Denali on the move: Advection and migration in the Mount McKinley restraining bend since ~6 Ma

Sean Bemis (U. of Kentucky**)

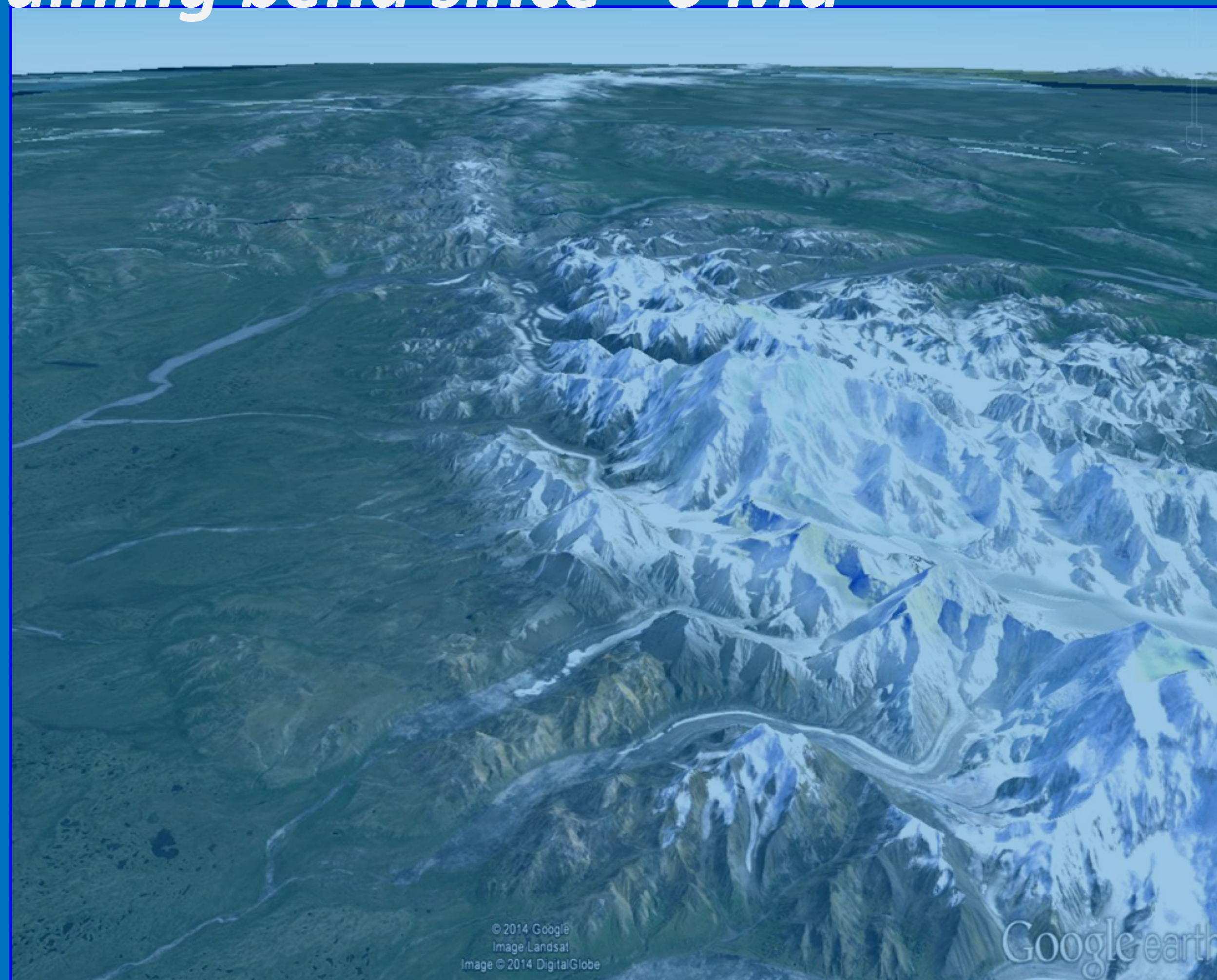
Jeff Benowitz (UAF)

Anne Fendick (U. of Kentucky)

Patrick Terhune (UAF)

Michele Cooke (UMass-Amherst)

Kevin Toehnbohm (UMass-Amherst)

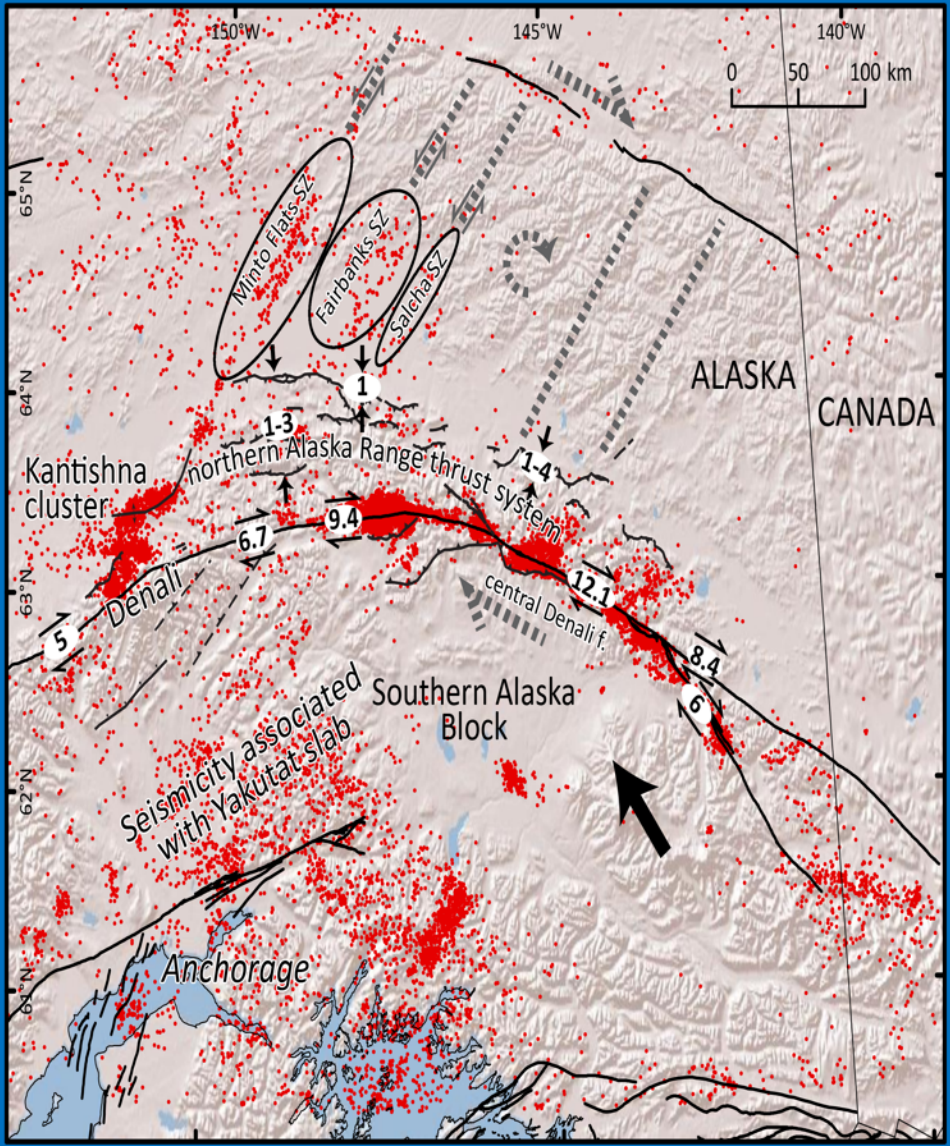


NSF EAR 1250461

**Beginning August 2017 – at Global Forum on Urban & Regional Resilience and Dept. of Geosciences, Virginia Tech.

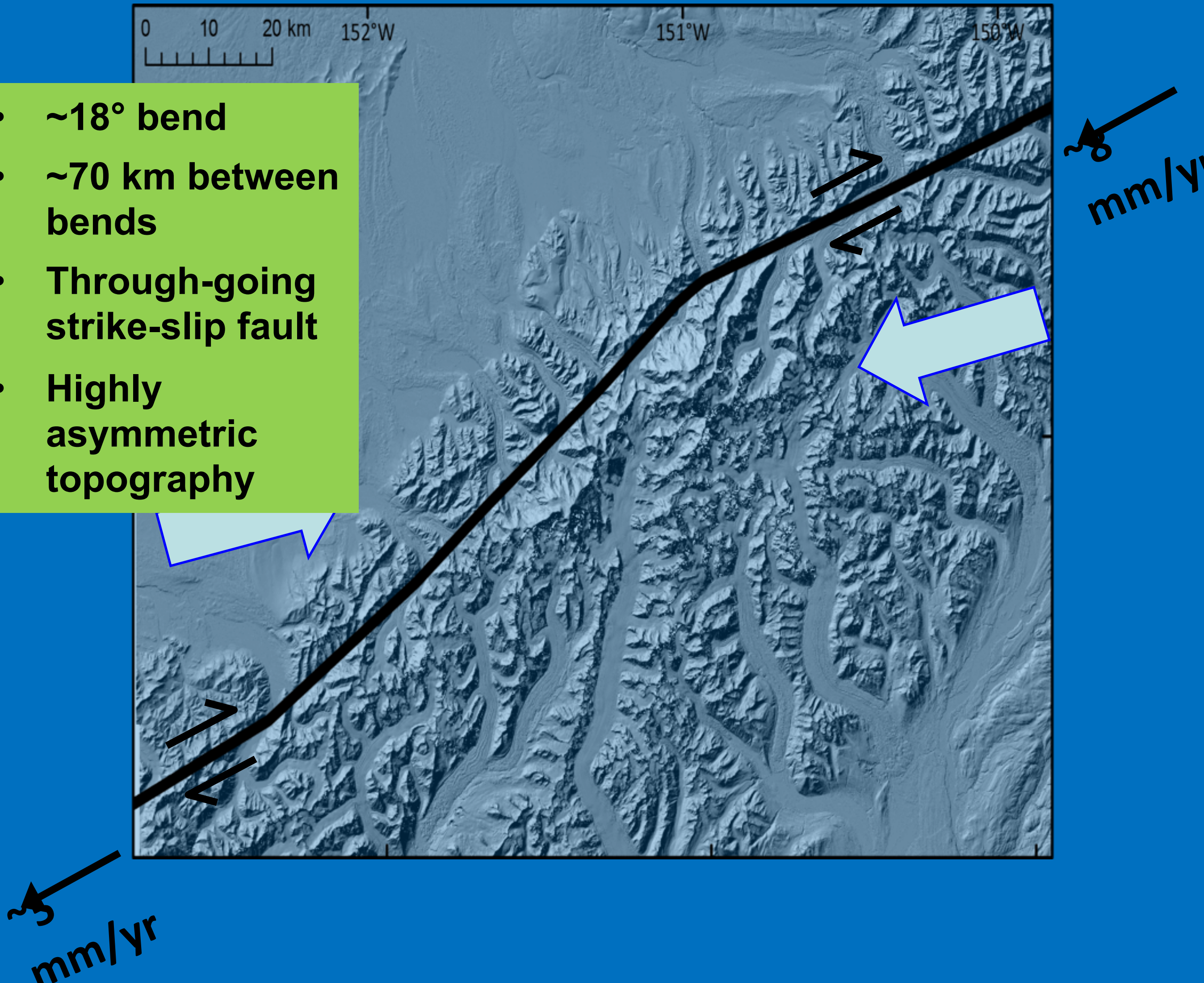
Motivation

- Type example of a large-scale, gentle restraining bend system
- Tectonic evolution of the highest point in North America
  - In the Alaska Range, modern high elevations correspond with zones of youngest exhumation
  - Anomalous, ~isolated topography/exhumation



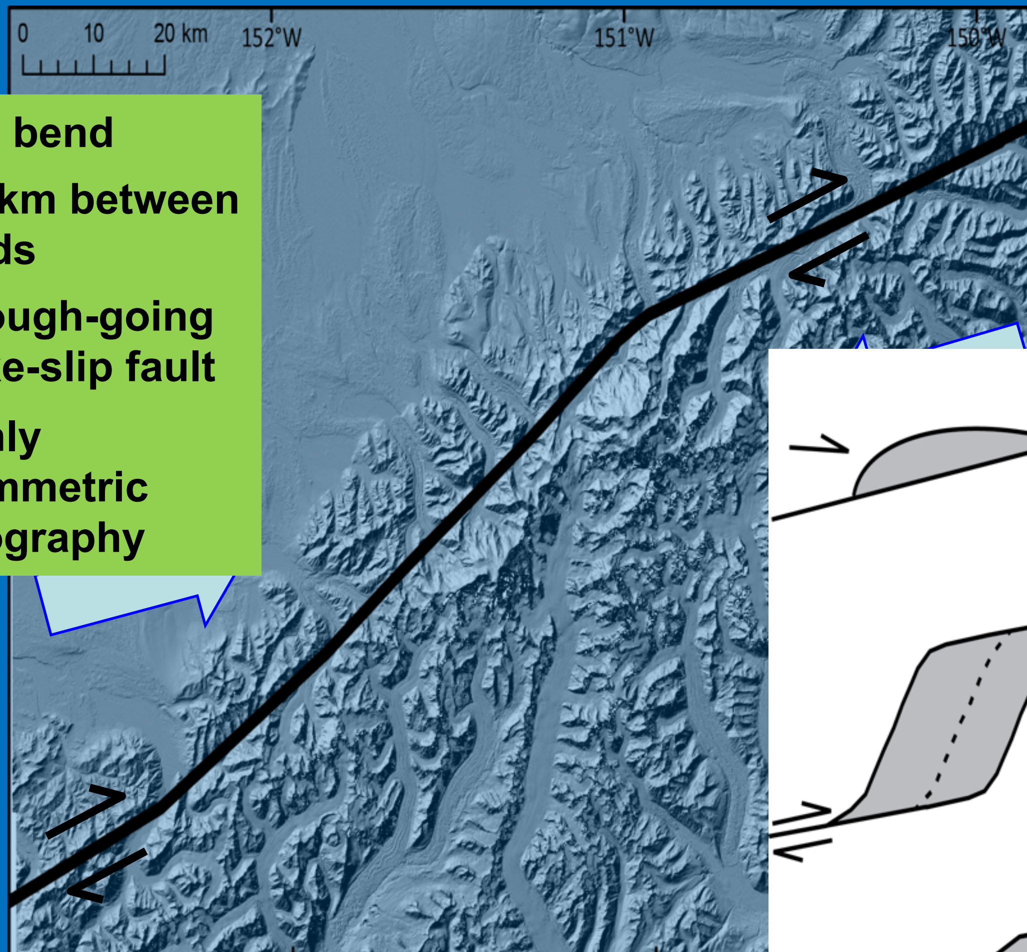
The geometric complexity formerly known as the ‘Mount McKinley restraining bend’

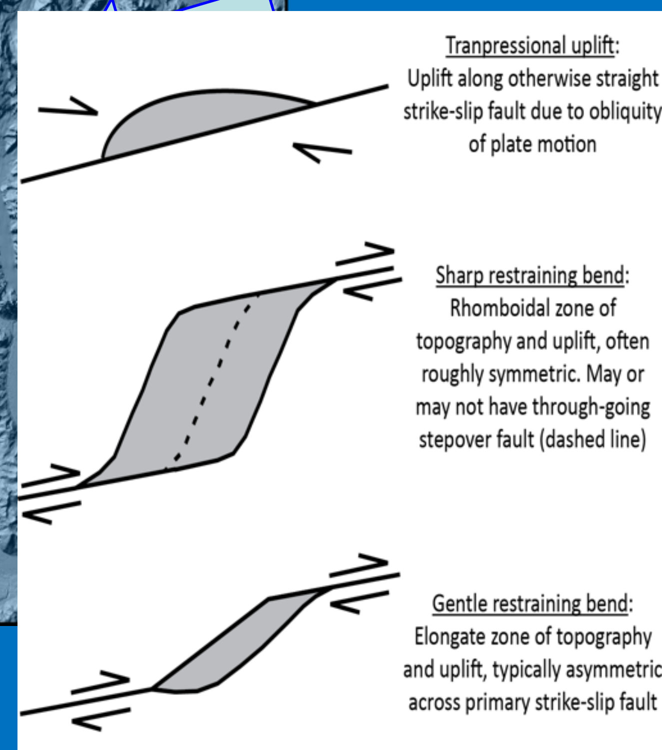
- ~18° bend
- ~70 km between bends
- Through-going strike-slip fault
- Highly asymmetric topography



The geometric complexity formerly known as the 'Mount McKinley restraining bend'

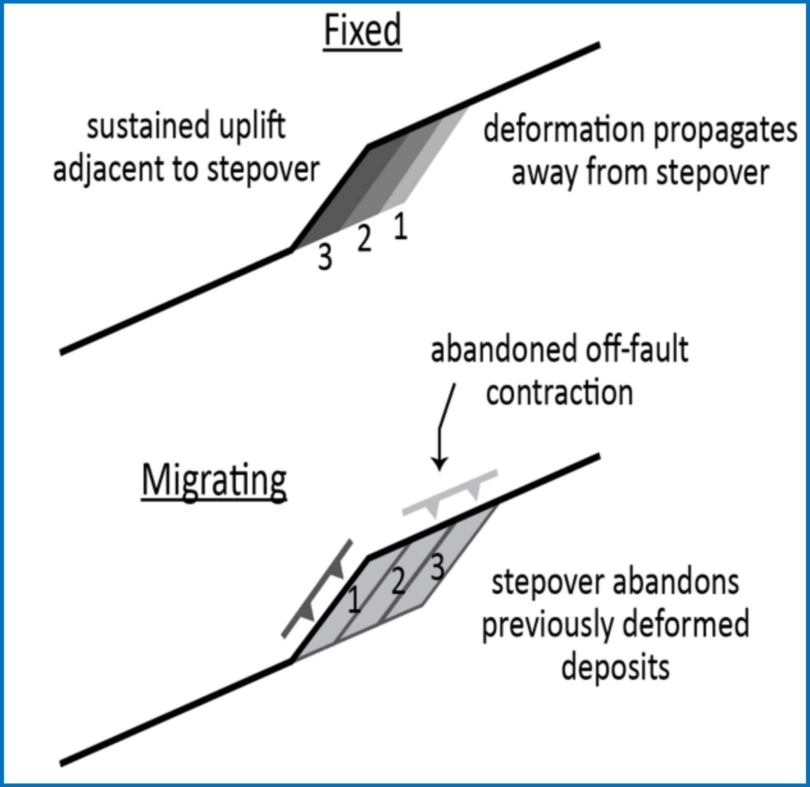
- ~18° bend
- ~70 km between bends
- Through-going strike-slip fault
- Highly asymmetric topography



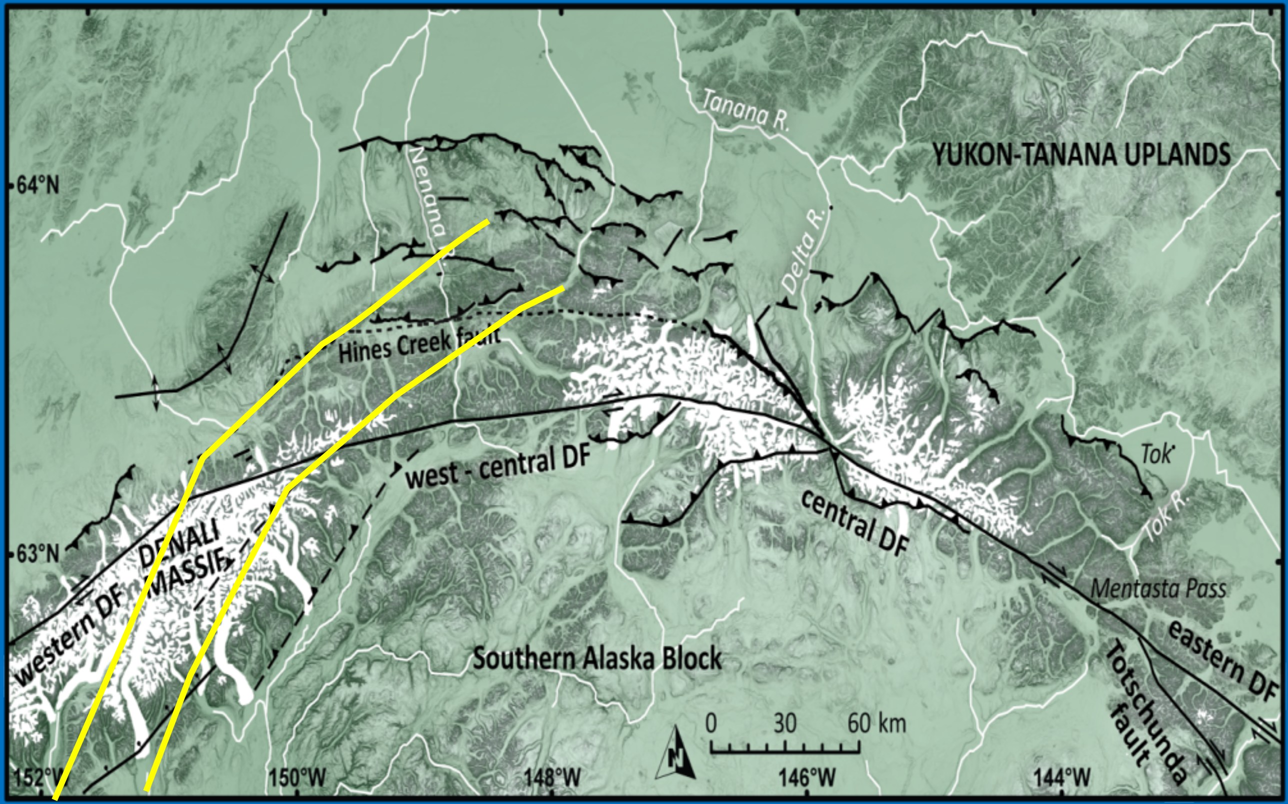


Deformation in gentle restraining bends

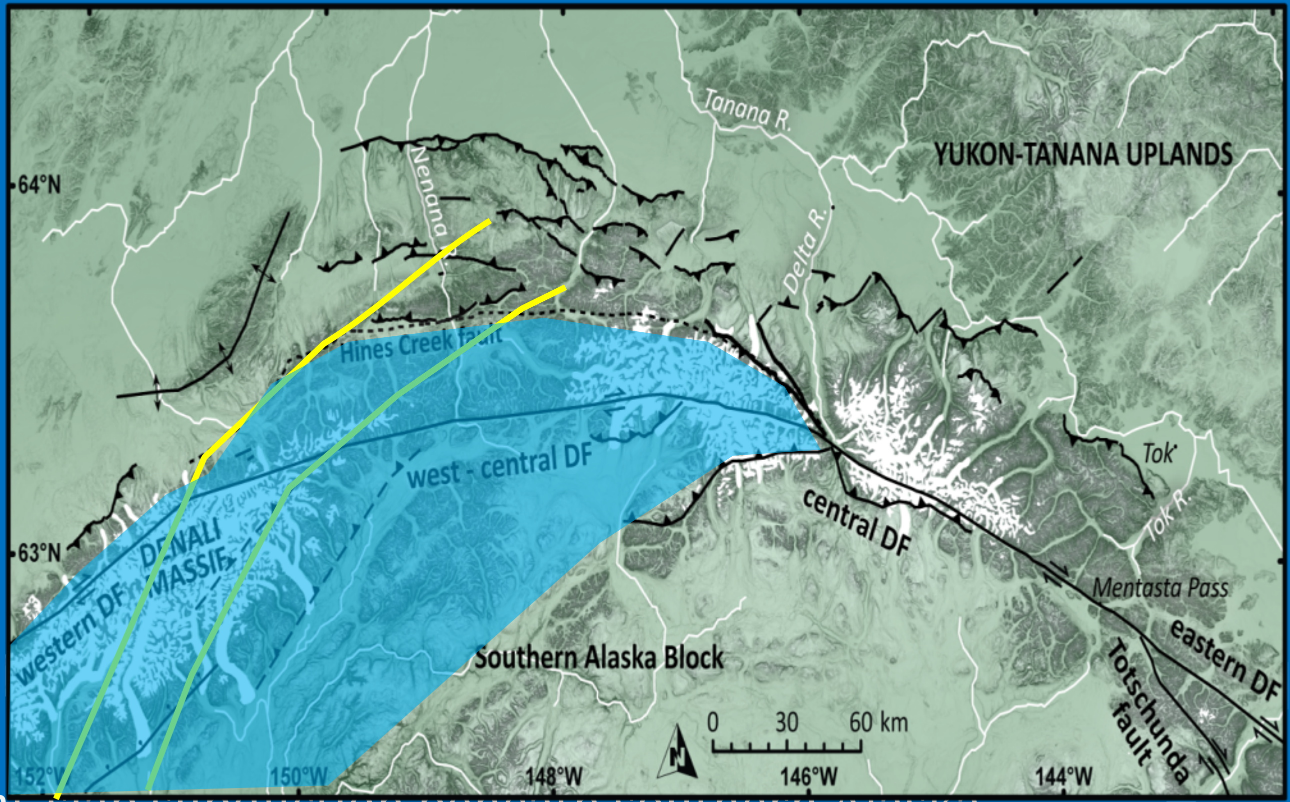
- How is crustal deformation accommodated in the restraining bend?
- How is extreme topography created – *<u>and maintained</u>* – in a restraining bend?
- What controls the production of asymmetric topography/faulting in gentle restraining bends?



Burkett et al. (2016), modified fom Wakabayashi (2007)

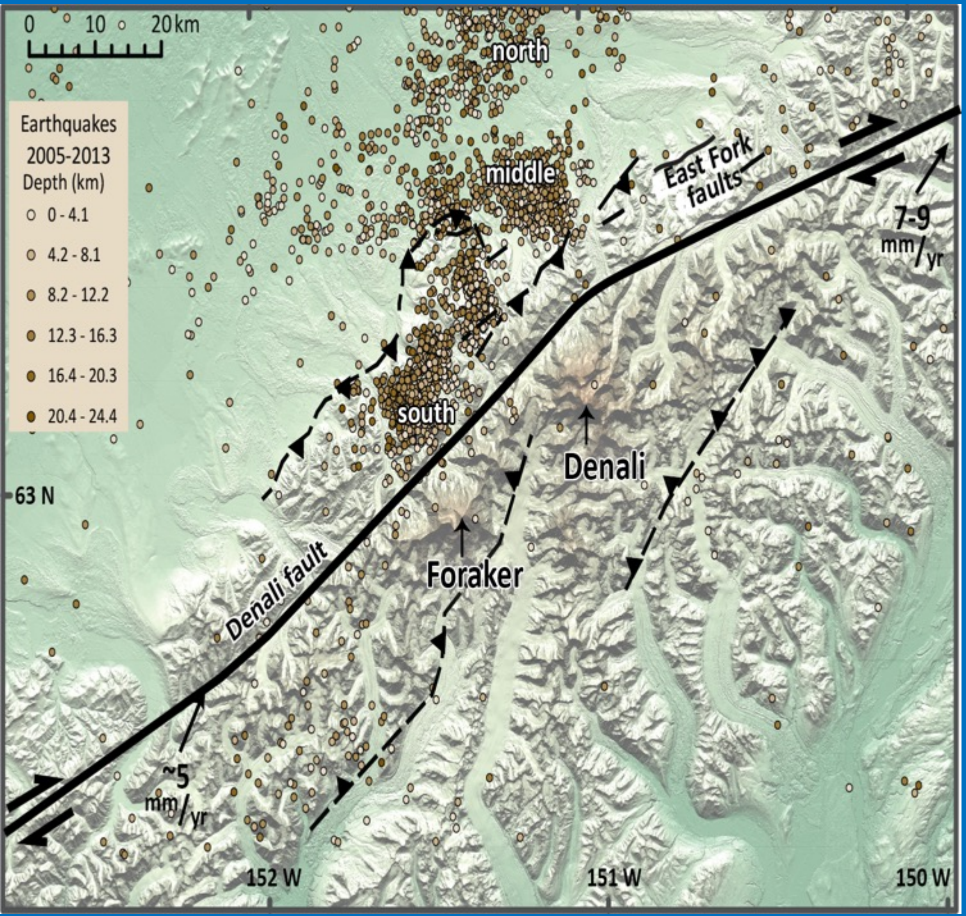


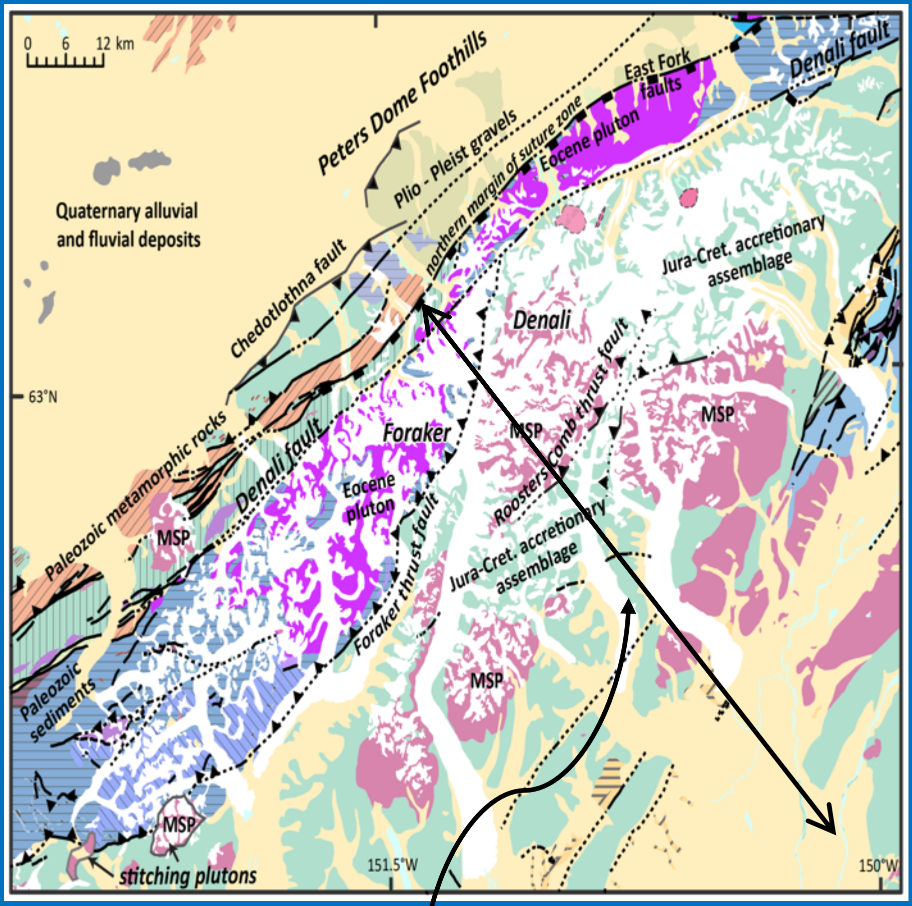
- Flat-slab subduction beneath southern Alaska
- Alaska Range suture zone (Ridgway et al., 2002; Fitzgerald et al., 2014)
- 25-30 Ma initiation of Alaska Range deformation (Lease et al., 2016)
- Rotation/indentation of Southern Alaska Block (Haeussler, 2008; Bemis et al., 2015)
- Highly slip-partitioned system (Bemis et al., 2015)



- Flat-slab subduction beneath southern Alaska
- Alaska Range suture zone (Ridgway et al., 2002; Fitzgerald et al., 2014)
- 25-30 Ma initiation of Alaska Range deformation (Lease et al., 2016)
- Rotation/indentation of Southern Alaska Block (Haeussler, 2008; Bemis et al., 2015)
- Highly slip-partitioned system (Bemis et al., 2015)

Geology and upper crustal seismicity

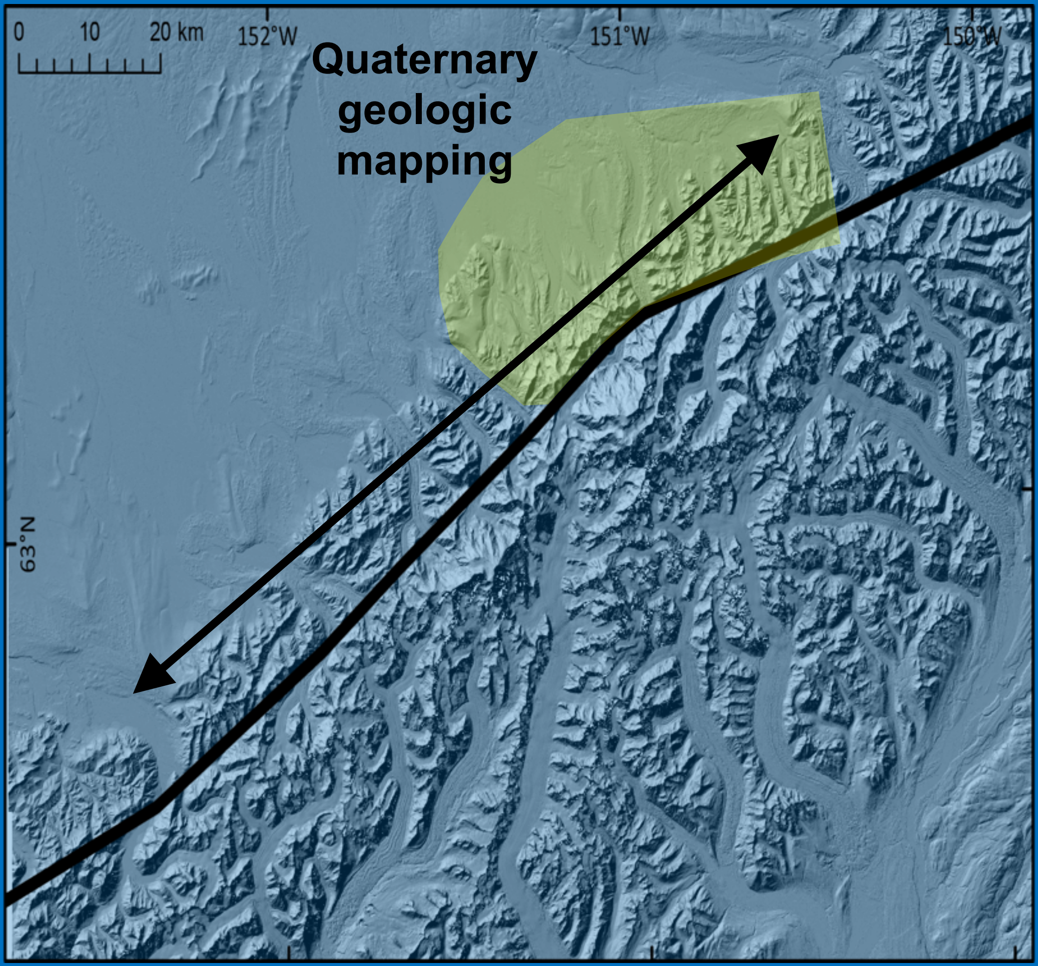




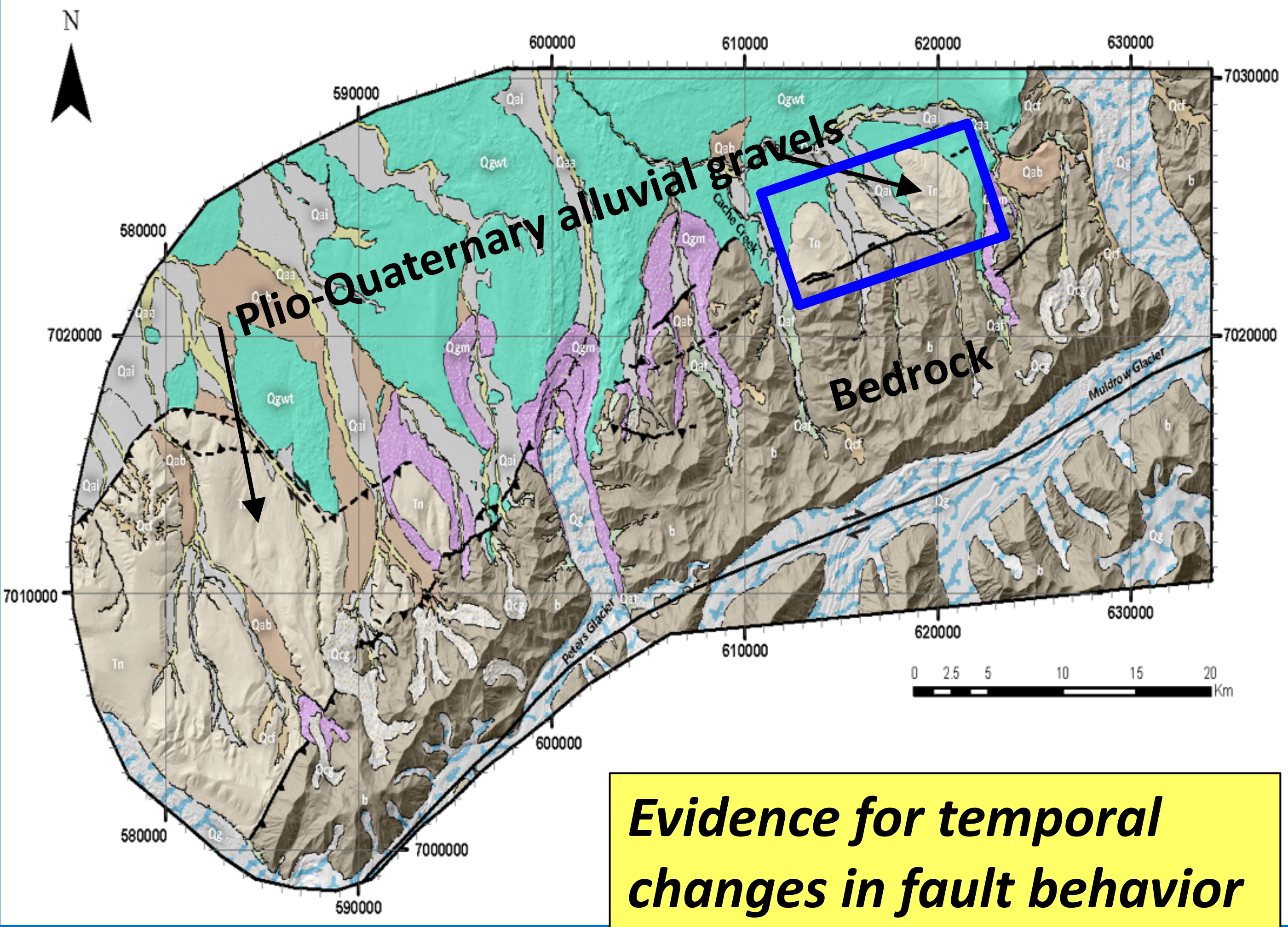
Kantishna Cluster seismicity

Alaska Range suture zone, intruded by Cenozoic plutons

Part 1: Active faults and relation to DF bends

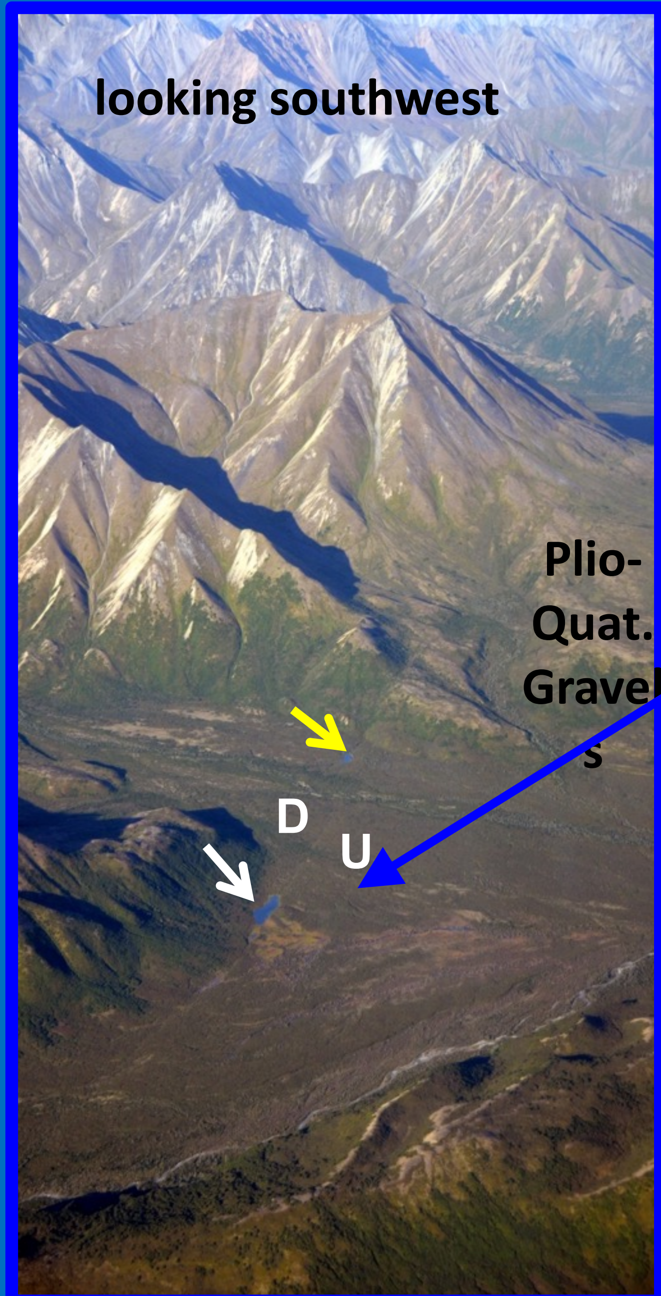


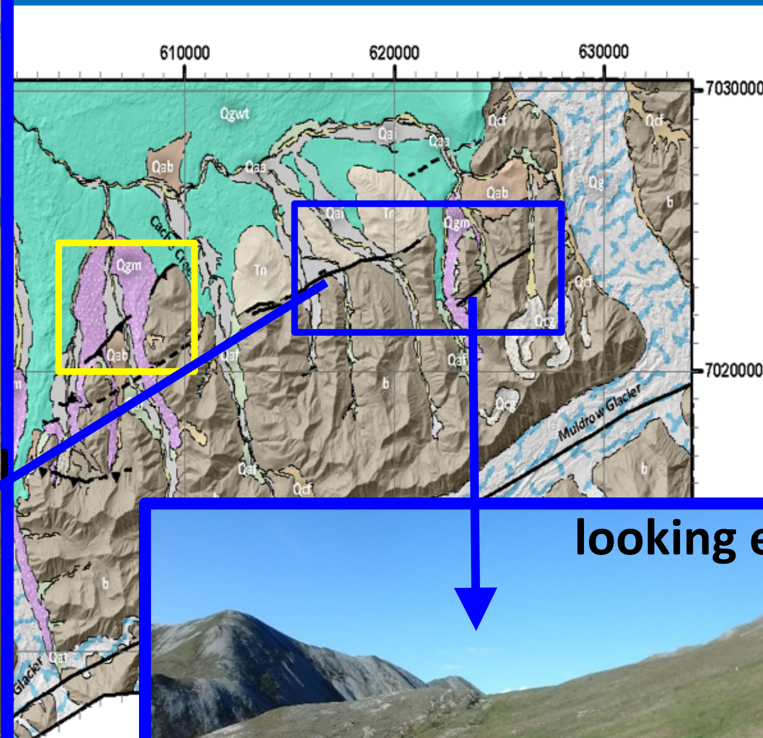
Temporal changes in fault behavior



Evidence for temporal changes in fault behavior – possible reverse fault reactivates as a normal fault

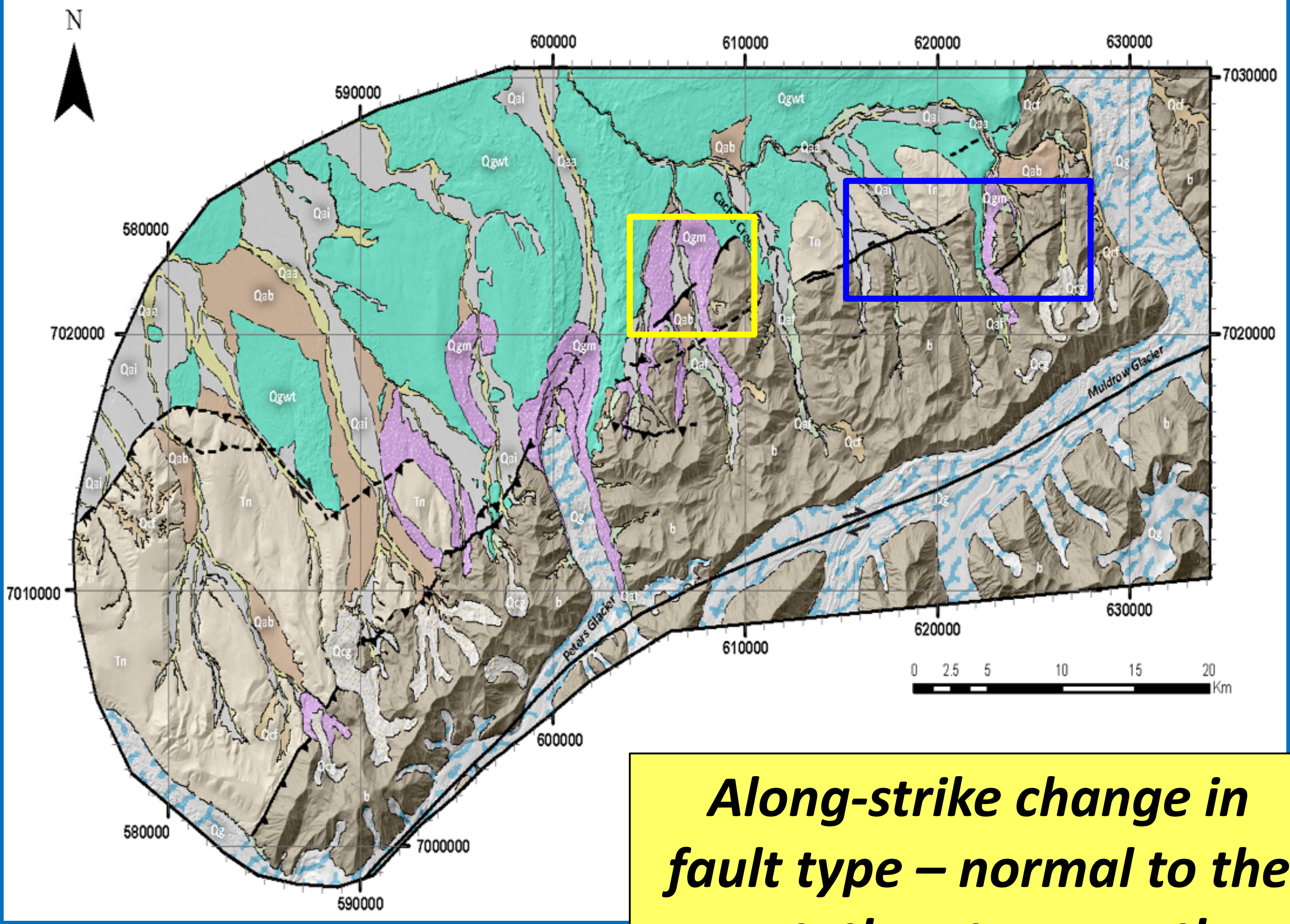
tive faults across
e bend





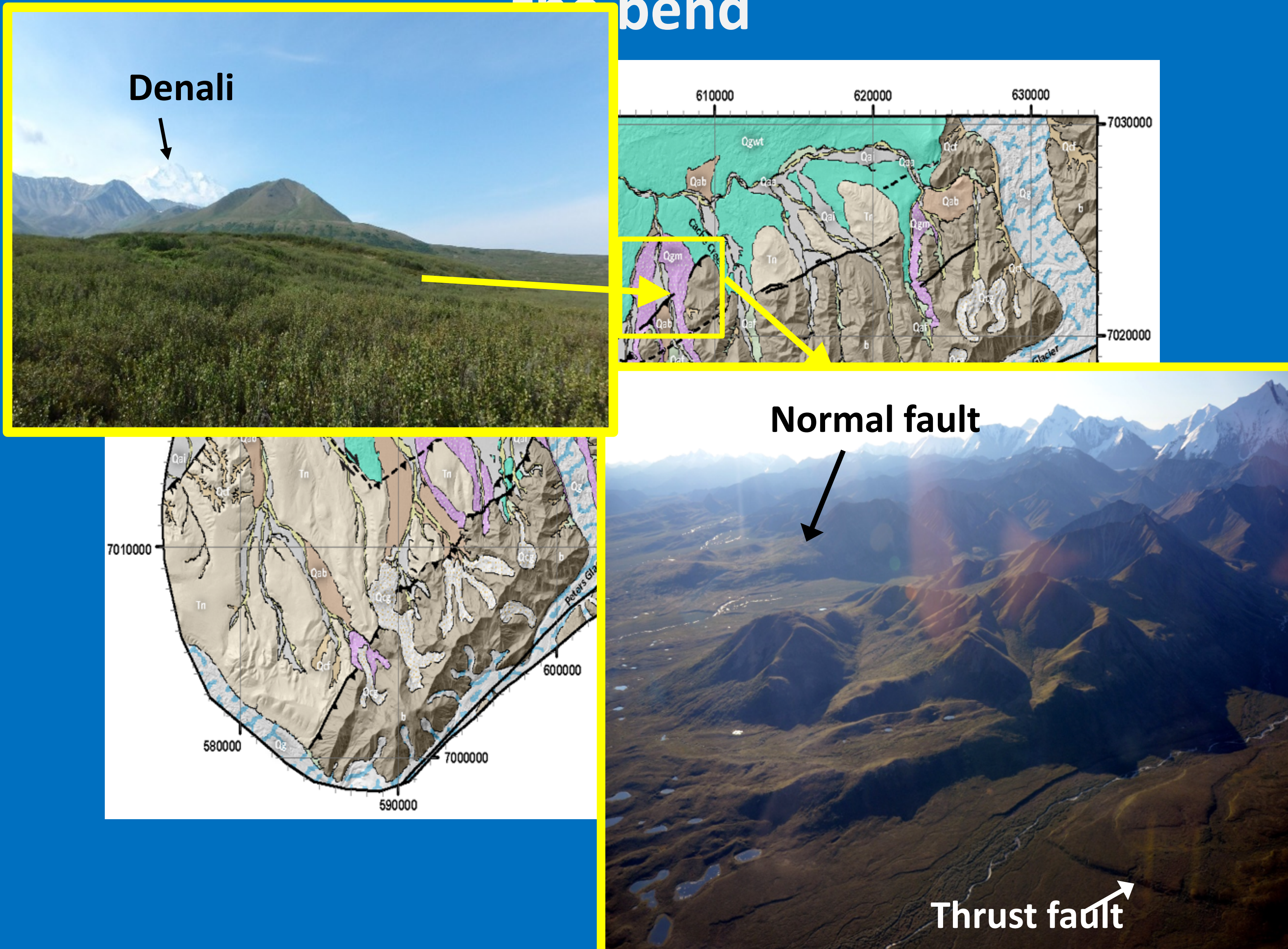
Alo
fau
eas
be

Changes in active faults across the bend

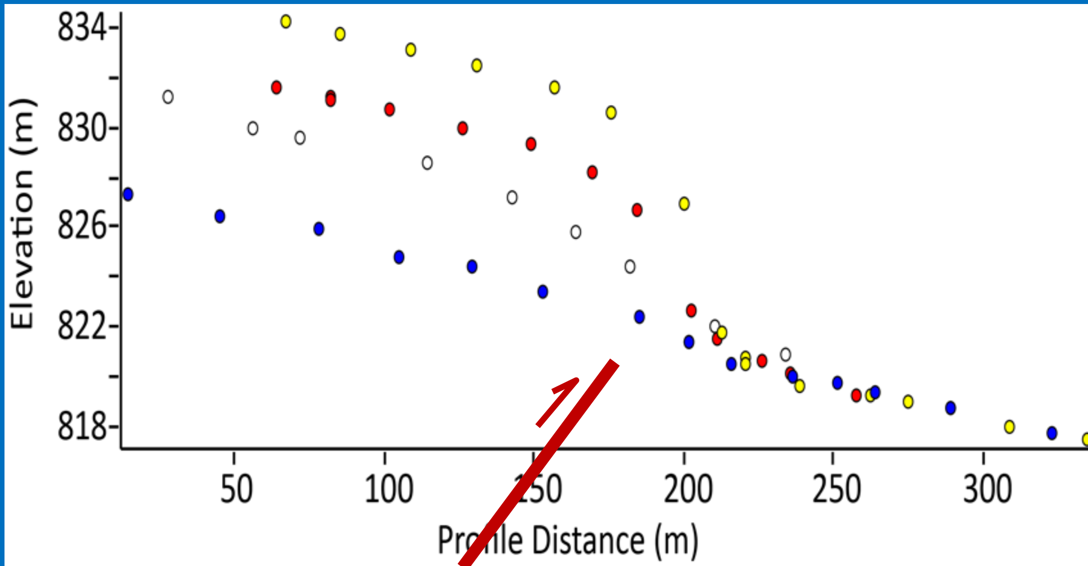


Along-strike change in fault type – normal to the east, thrust nearer the bend apex.

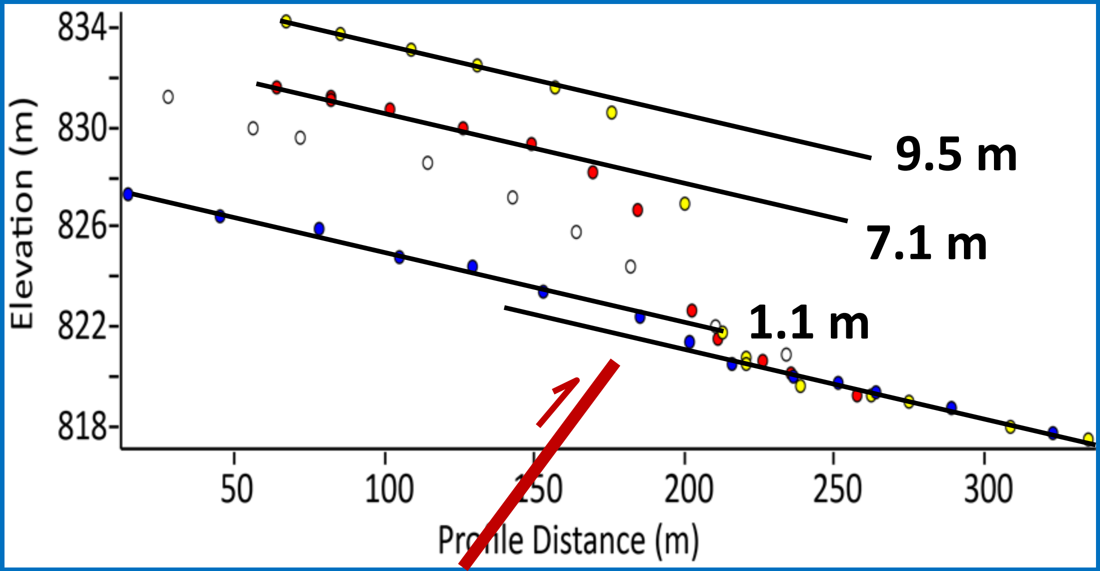
Changes in active faults across the bend



Slip rate at Carlson Creek



- Sequential uplift of thrust fault HW
- Preliminary IRSL ages
  - Upper two surfaces ~10 ka and 6 ka
- Dip uncertain, 45°-60°?

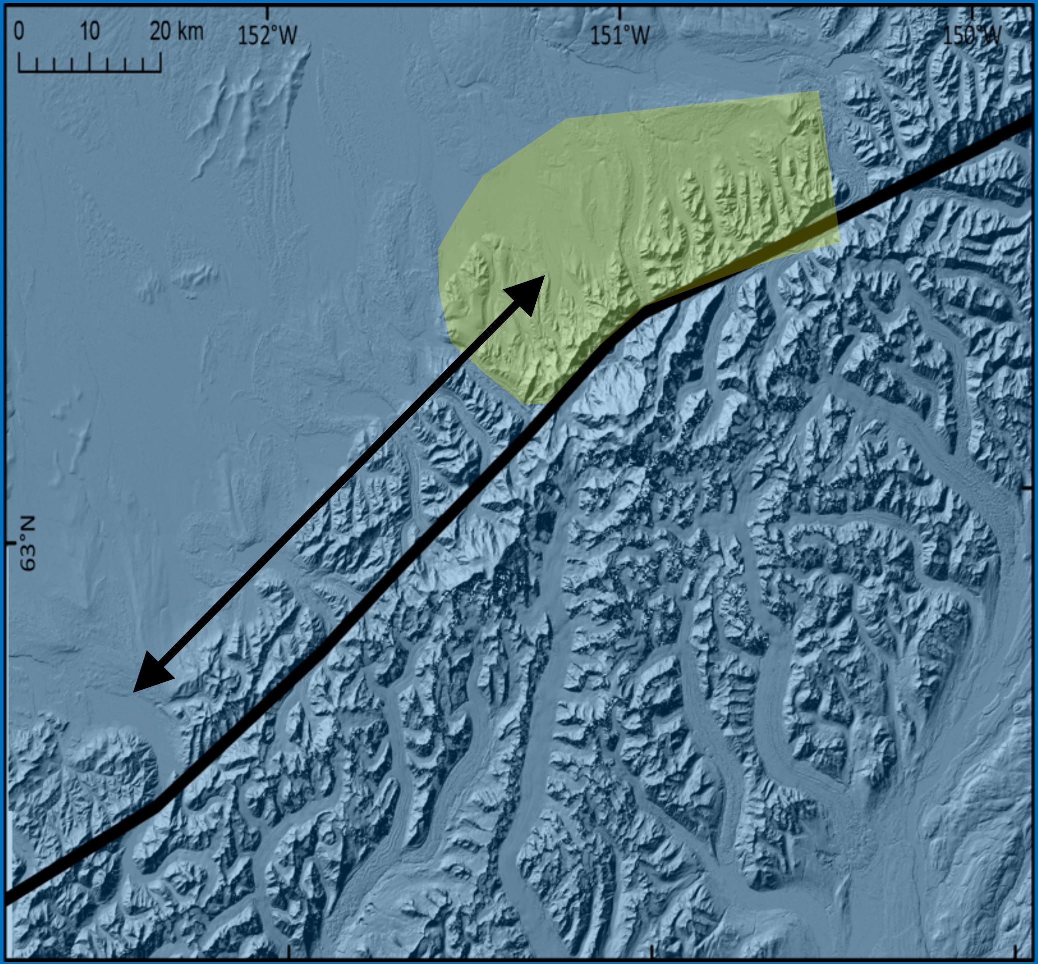


Slip rate at Carlson Creek

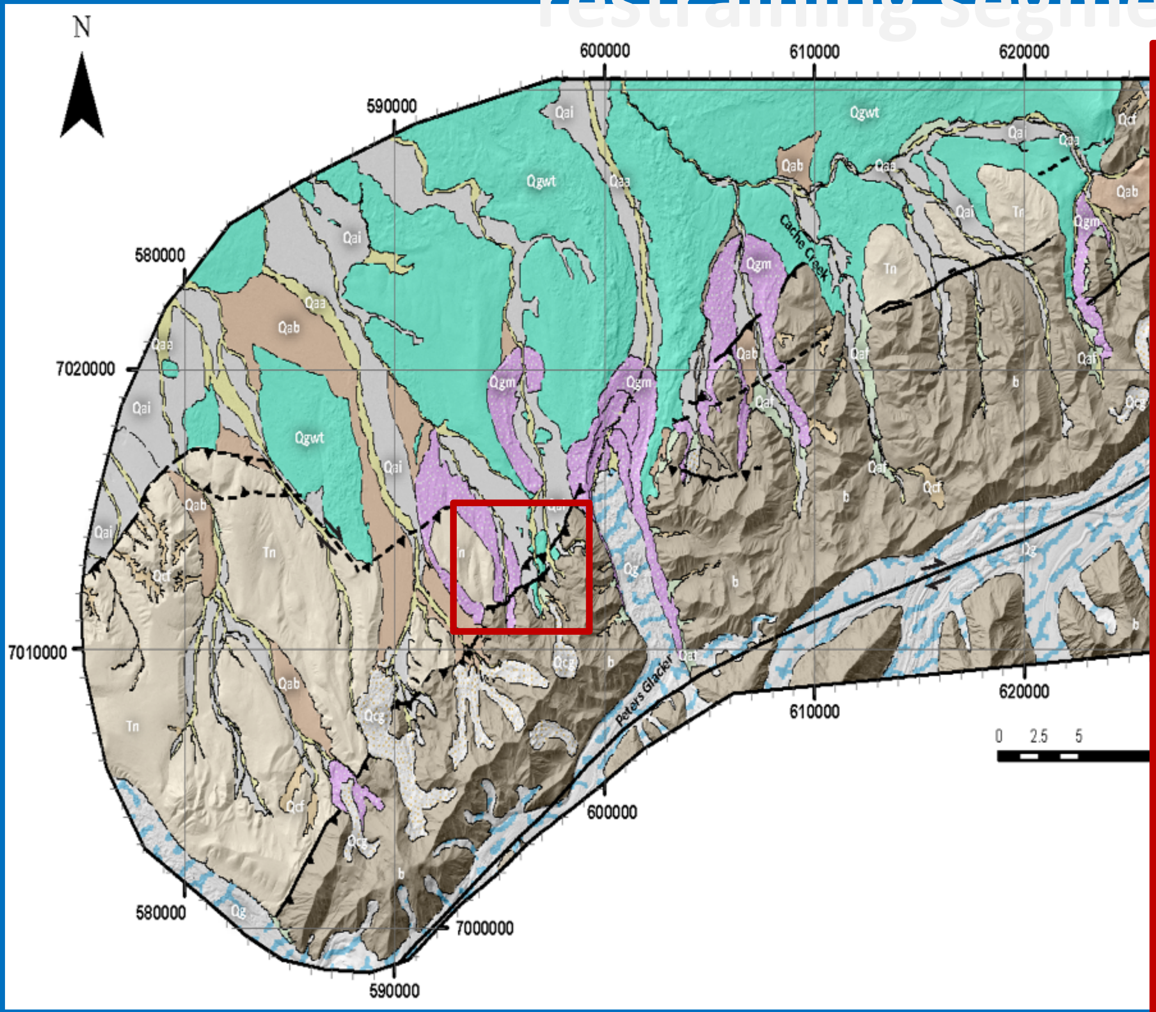
1-2 mm/yr

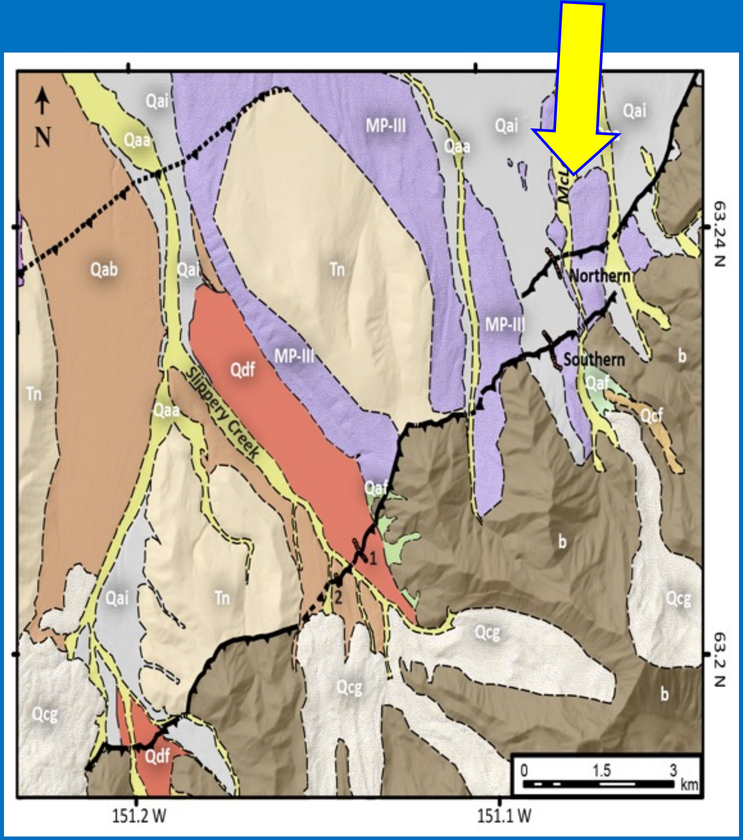
- Sequential uplift of thrust fault HW
- Preliminary IRSL ages
  - Upper two surfaces ~10 ka and 6 ka
- Dip uncertain, 45°-60°?

Deformation adjacent to the restraining segment

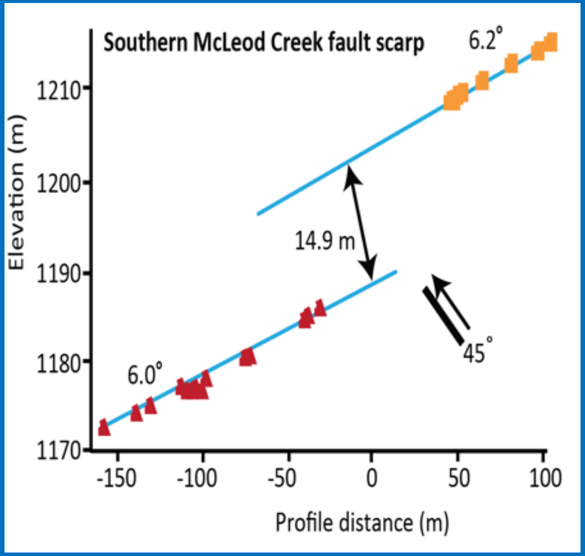


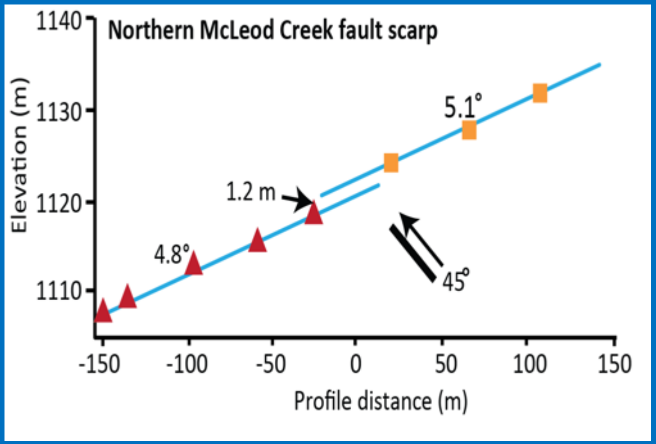
Deformation adjacent to the restraining segment



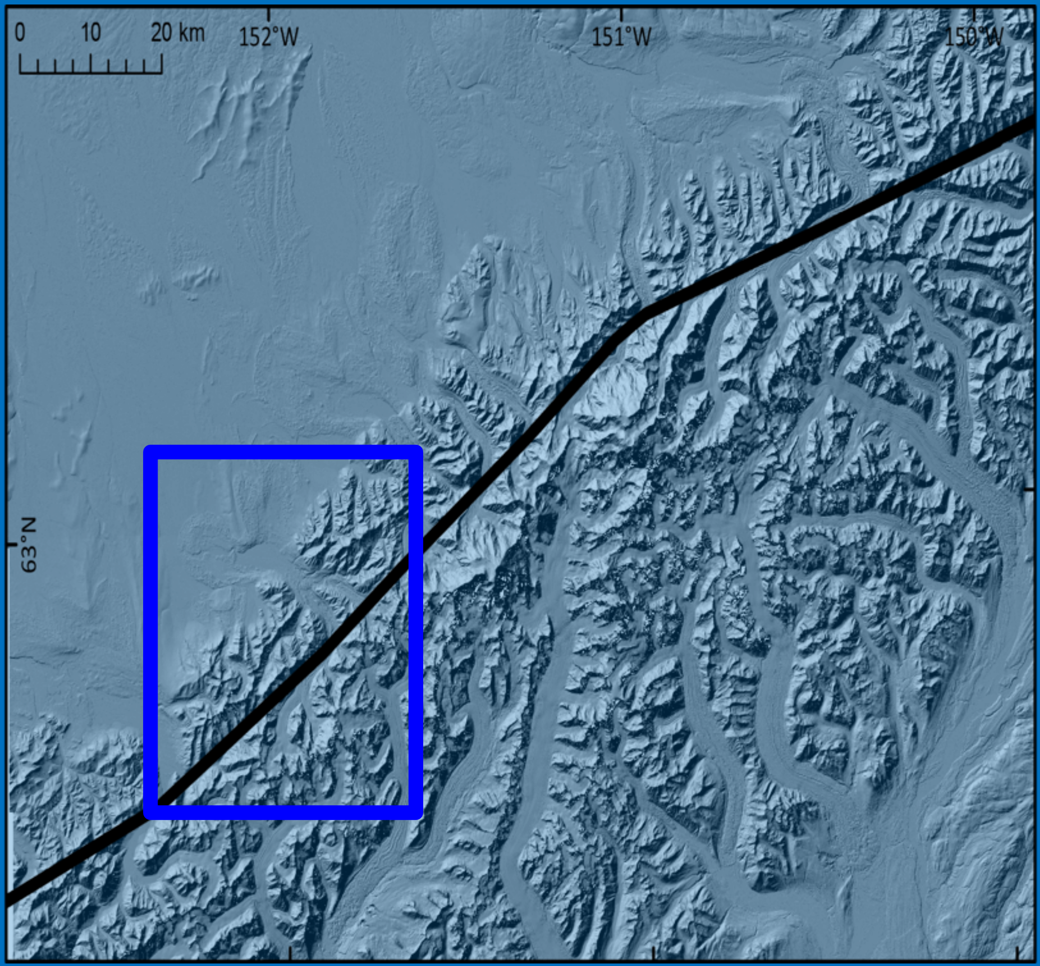


- McLeod Creek - slip rate constraints
- 1-2 mm/yr

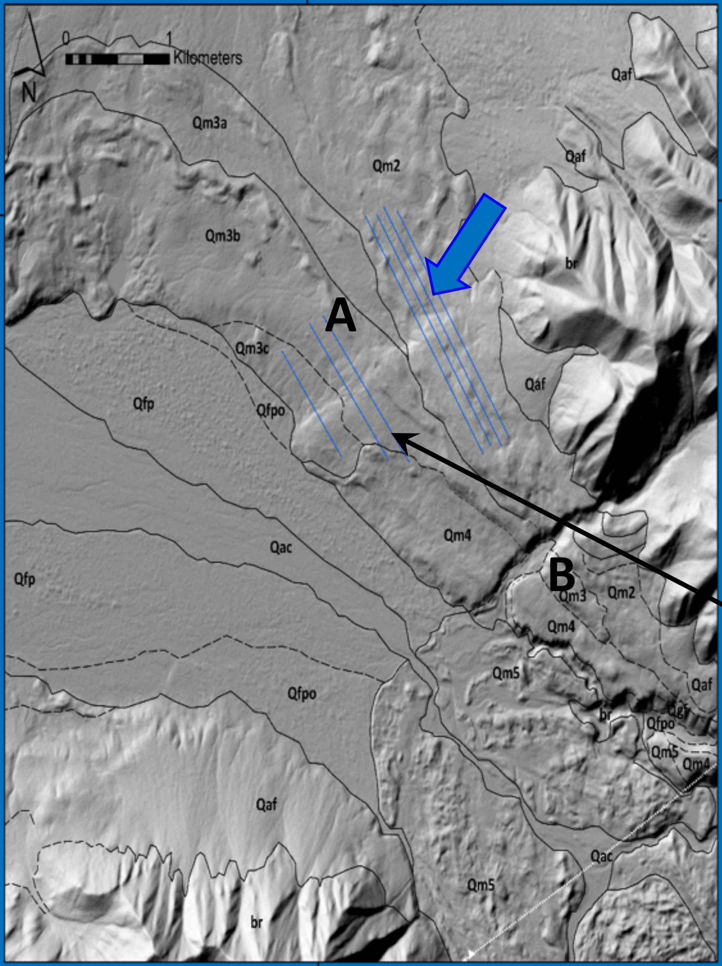


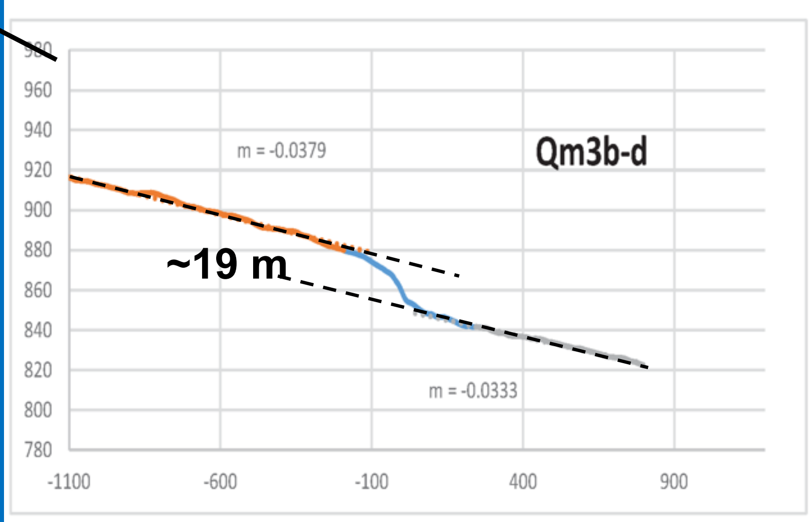


Along-strike change in Quaternary deformation across the western end of the MMRB?



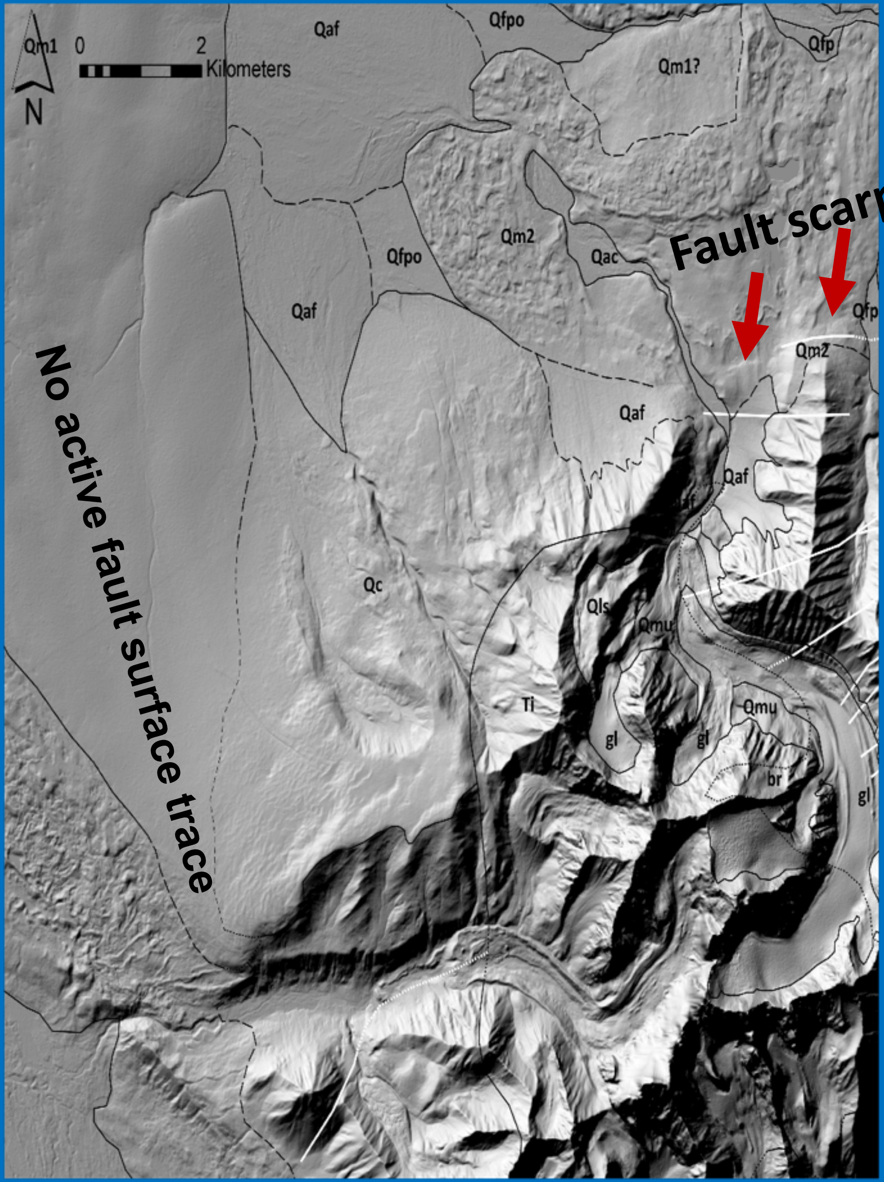
Chedotlothna fault





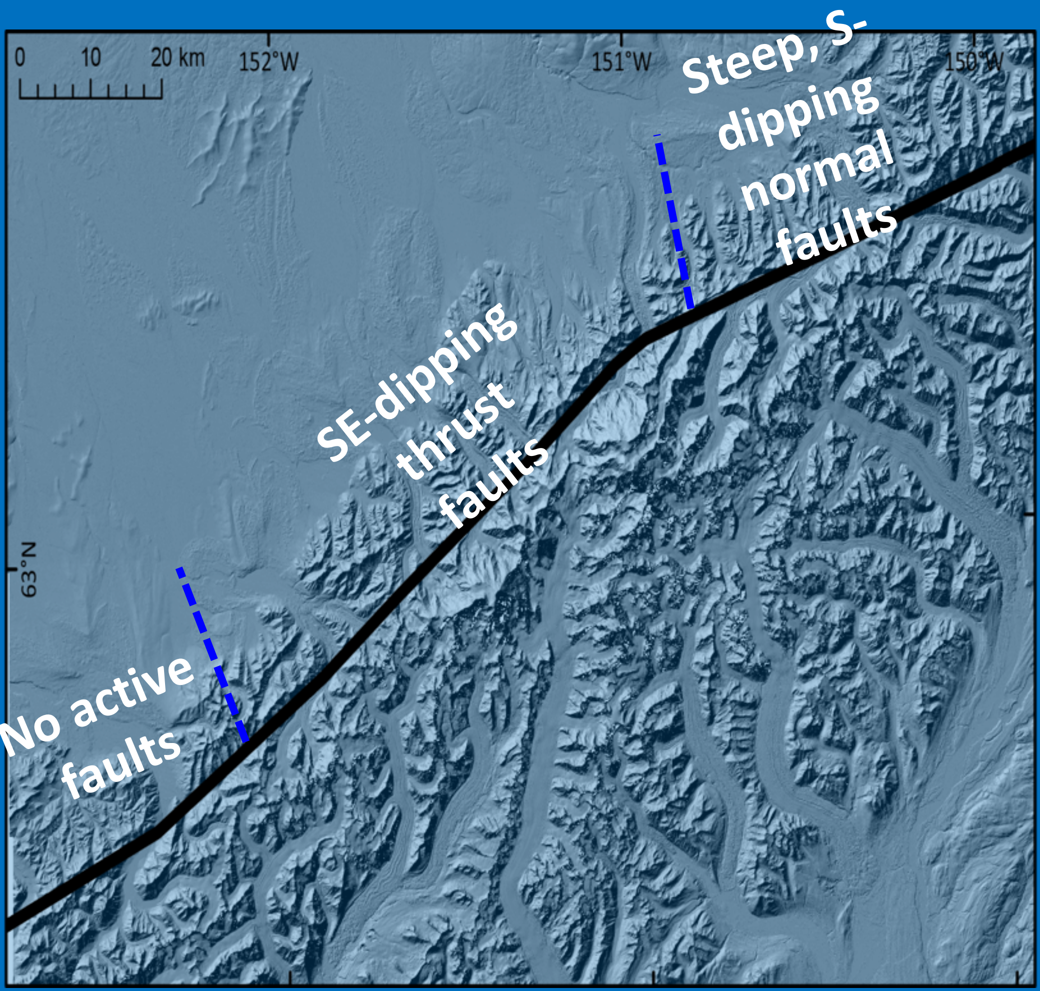
^{10}Be surface exposure ages of ~16 ka at sites A and B

Where does the Chedotlothna fault go?

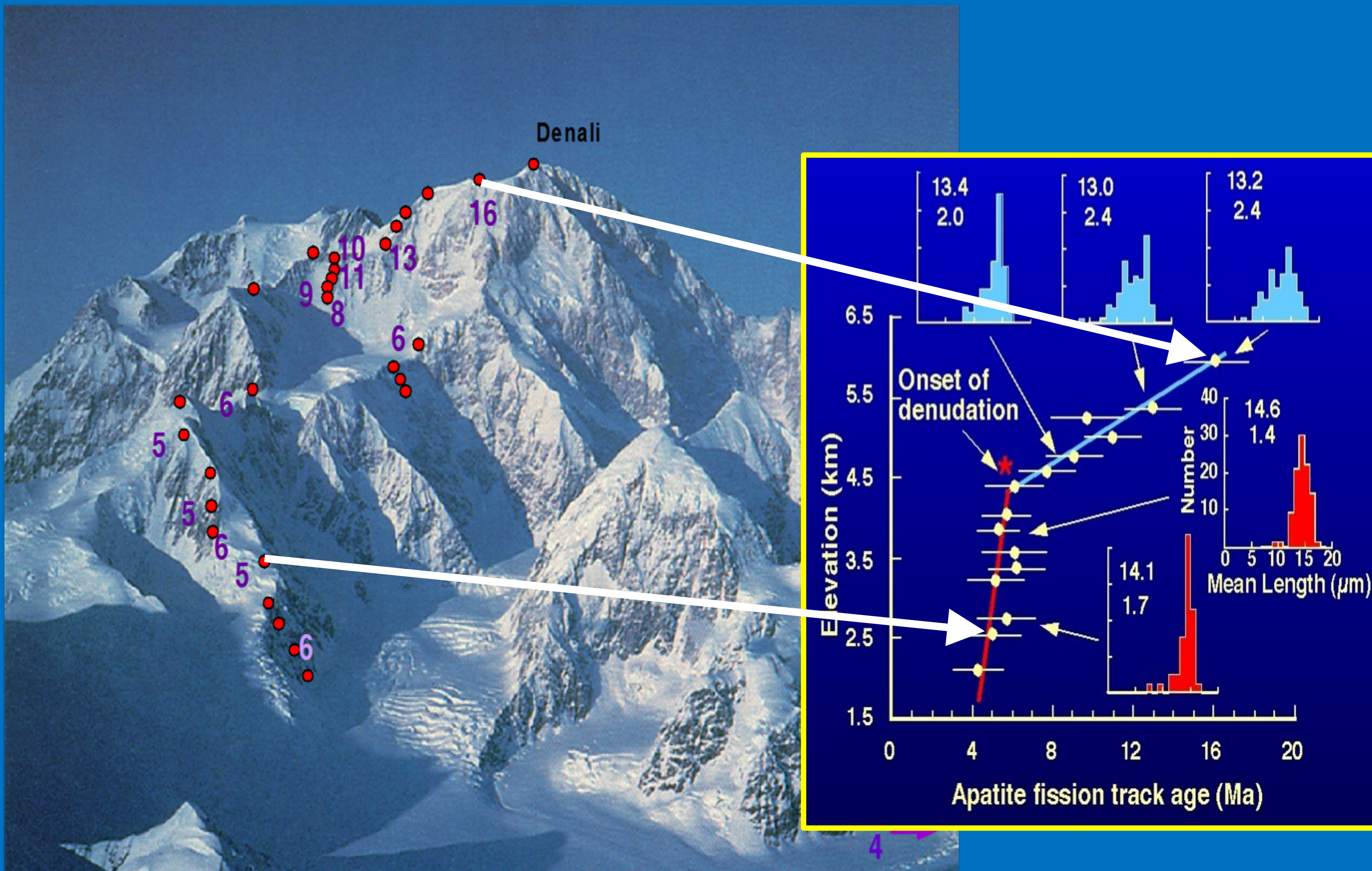


- Active faulting north of the Denali fault ends to west
- Corresponds with where the Denali fault leaves the restraining bend (just south of this map)

Generalized structural observations



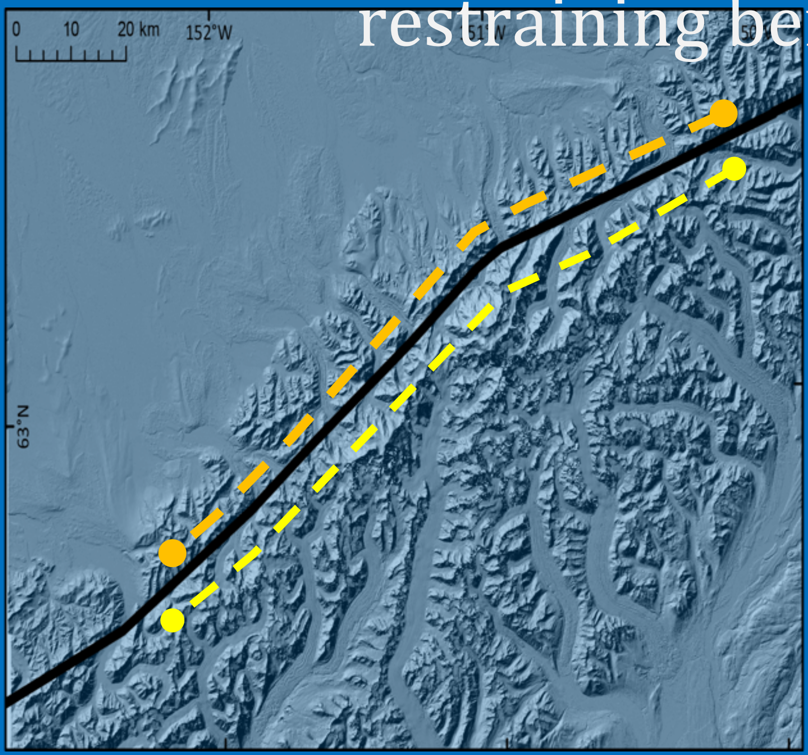
Part 2: Low-T thermochronology

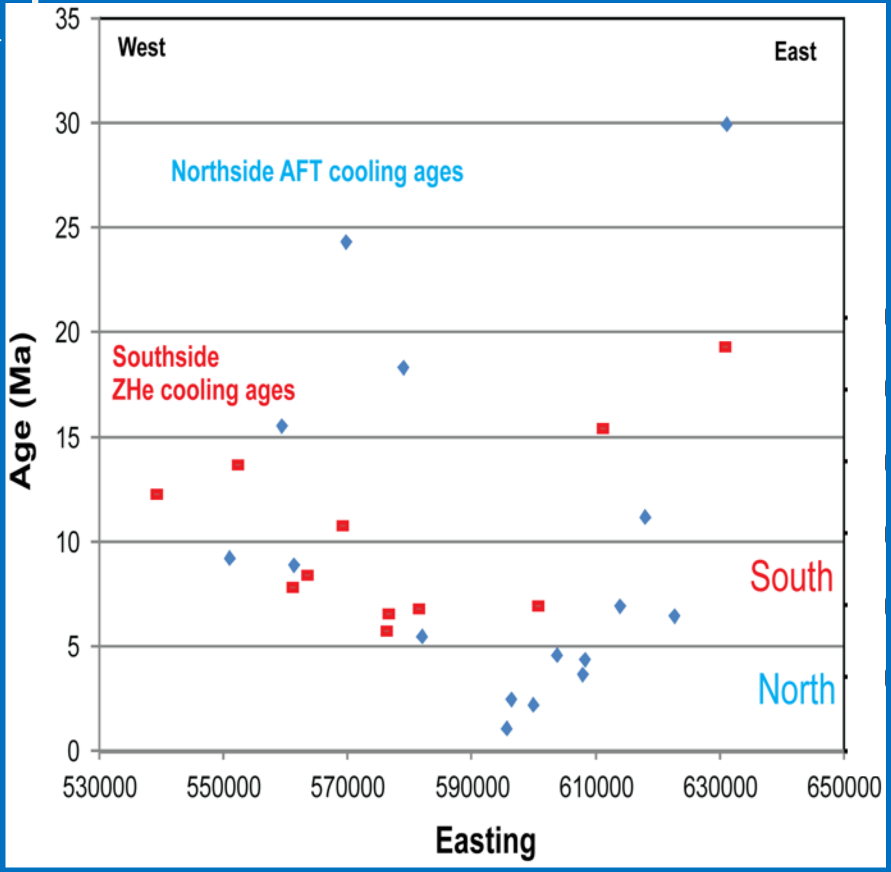


Fitzgerald et al. (1995)

New low-T thermochronology data

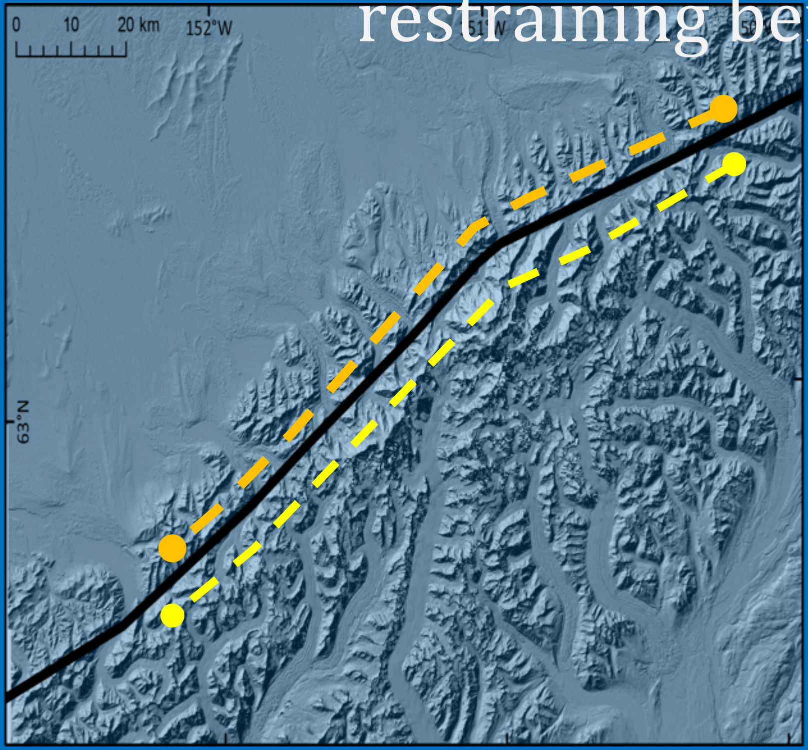
- Fault-parallel transects through restraining bend

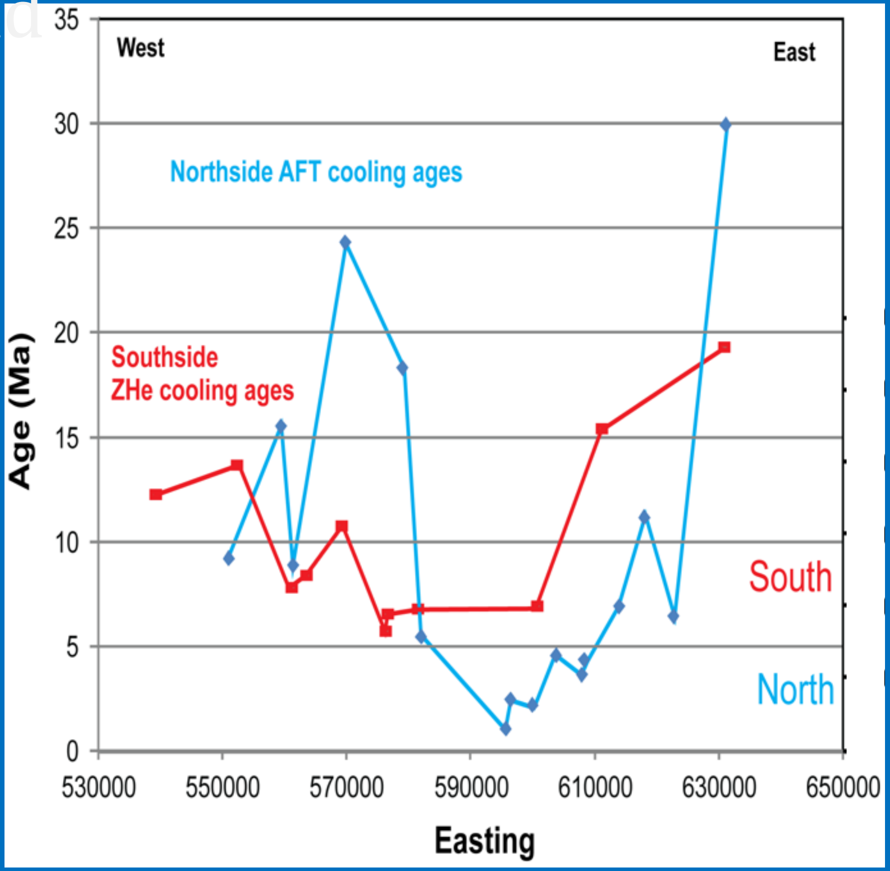




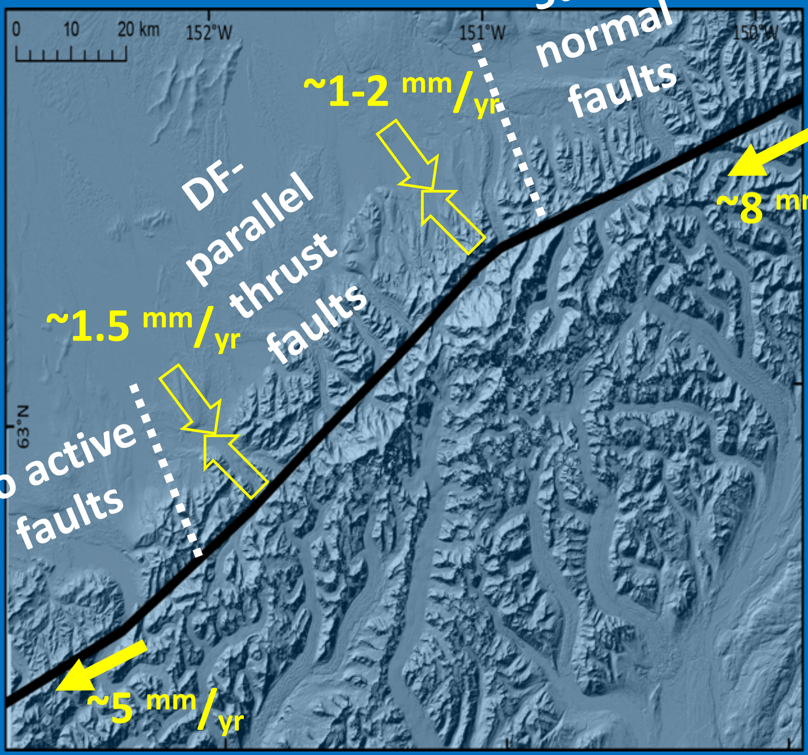
New low-T thermochronology data

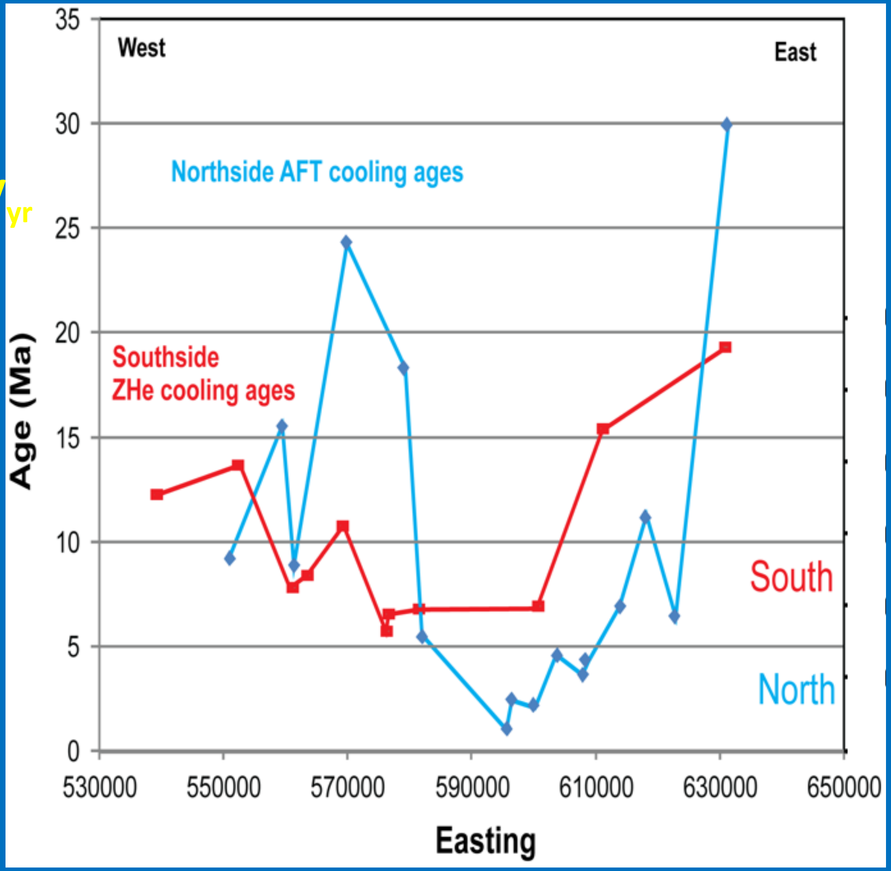
- Fault-parallel transects through restraining bend





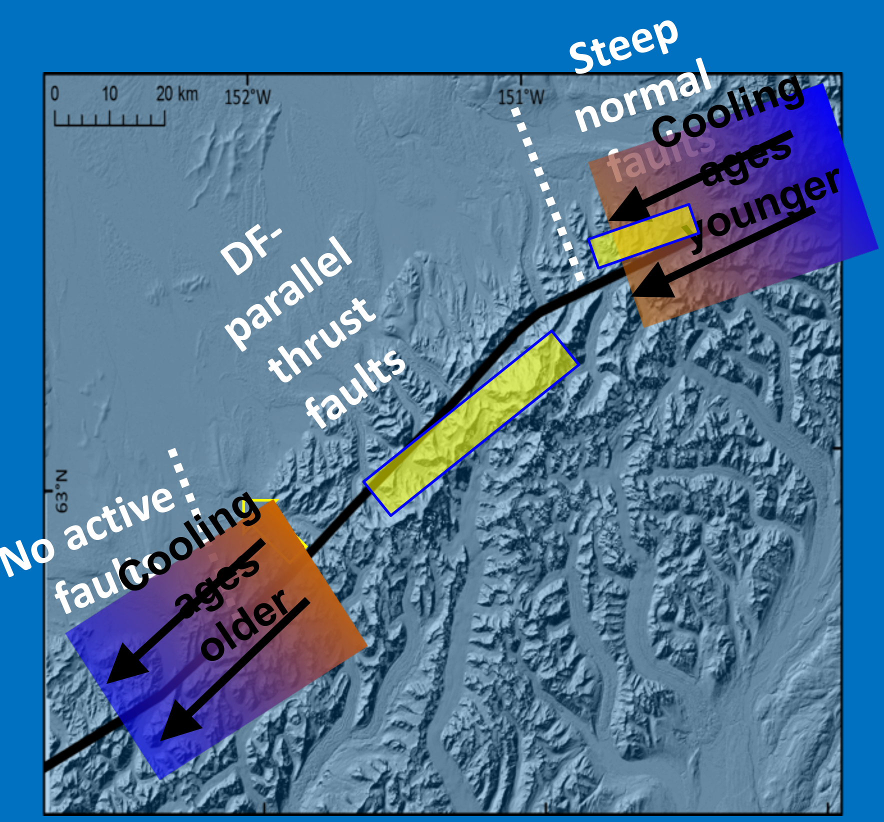
Evolution of a gentle restraining bend

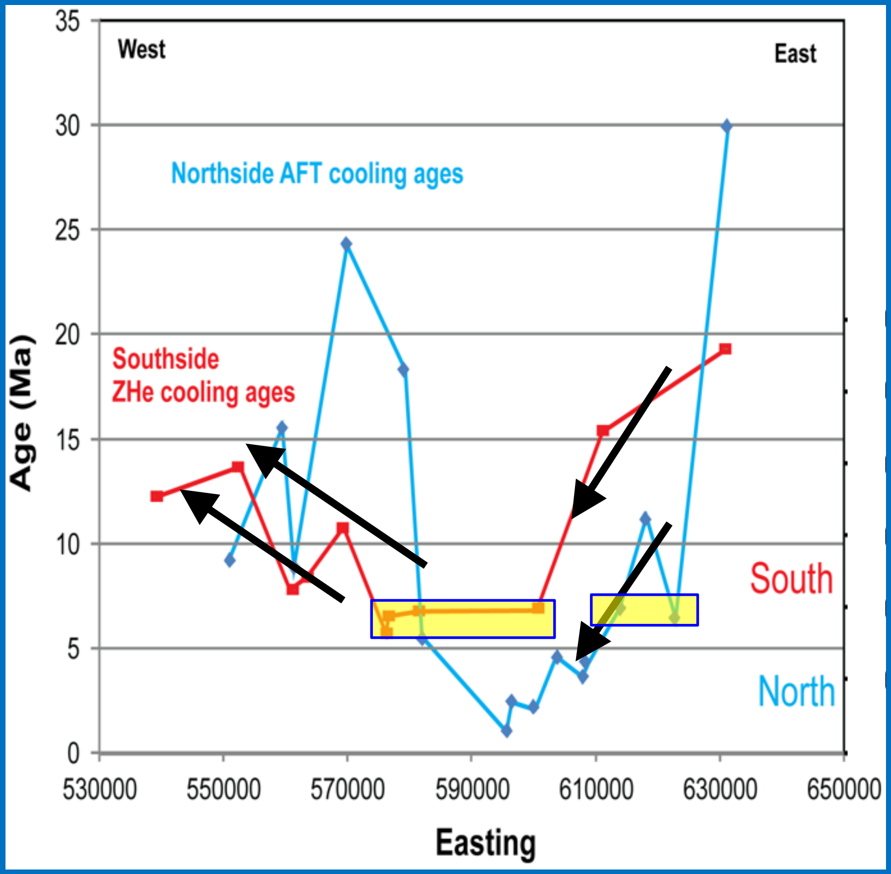




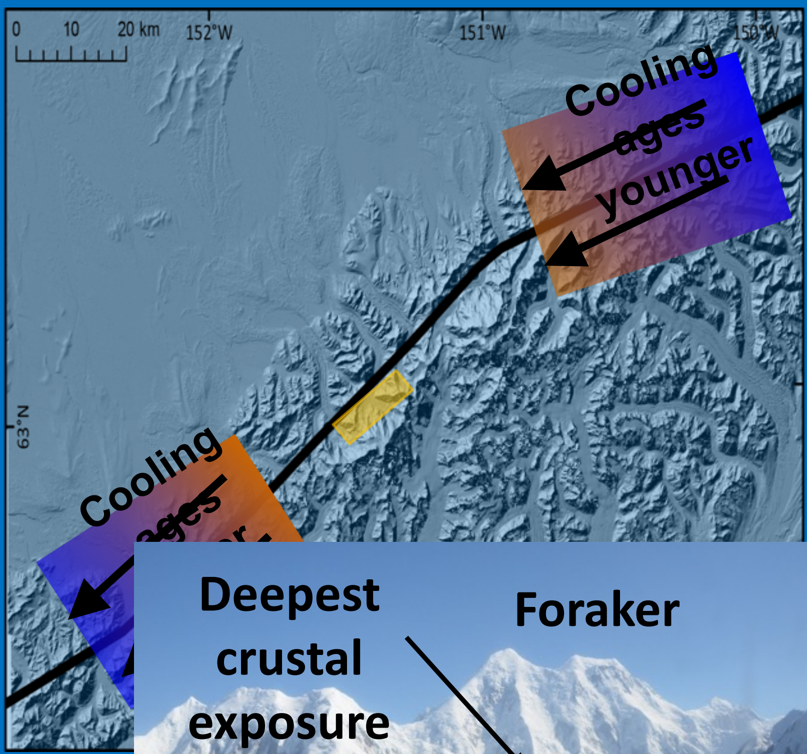
- Basic geologic constraints

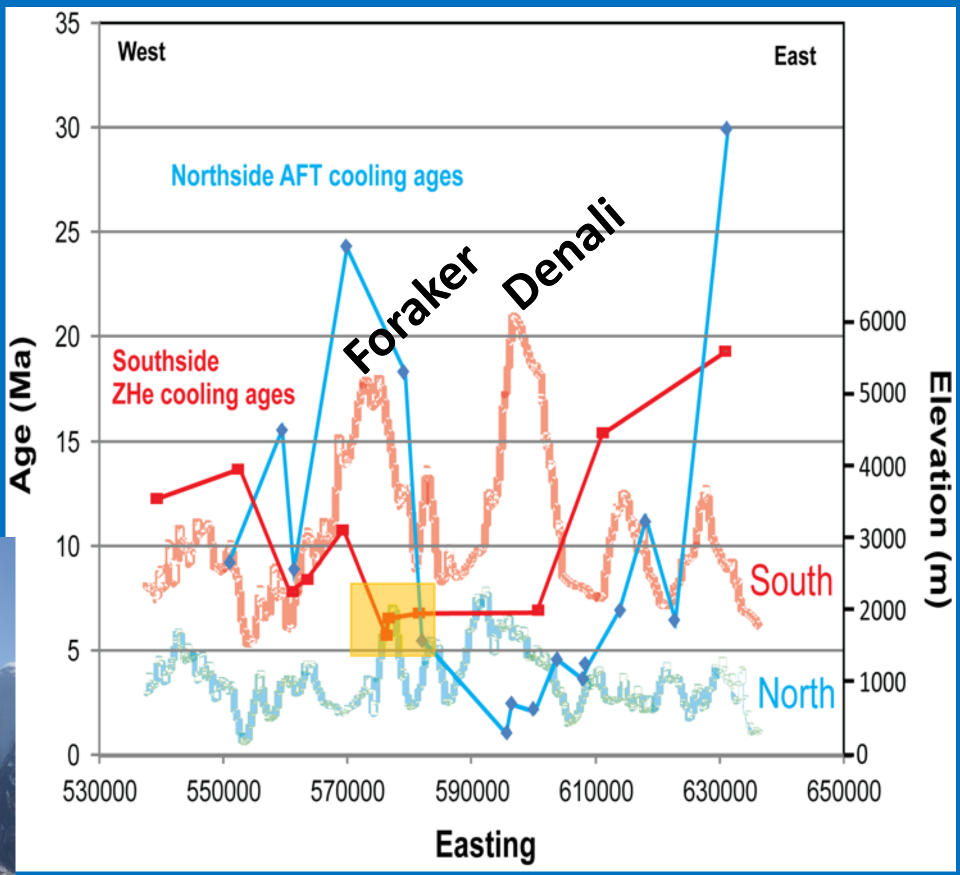
Evolution of a gentle restraining bend



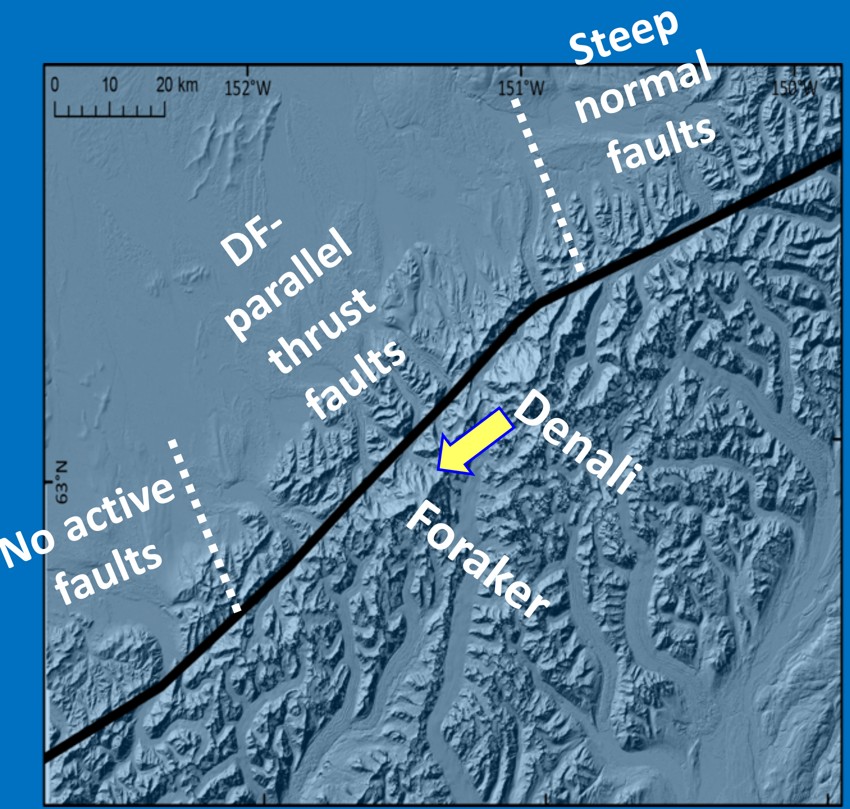


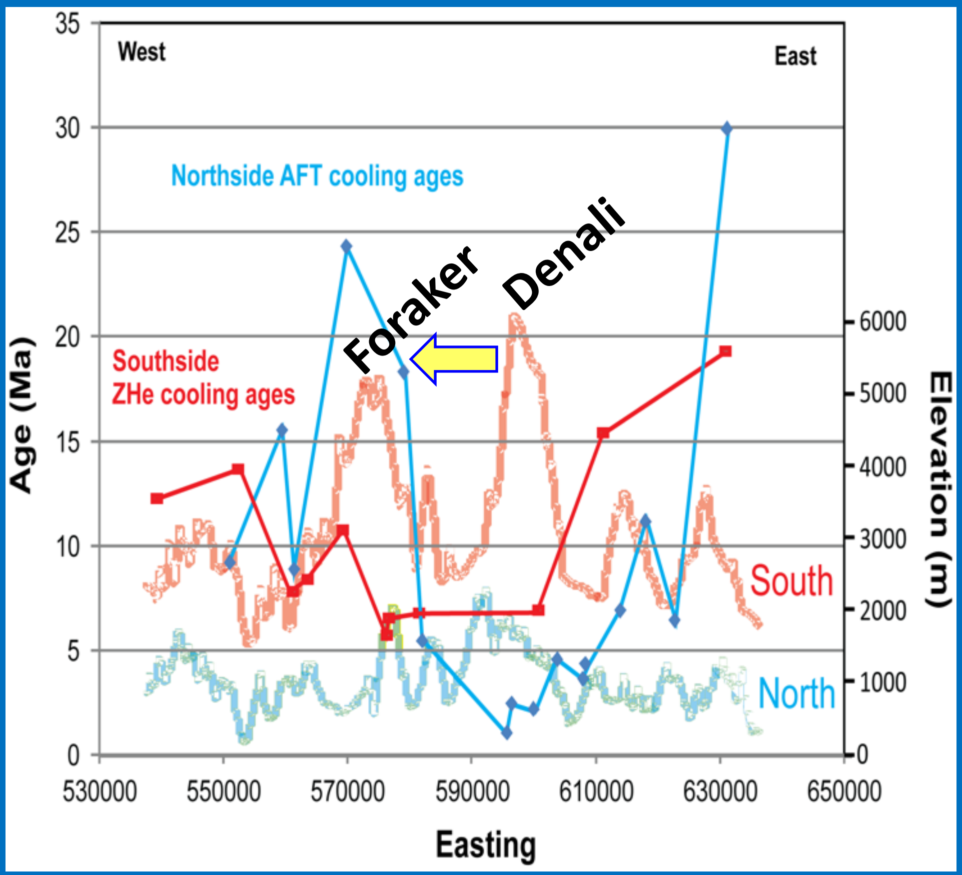
Evolution of a gentle restraining bend





Evolution of a gentle restraining bend

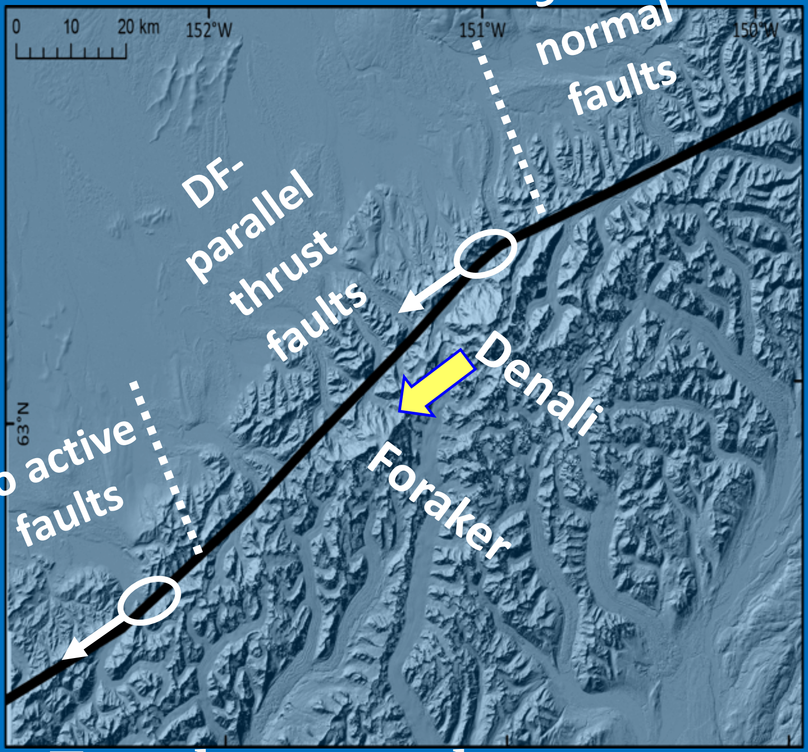


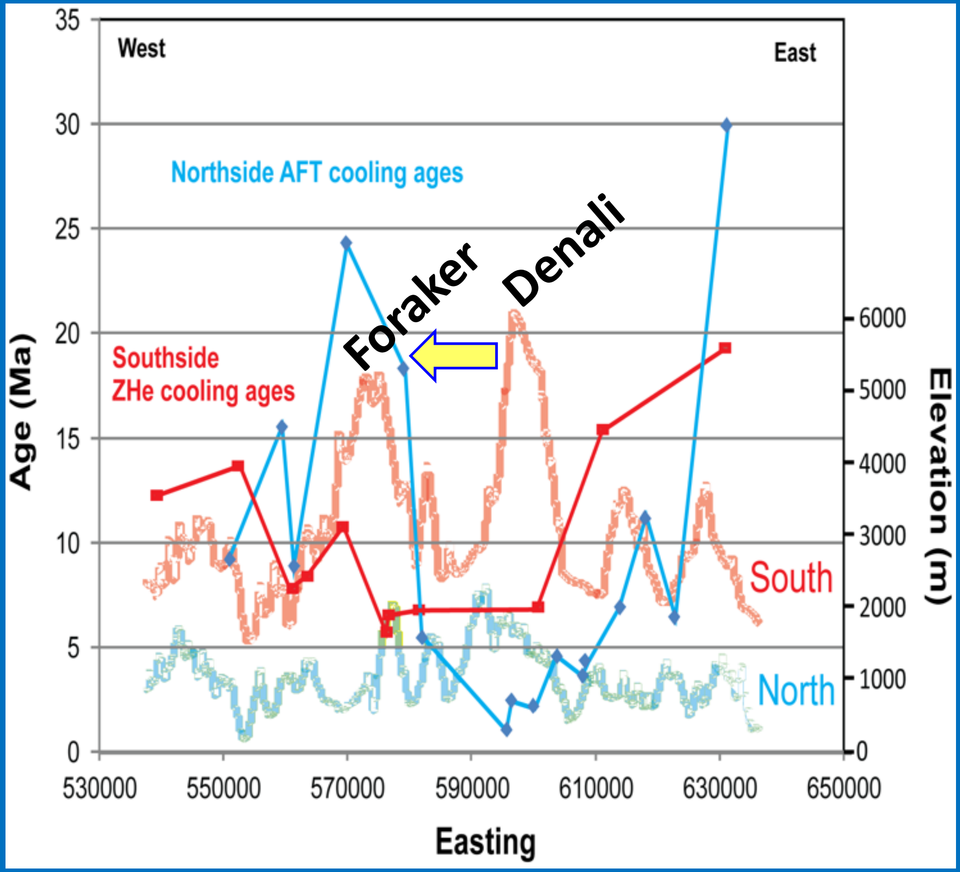


Foraker = paleo-Denali

- Still going up, but riding the tectonic wave

Evolution of a gentle restraining bend

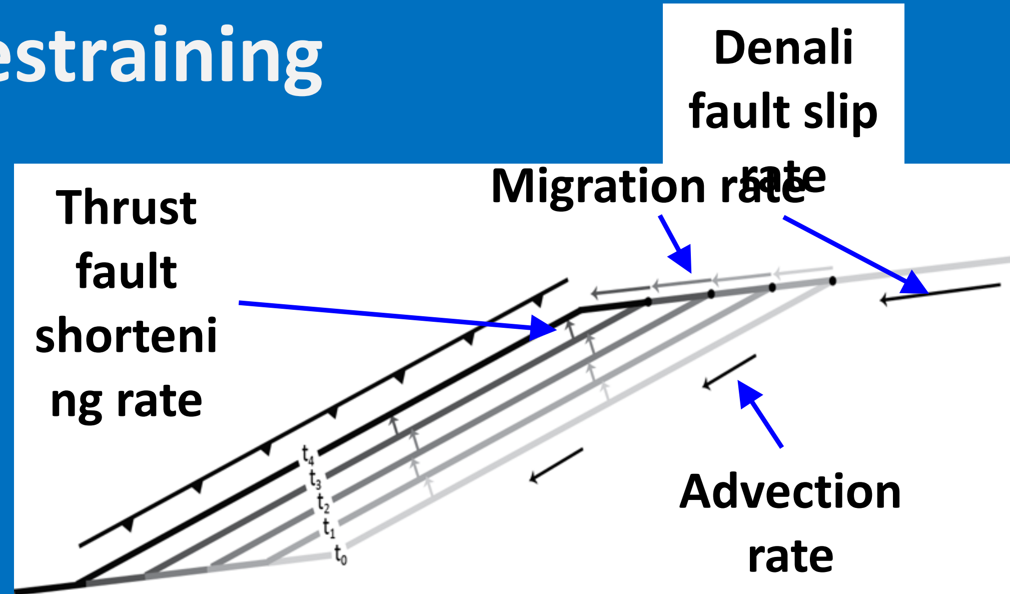


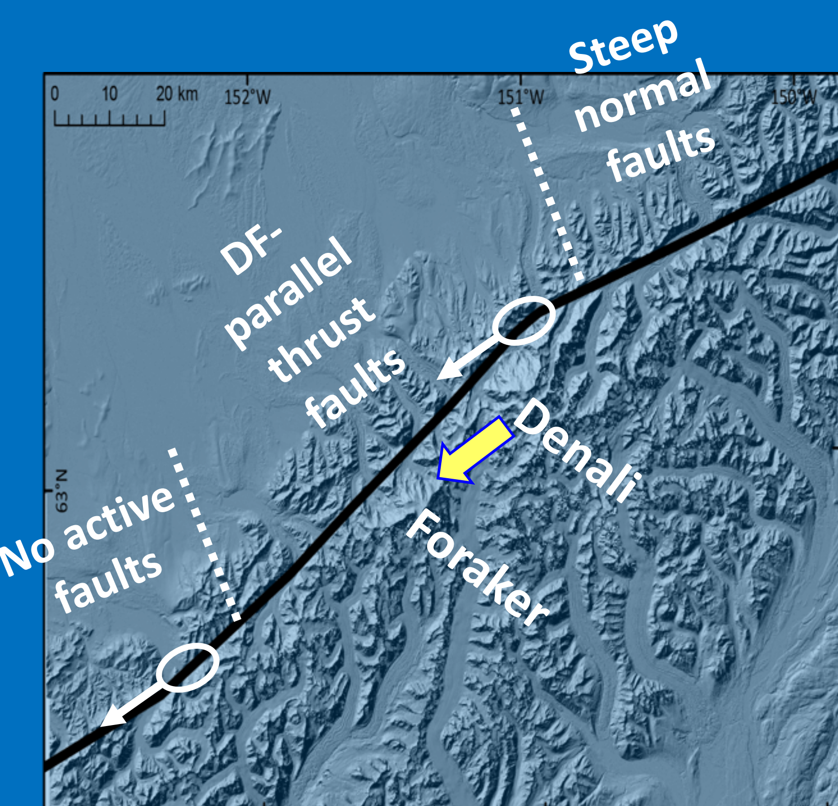


Foraker = paleo-Denali

- Still going up, but riding the tectonic wave

Evolution of a gentle restraining bend

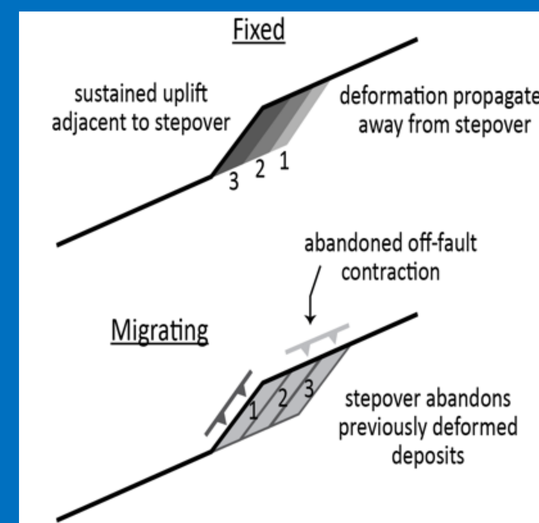




Foraker = paleo-Denali

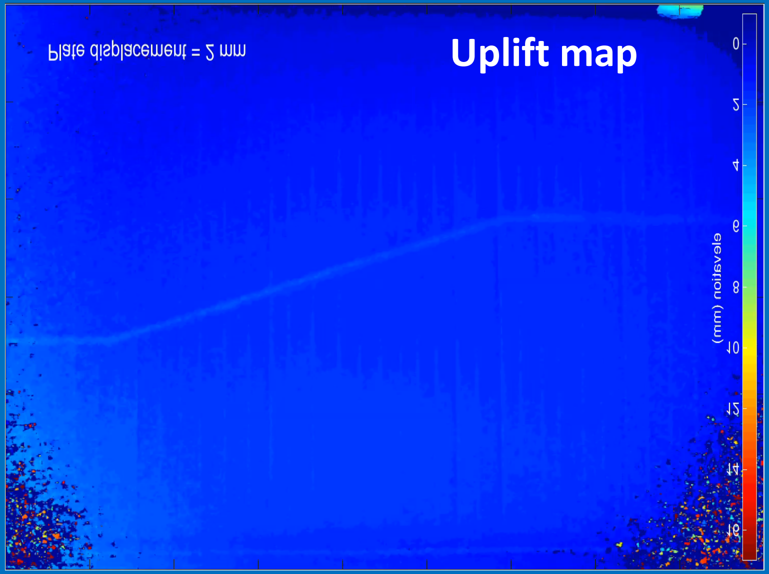
- Still going up, but riding the tectonic wave

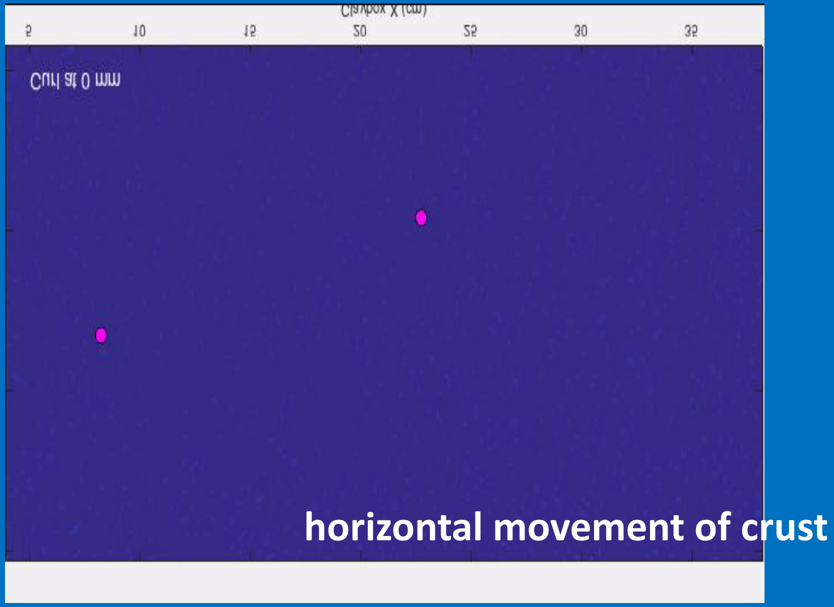
- DF maintains primary fault trace
- DF trace migrates in HW of NW-vergent thrust faults
- Material remains within bend for millions of years



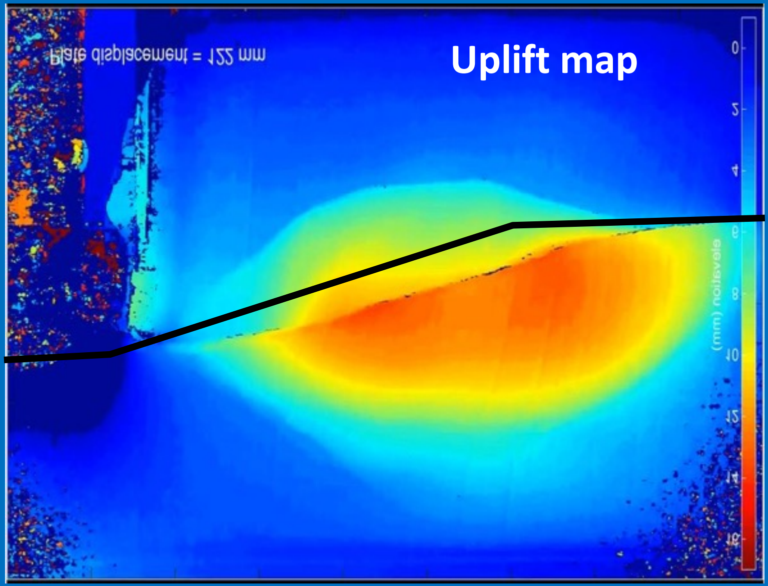
Part 3: Supporting Data

Scaled physical experiments simulating deformation in a MMRB-like restraining bend

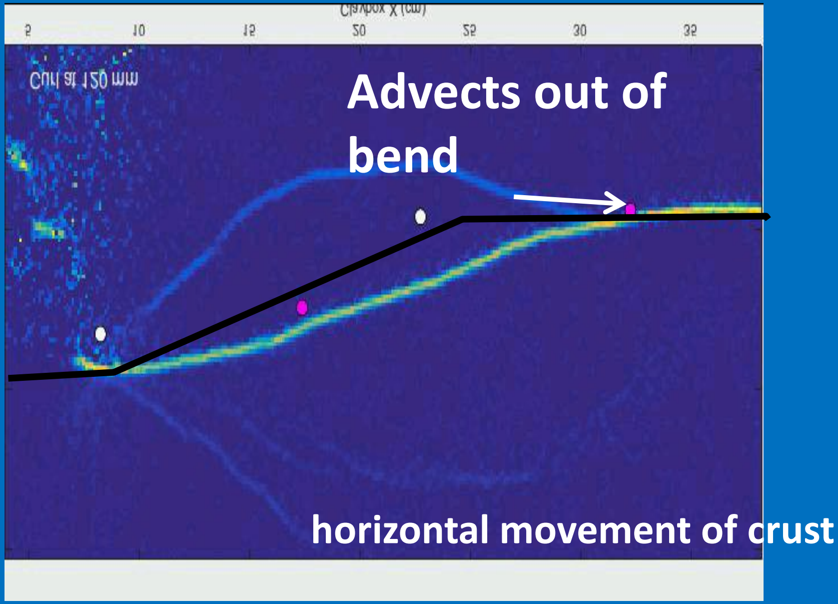




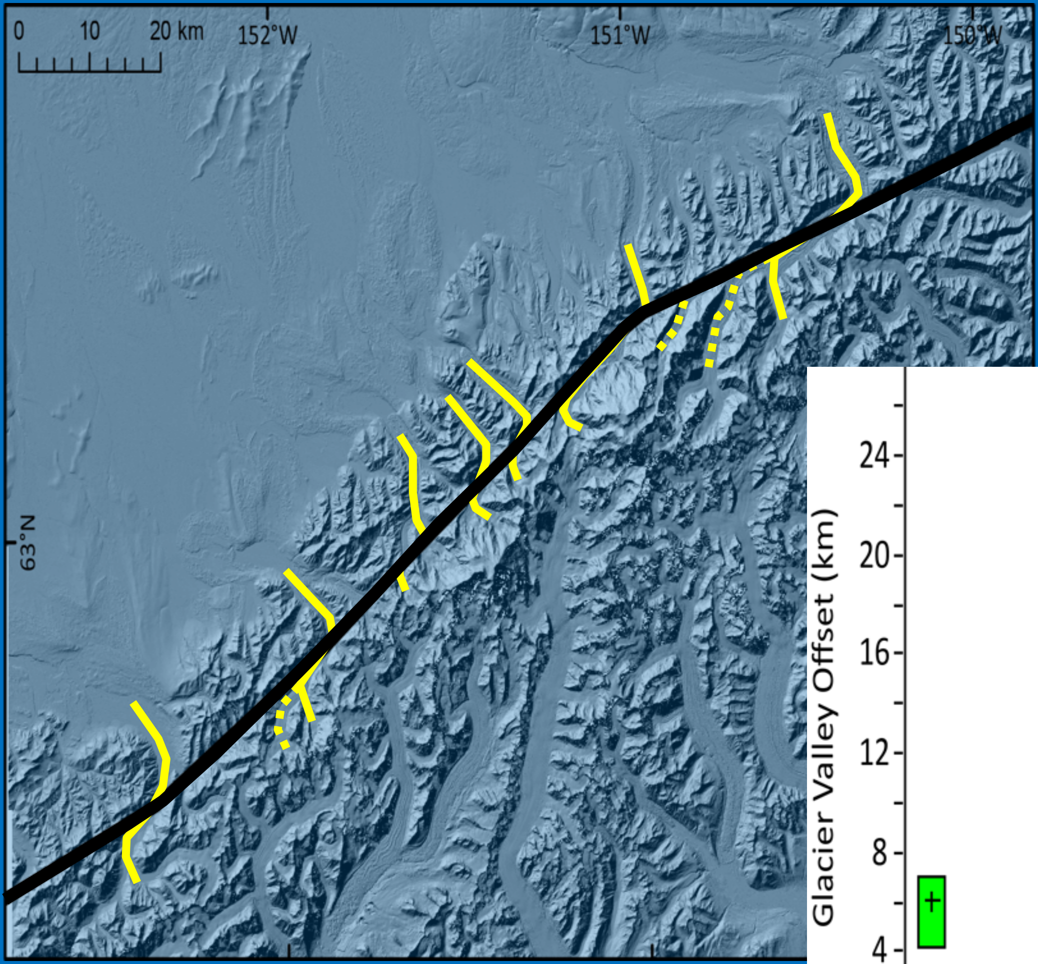
Scaled physical experiments simulating deformation in a MMRB-like restraining bend

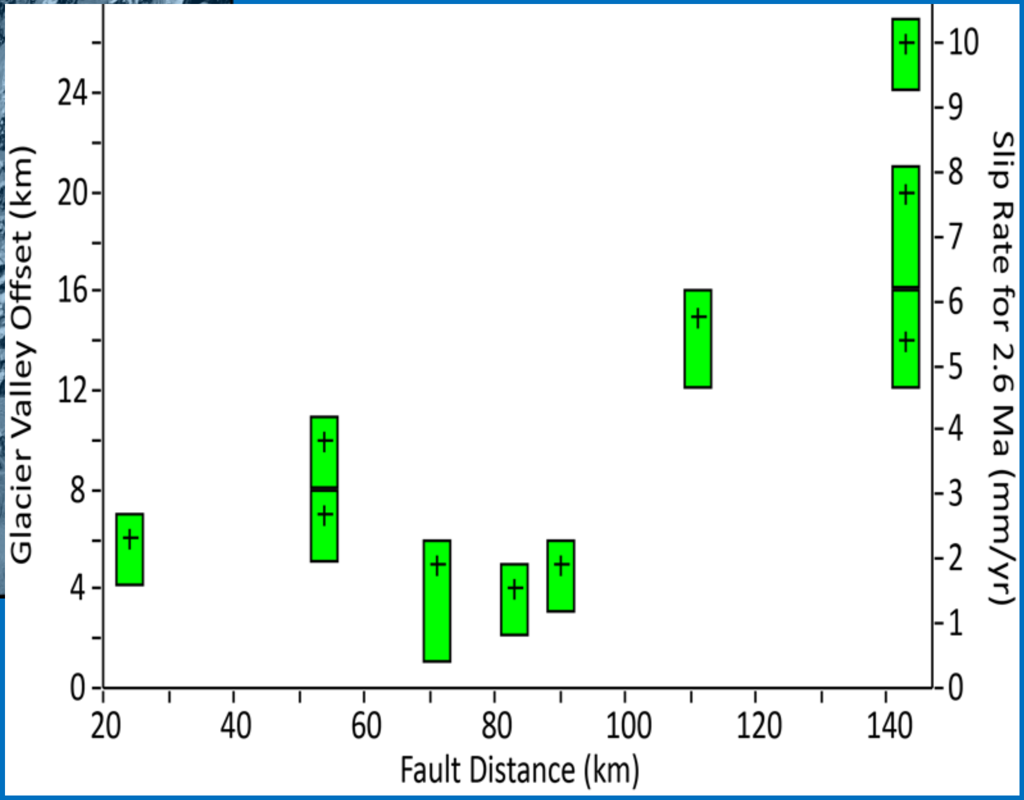


- Characteristically produces asymmetric topography (Hatem et al. (2015)
- Surface trace of primary fault migrates laterally
- Points advect through the bend

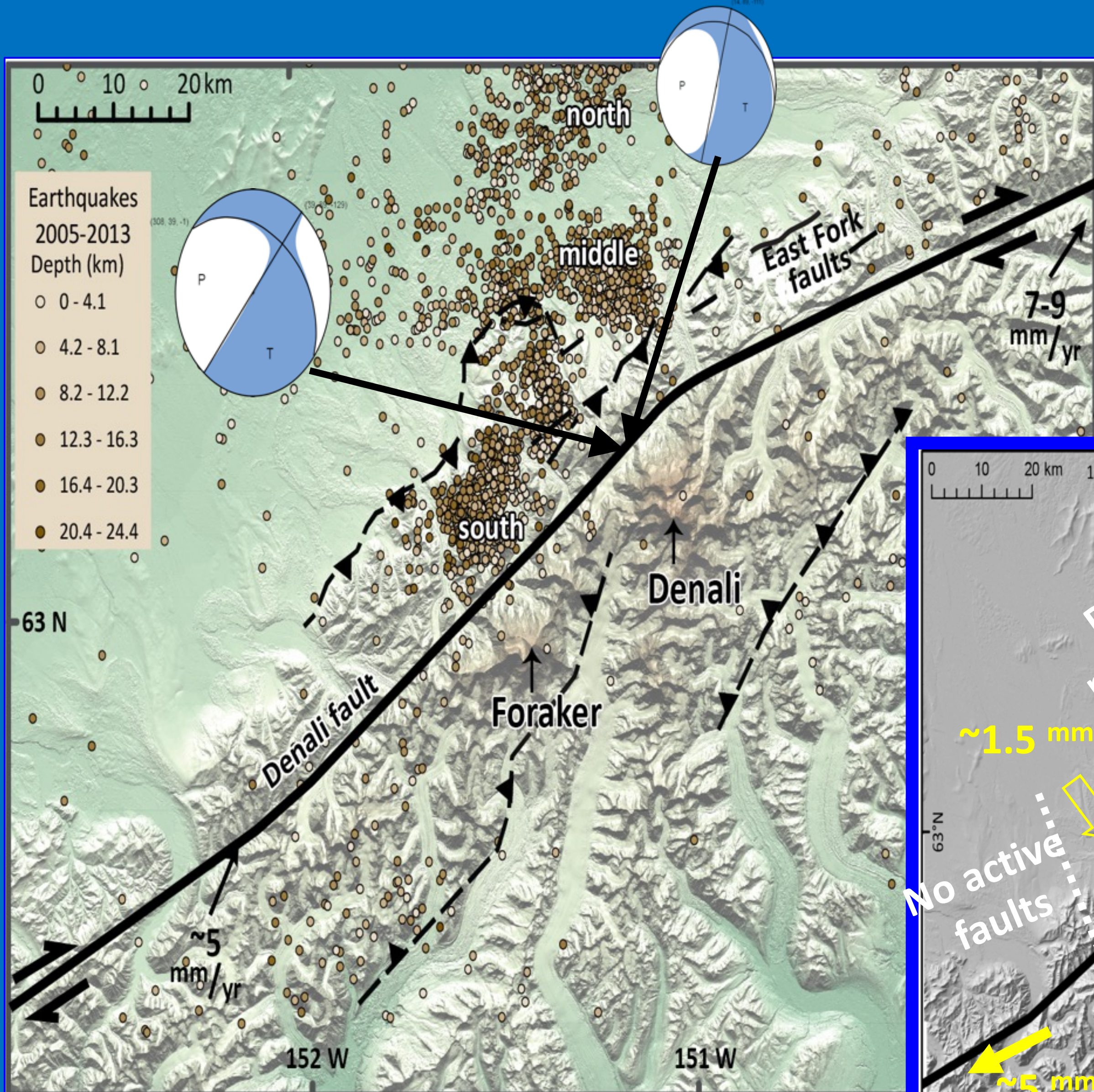


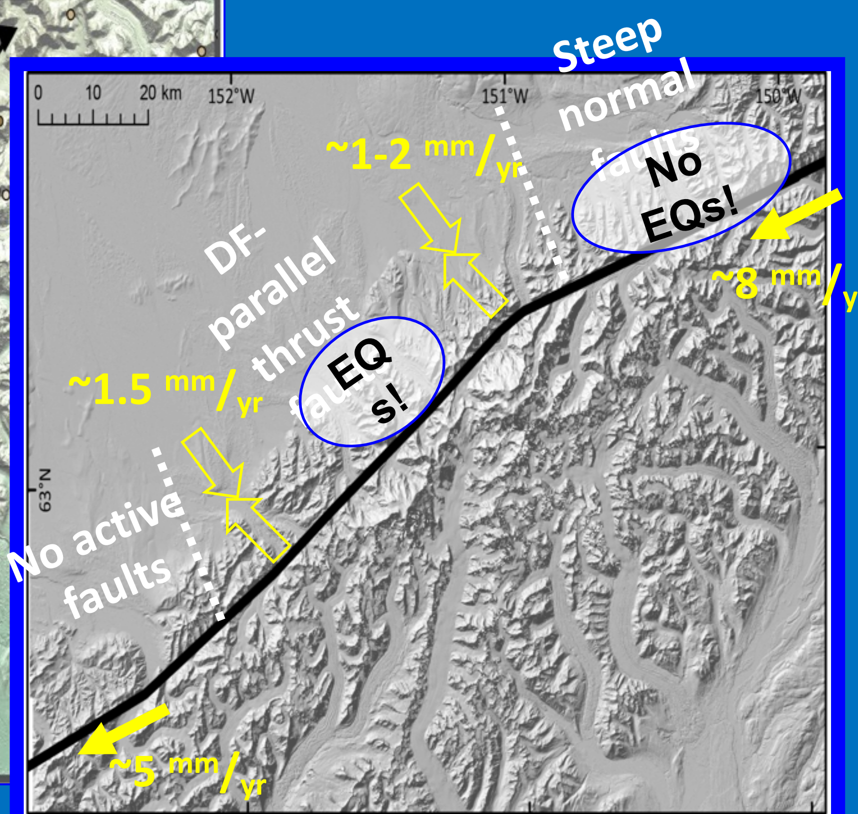
Speculative geomorphic fault offsets - glacial valleys





Seismicity of the Denali area

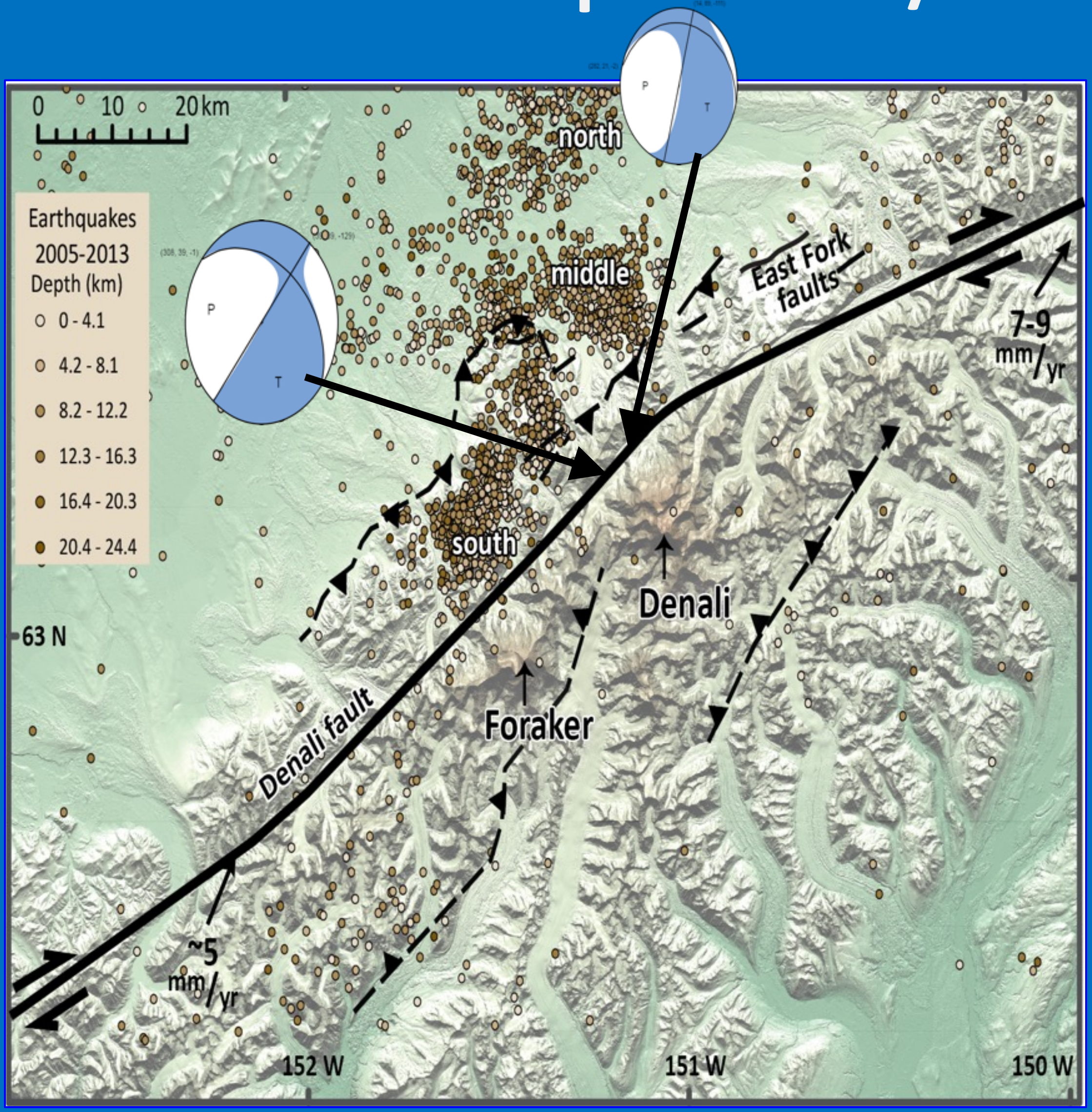




Implications/Conclusions

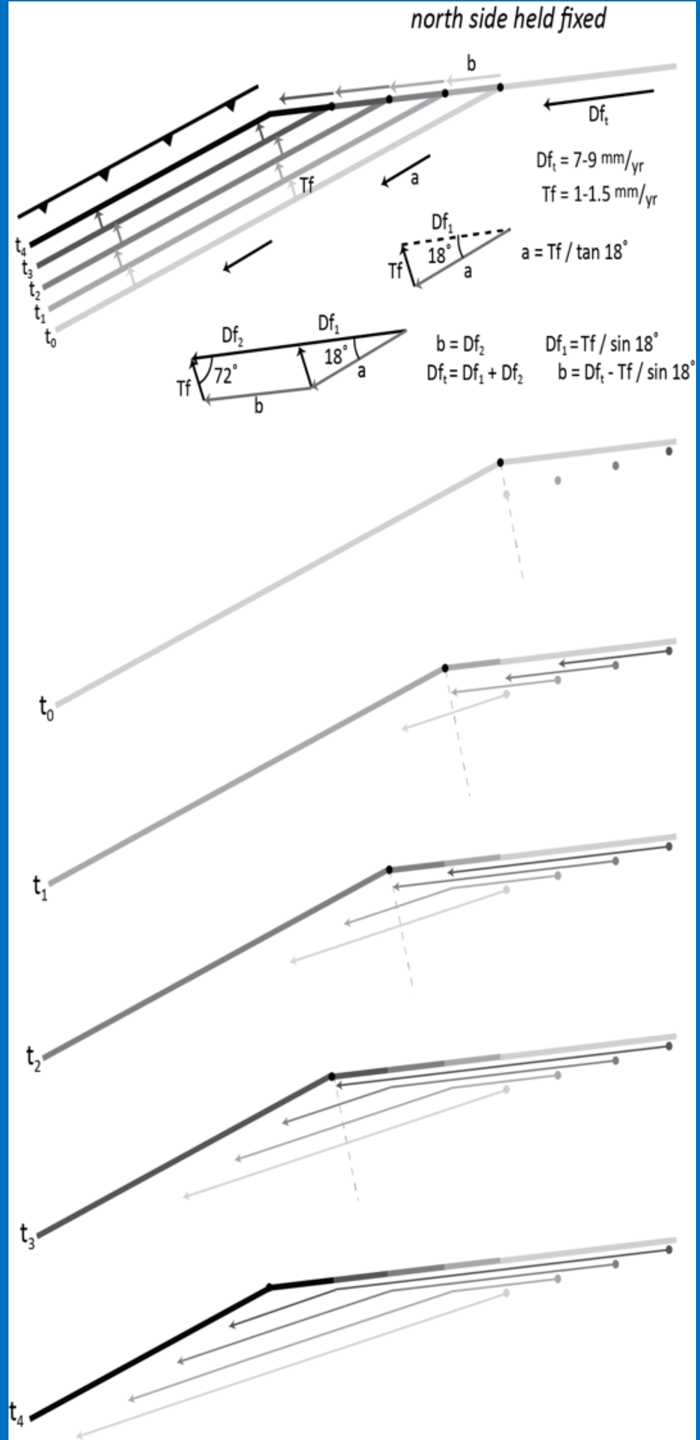
- MMRB sustained a single primary fault trace through ~6 m.y. of restraining bend evolution
- Long-lived, long-length stepover fault keeps crust within material within restraining bend for millions of years
- Crustal strength heterogeneity is not required to produce observed asymmetric topography
- Relief/elevation of Denali produced by persistent, localized contraction
  - Possibly enhanced by riding up HW of NW-vergent thrust faults
  - Likely also enhanced through climatic/erosional effects

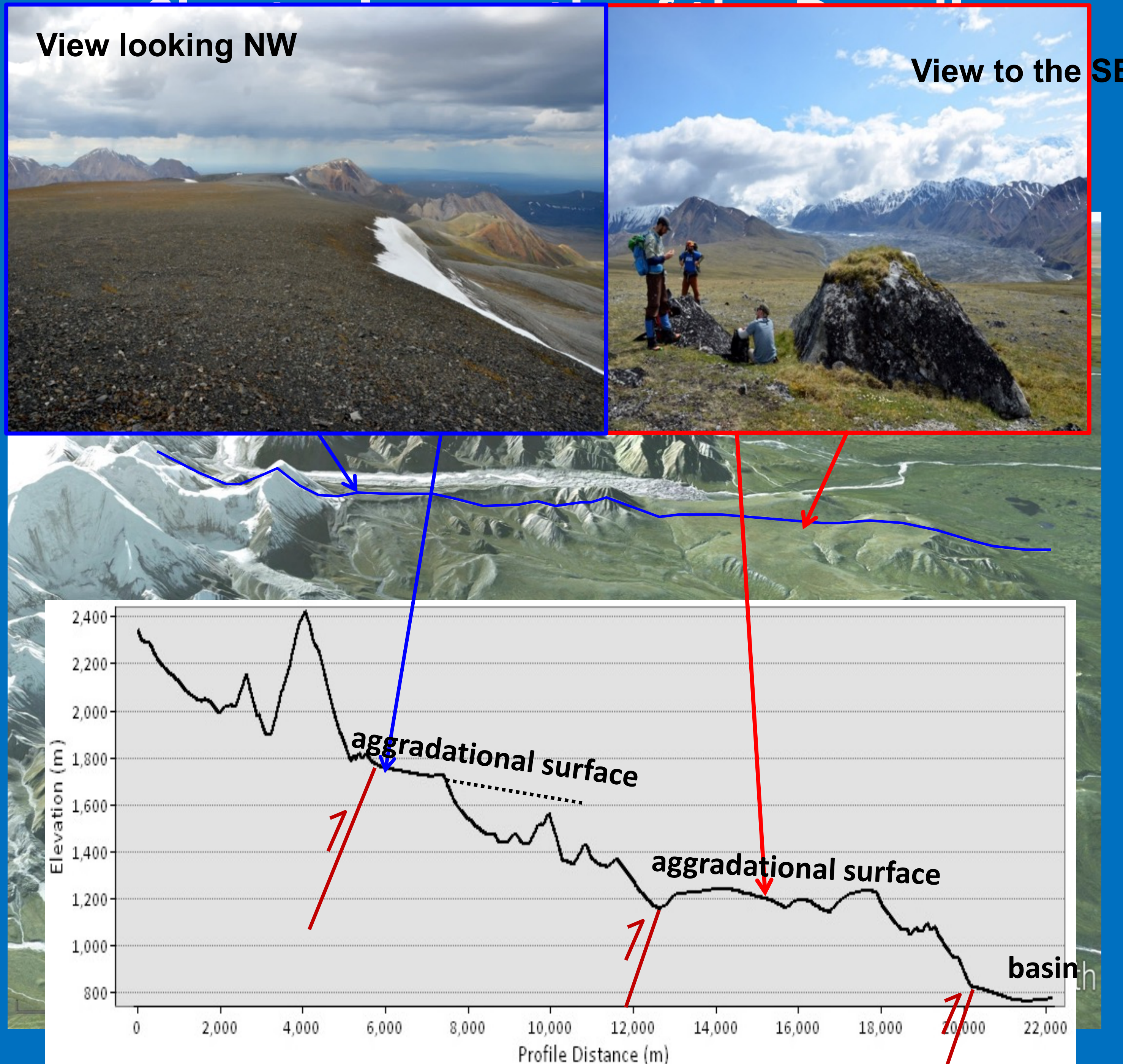
Implications/Conclusions



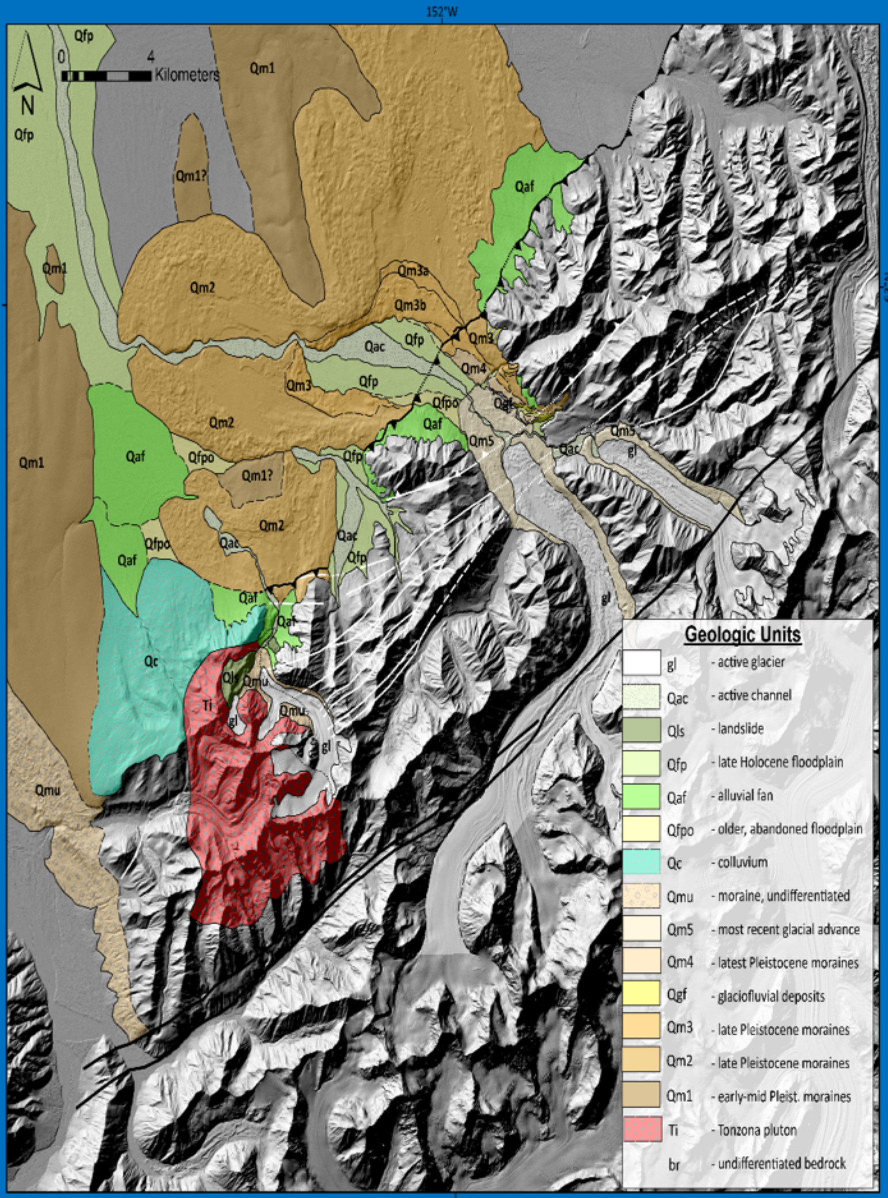
- Active faults associated with Kantishna Cluster seismicity
- ‘Process zone’ ahead of rolling-hinge-like migration of the bend in the Denali fault?

Questions?


north side held fixed
b
Df_t
Df_t = 7-9 mm/yr
Tf = 1-1.5 mm/yr
Tf
a
Df_1
18°
Tf
a
a = Tf / tan 18°
t_4
t_3
t_2
t_1
t_0
Df_2
Df_1
72°
18°
Tf
a
b
b = Df_2
Df_t = Df_1 + Df_2
Df_1 = Tf / sin 18°
b = Df_t - Tf / sin 18°
t_0
t_1
t_2
t_3
t_4


View looking NW
View to the SE
aggradational surface
aggradational surface
basin
Elevation (m)
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
Profile Distance (m)

Quaternary mapping



- *White faults – inactive faults in bedrock (Reed and Nelson, 1980)*
- *Black faults – active*