The Bitterroot Fault, Western Montana:

Quaternary mapping, ^{10}Be dating of glacial deposits, and slip rates of the Bitterroot fault

Yann Gavillot[1,], Jeffrey Lonn[1], Michael Stickney[1], and Alan Hidy[2].

Paleoseismology of the Bitterroot fault

Yann Gavillot[1,], Christopher DuRoss[3], Sylvia Nicovich[4], Alexandra Hatem[3], Ellen Lamont[4], Colleen Elliott[1], Ralph Klinger[4], Nadine Reitman[3], Michael Stickney[1], Amanda Rossi[1], Camille Collett[3], Colin Chupick[4], and Shannon Mahan[4].

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MBMG Montana Bureau of Mines and Geology

Montana Tech

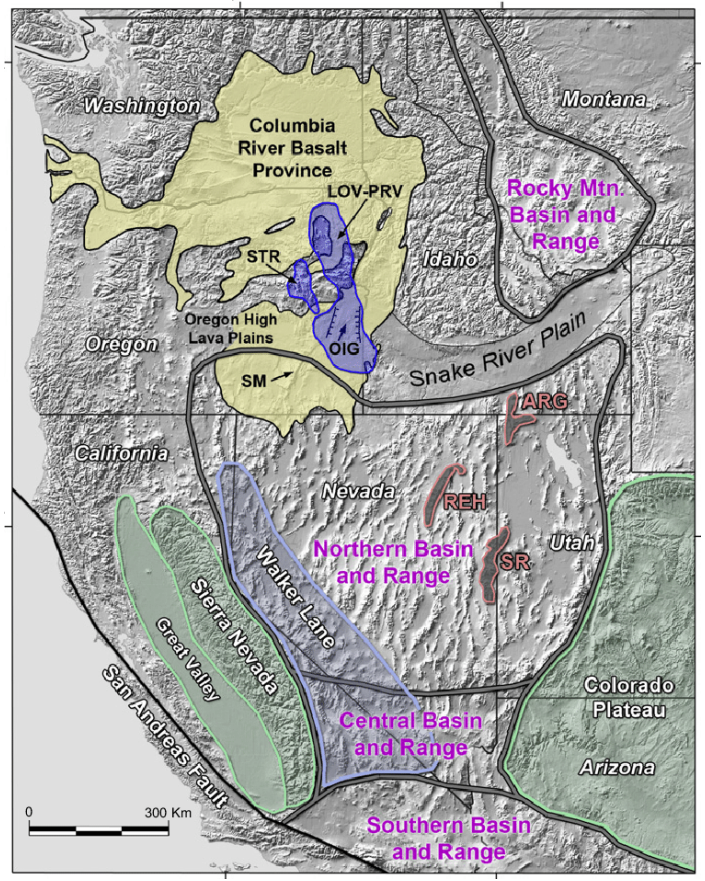
USGS science for a changing world

Bureau of Reclamation

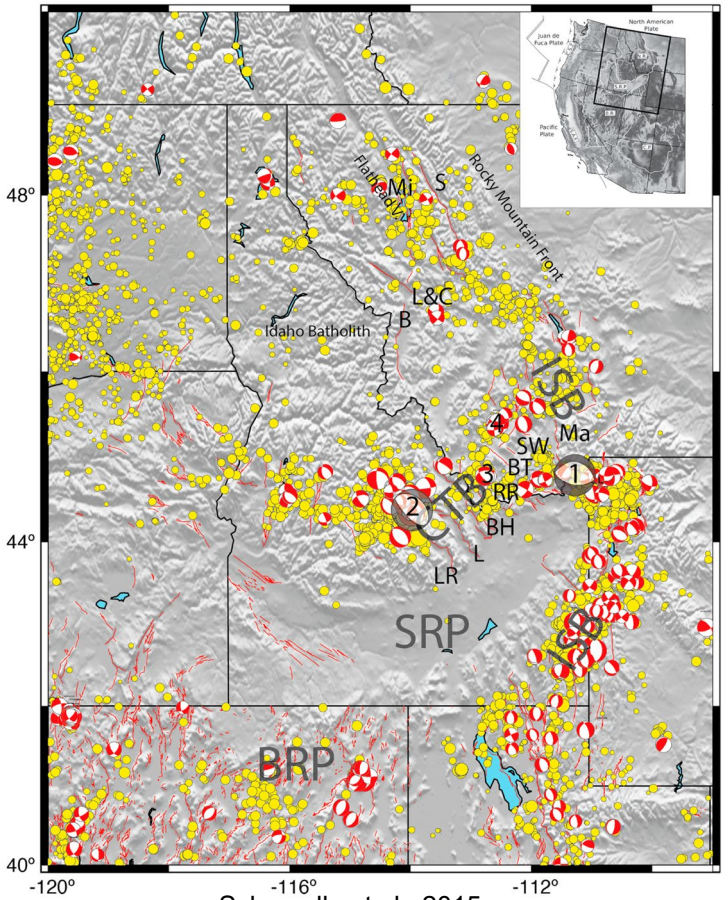
Lawrence Livermore National Laboratory

nehrp

Regional setting of the Northern Rockies Basin and Range and Intermountain Seismic Belt

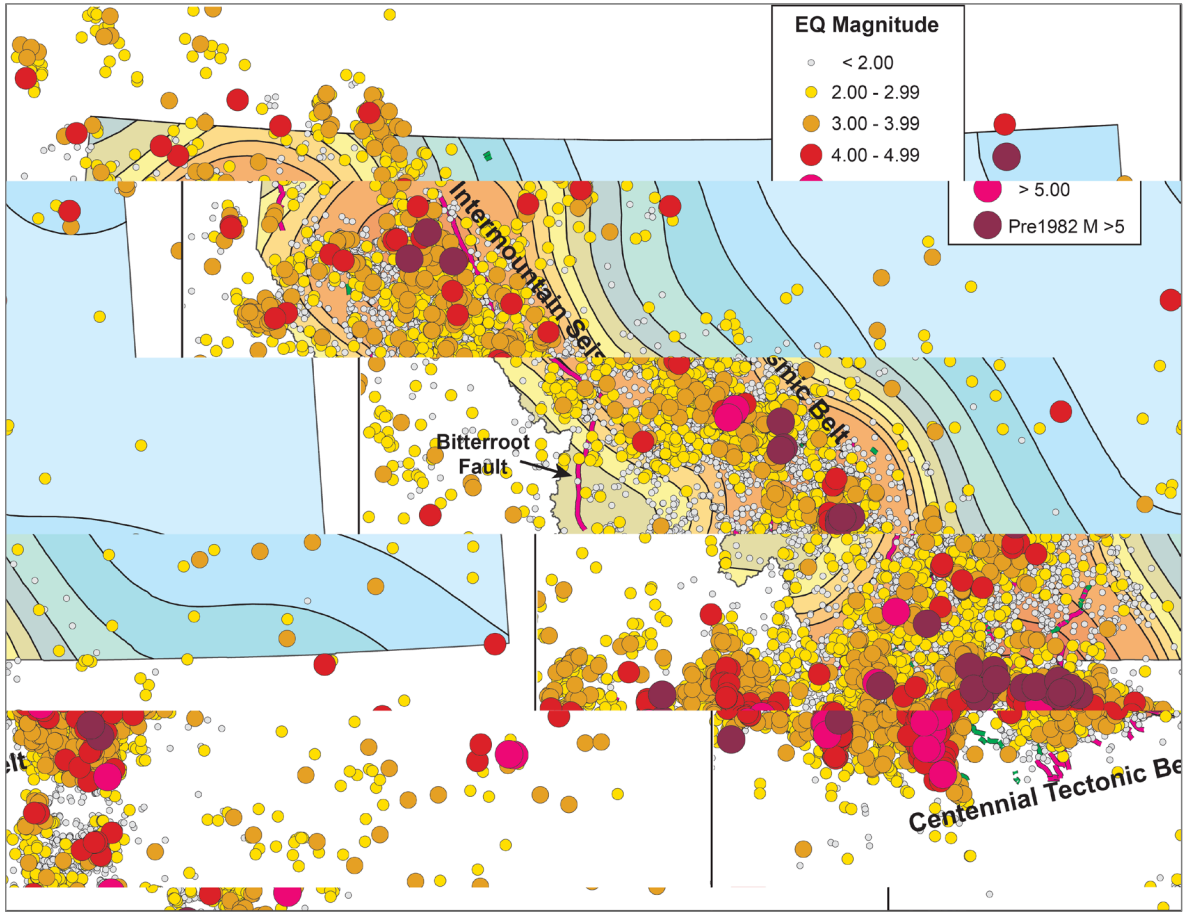


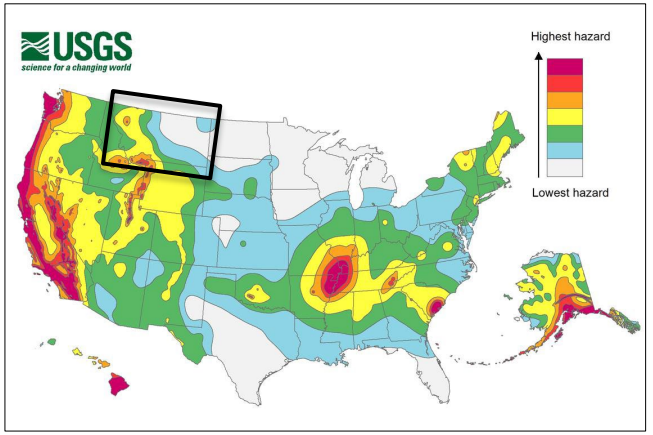
Camp, et al., 2015



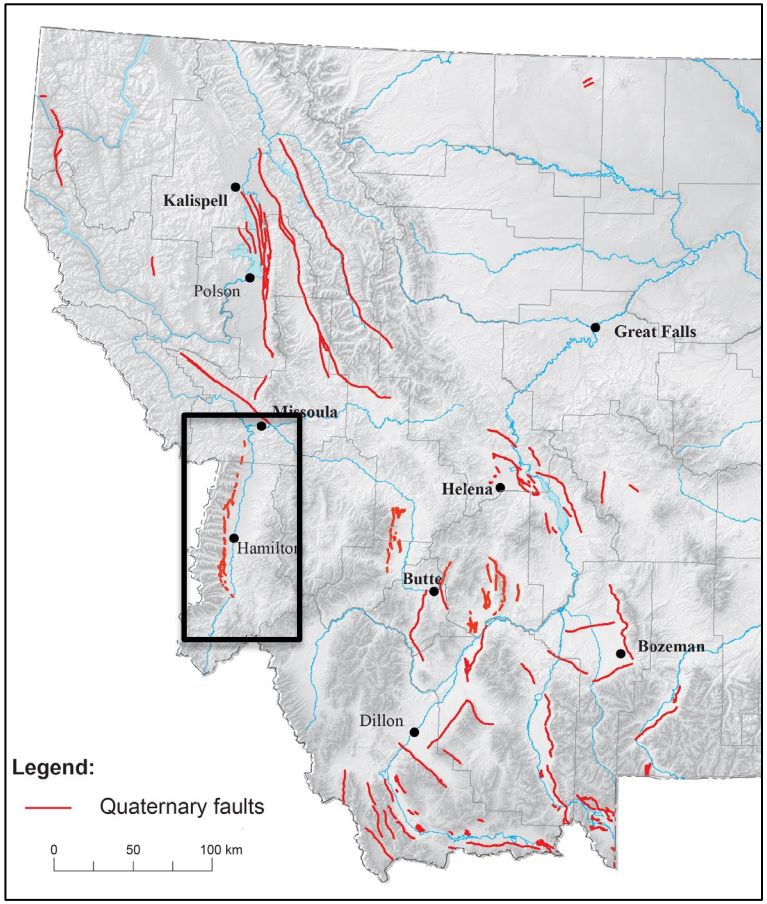
Schmeelk, et al., 2015

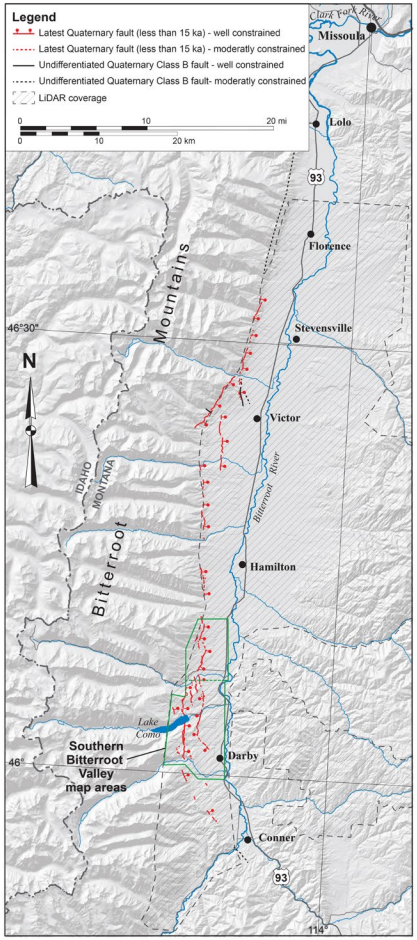
Montana Seismic Hazards and Seismicity



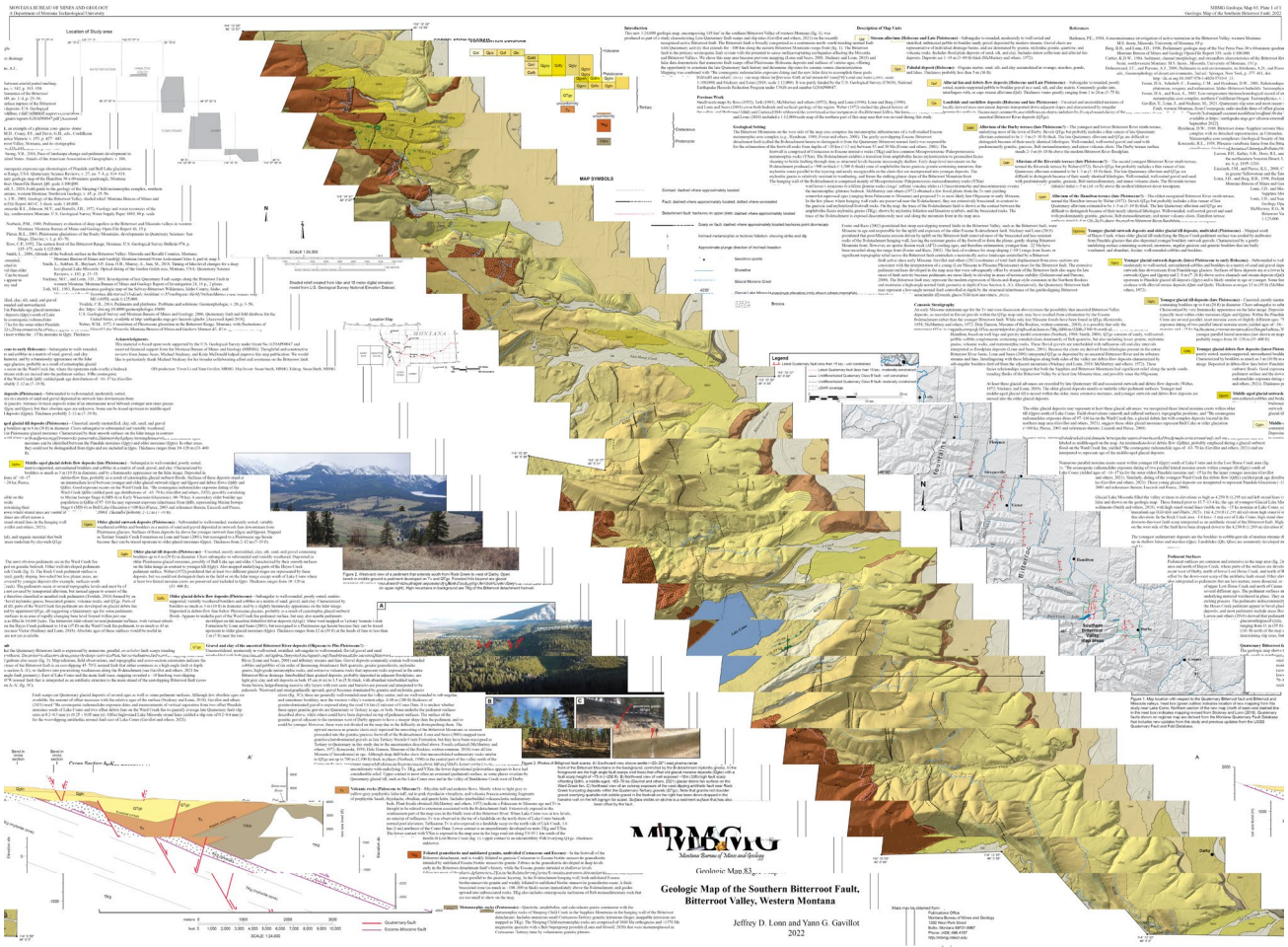


Montana Quaternary faults: The Bitterroot Fault

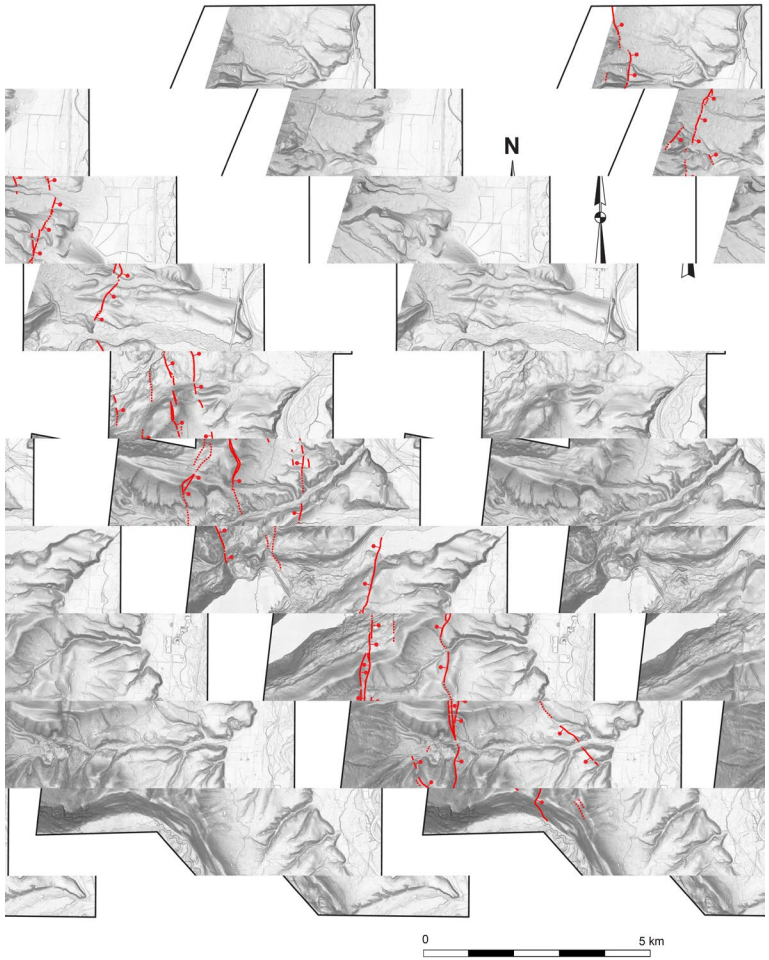


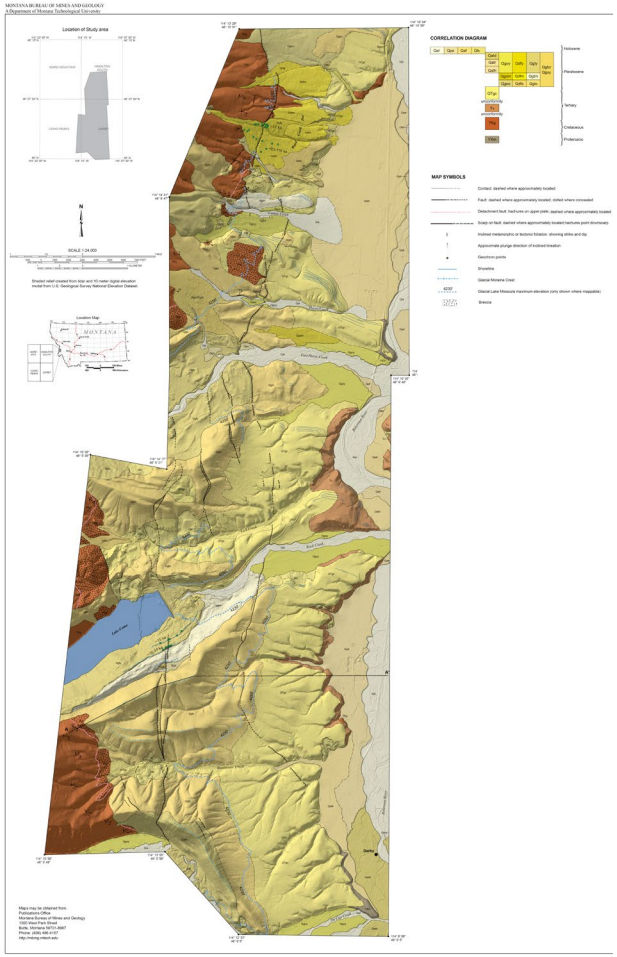


Quaternary and fault mapping

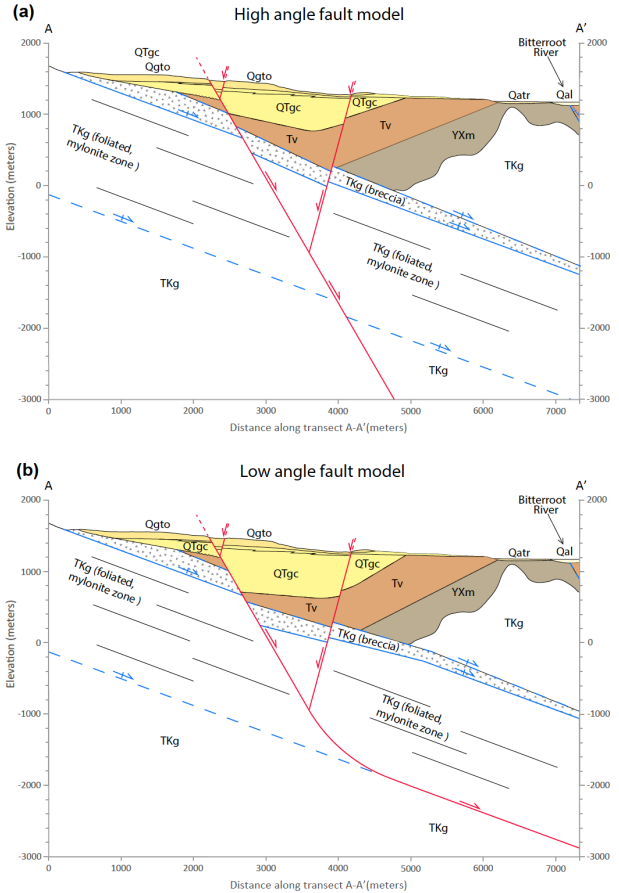


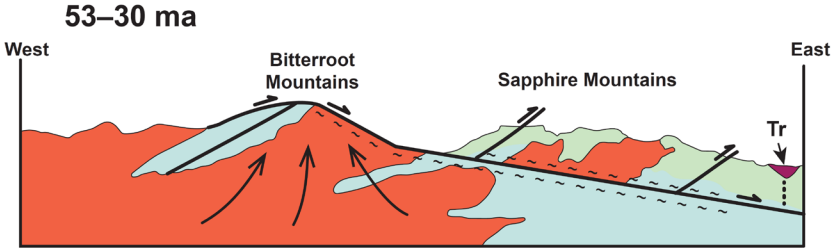
Quaternary and fault mapping

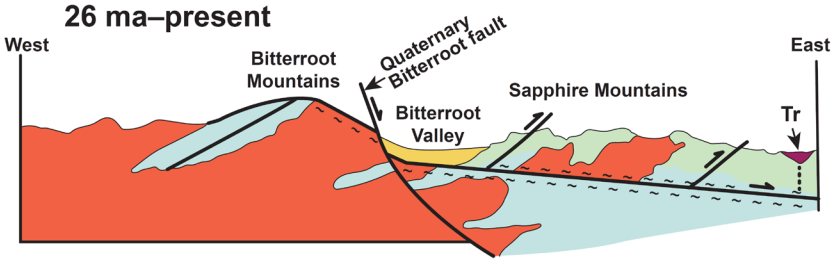




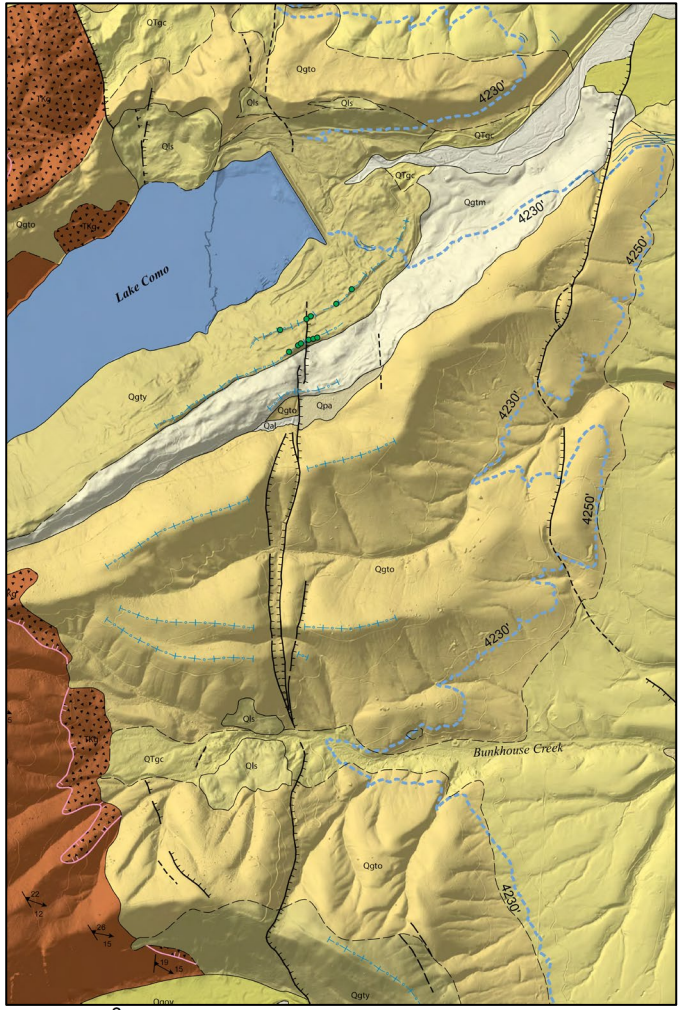
Fault geometry and kinematic history

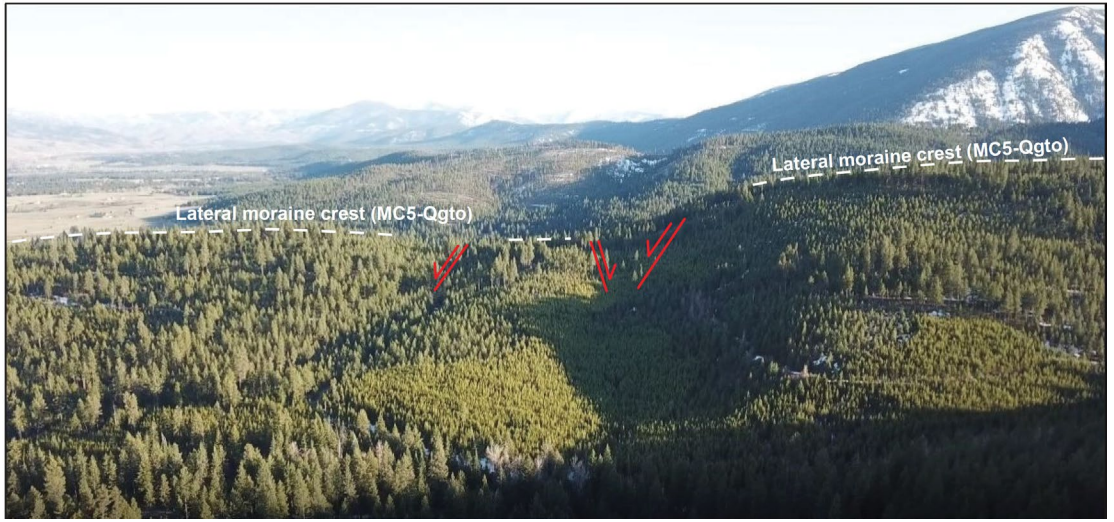


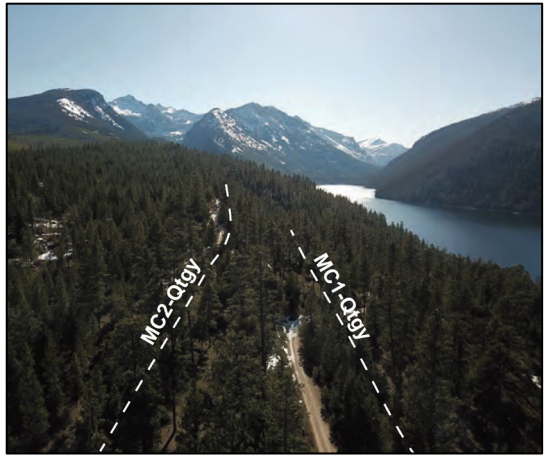




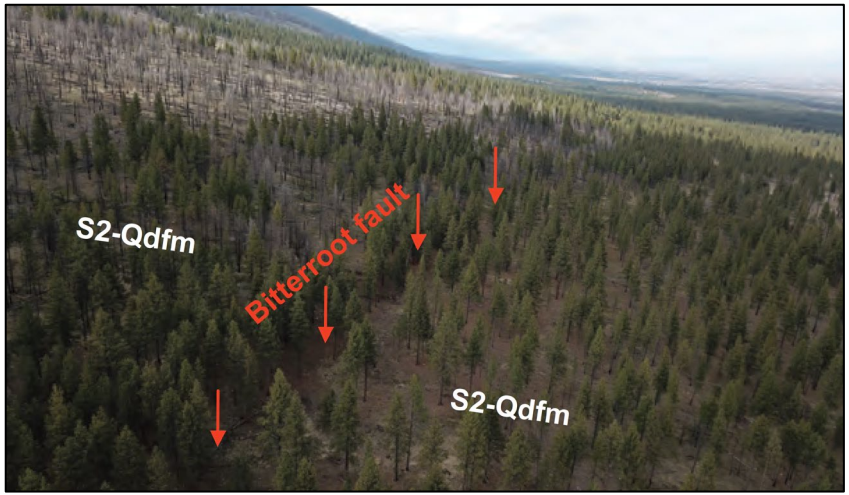
Courtesy of Jeff Lonn, 2020


N
Lake Como
Bunkhouse Creek
Qgto
Qgty
Qgtm
QTgc
Qls
Qpa
Qgoy
4230'
4250'
0
5 km


Lateral moraine crest (MC5-Qgto)
Lateral moraine crest (MC5-Qgto)

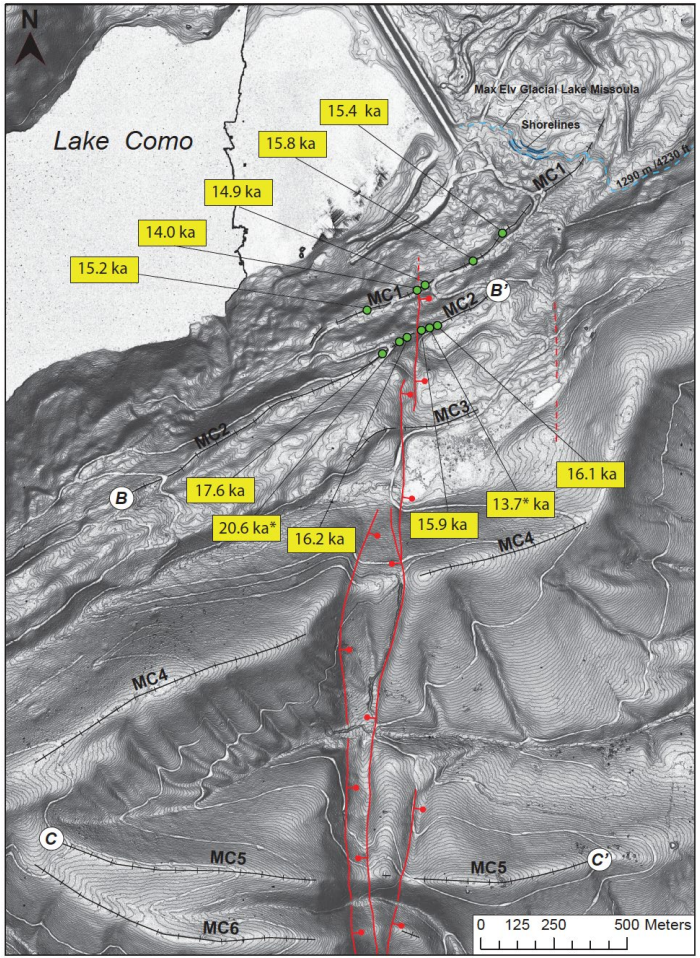

MC2-Qtgy
MC1-Qtgy

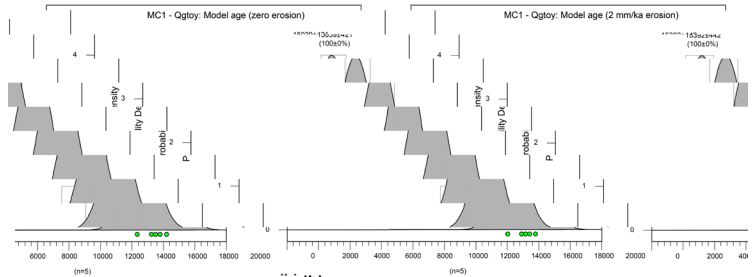

N
TKg
Qdfy
Qgto
Qgoy
Qdfm
4250'
18
17
16
10
17
15
Qal
Qdfm
fan
QTgc
Qdfy
Ward Creek
Qdfm
QTgc
33
15
Qaf
Qdfm
Qal
27
27
17
16
4250'
Qdfm
Qdfo
QTgc
Qpa
Qls
Qaf
Qgto
Qgto
QTgc
Qls
27
Qgty
Qgtm
Qgoy
Camas Creek
Qgtm
4250'
Qgoy
Qal
Qls
Qgto
Qgto
0
2km

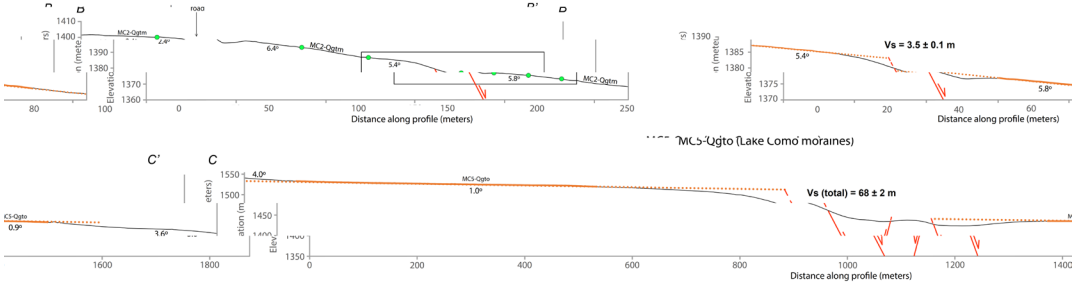

S2-Qdfm
Bitterroot fault
S2-Qdfm

Cosmogenic ^{10}Be dating on boulders in glacial deposits

Lake Como: Offset glacial lateral moraines



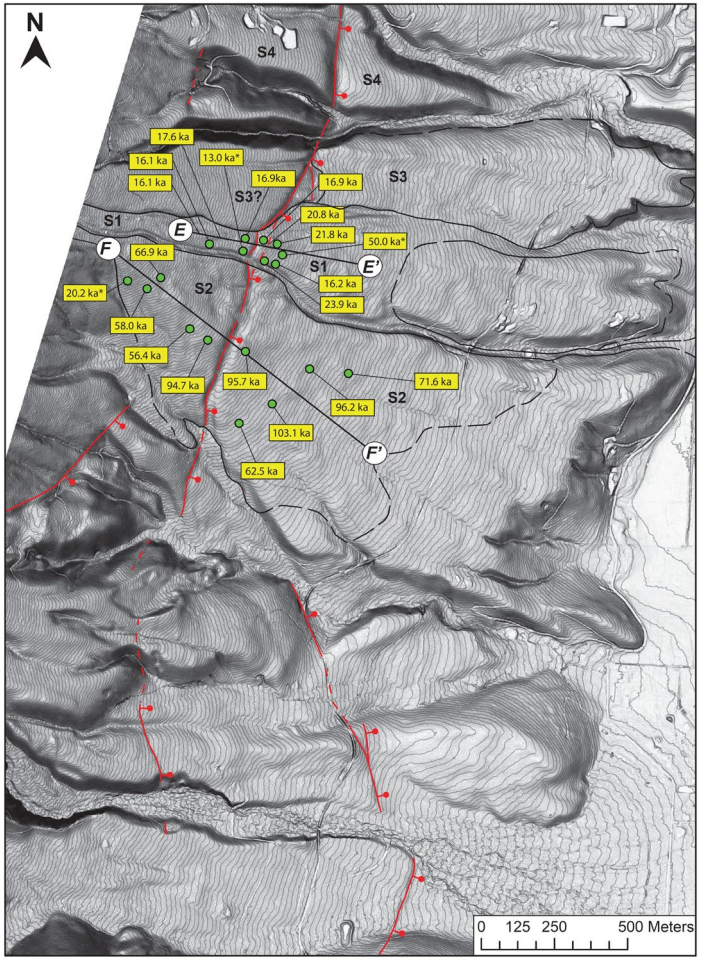


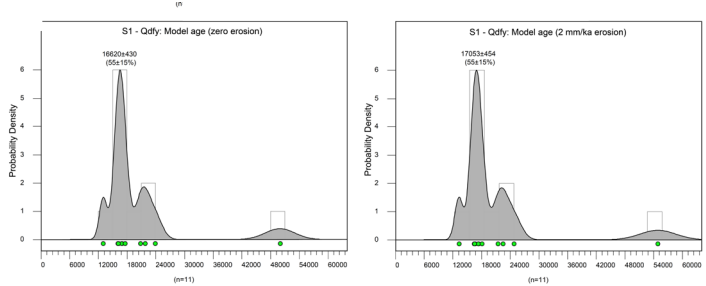


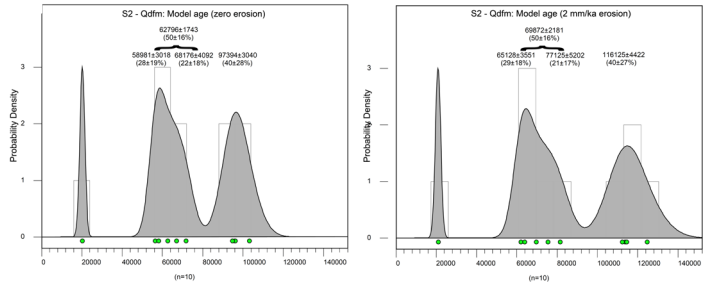
MC2: Vs rate = 0.2 mm/yr **Fault slip rate = 0.2 – 0.3 mm/yr**

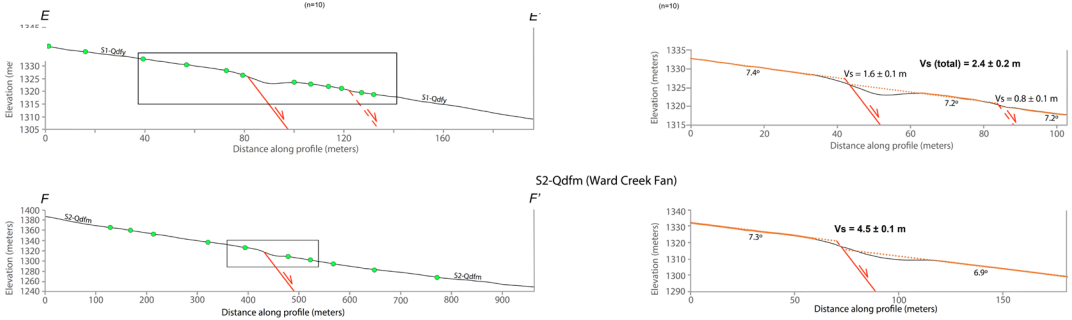
MC5: Vs rate = 0.4 – 0.7 mm/yr **Fault slip rate = 0.5 – 0.8 mm/yr***

Ward Creek Fan: Offset glacial debris fans





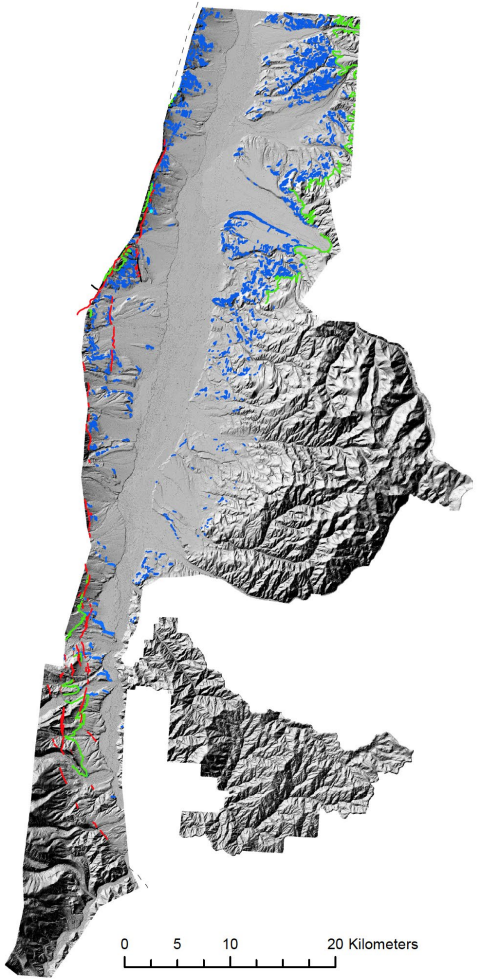


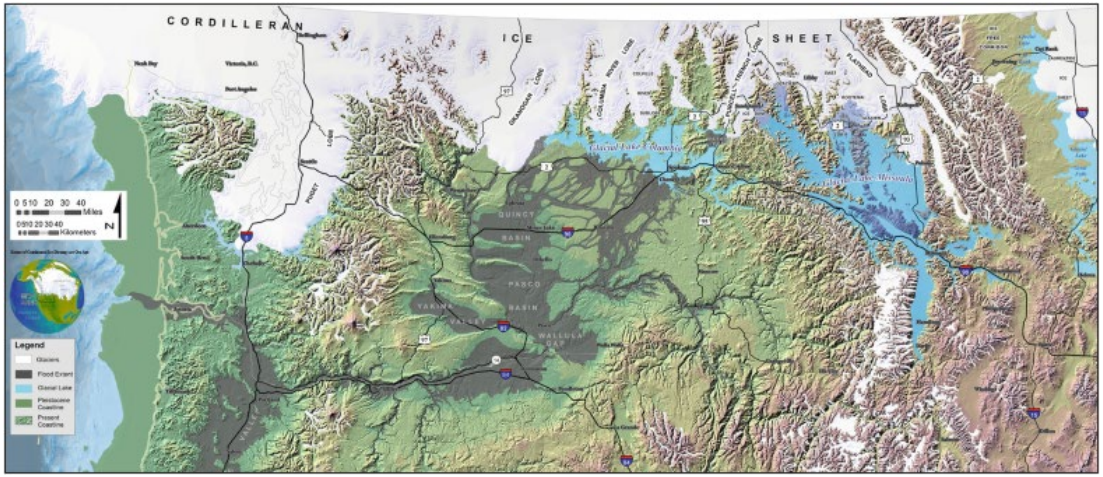


S1: Vs rate = 0.1 – 0.2 mm/yr **Fault slip rate = 0.1 – 0.2 mm/yr**

S2: Vs rate = 0.1 mm/yr **Fault slip rate = 0.1 mm/yr**

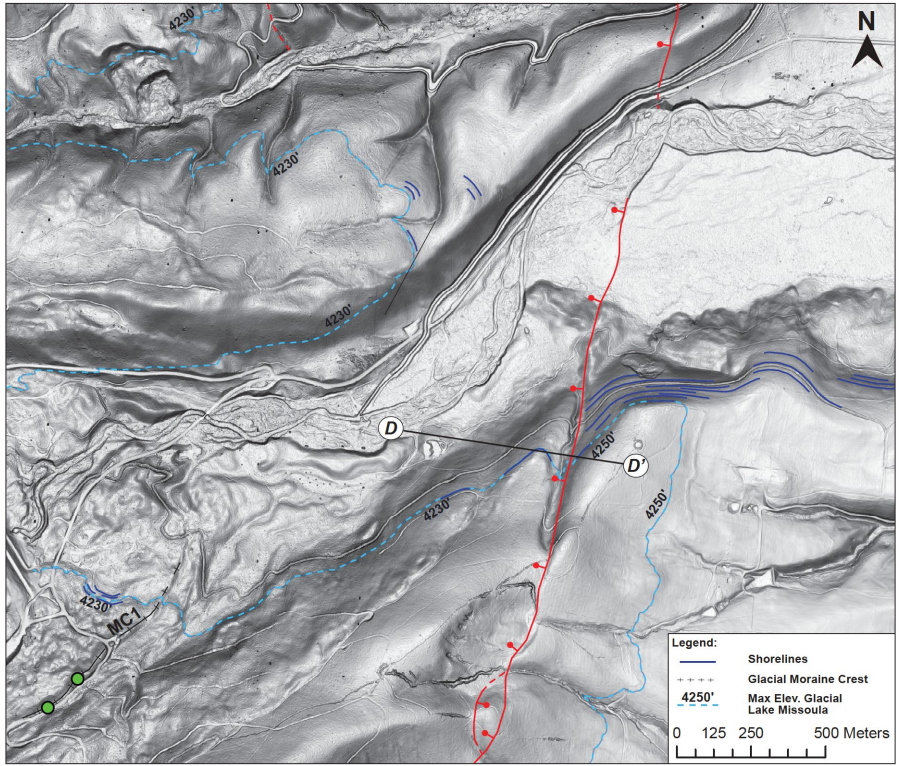
Glacial Lake Missoula

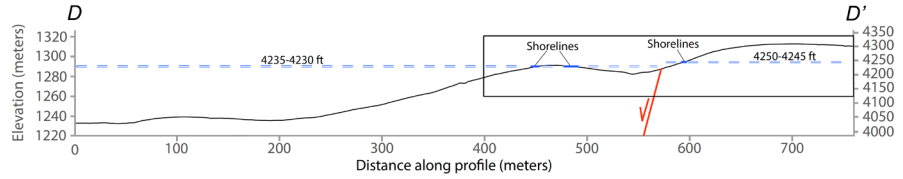


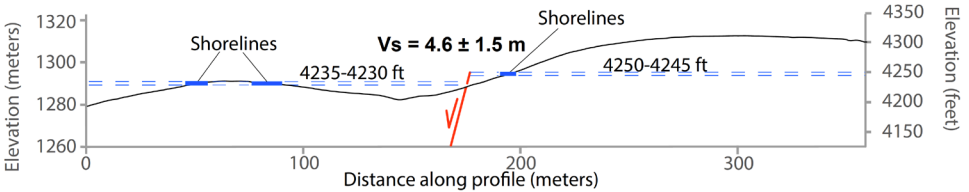


Map and photos: Ice Flood Institute (upper); John Hyndman (left), Marli Miller (right)

Rock Creek: Offset Glacial Lake Missoula max elevation shorelines

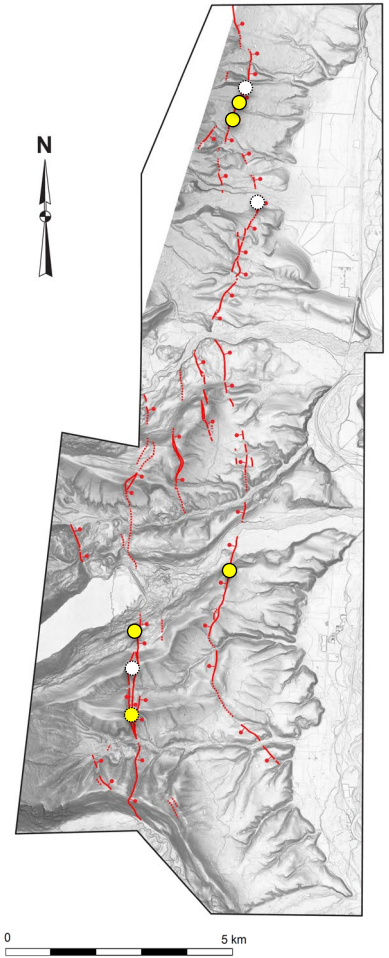






Vs rate = 0.2 – 0.4 mm/yr **Fault slip rate = 0.2 – 0.4 mm/yr**

Seismic source characterization: Fault Slip Rates



Vertical separation and fault slip rates for the Bitterroot fault.

	separation (m) Terrace surf.	Min surface age (ka)	Max surface age (ka)	Fault dip (degrees)	Vert. separation rate (mm/yr)	Fault slip rate (mm/yr)
Lake Como						
MC2 - Pinedale moraine	3.5 ± 0.1	16.4 ± 0.6	16.8 ± 0.6	62.5 ± 7.5	**0.20–0.23**	**0.21–0.28**
MC5 - Bull Lake moraine	68 ± 2	110 ± 2.5*	138 ± 5.6*	62.5 ± 7.5	**0.44–0.68***	**0.47–0.83***
Rock Creek						
Glacial Lake Missoula shorelines	4.6 ± 1.5	15.0 ± 0.4	15.4 ± 0.4	75 ± 5	**0.19–0.42**	**0.20–0.44**
Ward Creek Fan						
S1 - Pinedale debris fan	2.4 ± 0.2	16.6 ± 0.4	17.1 ± 0.5	52.5 ± 7.5	**0.13–0.16**	**0.15–0.23**
S2 - Medium-aged debris fan	4.5 ± 0.1	62.8 ± 1.7	69.9 ± 2.2	52.5 ± 7.5	**0.06–0.08**	**0.07–0.11**

Note: Measured values of vertical separation, fault dip, and range of surface ages for offset marker units. Using these parameters, we calculated vertical separation rates, extension rate, and fault slip rates with corresponding uncertainties, which are based on the maximum and minimum possible values in the rate calculation.

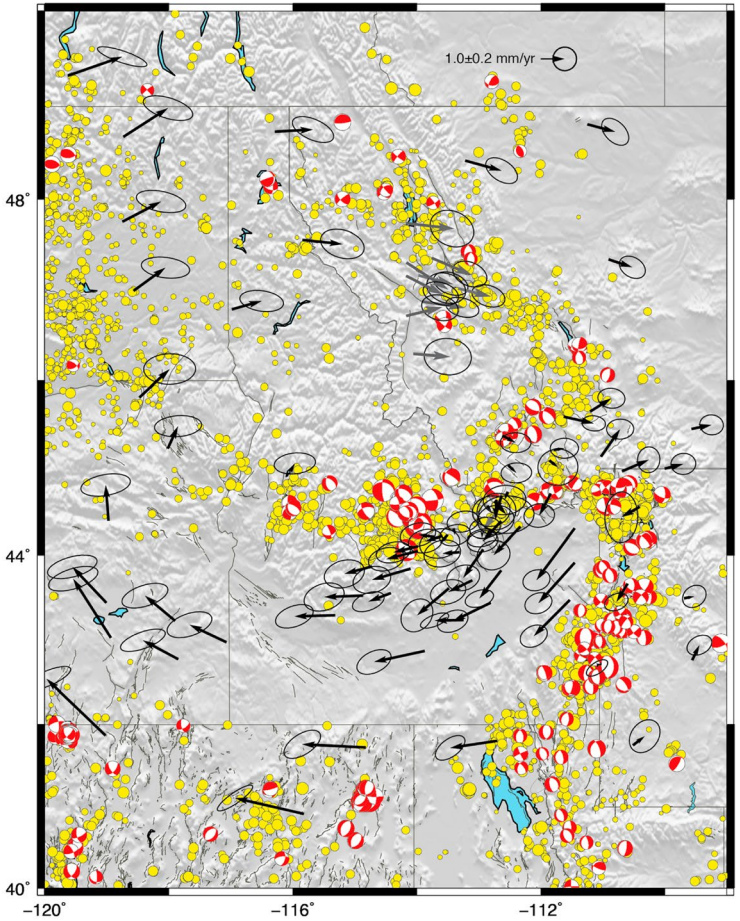
* Represent preliminary results on MC5 awaiting forthcoming additional boulder age results.

Post Late Pinedale = 0.2 – 0.3 mm/yr

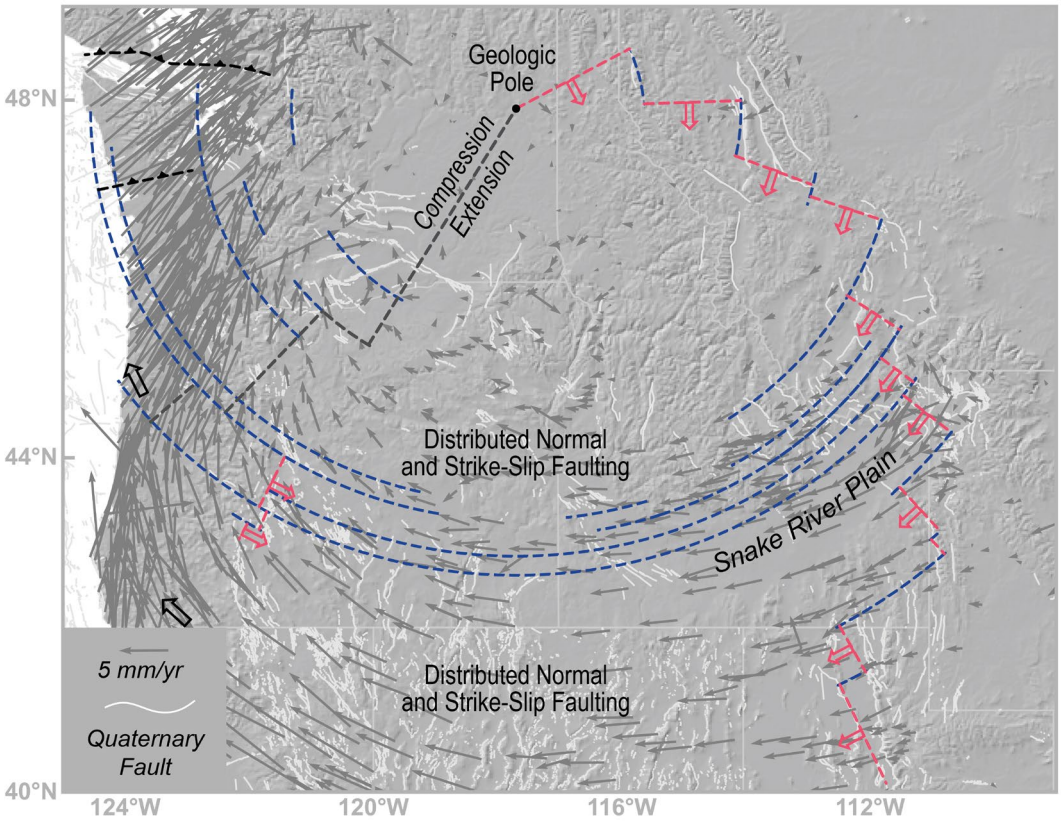
Post < 63-70 ka = 0.1 – 0.2 mm/yr

Post Bull Lake = 0.5 – 0.8 mm/yr*

Regional strain rates

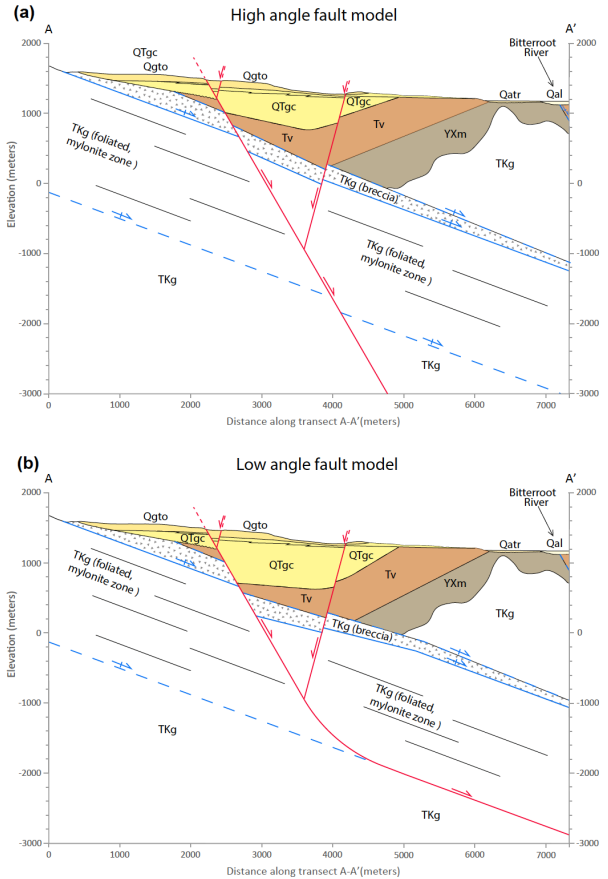


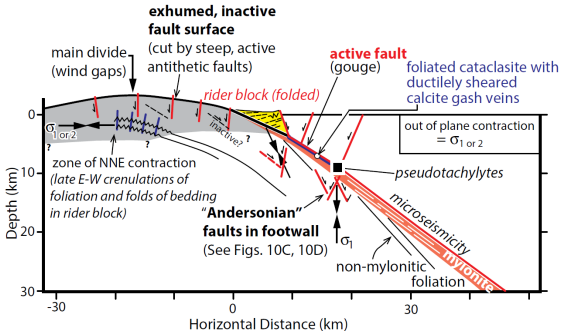
Schmeelk, et al., 2015



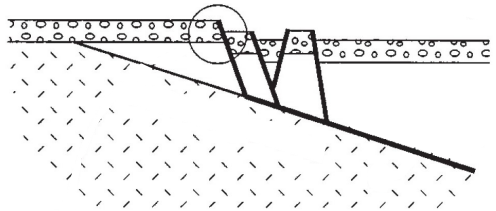
Yakovlev et al., 2020.

Seismic source characterization: Fault Geometry

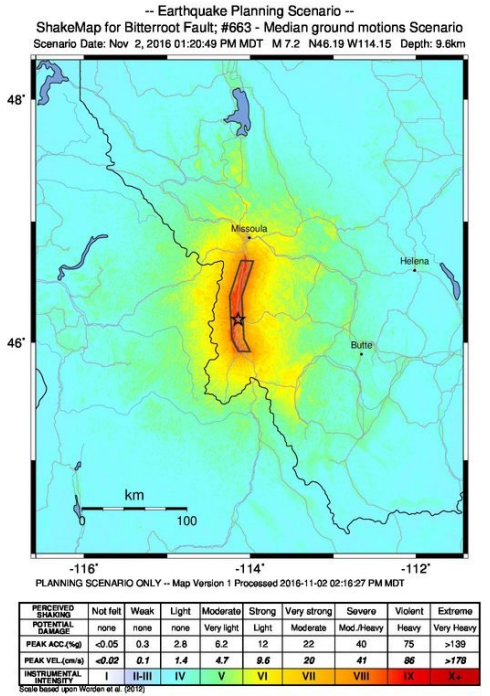




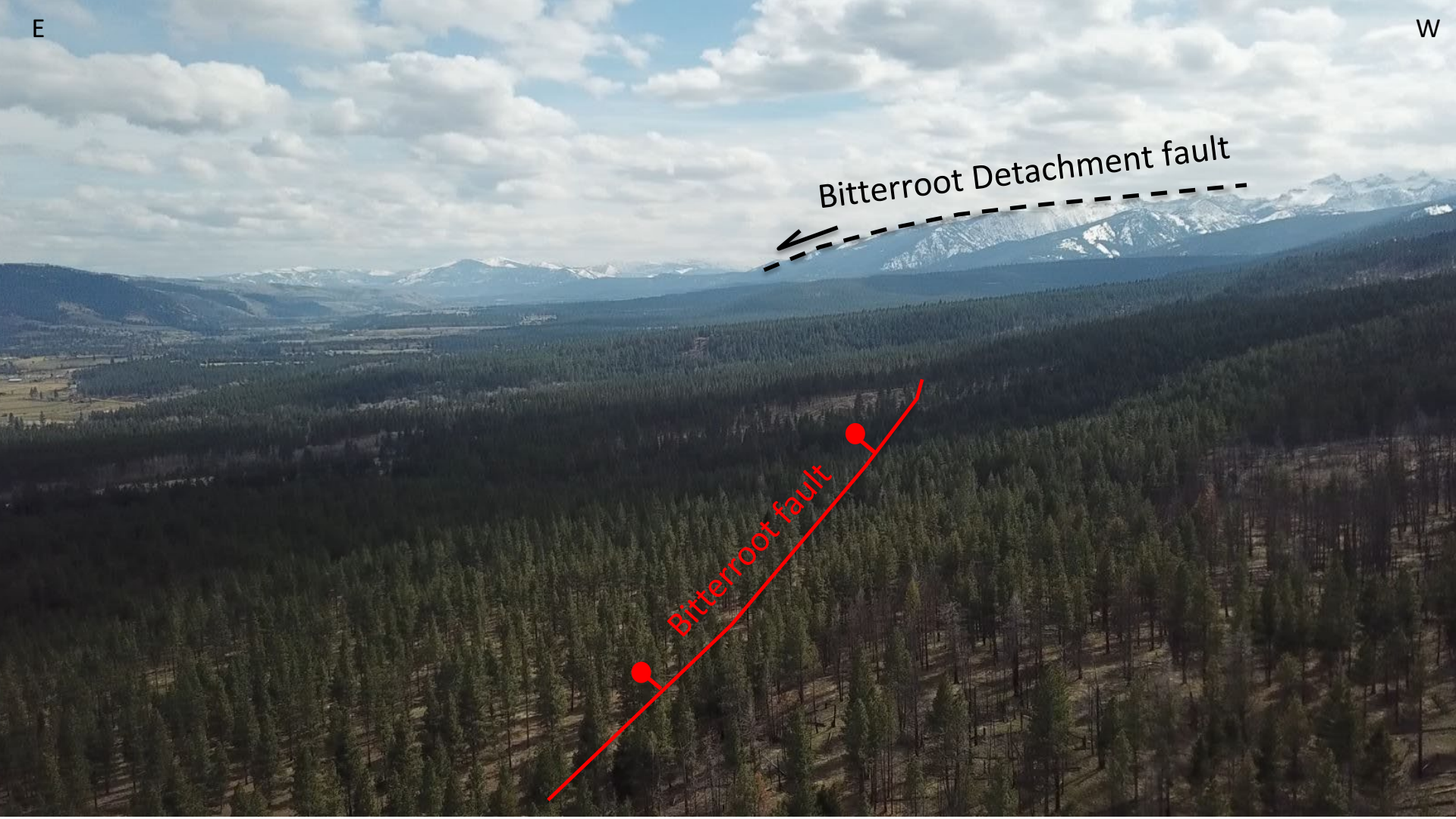
Suckling-Dayman MCC, Papua New Guinea (Little et al., 2019)

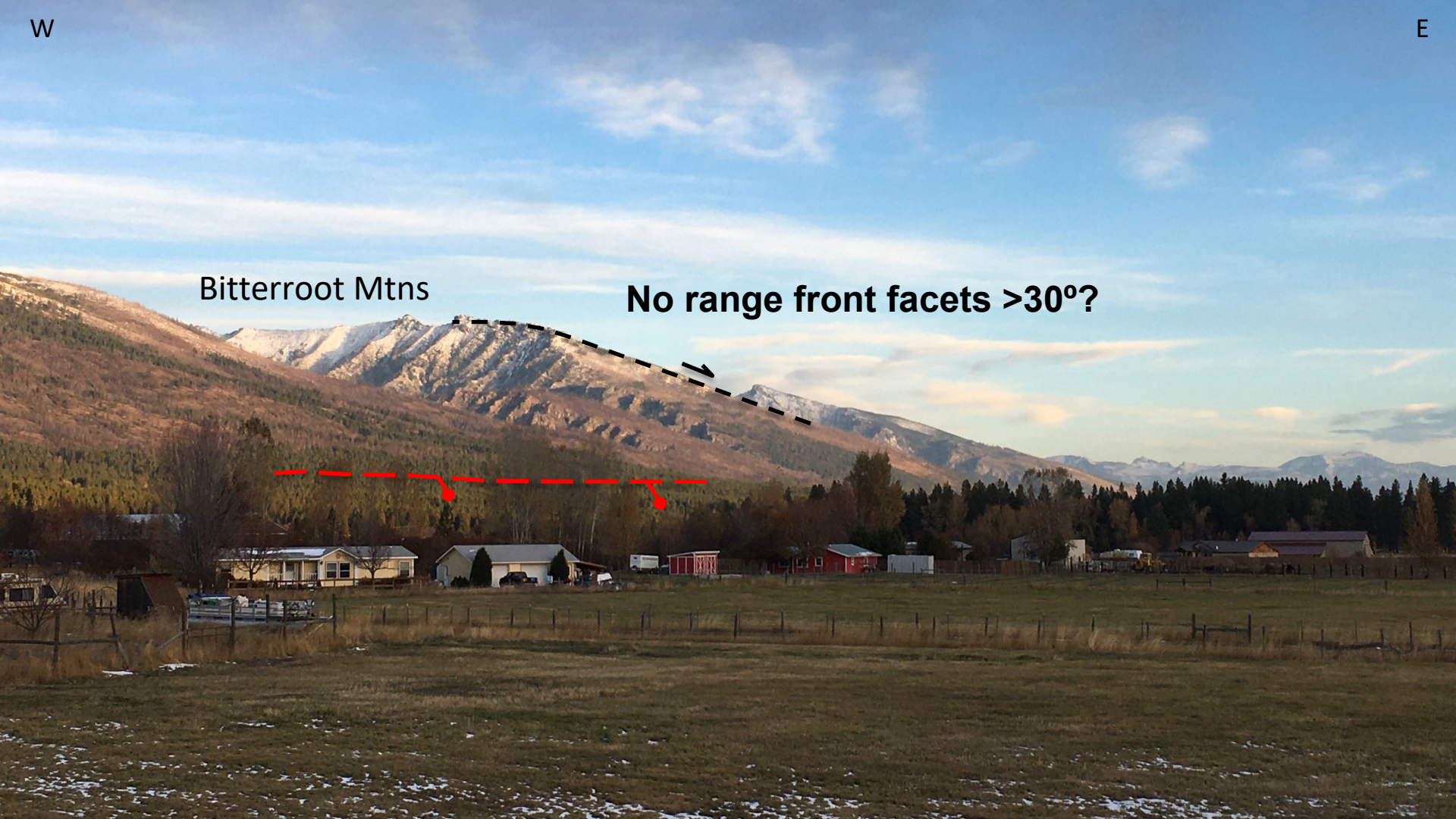


Sierra El Mayor, Baja California (Axen et al., 1999)

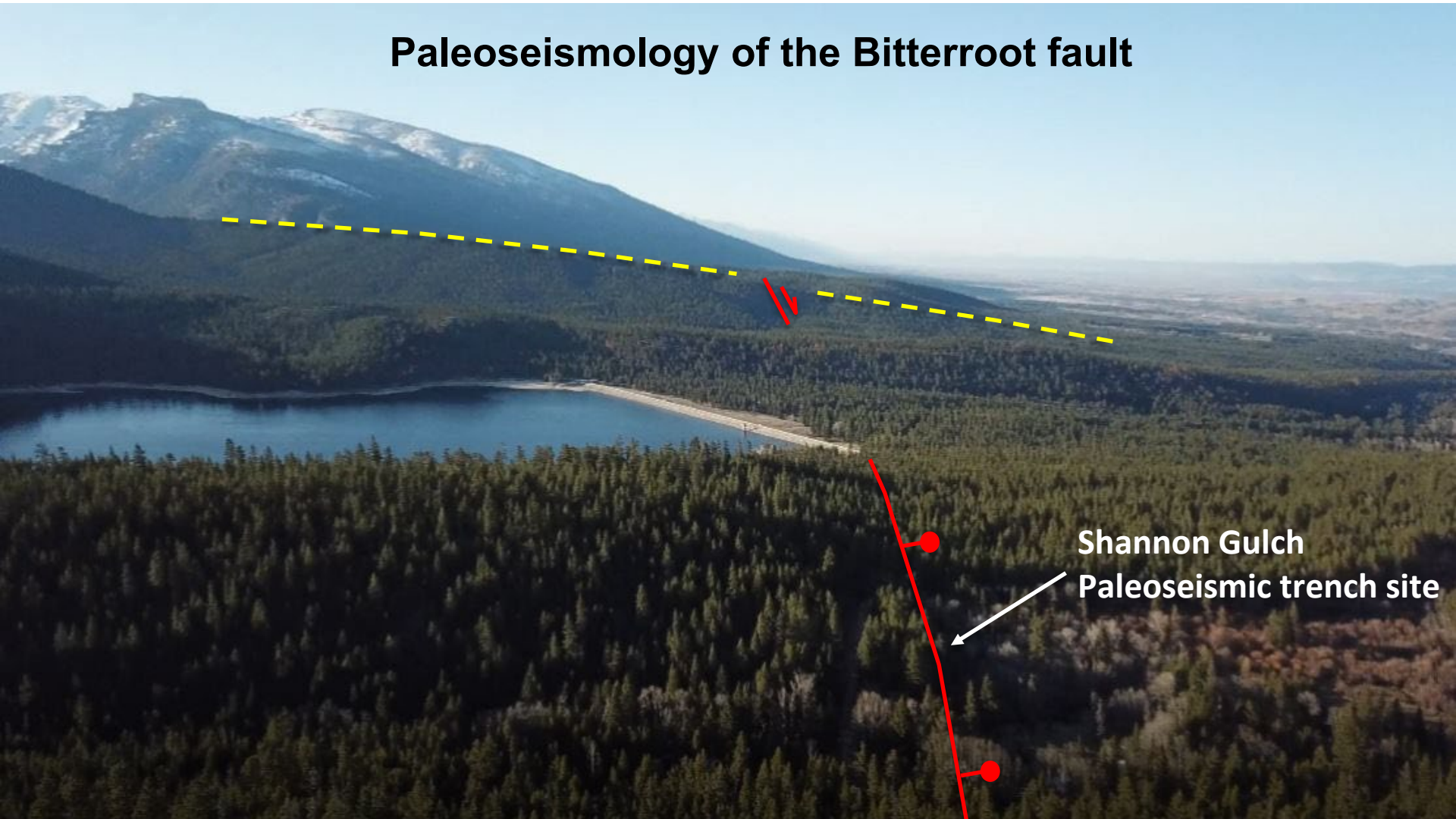


USGS National Earthquake Information Center, 2016.

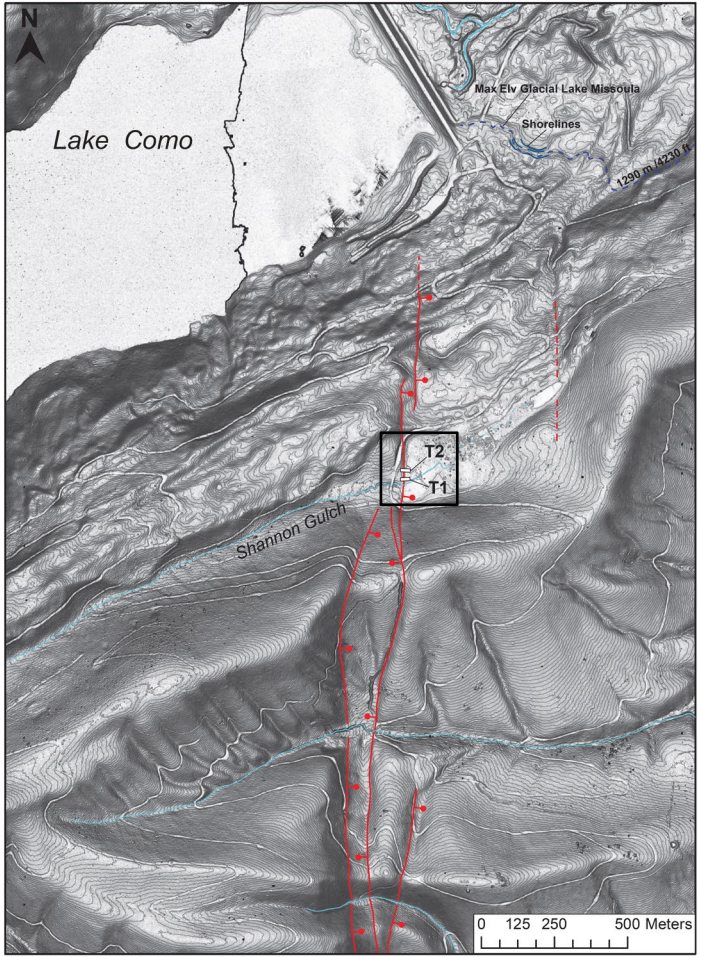

E
W
Bitterroot Detachment fault
Bitterroot fault


W
E
Bitterroot Mtns
No range front facets >30º?

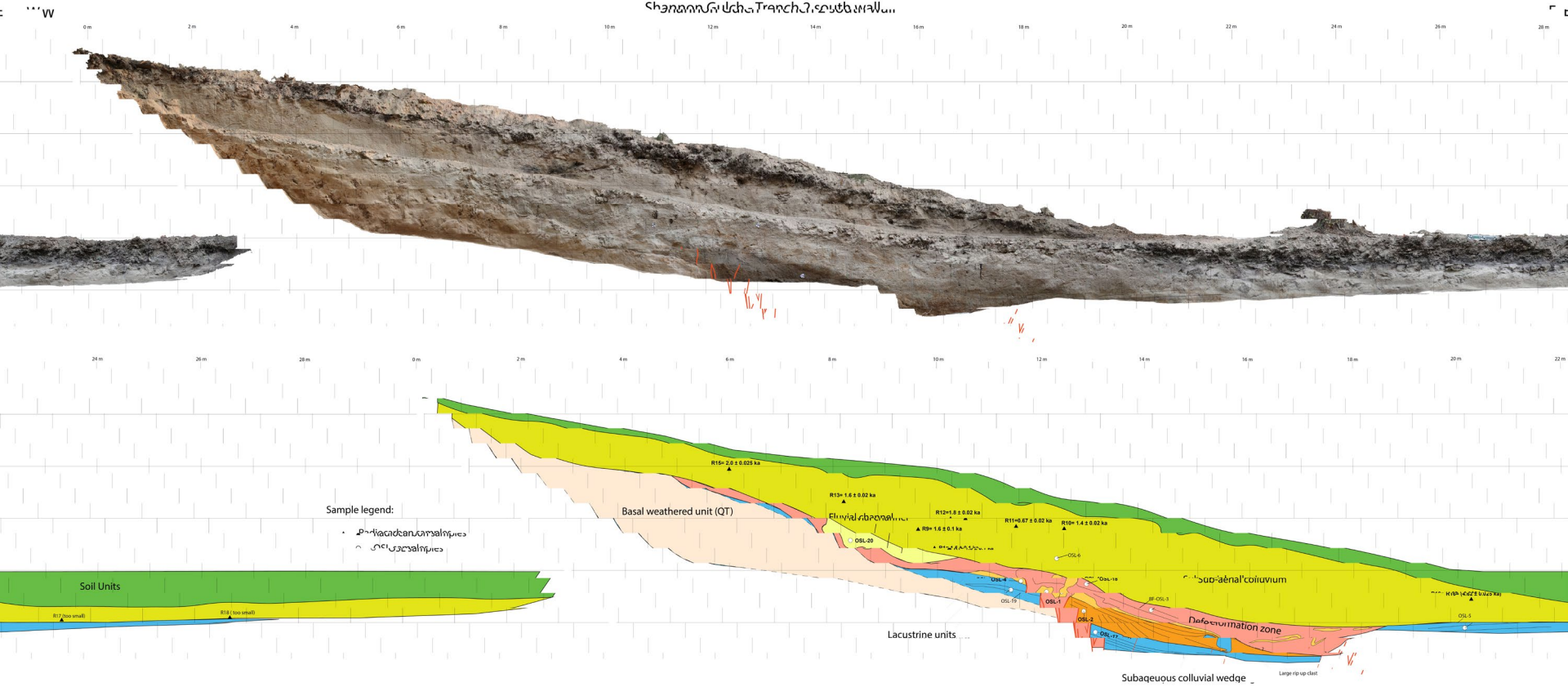
Paleoseismology of the Bitterroot fault



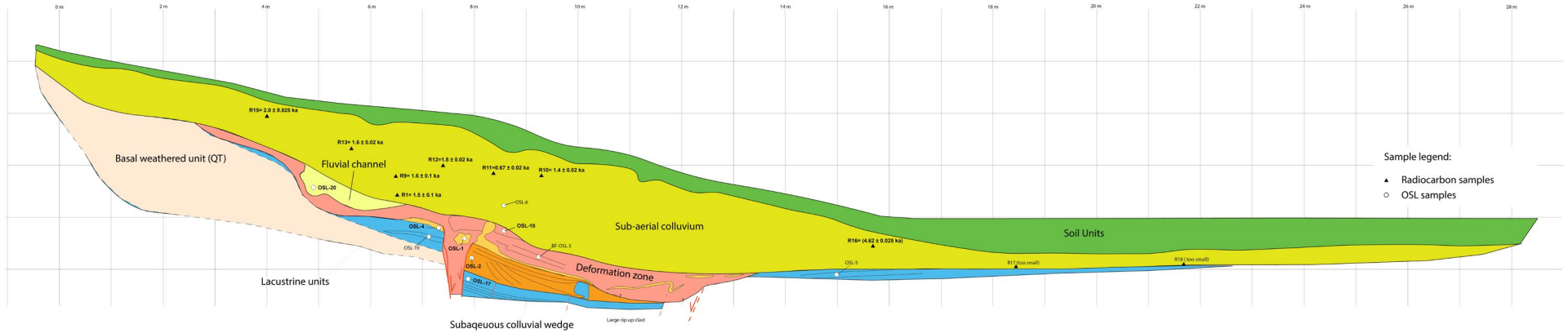
Shannon Gulch trench site – September 2021

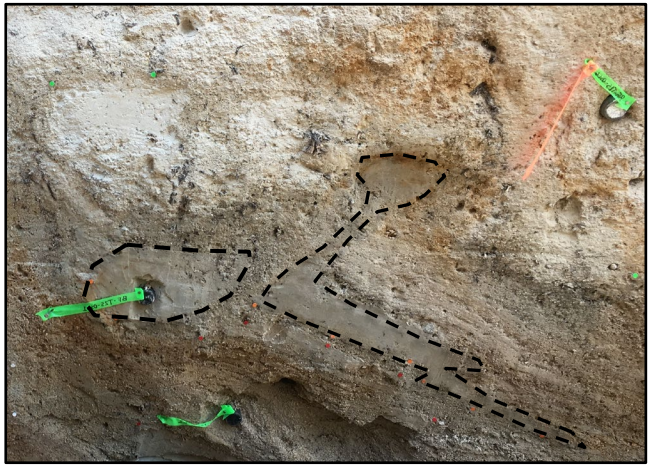


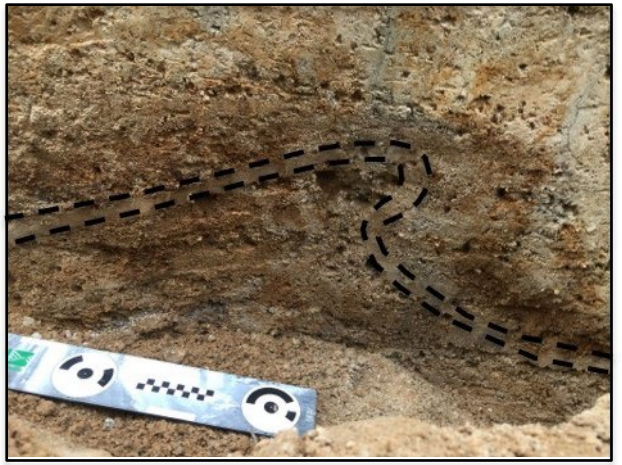
Shannon Gulch trench site – September 2021



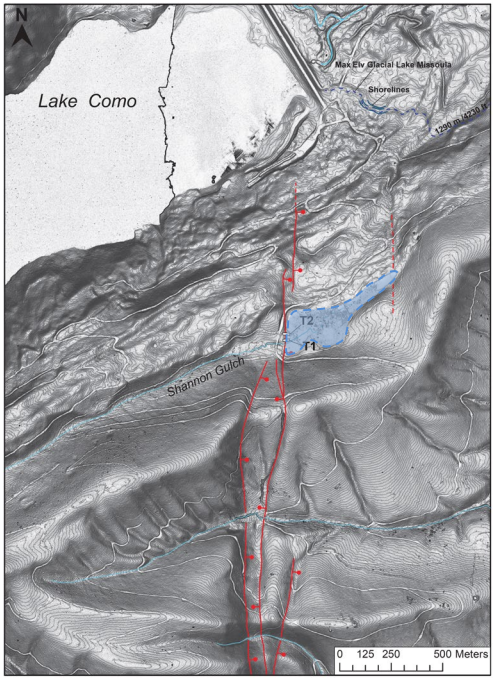
Shannon Gulch trench site – September 2021

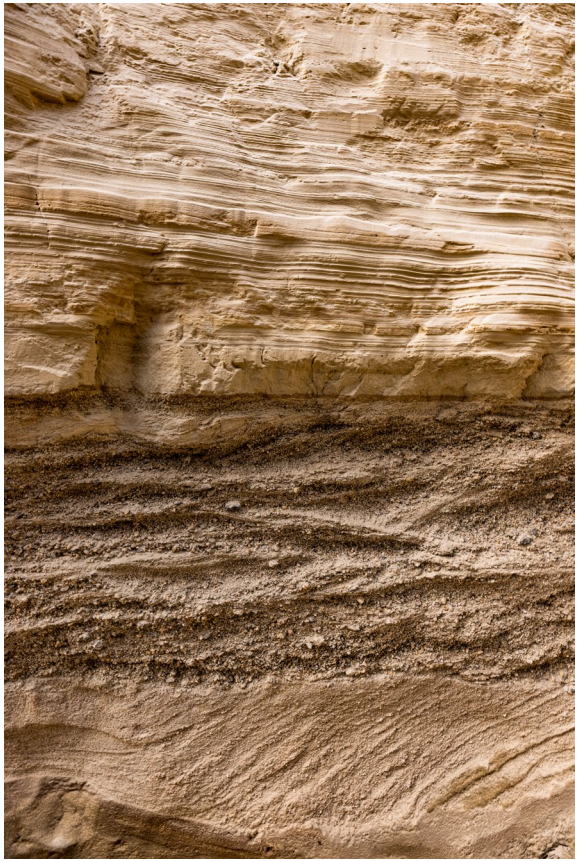




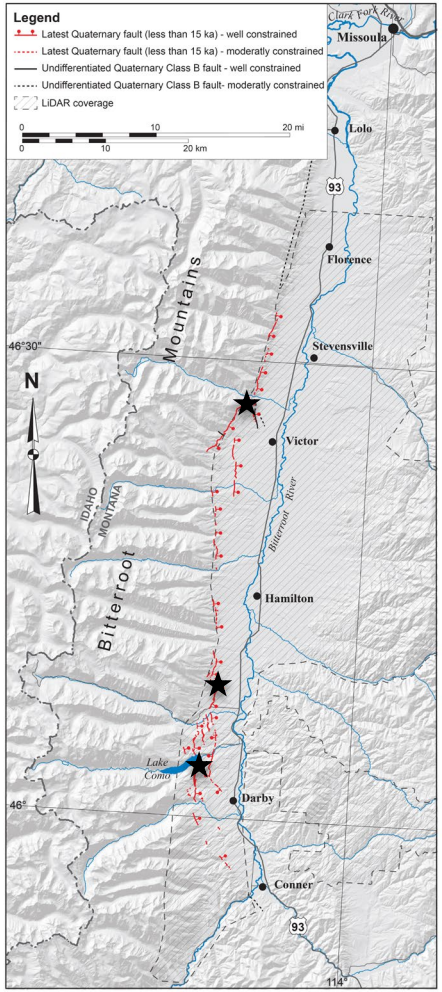


Late to post-Pinedale local lakes controlled by the Bitterroot fault?

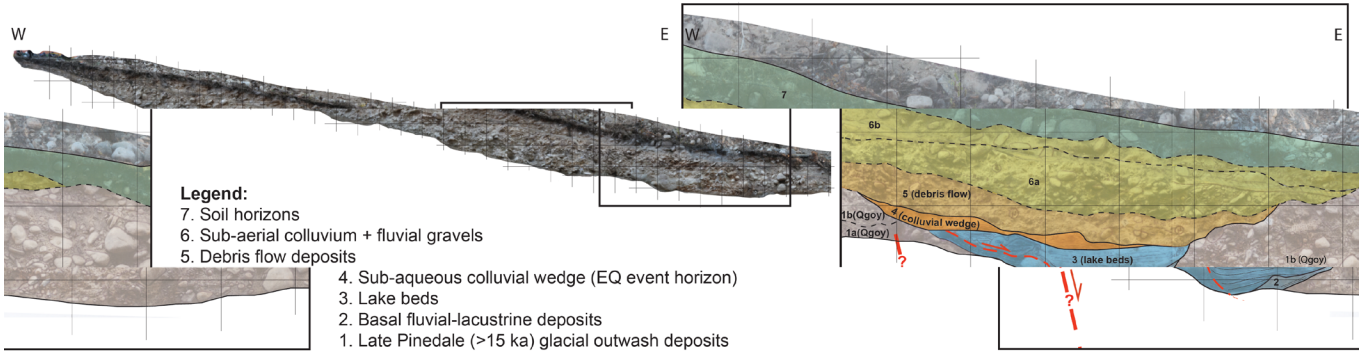




Camas Creek Trench site – September 2022

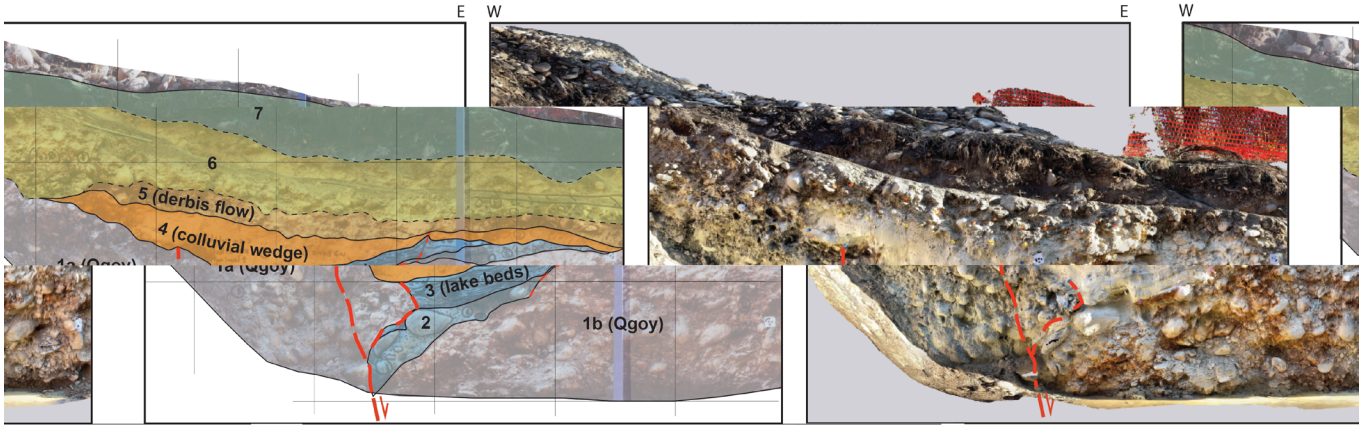


Camas Creek - Trench 1 south wall

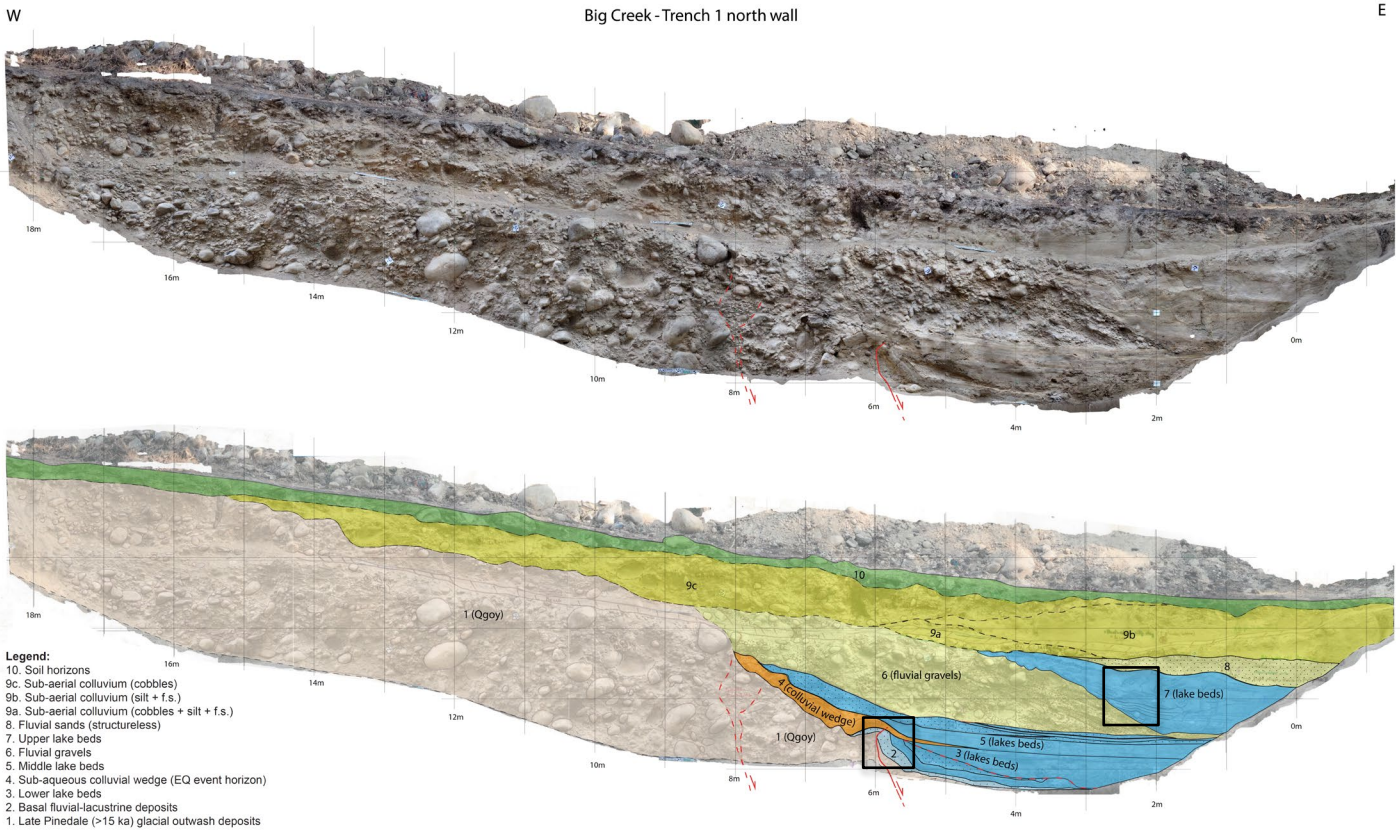


Legend:
7. Soil horizons
6. Sub-aerial colluvium + fluvial gravels
5. Debris flow deposits
4. Sub-aqueous colluvial wedge (EQ event horizon)
3. Lake beds
2. Basal fluvial-lacustrine deposits
1. Late Pinedale (>15 ka) glacial outwash deposits

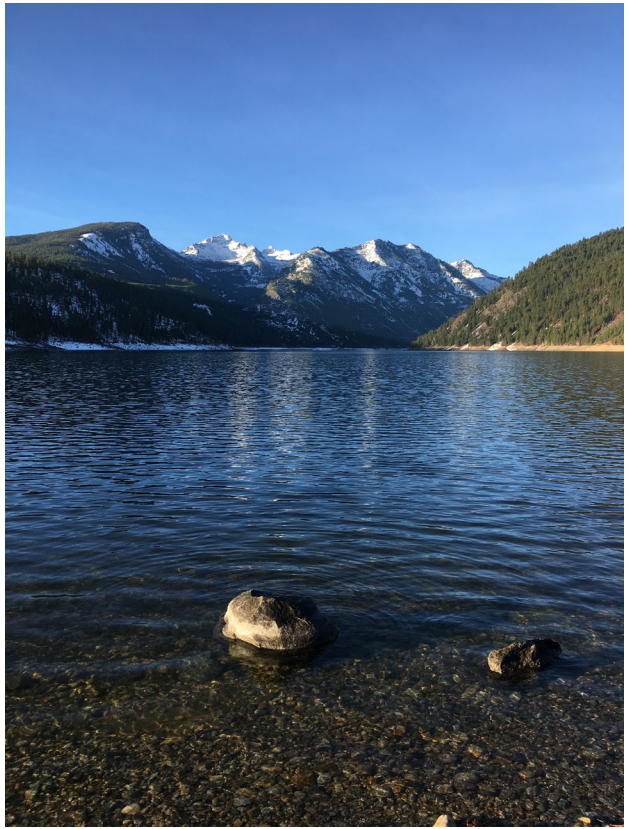
Camas Creek - Trench 2 south wall



Big Creek Trench site – September 2022

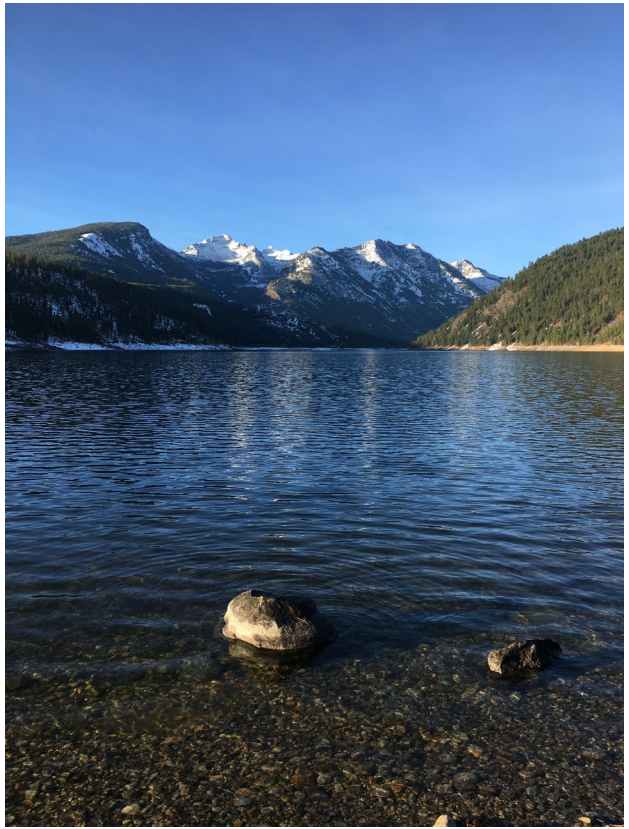


Key take away points



- New mapping of the Southern Bitterroot fault indicate multiple Quaternary fault scarps that offset Pinedale and Bull Lake glacial deposits.
- Structural and geomorphic map relations indicate both high angle and low angle fault models provide viable interpretations of subsurface fault geometry.
- ^{10}Be age results provide chronology of Pinedale glacial moraine deposits between ~15-17 ka, and glacial debris fans deposits between ~16-70 ka.
- Post Late Pinedale slip rates range between 0.2-0.3 mm/yr.
- Long-term slip rates (since ~140-110 ka) show larger range of 0.1-0.8 mm/yr.
- Seismic hazards models and empirical scaling relationships indicate an earthquake potential of Mw 7.2 for ~100 km long normal fault rupture, and assumes a high angle fault model.
- A low angle fault model could generate an earthquake of Mw >7.2 which poses significant potential seismic hazards for the Bitterroot-Missoula valleys.

Future work and research questions



- **Along strike variability and long-term slip rates:**
  - **More ^{10}Be samples are currently in queue on additional offset surfaces.**
  - **Extend detailed fault and quaternary mapping along-strike.**
  - **Test alternative structural models of High angle fault vs Low Angle fault.**

- **Paleo-earthquake chronology and segmentation of the Bitterroot fault (collaborating with USGS and Bureau of Reclamation):**
  - **Southern Bitterroot fault section (2 sites)**
  - **Northern Bitterroot fault section (1 site; awaiting new lidar for northern extent for more sites).**

Lake Como CHIRP Survey