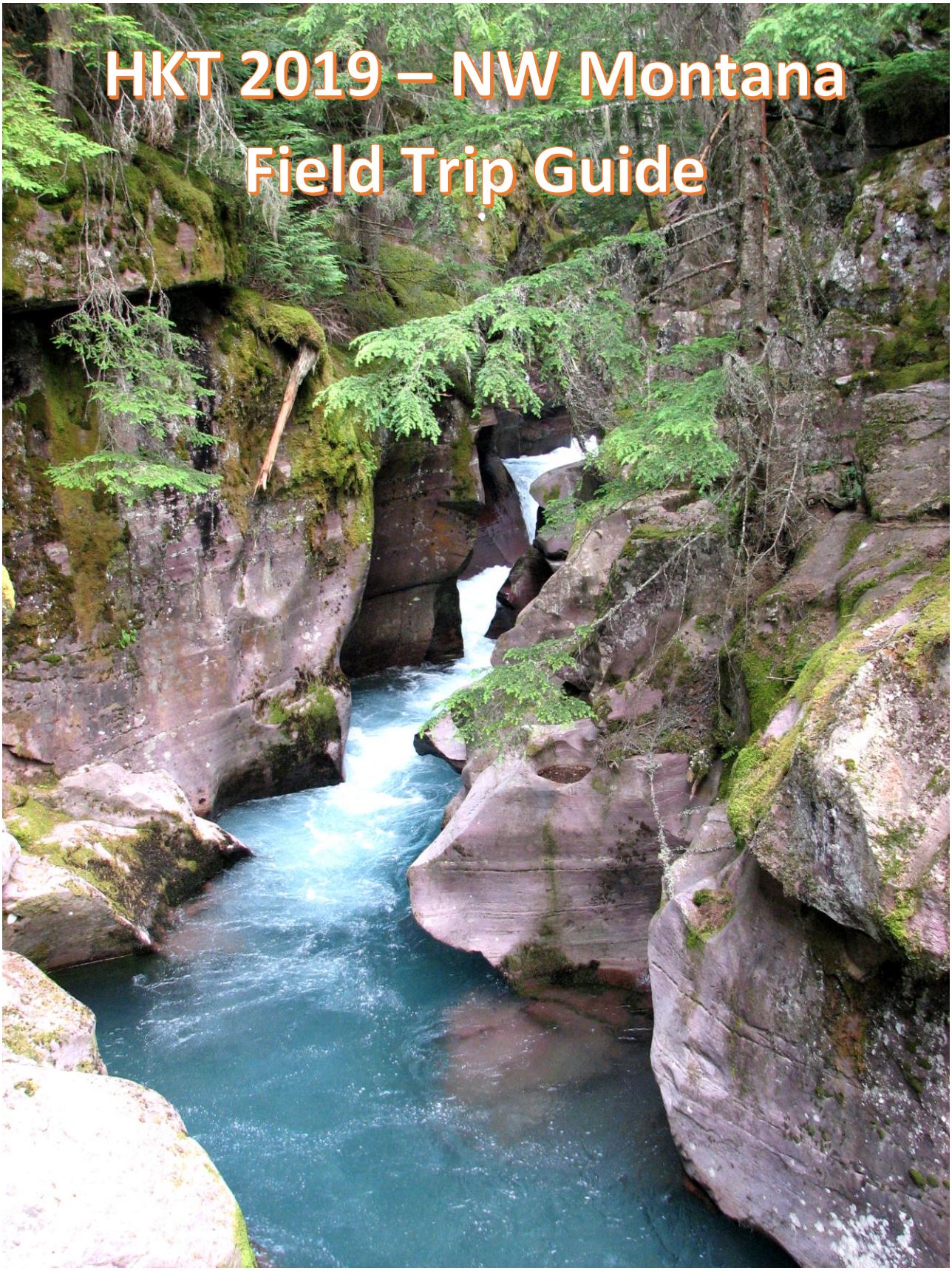
HKT 2019 – NW Montana Field Trip Guide



HKT 2019 (Bozeman): Preconference Field Trip Guide

Structural Geology and Tectonic History of Western Montana

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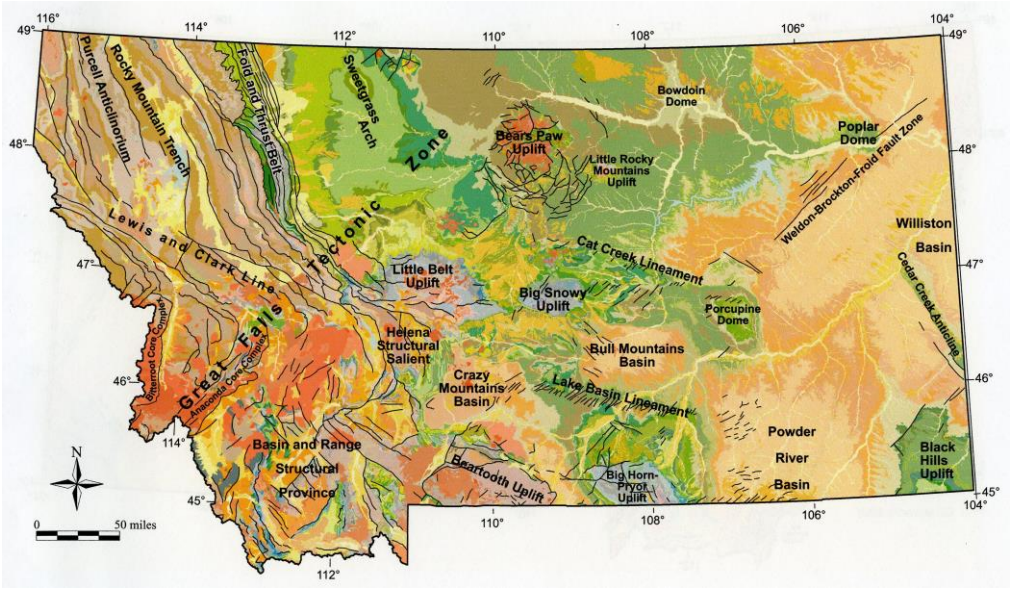
Overview:
Bozeman lies at the complex tectonic intersection of three major North American Phanerozoic tectonic provinces—the Sevier fold-thrust belt, Laramide province, and northern Basin and Range (Northern Intermountain Seismic Belt). These provinces overlap Precambrian rocks, including the Mesoproterozoic Belt Basin and a Paleoproterozoic collisional suture zone involving Archean cratons. The pre-conference field trip will investigate outcrop to mountain-scale exposures of fold-and-thrust belt structures in the Northern Rocky Mountains near Glacier National Park, including the Sawtooth imbricate belt south of Glacier NP. We will also see Late Cretaceous arc-derived igneous rocks (including the massive Boulder batholith), Laramide basement-cored uplifts, and mid- and late Cenozoic extensional structures that overlap older contractional structures (e.g., Eocene metamorphic core complexes, and Miocene to recent Basin and Range structures). Topics covered will be diverse, ranging from the Precambrian and Phanerozoic tectonic evolution of the Central and Northern U.S. Rockies, to Pleistocene glaciations and mega-glacial lake outburst floods (GLOFS).



Source: Montana Bureau of Mines and Geology, Geologic Map of Montana Booklet (2007)

Field trip safety rules:

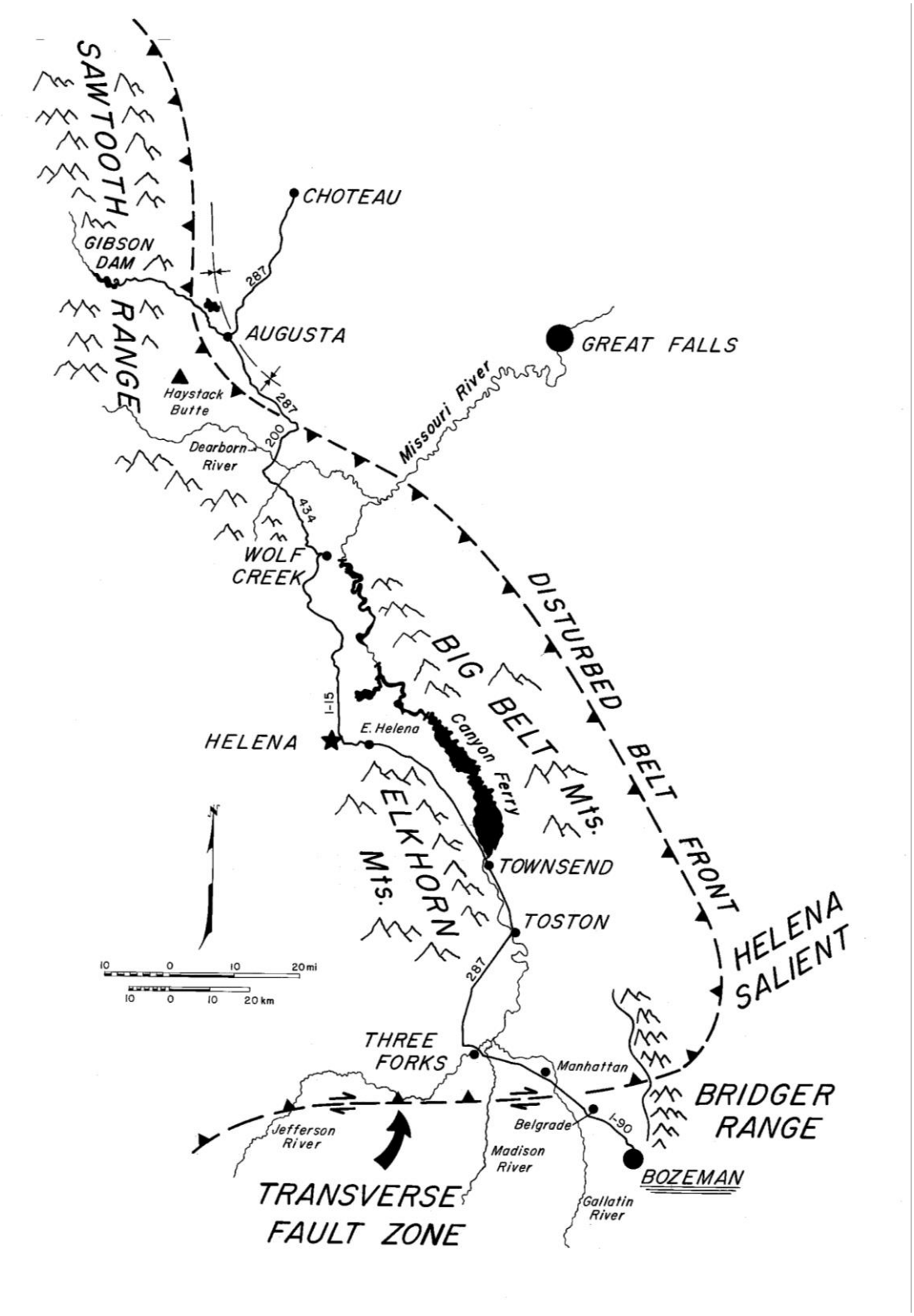
1. Wear seatbelts at all times in the vehicles.
2. Listen to all instructions from your drivers before exiting the vehicles.
3. Please do not stand on or near active roadways with traffic; follow your field trip leaders and stay well away from roads.
4. If we do have to cross a road, please do so quickly and never stand or linger in the road, and be aware of cars/trucks at all times.
5. Some stops will involve short hikes; please walk carefully and do not stray from the group very far.
6. If you are examining rocks on a slope, watch your footing. Avoid climbing up slopes with loose rocks that can roll or fall on people below.
7. Please listen to and follow all instructions from your field trip leaders.
8. Please respect the environment and do not litter or disturb plants and animals. There may be rattlesnakes at some stops (and bears at others), so follow instructions of your field trip leaders.
9. Please – no alcohol or smoking in the vehicles or during the field trip (evenings are excluded).
10. We will conduct a "head count" for each vehicle before departing from a stop.
11. **SAFETY FIRST – at all times**

Day #1 – Sunday, June 2, 2019

Overview:
Depart Bozeman at 0800, heading west on Interstate 90 (I-90) towards Butte, Montana. Today, we will travel north to the beautiful Sun River Canyon along the "Rocky Mountain Front Ranges." This route will traverse the Helena salient of the Sevier fold-and-thrust belt in western Montana, which underwent orogenic shortening during the Late Cretaceous and Paleogene. The "basin and range" topography seen today is the result of several episodes of Cenozoic crustal extension (orogenic collapse), beginning in the Eocene around 50 million years ago. North of the Helena salient (north of Wolf Creek) we will traverse the "foothills imbricate belt" comprised of highly deformed Cretaceous sedimentary rocks immediately east of the Rocky Mountain Front Ranges. At Augusta, Montana, we will turn onto a dirt road that will take us into Sun River Canyon, where we will enjoy a beautiful traverse through a westward-steepening stack of thrust sheets involving Cambrian through Cretaceous sedimentary rocks. Weather and time permitting, we will conclude our day with a short hike along the north shore of Gibson Reservoir for a closer look at thrust-stacked Paleozoic rocks. We will spend the night at rustic Sun Canyon Lodge and hopefully enjoy a nice campfire in the heart of the Northern Rockies.

Note #1: *Unless noted otherwise, all geologic maps shown below are from the Montana Bureau of Mines and Geology in Butte, Montana.*

Note #2: *We may, at the discretion of the field trip leaders, stop at some other locations along our route that are not "numbered stops" as listed below. We will keep everyone informed about where we are and what we are seeing, but we want to have some flexibility in our stop locations. Thanks for understanding.*

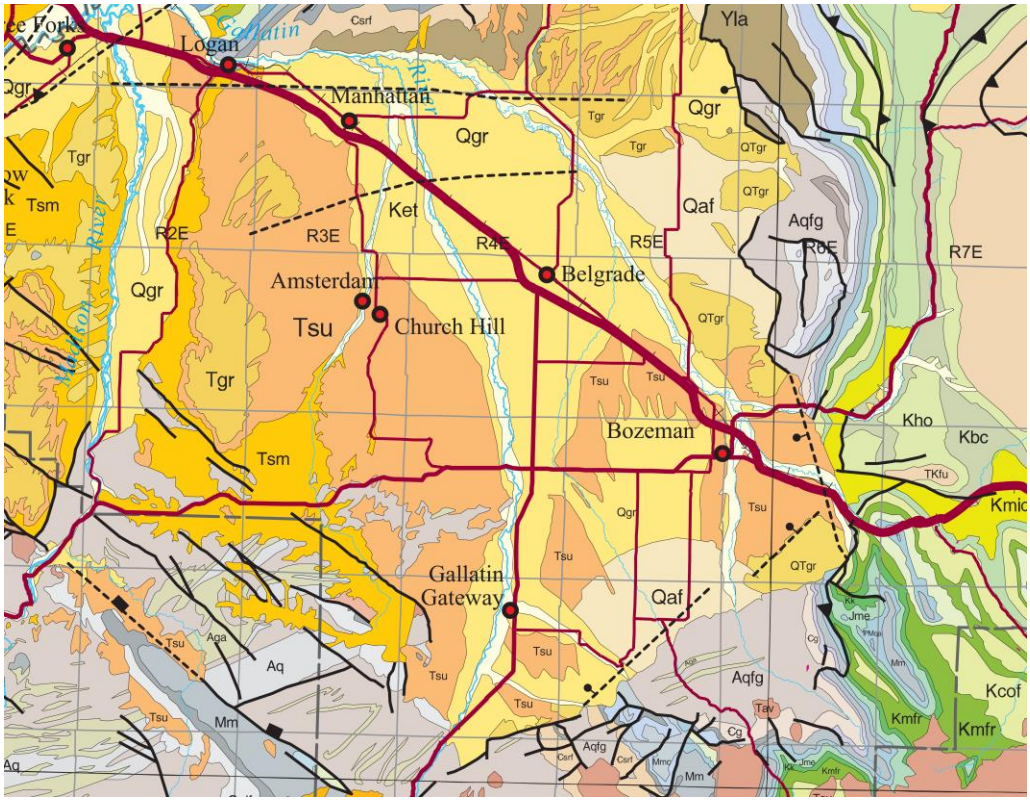


Field trip route from Bozeman, MT to the Sawtooth Range and Sun River Canyon (Gibson dam and reservoir) along the Rocky Mountain Front Ranges. (Map by D. Lageson)

DEPARTURE – 0800

Location: Bozeman, MT – Gaines Hall Service Drive (loading dock and parking area behind Gaines Hall)

Purpose: Introductions, brief overview of safety rules, load-up and hit the road!



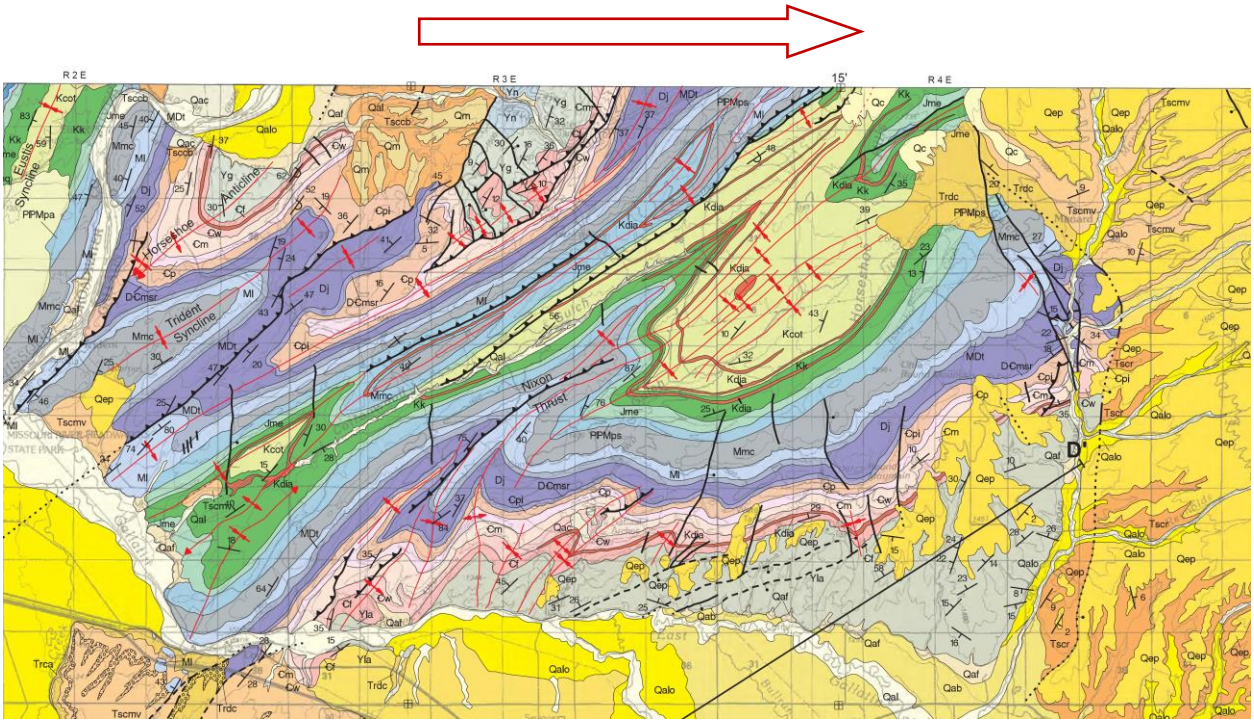
(MBMG Geologic Map of Montana; 1:500,000)

Montana State University (foreground) and Bozeman; Bridger Range in background.

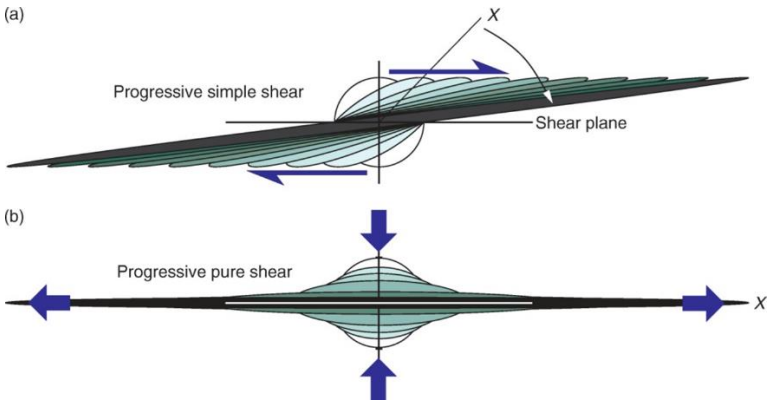
STOP #1

Location: Logan, MT

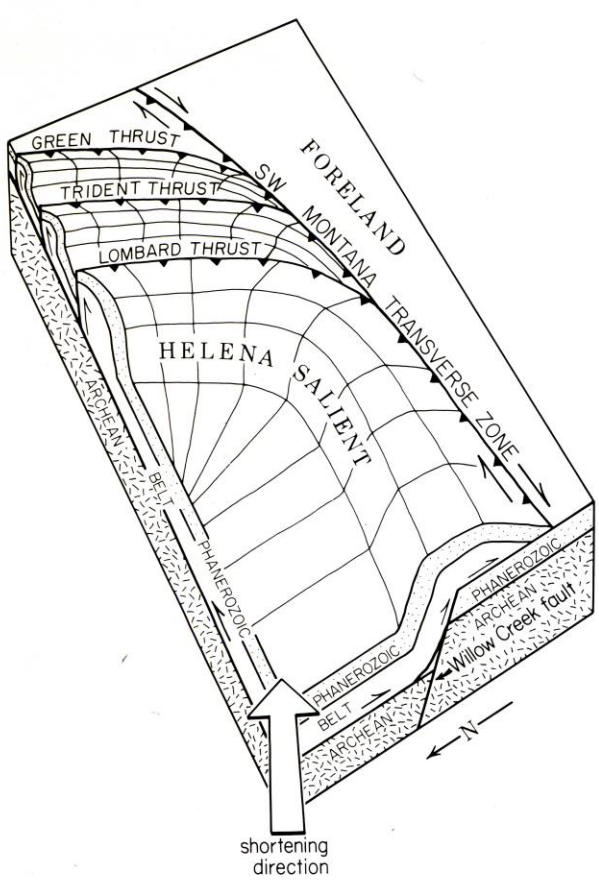
Purpose: Overview of the south margin of the Helena salient of the Sevier fold-and-thrust belt, as well as an arm-waving overview of the Gallatin Valley and greater Three Forks Basin. This location is on the Perry Line (SW Montana transverse fault zone), forming the south margin of the Mesoproterozoic Belt Basin, reactivated as the south margin of the Helena salient of the Sevier fold-and-thrust belt. Contractional structures comprise a regional-scale transverse lateral ramp along the old Perry Line.

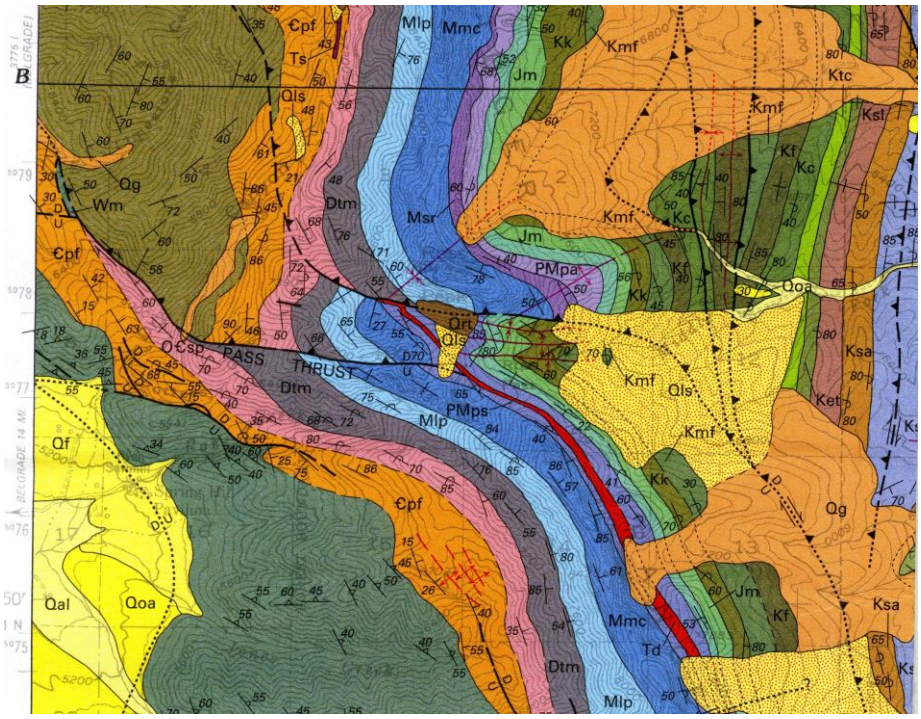


(MBMG Geologic Map of the Bozeman 30' X 60' quadrangle; 1:100,000)



(Source: Fossen, H., 2016, Structural Geology: Cambridge University Press, p. 47)



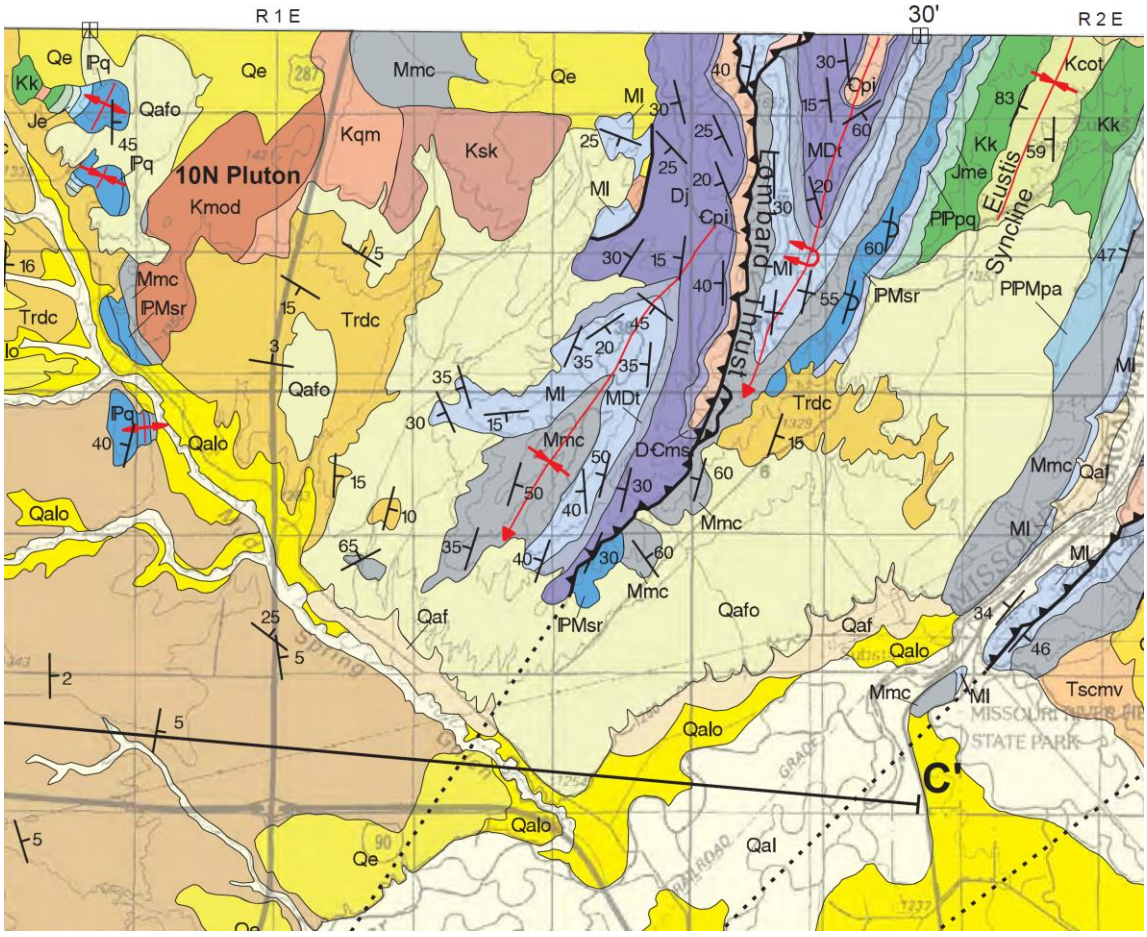


(**Top:** Transverse lateral ramp, from Schmidt, O'Neill and Brandon, 1988, GSA Memoir 171, p. 181; **Bottom:** Ross Pass fault zone in the central Bridger Range, from Skipp, Lageson and McMannis, 1999, USGA Geologic Investigations Series I-2634.)

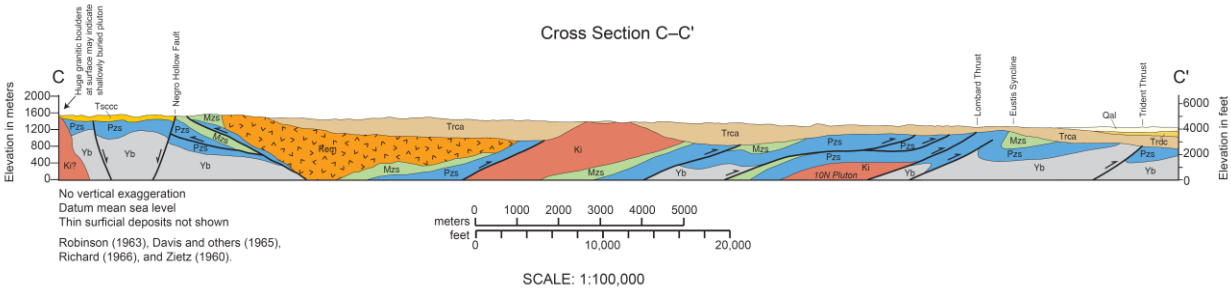
STOP #2

Location: Wheat Montana at Junction of I-90 and Highway 287

Overview: Quick restroom break, and then continue northbound on HWY 287



(MBMG Geologic Map of the Bozeman 30' X 60' quadrangle; 1:100,000)

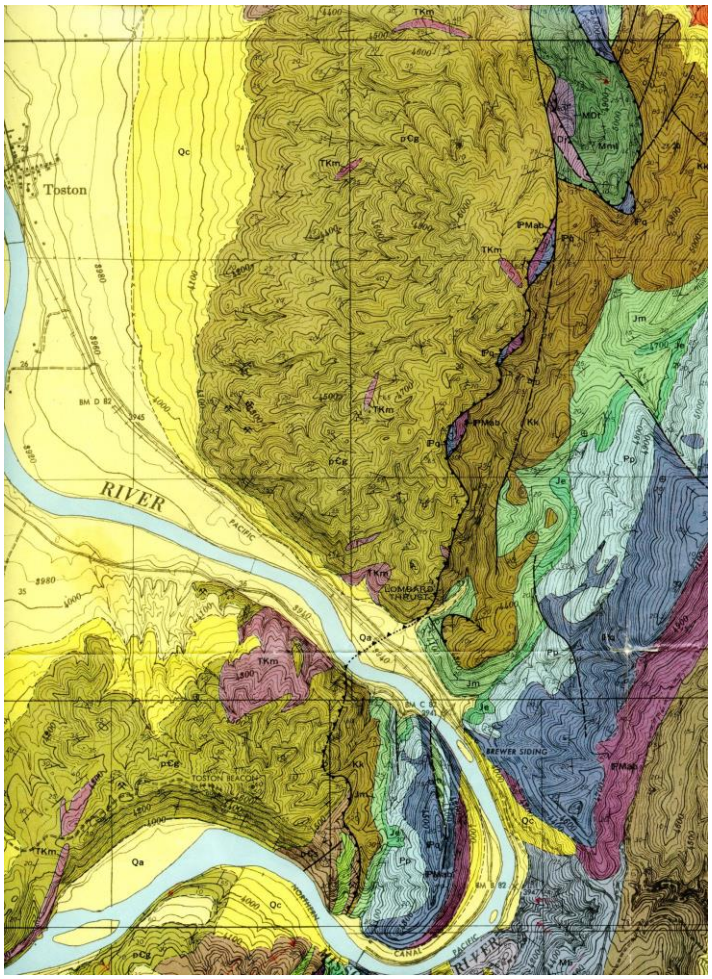


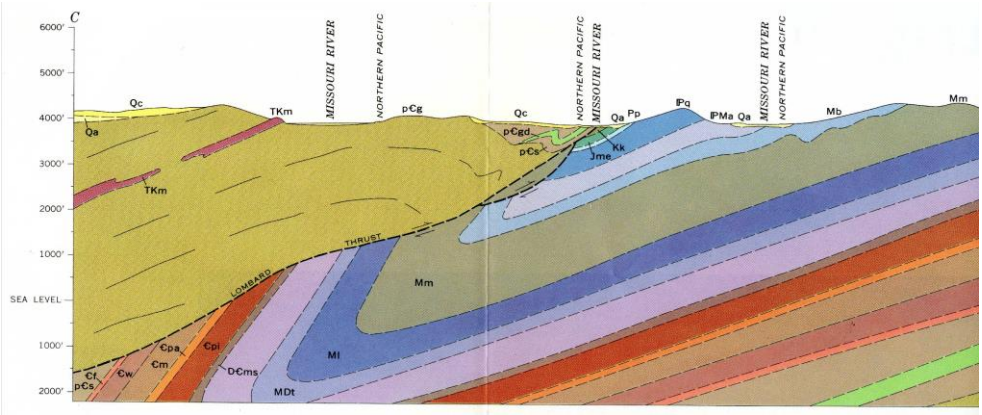
(Cross-section C-C' from MBMG Geologic Map of the Bozeman 30' X 60' quadrangle; 1:100,000)

STOP #3

Location: Trace of the Eldorado-Lombard thrust system near Toston, MT.

Overview: The Lombard thrust is a major out-of-sequence thrust fault that carries Mesoproterozoic strata of the Belt Supergroup (Yg at this location) and the Cretaceous Boulder batholith in its hanging wall to the west. Watch for rattlesnakes – this locality is full of them!



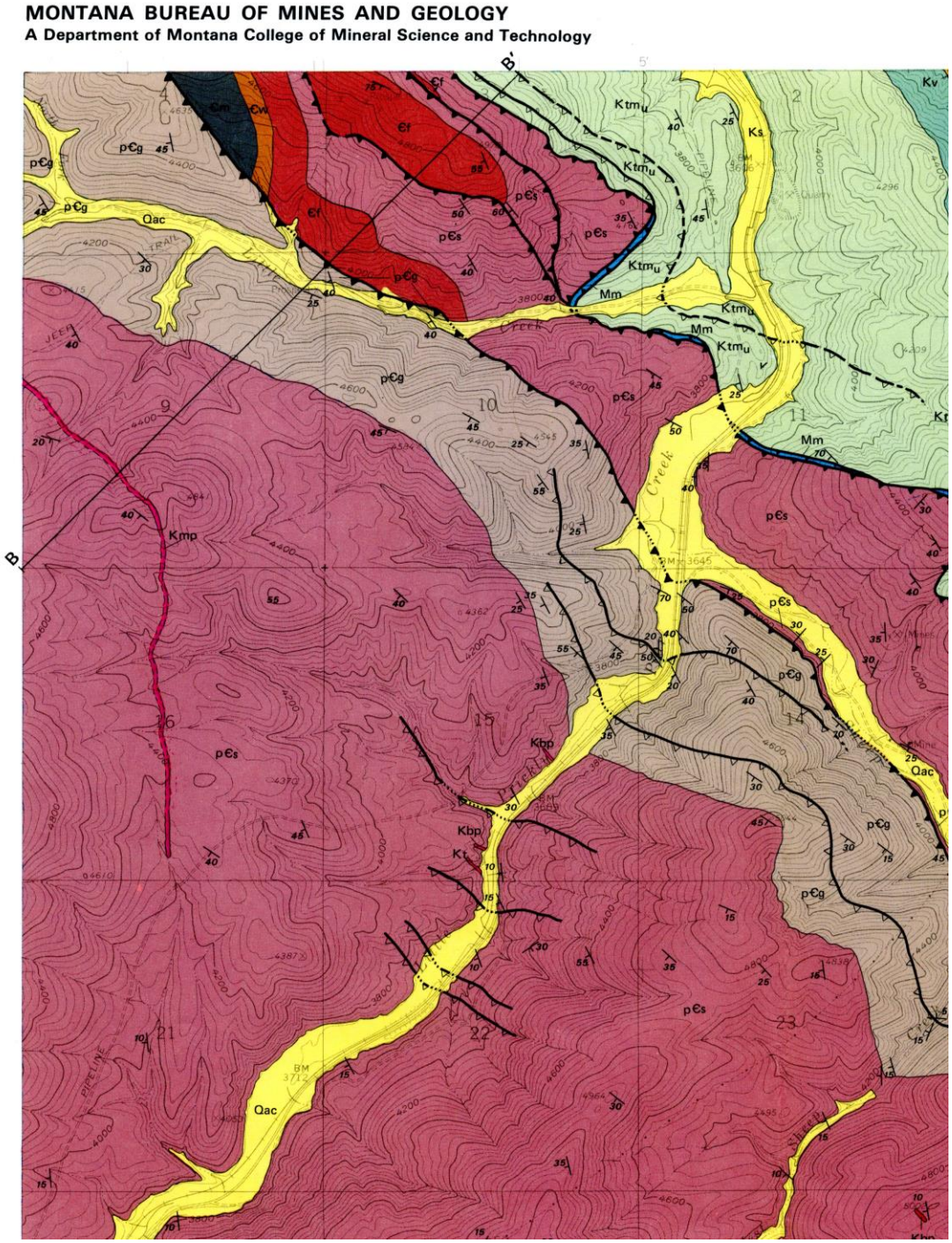


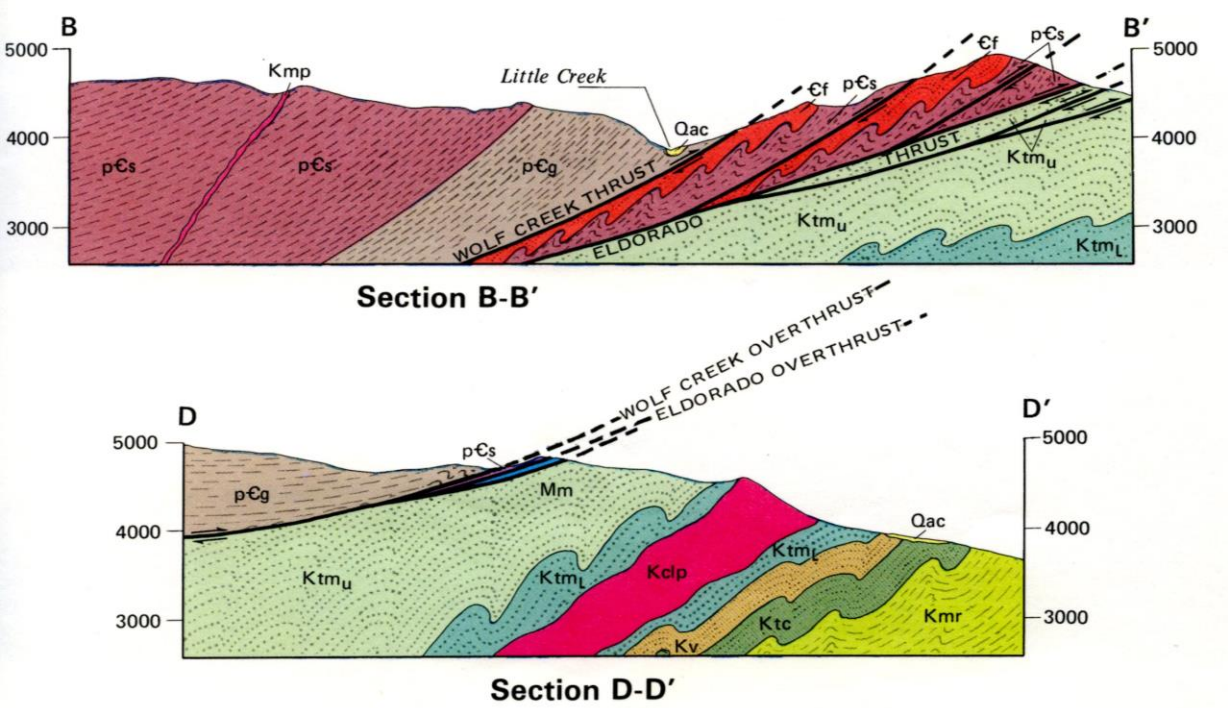
(Map and cross-section from Geologic Map of the Toston quadrangle, Southwestern MT; USGS Map I-486, 1:24,000)

STOP #4

Location: Little Prickly Pear Canyon along I-15 northbound

Overview: Restroom break and geologic overview of Mesoproterozoic Belt Supergroup and Sevier fold-and-thrust belt structures along the Rocky Mountain Front.





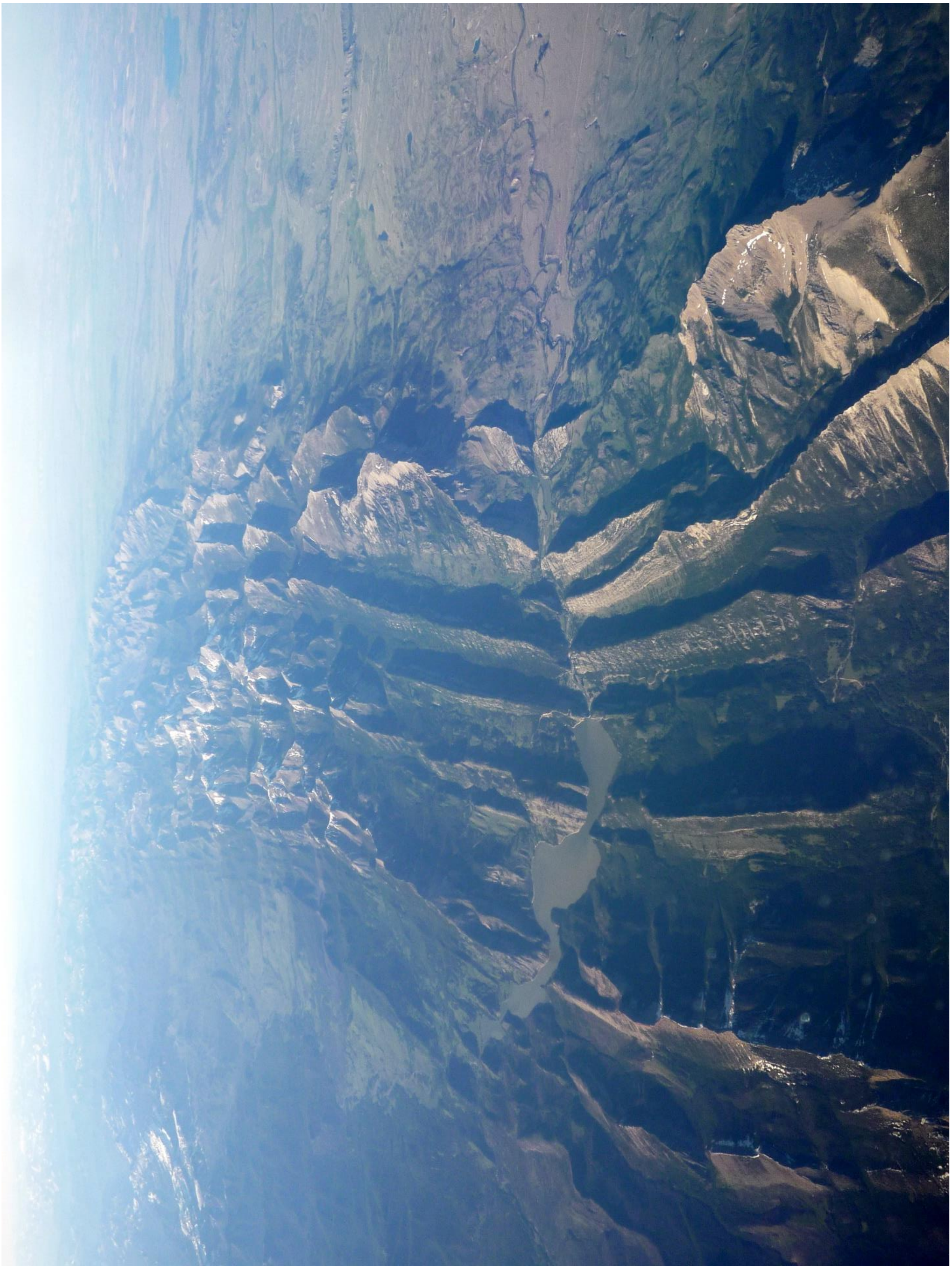
(Map and cross-section from MBMG Geologic Map 26, Sheep Creek & Rattlesnake Mtn. quadrangles, by M. Bregman, 1981)

STOP #5

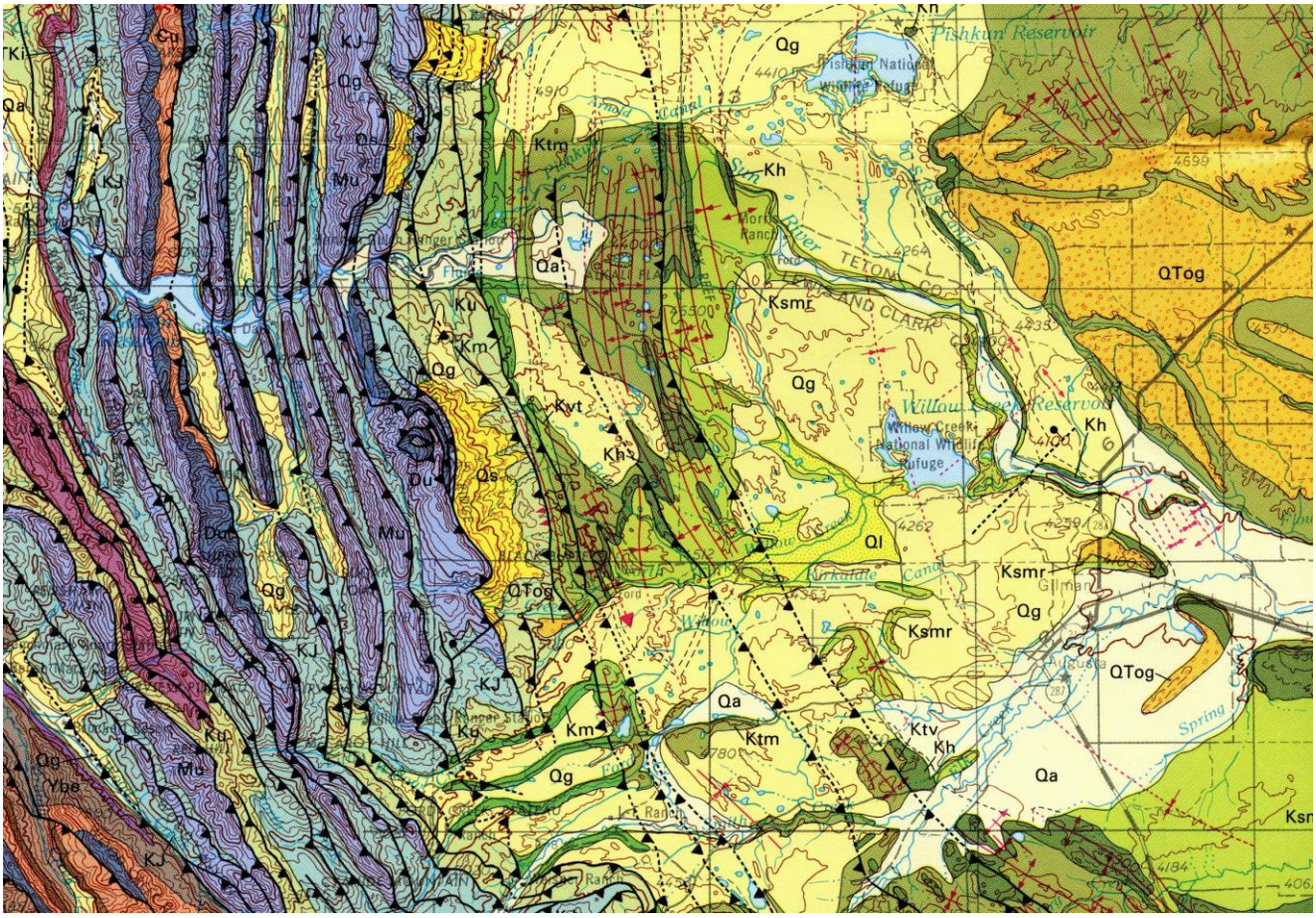
Location: Upright box and chevron folds in Cretaceous rocks within the foothills imbricate belt

Overview: This brief stop is within the foothills deformed belt, east of the Rocky Mountain Front Ranges of the fold-and-thrust belt. The sedimentary rocks in this belt are tightly folded, imbricated and internally thinned and thickened, resulting in predominantly Ramsay class 1-C folds. Units involved include the Lower Cretaceous Kootenai and Blackleaf Formations (undivided).

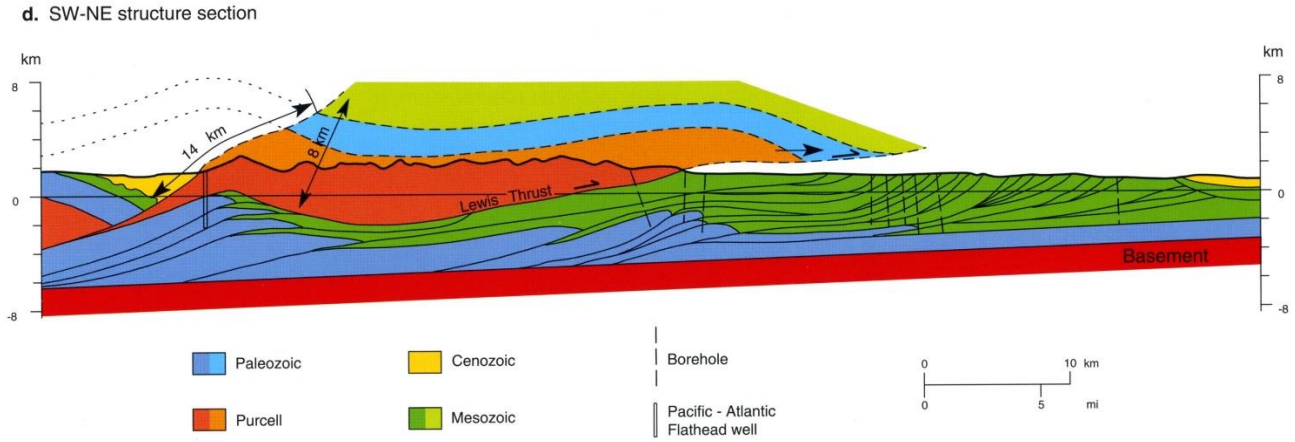
(Photo by D. Lageson – circa 1980s)



(The Sawtooth Range / Rocky Mountain Front: https://commons.wikimedia.org/wiki/File:2009-0603-10-Air-RockyMountainFront.jpg)



(Map cropped from USGS Map I-1300, Geologic & Structure Map of the Choteau 1° x 2° quadrangle, Montana, by Mudge et al.)



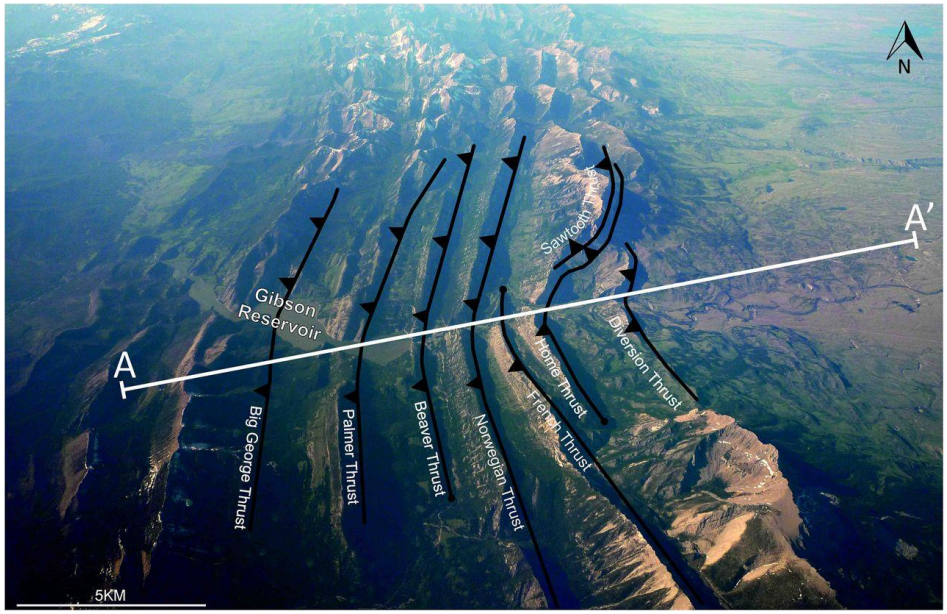
(From: Geological Atlas of the Western Canada Sedimentary Basin, Canadian Society Petroleum Geologists & Alberta Research Council, 1994, p. 18)

STOP #6

Location: Diversion thrust at entrance to Sun River Canyon

Overview: Construction of Diversion dam was to provide irrigation water to farmers and ranchers out on the high plains. The dam is located in a narrow canyon in the Sun River member of the Mississippian Castle Reef Dolomite. The Diversion thrust dies out a short distance to the north and south through lateral displacement transfer. Black shales and thin sandstone beds of the Cretaceous Blackleaf Formation (Vaughn and Taft Members) are visible in the footwall right below the thrust.

(Photo by D. Lageson)



(From: Dave J. McCarthy, Patrick A. Meere and Michael S. Petronis
Geological Society, London, Special Publications, 487, 30 January 2019, https://doi.org/10.1144/SP487.6)

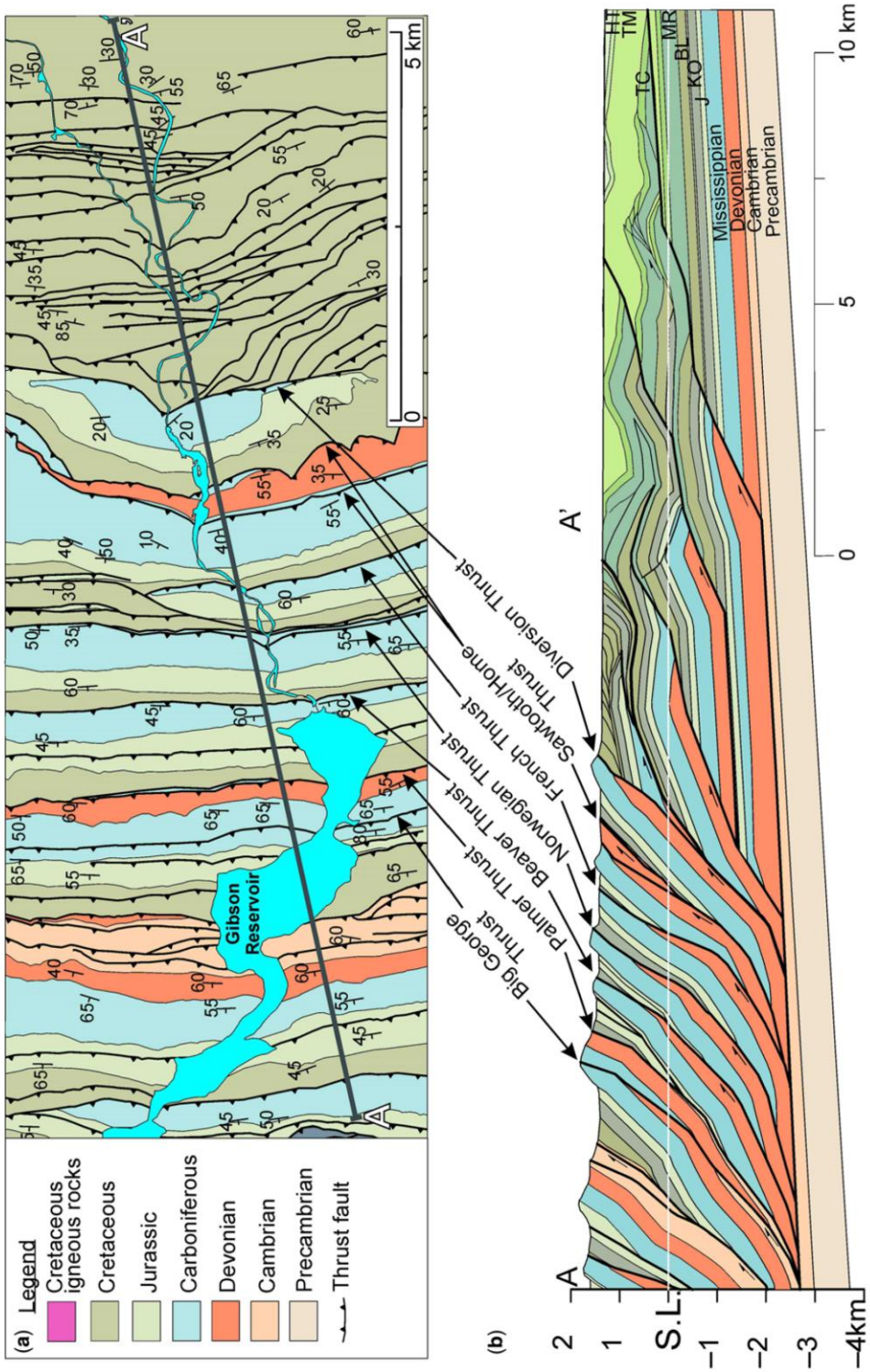


Fig. 3. (**a**) Geological map of the Sun River area (redrawn from Mudge 1982). (**b**) Cross-section of line indicated in above map as A–A′ (redrawn from Fuentes *et al.* 2012). J, Jurassic; KO, Kootenai Formation; BL, Blackleaf Formation; MR, Marias River Shale Formation; TC, Telegraph Creek and Virgelle Formation; TM, Two Medicine Formation; Horsethief and Bearpaw Formation.

(From: Dave J. McCarthy, Patrick A. Meere and Michael S. Petronis
Geological Society, London, Special Publications, 487, 30 January 2019, https://doi.org/10.1144/SP487.6)

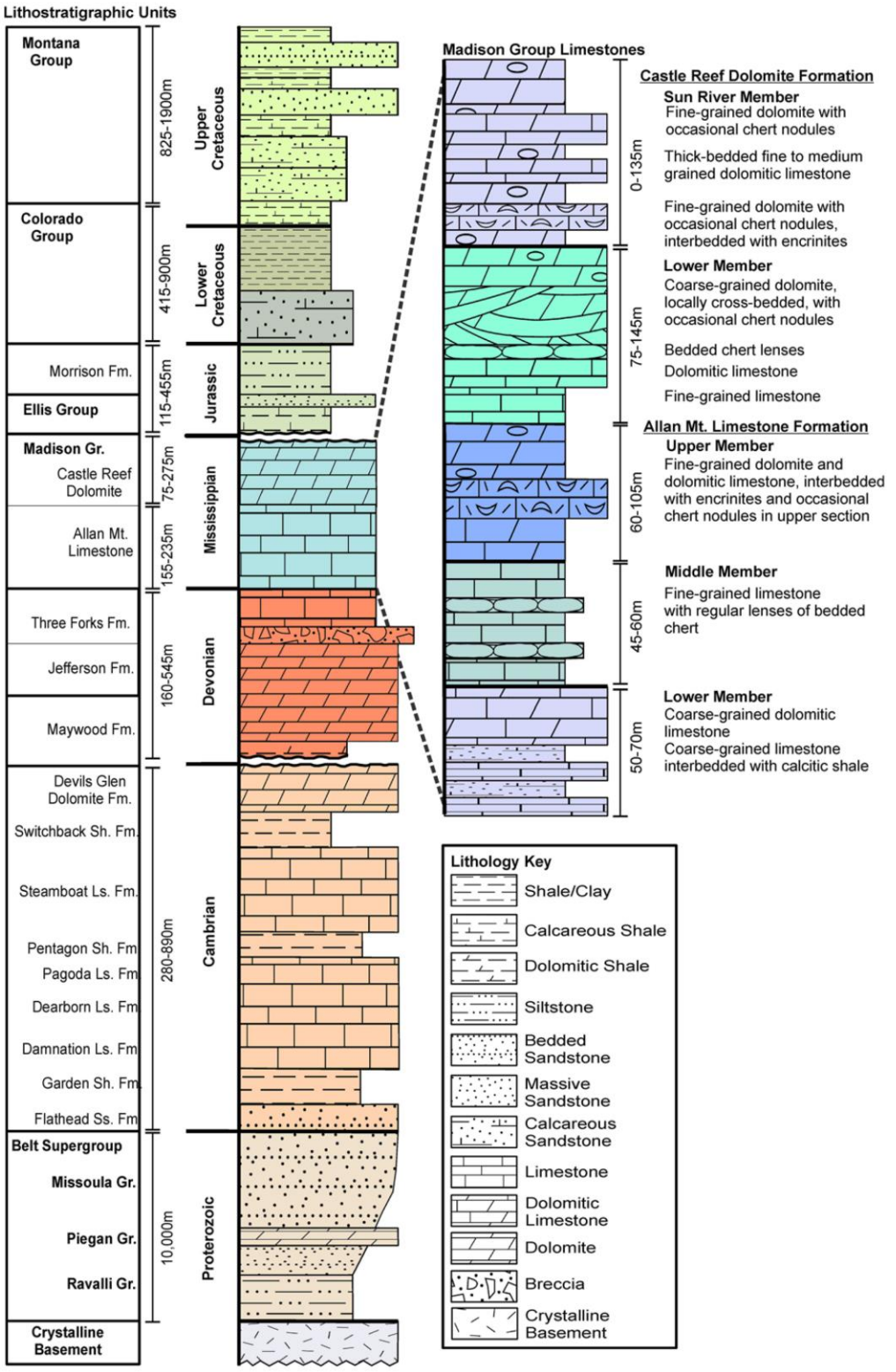


Fig. 4. Stratigraphic succession encountered in the Sawtooth Range (modified from Mudge 1972*a*; Holl & Anastasio 1992; Fuentes *et al.* 2012).

(From: Dave J. McCarthy, Patrick A. Meere and Michael S. Petronis
Geological Society, London, Special Publications, 487, 30 January 2019, https://doi.org/10.1144/SP487.6)

STOP #7

Location: French thrust fault

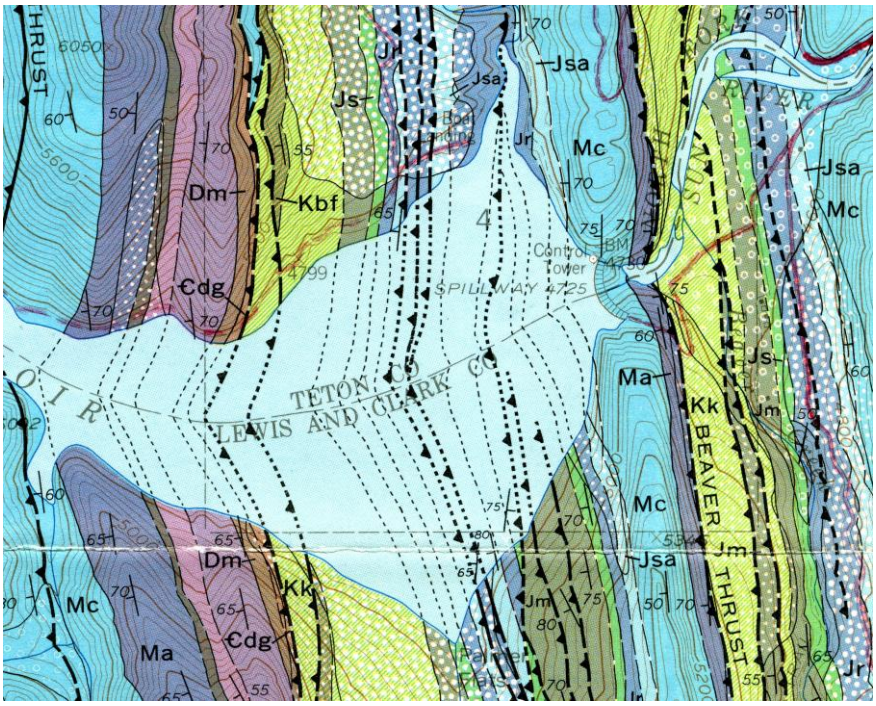
Overview: Beautiful road-cut exposure of the French imbricate thrust fault in Sun River Canyon. Hanging wall consists of Mississippian Castle Reef Dolomite and footwall is the Lower Cretaceous Kootenai Formation. Note the syncline in the hanging wall, as well as damage zone adjacent to the fault.

(Photos by D. Lageson)

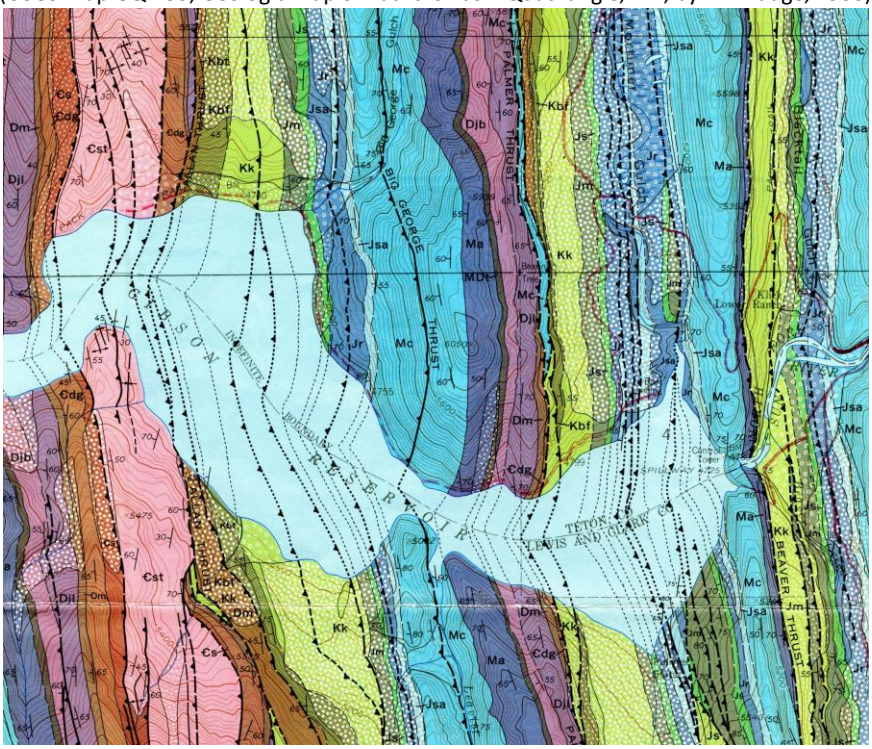
STOP #8

Location: Hanging wall of Beaver thrust at overlook directly above Gibson dam

Overview: The Beaver thrust carries Mississippian through Lower Cretaceous rocks in its hanging wall. The Mississippian Castle Reef Dolomite forms the resistant ridge on which this spectacular overlook is located. Tectonic disjunctive spaced cleavage is common in carbonate rocks throughout the Sawtooth Range.



(USGS Map GQ-453, Geologic Map of Patricks Basin Quadrangle, MT, by M. Mudge, 1966)



Day #2 – Monday, June 3, 2019

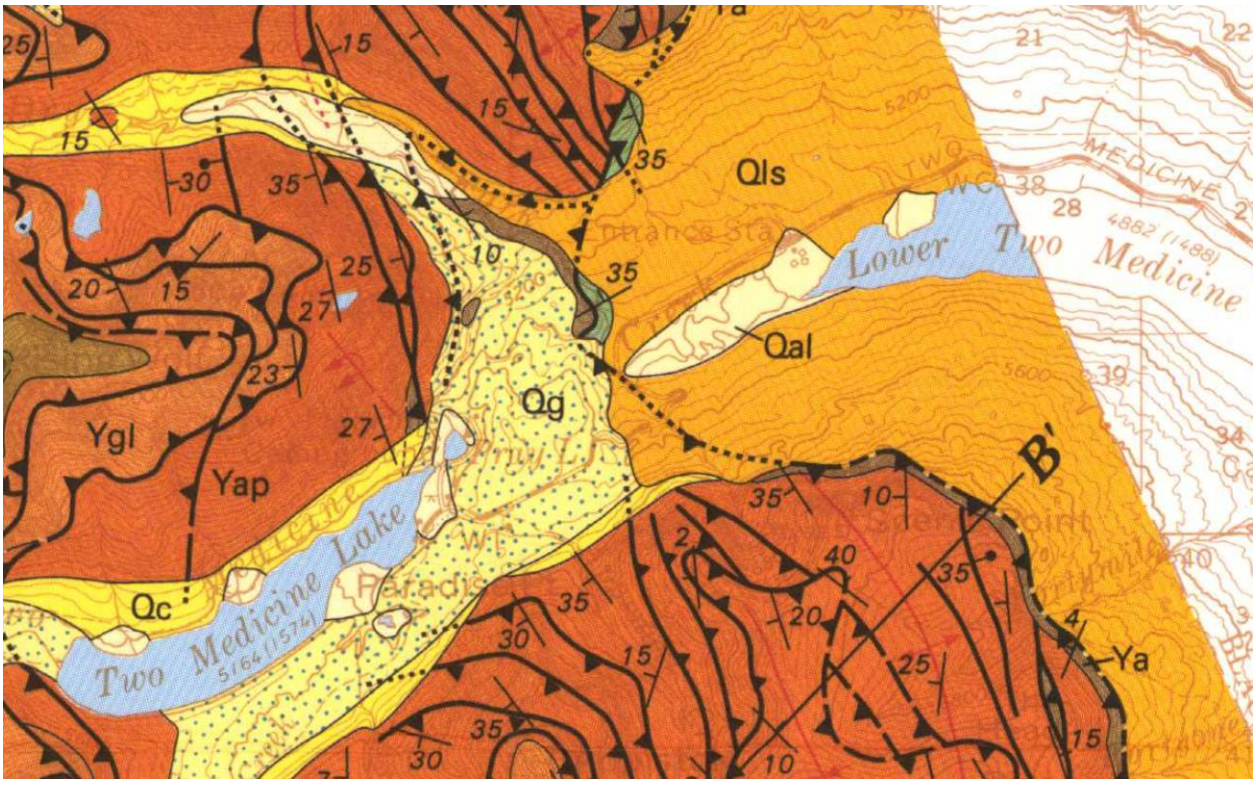
Overview:
After breakfast, depart Sun Canyon Lodge at 0800 and drive back to Augusta, Montana. Continue northbound on Highway 287 to Choteau, Bynum, Dupuyer and Browning (home of the Blackfeet Indian Reservation). Near East Glacier, we will see the world-famous Lewis thrust fault up-close, placing Mesoproterozoic Belt Supergroup rocks over Cretaceous marine shale and sandstone. At Saint Mary, we will cross over Glacier National Park at Logan Pass on the famous "Going-to-the Sun" road, descending to Lake McDonald and our lodging for the night at Apgar, near West Glacier.

Day 2 – STOP #1
Location: South of Choteau
Overview: Panoramic view of the Cretaceous Two Medicine Formation, a world-famous dinosaur-bearing unit in western Montana. The dinosaur nesting site ("Egg Mountain") discovered many years ago by Jack Horner is off in the distance.

Day 2 – STOP #2
Location: East Glacier Lodge
Overview: Brief rest stop to view this spectacular old National Park Service Lodge.

Day 2 – STOP #3
Location: Lewis thrust at falls between Upper and Lower Two Medicine Lake (Running Eagle Falls, also known as Trick Falls). The waterfall is named for Pitamakan, or Running Eagle, a female warrior leader of the Blackfeet Nation in the early 1700s, who experienced a four-day vision quest in the mountains high above the falls. Running Eagle led war parties on many highly successful raids, and was the only woman in the Blackfeet tribe ever to do so, or to be given a man's name.
Overview: This locality offers a close-up view of the famous Lewis thrust, placing Mesoproterozoic rocks over Cretaceous strata. Belt rocks in the hanging wall are highly imbricated.

Hanging wall rocks are the Altyn Formation, which has been drastically truncated at this locality by the Lewis thrust. The Altyn consists of light-gray to brownish-yellow dolomite with common stromatolites; asphaltic veins are common near the Lewis thrust contact.



(USGS Map I-1508-F, Geologic Map of Glacier National Park, by James Whipple, 1992)

(https://www.alltrails.com/trail/us/montana/running-eagle-falls-trail)

Day 2 – STOP #4

Location: From St. Mary Lake, we will have multiple roadside stops along the east side of Going-to-the-Sun (be extra vigilant of car traffic)

Overview: This spectacular road traverses the central part of Glacier National Park from the Lewis thrust fault on the east, to a large extensional normal fault on the west at Lake McDonald. In between, we will travel up-section from the Lewis thrust through the Altyn, Appekunny, Grinnell, Empire, Helena (Siyeh) + Purcell sill, and Snowslip Formations of the Mesoproterozoic Belt Supergroup.

(https://upload.wikimedia.org/wikipedia/commons/4/43/Going-to-the-Sun_Road.jpg)

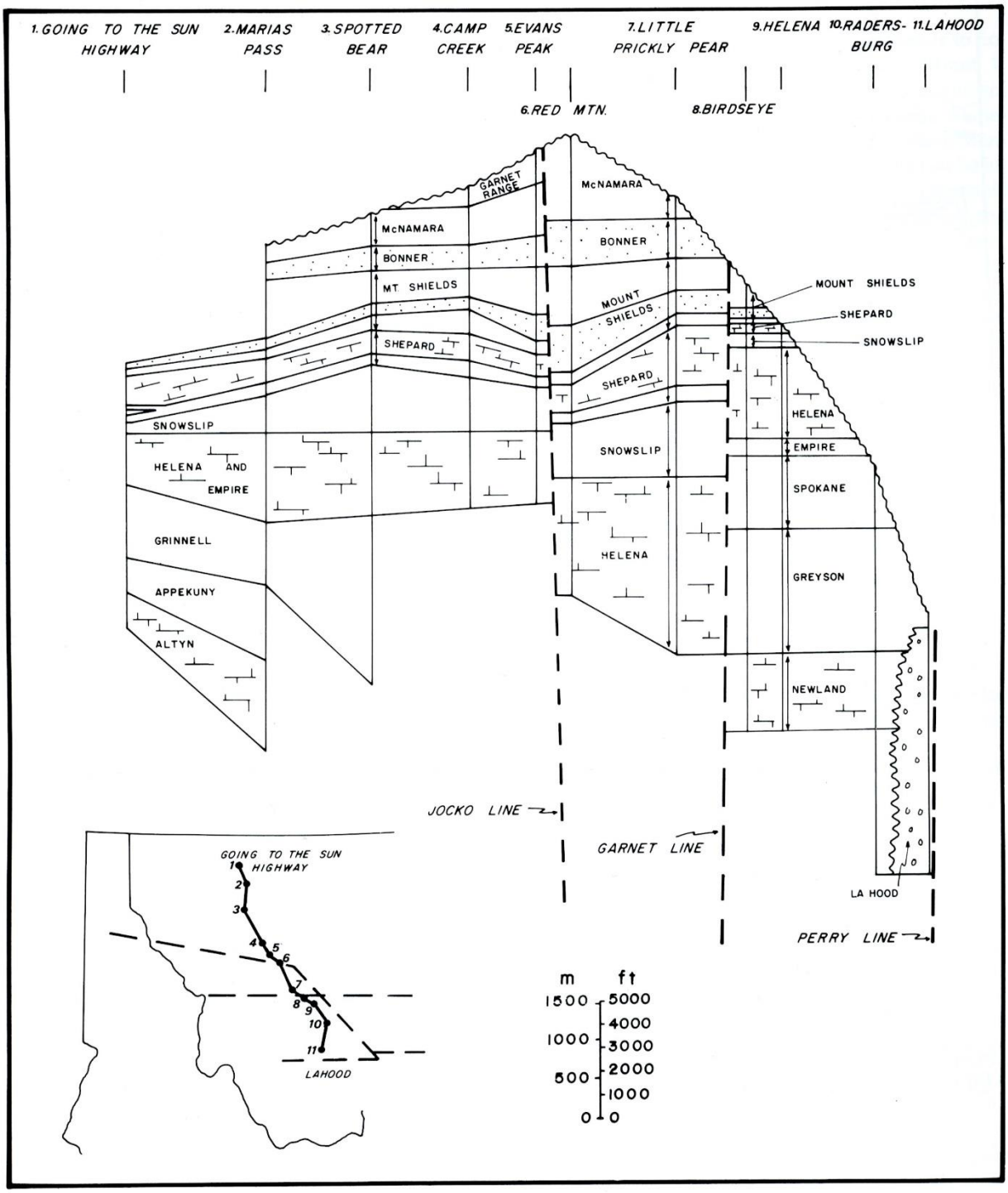
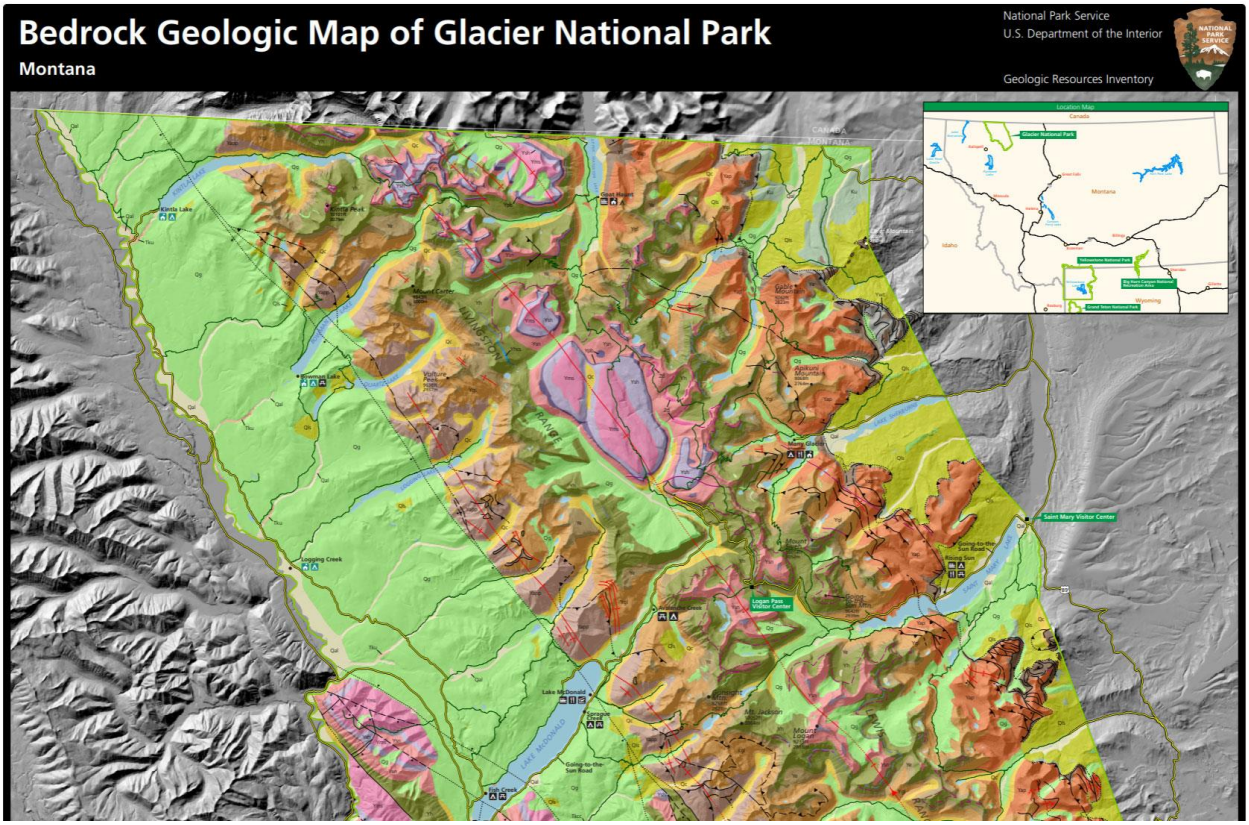


Figure 3—Inferred Proterozoic structural cross section from Glacier National Park to LaHood, Montana, showing down-to-the-south growth faulting along the Jocko line and down-to-the-north growth faulting along the Garnet line bounding the Ovando graben block. Faulting along the Perry line was down-to-the-north. Pre-Flathead Formation erosion cut downward through the section toward the southern part of the basin.

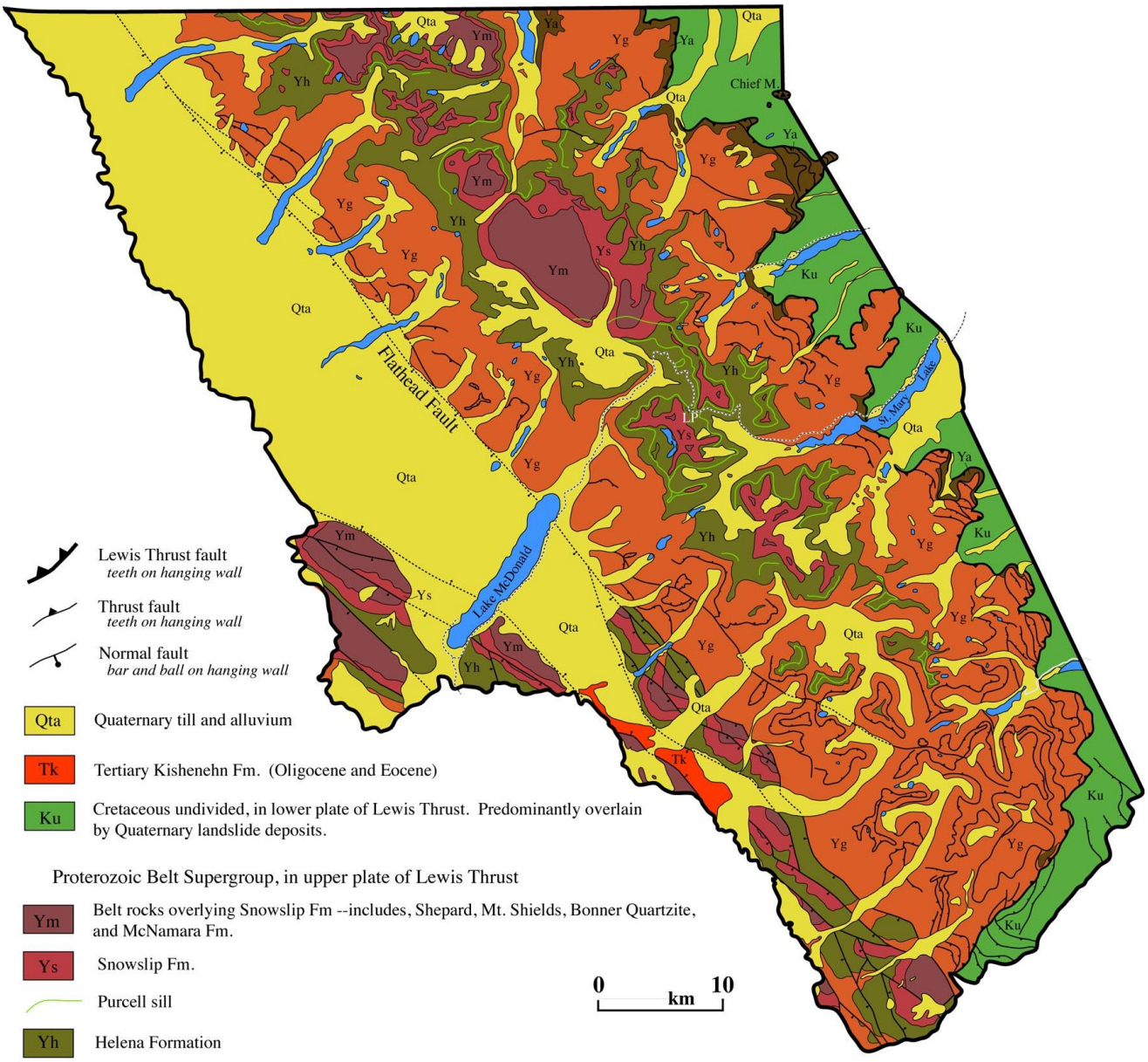
(From Don Winston, 1986, MBMG Special Publication 94, p. 248)



(https://www.nps.gov/articles/nps-geodiversity-atlas-glacier-national-park.htm)

Typical stromatolites from the “Middle Belt Carbonate” (D. Lageson photo)

Glacier National Park, Montana



Lewis Thrust fault
teeth on hanging wall

Thrust fault
teeth on hanging wall

Normal fault
bar and ball on hanging wall

Qta — Quaternary till and alluvium

Tk — Tertiary Kishenehn Fm. (Oligocene and Eocene)

Ku — Cretaceous undivided, in lower plate of Lewis Thrust. Predominantly overlain by Quaternary landslide deposits.

Proterozoic Belt Supergroup, in upper plate of Lewis Thrust

Ym — Belt rocks overlying Snowslip Fm --includes, Shepard, Mt. Shields, Bonner Quartzite, and McNamara Fm.

Ys — Snowslip Fm.

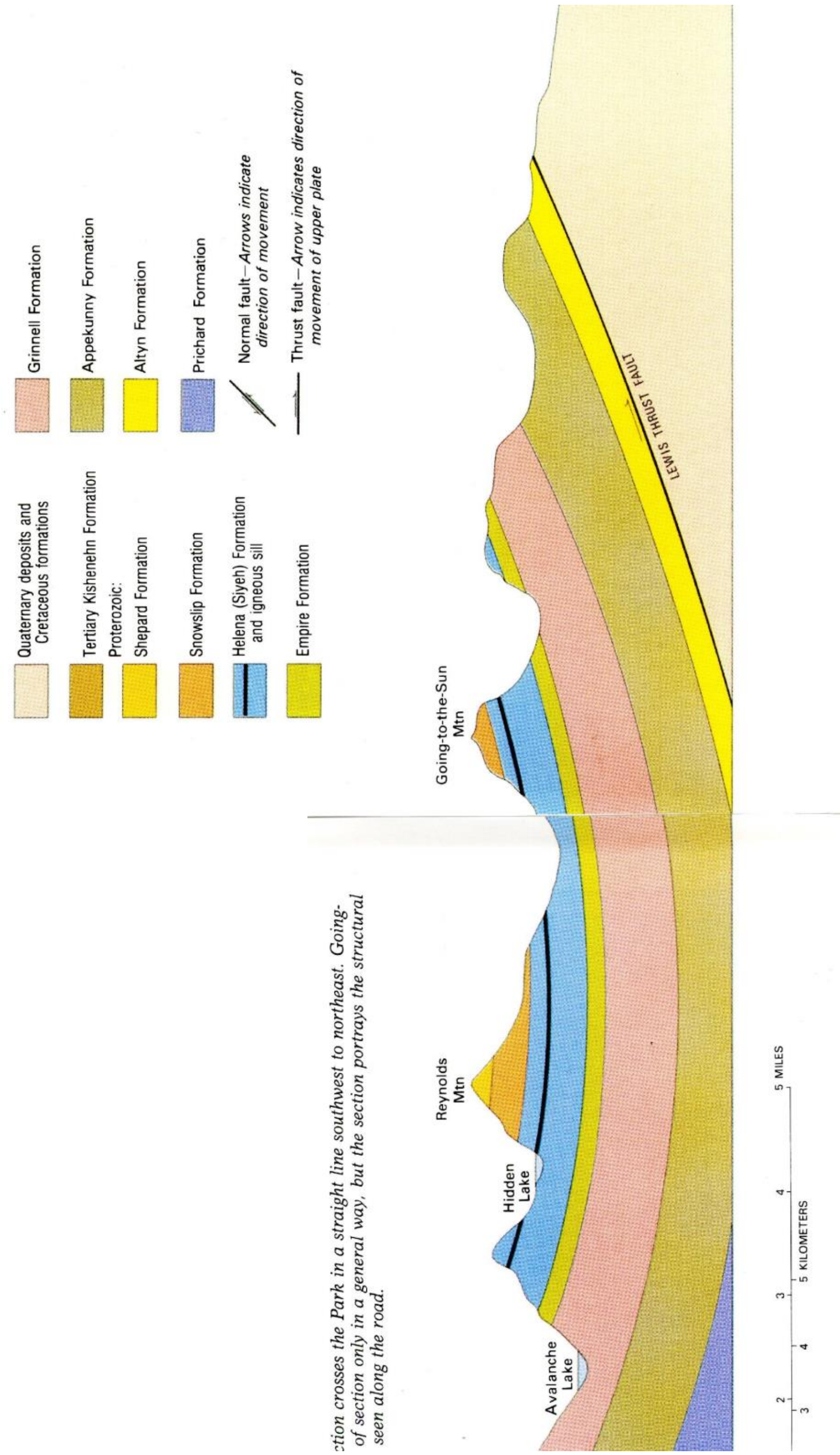
Purcell sill

Yh — Helena Formation

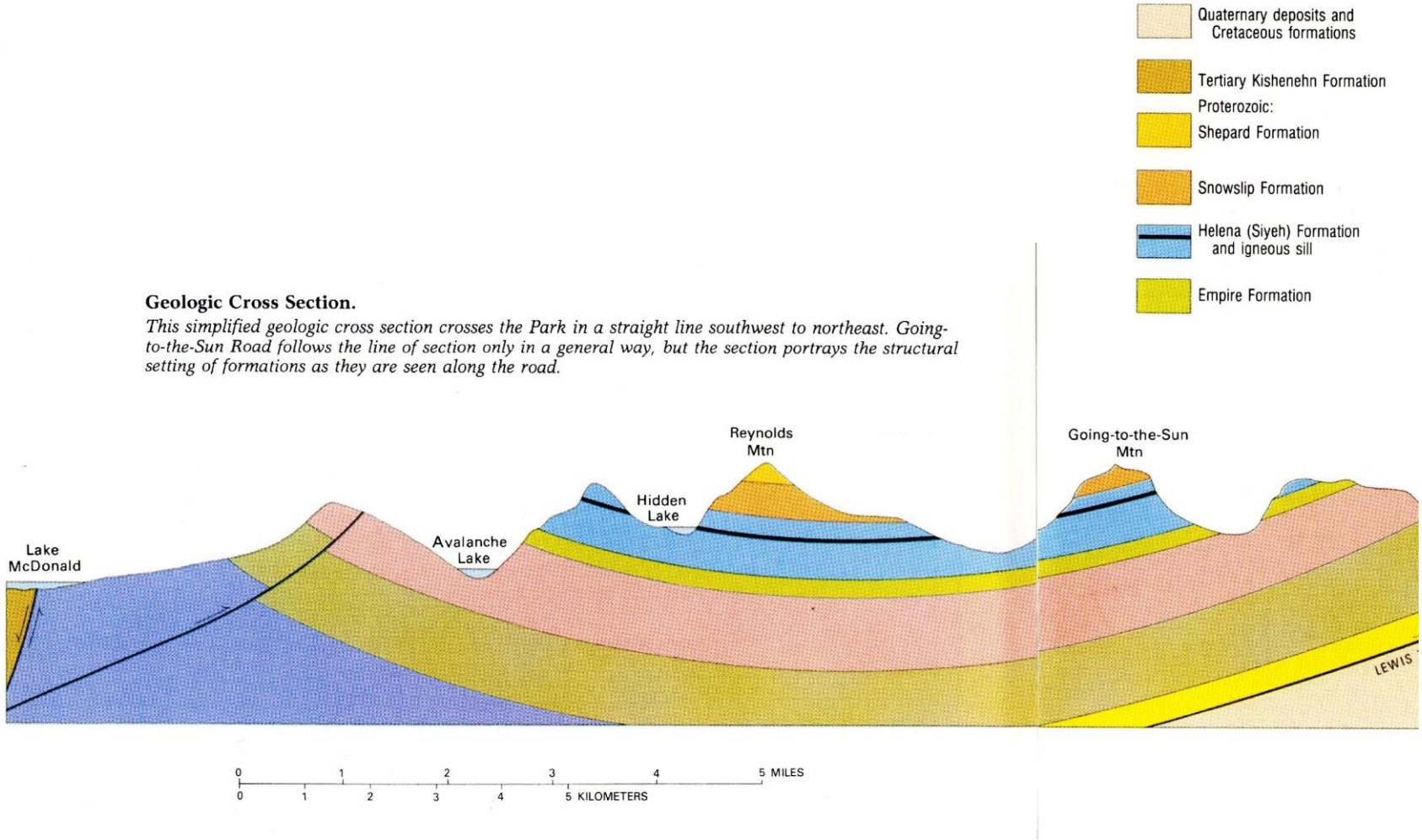
Yg — Appekunny, Grinnell, and Empire Formations. Includes the Prichard Fm. on the west side of the park.

Ya — Altyn Dolomite. Includes Waterton Fm., near north end of the park.

Modified from Whipple, USGS I-1508-F
by Marli Bryant Miller, University of Oregon

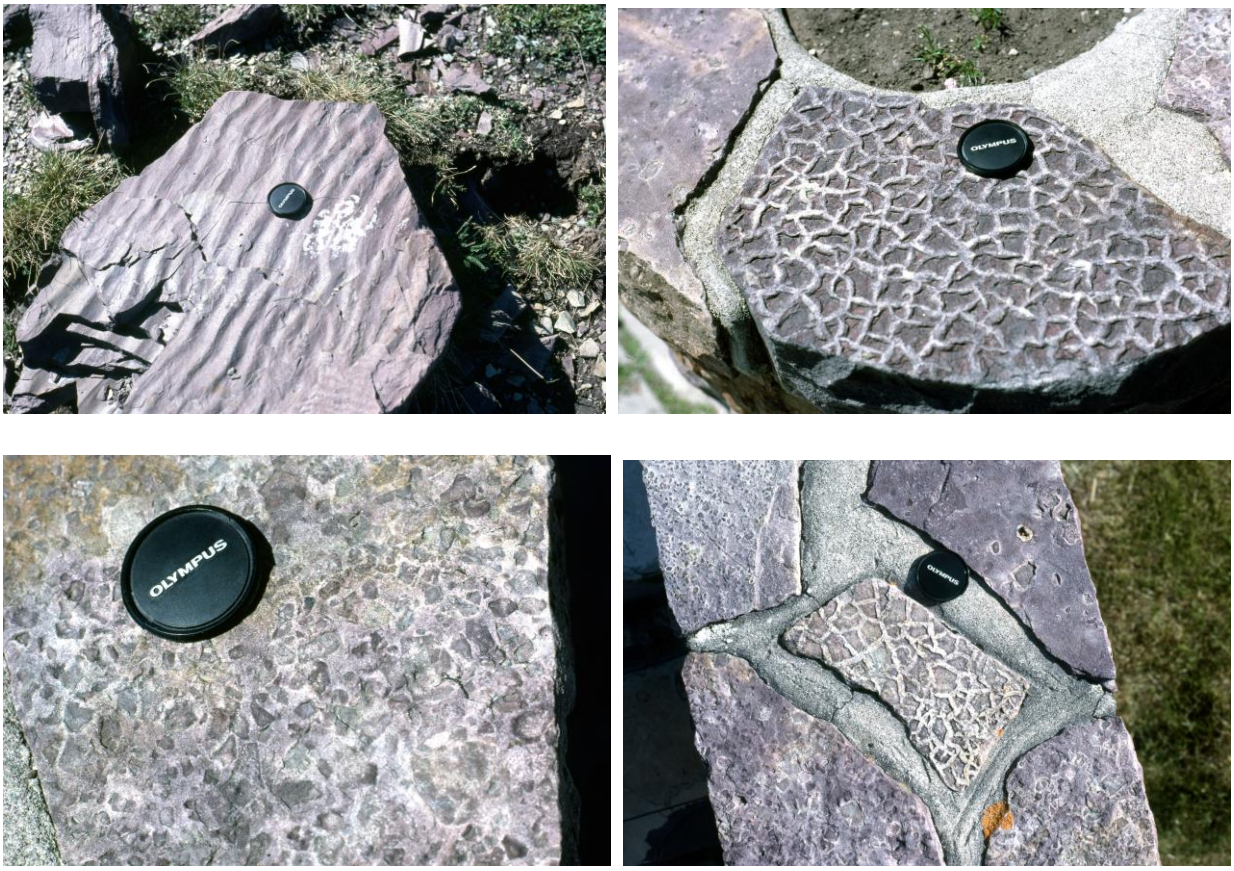


(From: Raup et al., 1983, Geology along Going-to-the-Sun Road, Glacier National Park, Montana: Glacier Natural History Association, USGS and NPS)

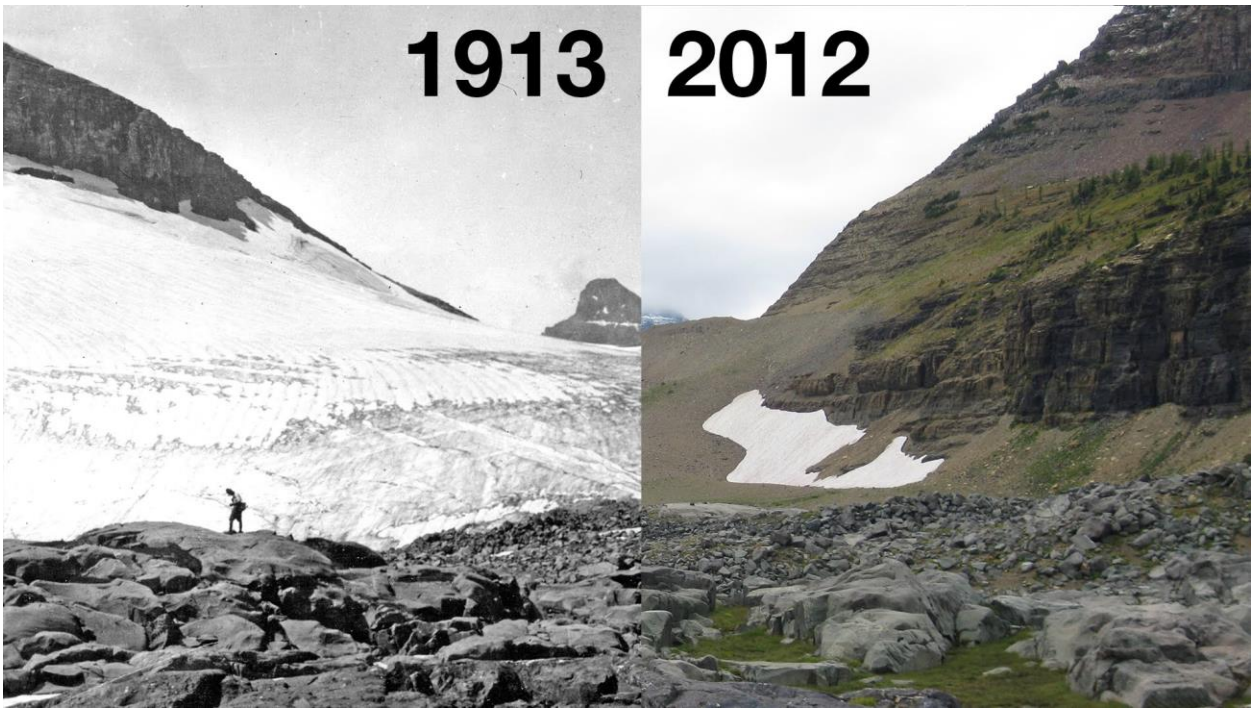


Geologic Cross Section.

This simplified geologic cross section crosses the Park in a straight line southwest to northeast. Going-to-the-Sun Road follows the line of section only in a general way, but the section portrays the structural setting of formations as they are seen along the road.



Typical sedimentary structures seen in Belt rocks in the retaining walls along Going-to-the-Sun Road (D. Lageson photos)



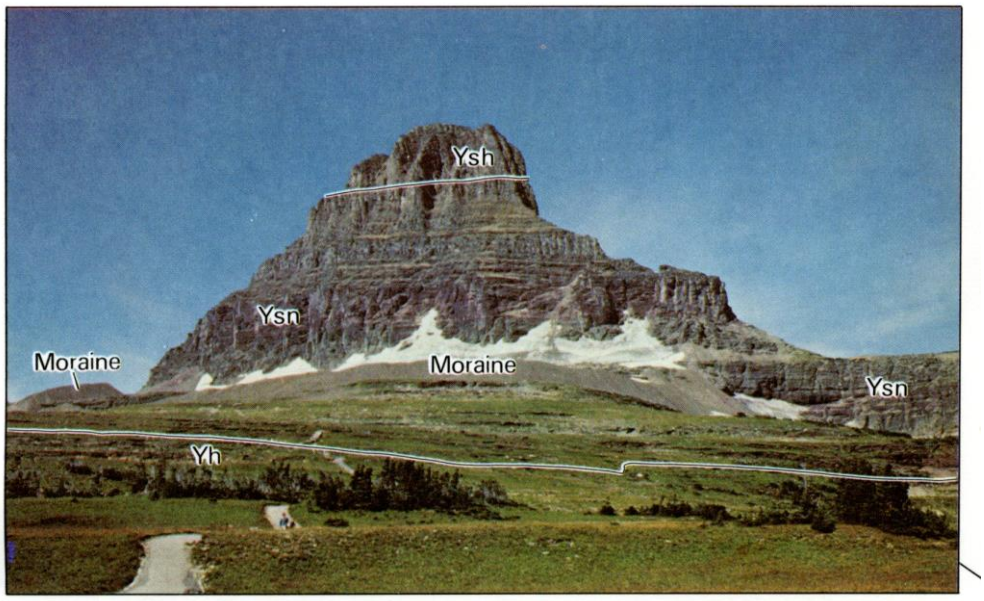
(NASA: Glacier National Park could lose all it glaciers by 2030)

Day 2 – STOP #5

Location: Logan Pass

Overview: At Logan Pass, gray to buff ledges of dolomite in the upper part of the Helena (Siyeh) Formation are at road level, overlain by red and green beds of the Snowslip Formation. Mount Clements is the prominent glacial horn that dominates the view, capped by the Shepard Formation.

(https://en.wikipedia.org/wiki/Clements_Mountain)



View 14.—Clements Mountain towers above an alpine meadow at Logan Pass on the Continental Divide. The lower meadow is underlain by the Helena Formation (Yh); the upper meadow and lower three-quarters of the mountain contain Snowslip Formation (Ysn). Shepard Formation (Ysh) caps the mountain. Glacial moraines around the mountain base formed as recently as the mid-1800's.

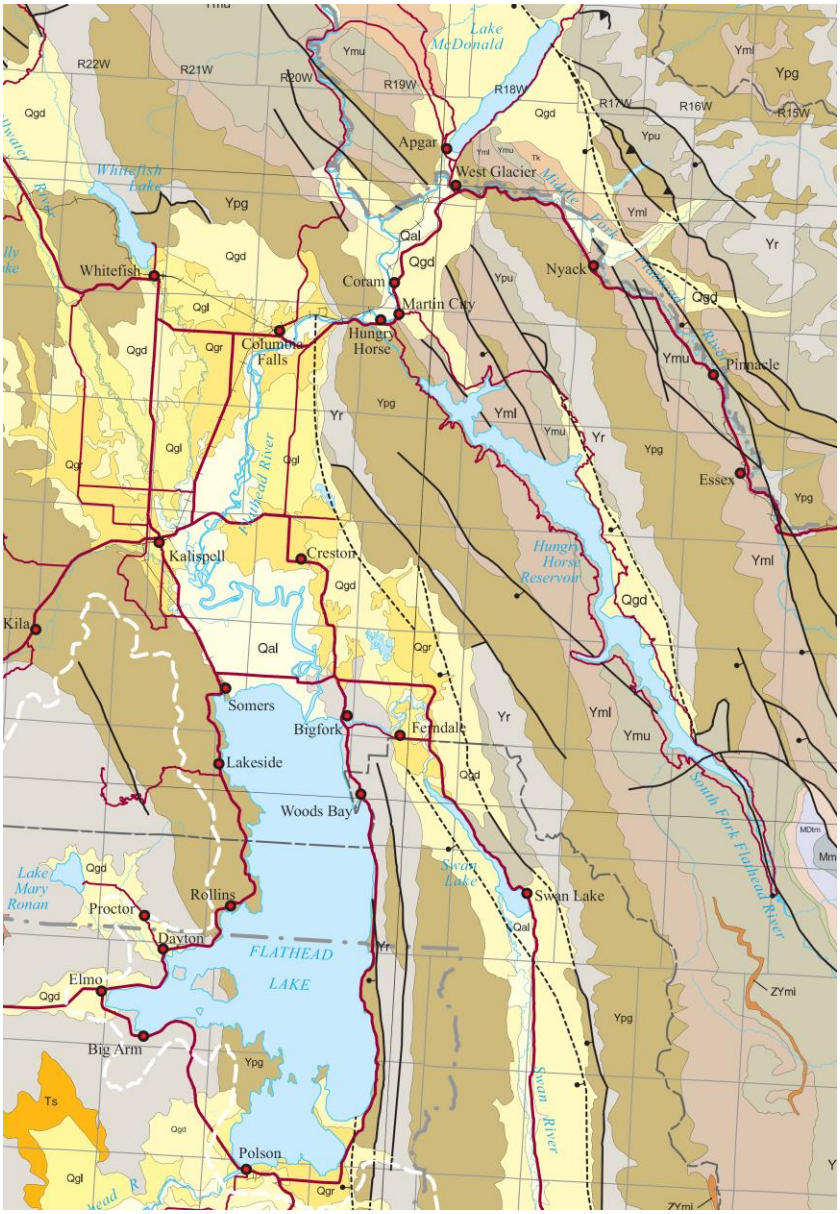
(Source: USGS Map I-1508-B)

Day #3 – Tuesday, June 4, 2019

Overview:

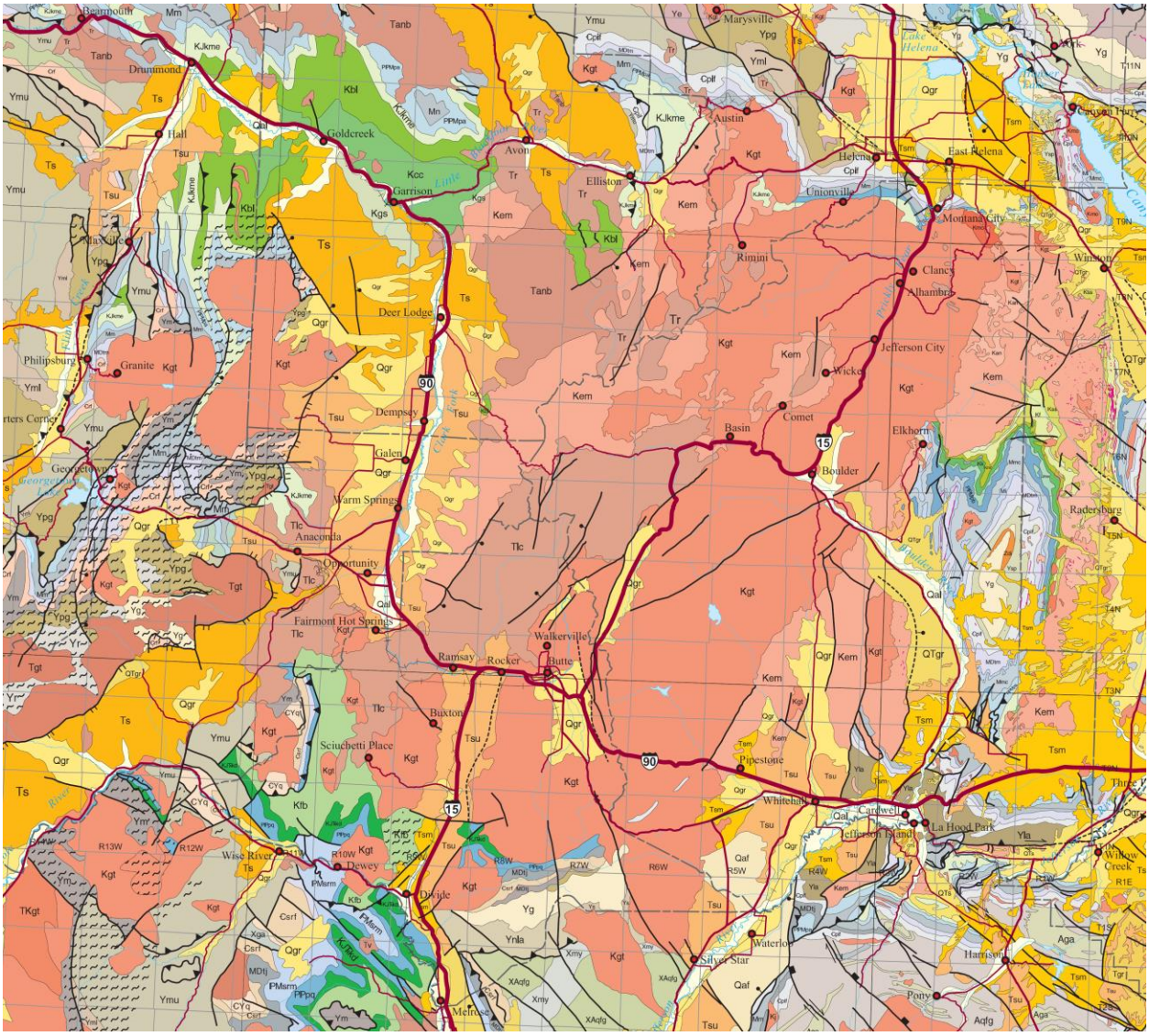
There is no getting around it – this will be a LONG day of driving and there is a lot of Northern Rocky Mountain geology to see! We need to return to the MSU campus and the HKT "icebreaker" by 5:00 pm. Plan to be ready to leave by 0800 once again – please be packed and on time. Our route will take us south along the east side of Flathead Lake and eventually to Missoula, MT where we will pick up I-90 and travel east to Drummond. At Drummond, we will head south along scenic Highway 1 through the Eocene Anaconda metamorphic complex, then on to the Butte mining district, crossing over Homestake Pass and the Boulder batholith.

Geologic map for the first half of the day:

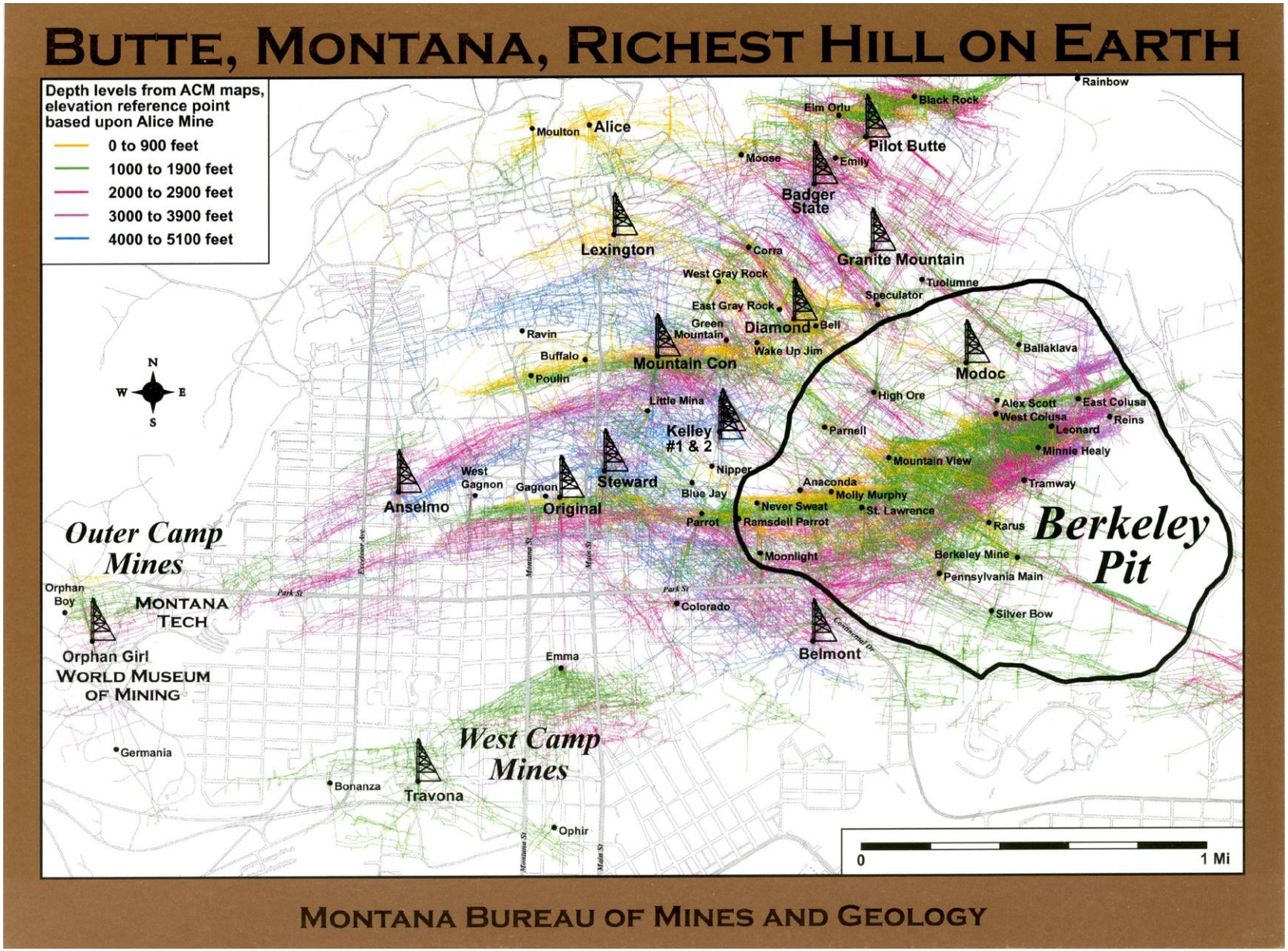


(MBMG Geologic Map of Montana; 1:500,000)

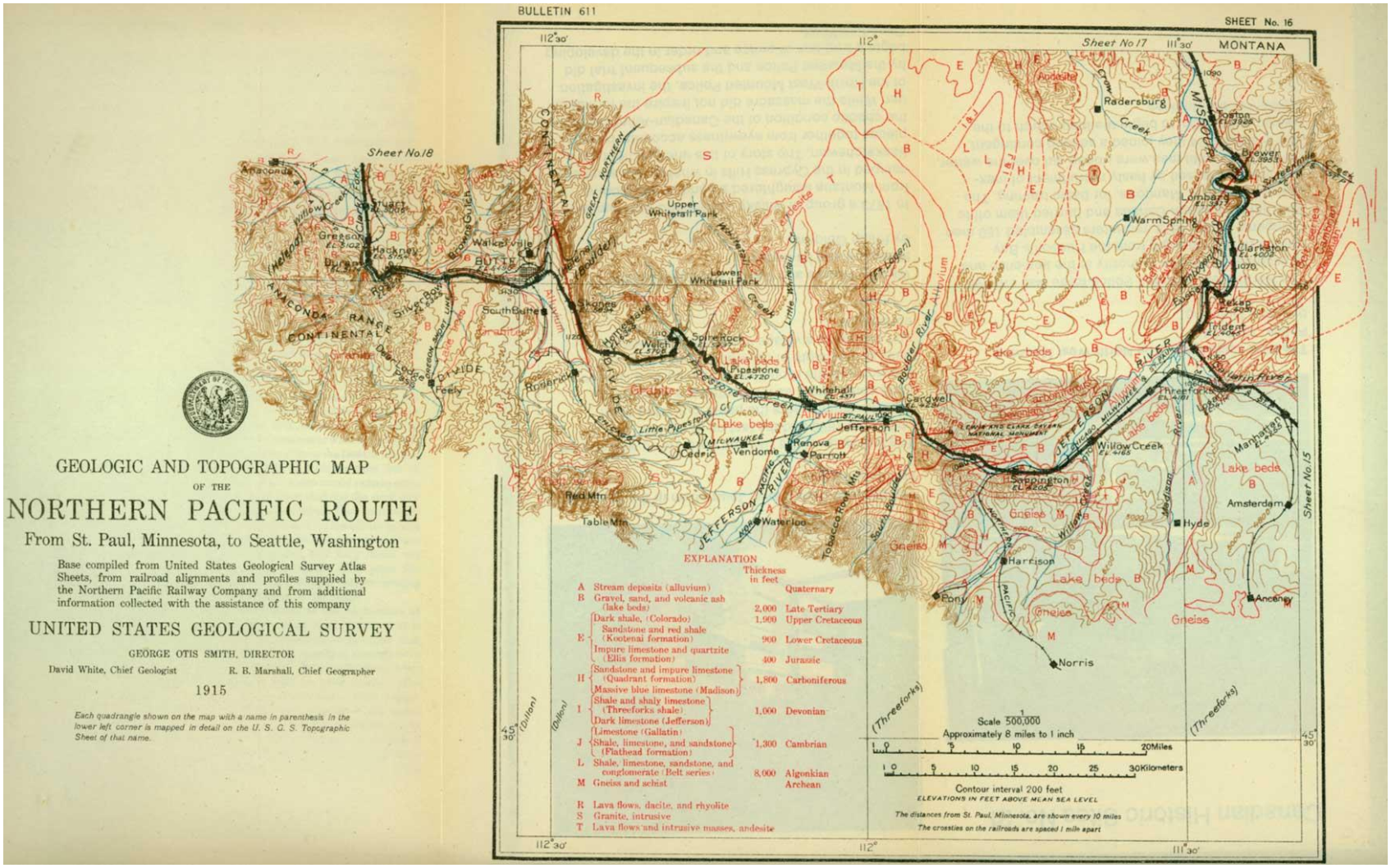
Geologic map for the second half of the day:



(MBMG Geologic Map of Montana; 1:500,000)



(Source: Montana Bureau of Mines and Geology)



EXPLANATION

		Thickness in feet	
A	Stream deposits (alluvium)		Quaternary
B	Gravel, sand, and volcanic ash (lake beds)	2,000	Late Tertiary
E	Dark shale, (Colorado)	1,900	Upper Cretaceous
	Sandstone and red shale (Kootenai formation)	900	Lower Cretaceous
	Impure limestone and quartzite (Ellis formation)	400	Jurassic
H	Sandstone and impure limestone (Quadrant formation)	1,800	Carboniferous
	Massive blue limestone (Madison)		
I	Shale and shaly limestone (Threeforks shale)	1,000	Devonian
	Dark limestone (Jefferson)		
J	Limestone (Gallatin)	1,300	Cambrian
	Shale, limestone, and sandstone (Flathead formation)		
L	Shale, limestone, sandstone, and conglomerate (Belt series)	8,000	Algonkian
M	Gneiss and schist		Archean
R	Lava flows, dacite, and rhyolite		
S	Granite, intrusive		
T	Lava flows and intrusive masses, andesite		

GEOLOGIC AND TOPOGRAPHIC MAP
OF THE
NORTHERN PACIFIC ROUTE
From St. Paul, Minnesota, to Seattle, Washington

Base compiled from United States Geological Survey Atlas Sheets, from railroad alignments and profiles supplied by the Northern Pacific Railway Company and from additional information collected with the assistance of this company

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

David White, Chief Geologist R. B. Marshall, Chief Geographer

1915

Each quadrangle shown on the map with a name in parenthesis in the lower left corner is mapped in detail on the U. S. G. S. Topographic Sheet of that name.

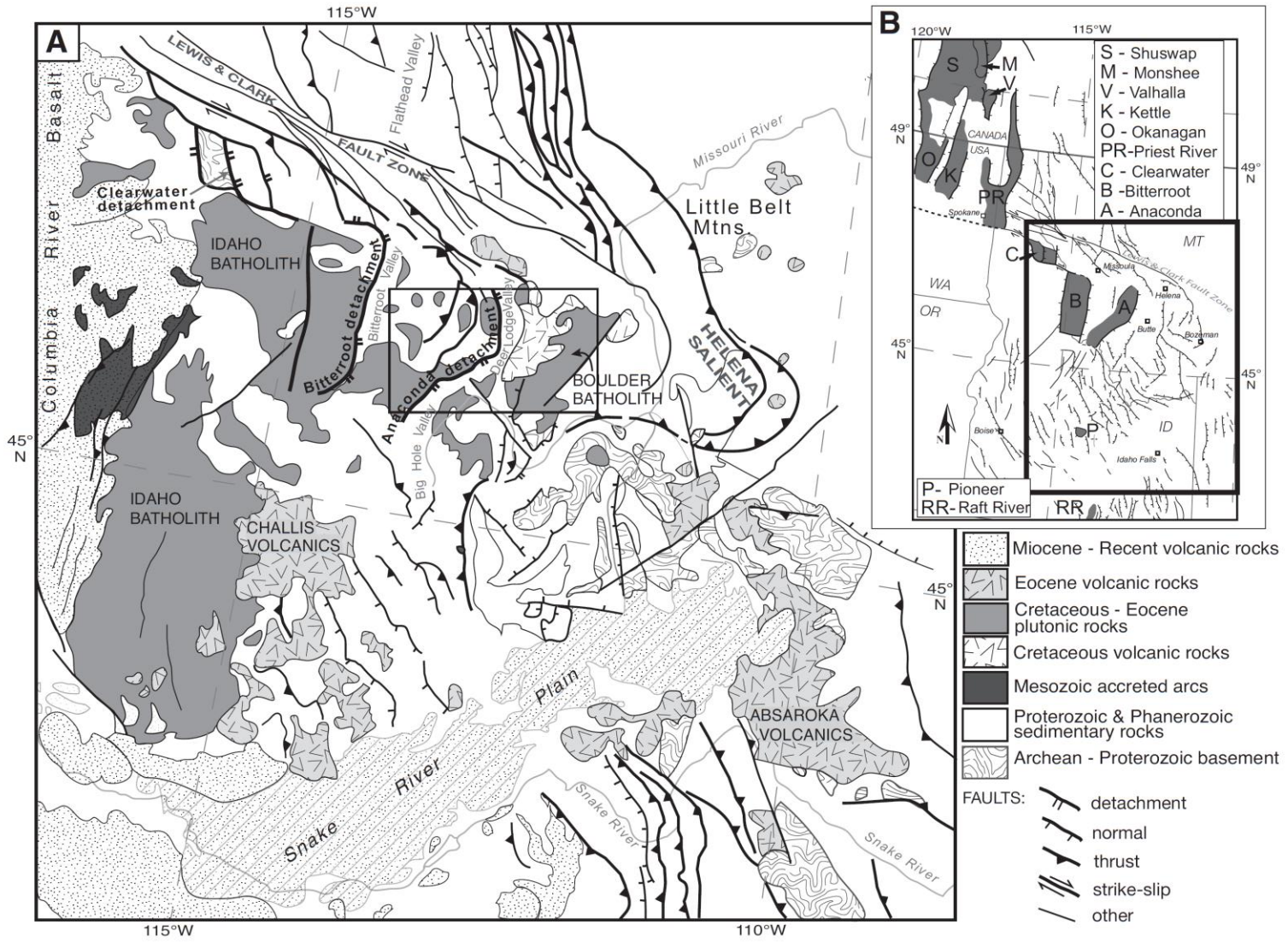


Figure 1. (A) Tectonic map of the northern U.S. Rocky Mountains showing major Phanerozoic structures and tectonic elements in the vicinity of the Anaconda detachment, which bounds the Anaconda metamorphic core complex. The box shows the area of the map in Figure 2. (B) Inset map showing a larger area depicting the location of the Anaconda metamorphic core complex and other Eocene metamorphic core complexes. The core complexes are shaded gray, with names corresponding to the abbreviations listed in the key. The box shows the area of the map in A.

(Foster, Grice and Kalakay, 2010, Extension of the Anaconda metamorphic core complex: Lithosphere, vol. 2, no. 4, p. 232-246)

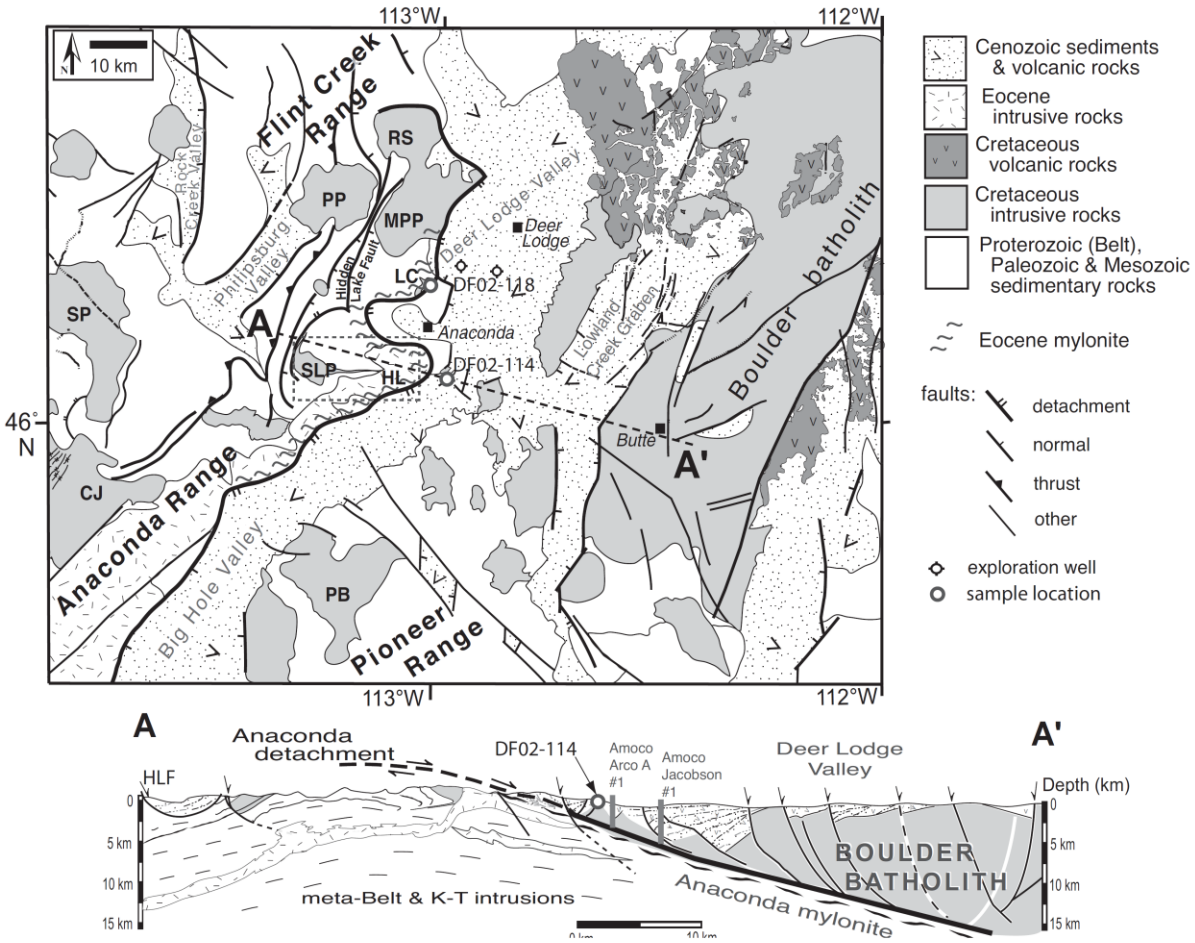


Figure 2. Geologic map and cross section of the central part of the Anaconda metamorphic core complex, Boulder batholith, and adjacent regions. The map was compiled from Emmons and Calkins (1913), Lewis (1998), Lonn et al. (2003), O'Neill et al. (2004), Foster et al. (2007), and Vuke et al. (2007). Locations of samples used for $^{40}Ar/^{39}Ar$ analyses that are not plotted on Figure 4 are also shown. Cretaceous intrusive rock at location DF02-114, in the hanging wall of the Anaconda detachment, is coarse-grained granodiorite interpreted to be the detached top of the Storm Lake pluton in the footwall. Abbreviations: SP—Sapphire pluton; CJ—Chief Joseph pluton; SLP—Storm Lake pluton; PB—Pioneer batholith; PP—Philipsburg batholith; MPP—Mount Powell pluton; RS—Royal Stock; HL—Hearst Lake plutonic suite; LC—Lost Creek Stock; HLF—Hidden Lake fault. The box shows the area of Figure 4.

(Foster, Grice and Kalakay, 2010, Extension of the Anaconda metamorphic core complex: Lithosphere, vol. 2, no. 4, p. 232-246)

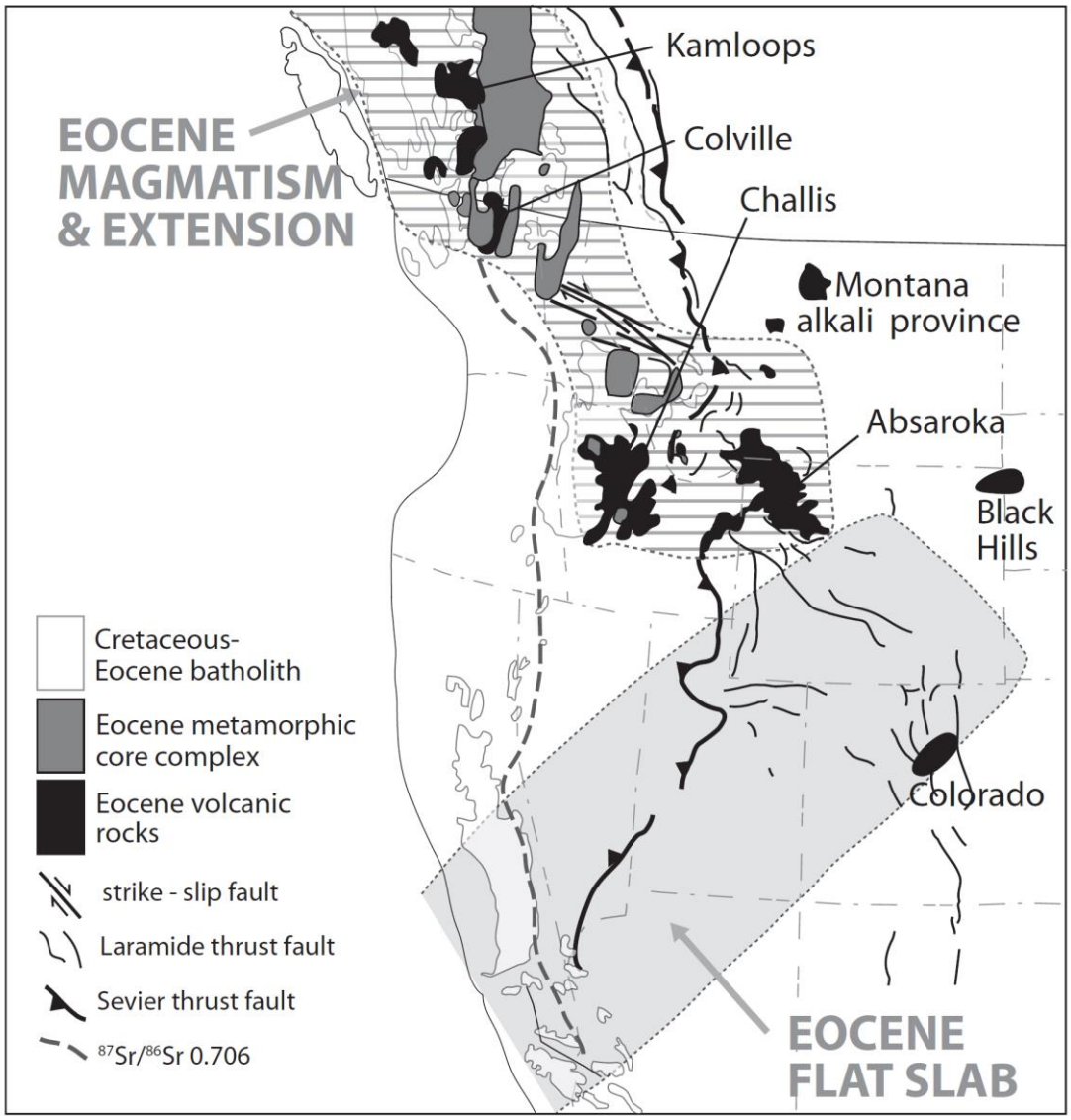
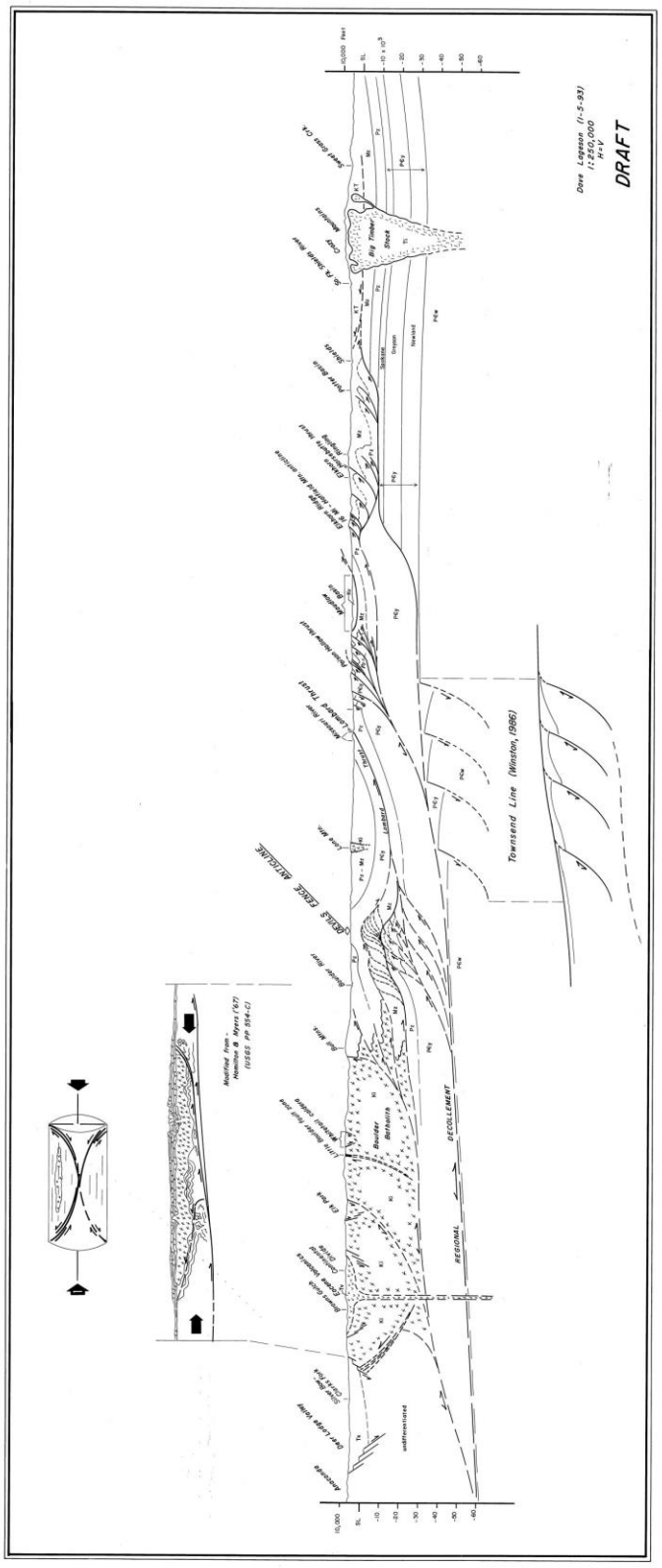


Figure 10. Map showing the relationship between Eocene magmatism and extension in the northern Cordillera and shallow-angle subduction of the Farallon slab. The base map was modified from Foster et al. (2007), with the western margin of the continent restored to approximate an early Eocene position by closing up Neogene extension in the Basin and Range Province and Columbia embayment. The position of the Eocene flat slab was inspired by Saleeby (2003) and Humphreys (2009a). The field of Eocene magmatism includes the Absaroka, Challis (and related fields), Colville, and Kamloops fields, along with plutonic rocks in the batholiths (e.g., Idaho-Bitterroot batholith) and metamorphic core complexes shown in Figure 1B.

(Foster, Grice and Kalakay, 2010, Extension of the Anaconda metamorphic core complex: Lithosphere, vol. 2, no. 4, p. 232-246)



(Regional cross-section over the Boulder batholith; the western margin of this x-section is no longer valid since the discovery of the Anaconda metamorphic core complex and its east-dipping detachment beneath the Deer Lodge Valley. By D. Lageson)

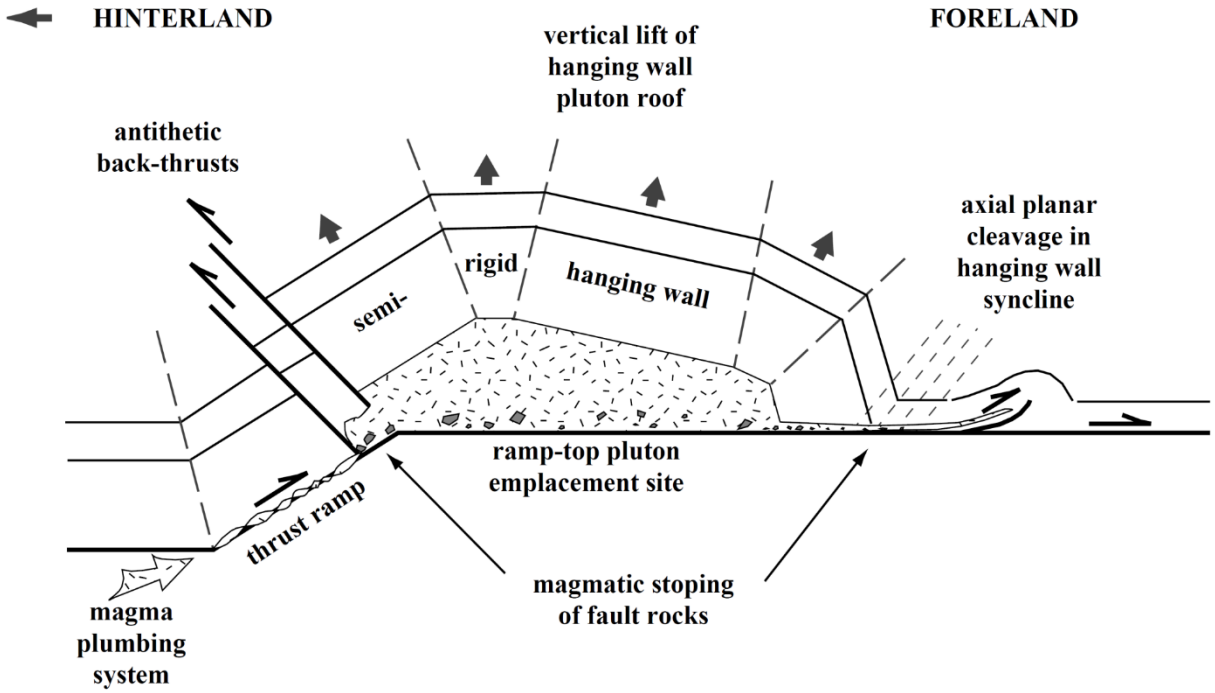
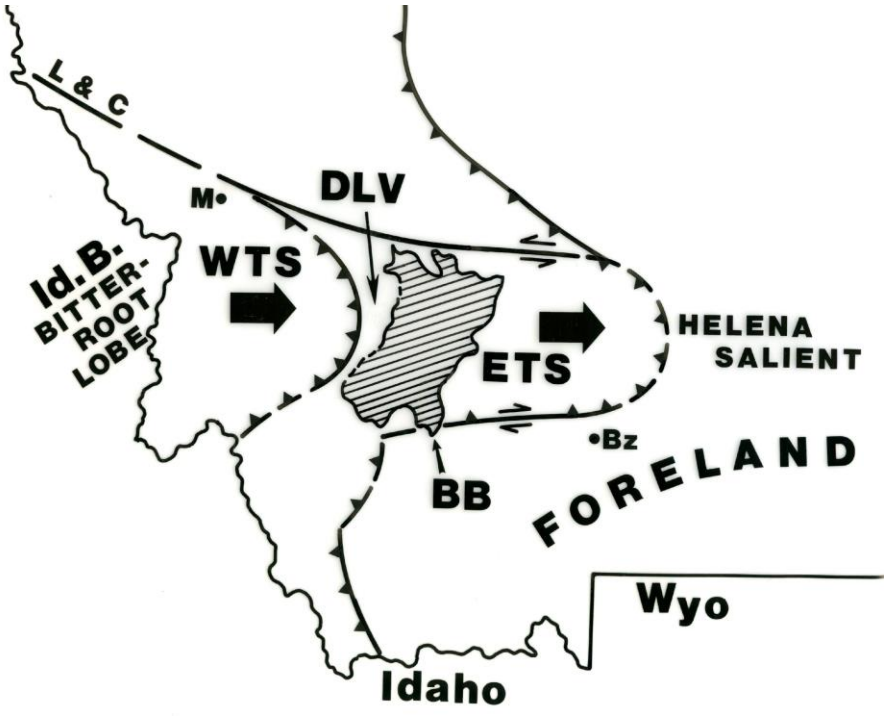
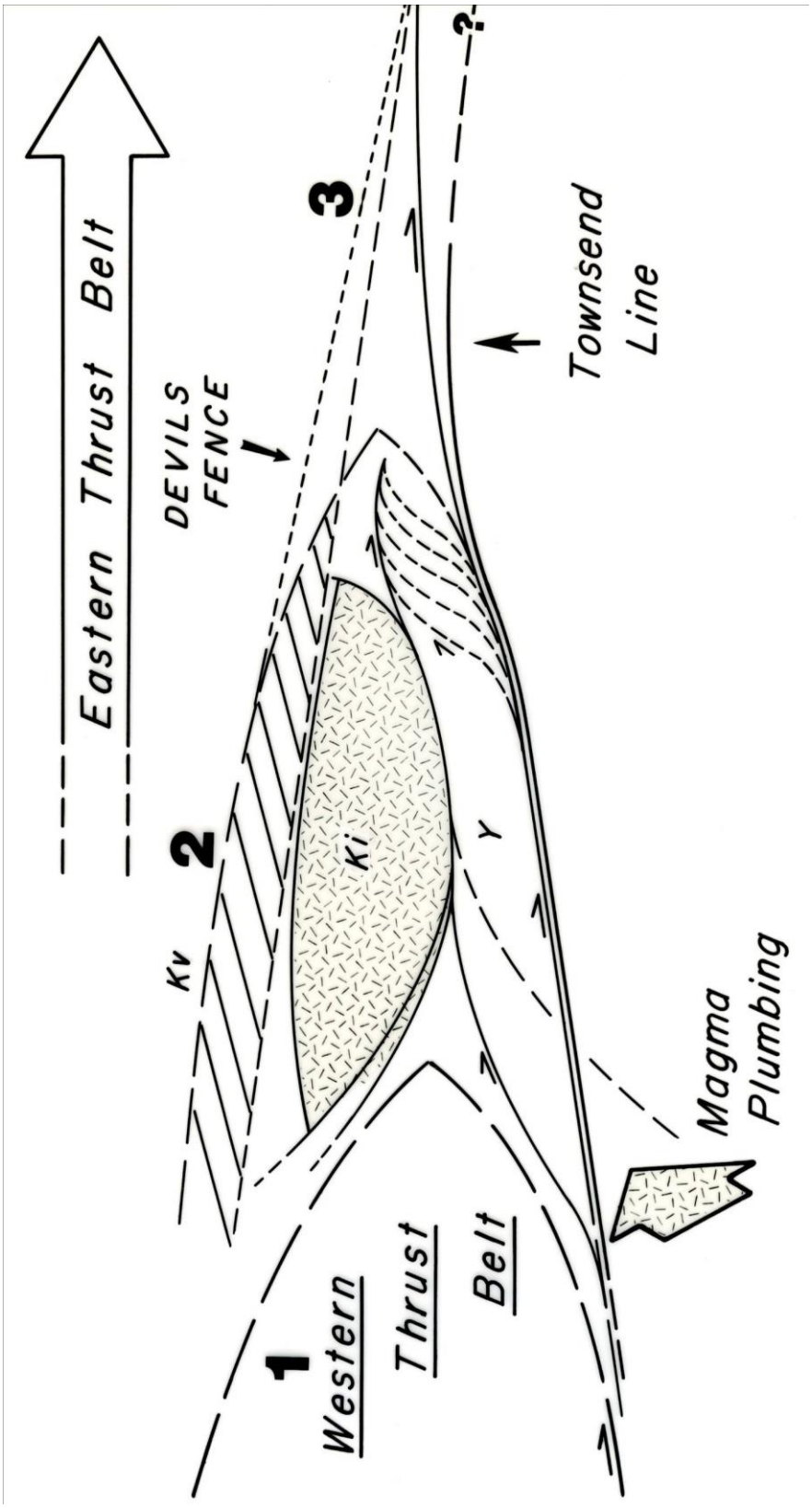


Fig. 8. Proposed emplacement model for magmatism in the southwest Montana thrust belt.



(D. Lageson)


Eastern Thrust Belt
DEVILS FENCE
Townsend Line
?
3
2
Kv
Ki
Y
Magma Plumbing
1
Western Thrust Belt

(D. Lageson)

Late Cretaceous seasonal monsoon hitting the Northern Rockies “Montanaplano”