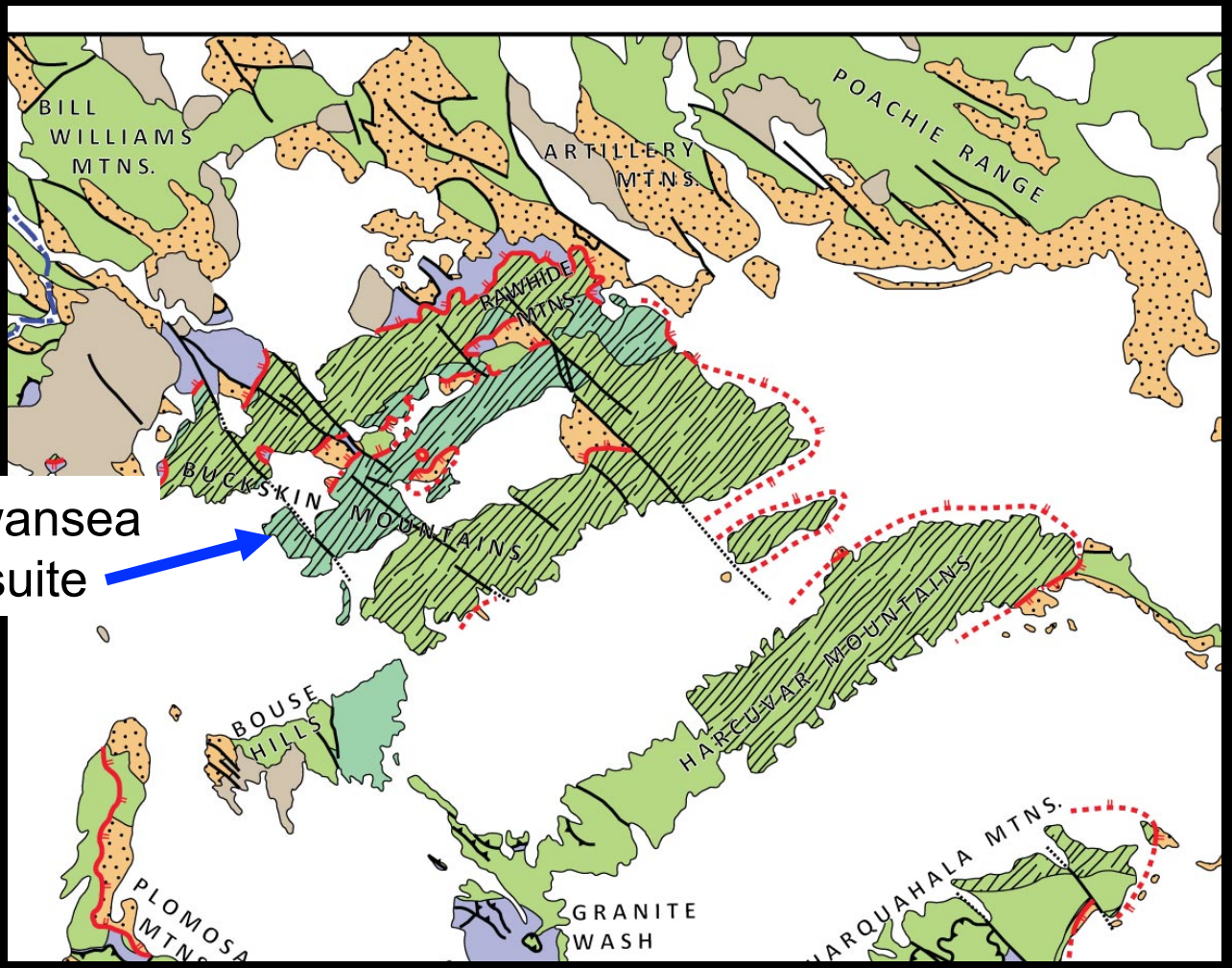
How can we recognize footwall normal faults in granitic footwall?

Footwall normal faults may have extended the footwall, leading to misleading tilt reconstructions based on thermochronology alone

Why does the Rawhide Buckskin core complex lack a footwall age gradient?



Was the Rawhide Buckskin footwall thermally reset by Miocene plutonism?



21.7 Ma Swansea plutonic suite

Thermochronologic constraints from the Harcuvars on the timing and rate of extension and the degree of footwall tilt may be the most reliable for the region

Conclusions

•Rapid tectonic exhumation at the Harcuvar core complex began at ca. 20 Ma and continued until at least 14 Ma

•There is no evidence of an earlier extensional event at ca. 27 Ma thermochronologically

•Rate of fault slip was ~7 mm/yr; no evidence for higher slip rates (*cf.* Carter et al., 2004)

• Footwall thermal gradient requires at least 10-15° of footwall tilt to the SW, implying a steeper initial dip to the bounding detachment

•Geologic evidence suggests a higher degree of footwall tilt (30-45°) and initial detachment fault dips of 40-65°

•The Harcuvar footwall may not be an intact fault block, leading to tilt discrepancy

•Thermochronologic data from the adjacent Rawhide-Buckskin core complex may have been reset by Miocene plutonism.

•The Harcuvar range may preserve the best thermochronologic record of the timing and rate of extension and degree of footwall tilting in the region.