PEAKS & COULOIRS OF SOUTHWEST MONTANA

A Guide to Backcountry Skiing in the Gallatin, Madison, Bridger, Tobacco Root, and Montana Absaroka Mountains

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A Journey Through Deep Time

a guest essay by **Chance Ronemus**

"If you free yourself from the conventional reaction to a quantity like a million years, you free yourself a bit from the boundaries of human time. And then in a way you do not live at all, but in another way you live forever." – John McPhee, Basin and Range (1981)

Skiers are familiar with the three-dimensional playground available to them in the mountains of southwest Montana. A basic understanding of the regional geology reveals an intricate story told in a fourth dimension hidden to most recreationalists—that of 'deep time'. Over many millions of years, the characters of this story—including violently colliding plates, ancient coral reefs, and erupting super-volcanoes—conspired to shape the mountains on which we ski. The mountain ranges gracing the pages of this guidebook were created and molded by this orchestra of geologic processes. Geology governs the topography, rock quality, and climate cooperating to produce a life-affirming powder run. Southwest Montana contains one of the most ancient and varied geologic histories on Earth. What follows is a brief distillation of this history, allowing the reader to peer into deep time.

Southwest Montana (Some Assembly Required)

On an early-season ski mission to Sacagawea Peak, a keen observer may notice fossils of ancient extinct marine corals occupying the walls of the cirque. By what strange series of events did organisms at home in warm tropical seas come to reside on icy mountain peaks? We must venture on a tour through time to find a satisfactory answer.

The journey begins relatively early in planet Earth's 4.6 billion-year history, as coherent chunks of continental crust, buoyant masses of solid aluminum- and silica-rich rock coalesced out of a hot, gooey Earth. The 'backbone' of Montana, the Wyoming Craton, was one of the earliest such chunks to form. Some of the oldest mineral grains in North America—up to almost four billion years old—can be found atop Beartooth Pass in the heart of the Wyoming Craton. Around 1.8 billion years ago, the Wyoming Craton collided with the Medicine Hat block, a chunk of continental crust to the north. Early collisions such as this caused these continental fragments to become 'stuck' together, forming the core of modern North America. These collisions produced the intense deformation seen in the rocks exposed across southwest Montana, including the Madison Range, Montana Absaroka Range, and the Tobacco Root Mountains. These processes metamorphosed (re-crystallized) these rocks into gneiss (pronounced "nice") as the lighter-colored minerals—such as quartz and potassium feldspar—became partially molten and flowed around the darker-colored minerals—such as plagioclase and hornblende. This flow resulted in the distinctive banding visible on the walls

Figure 1: Tight 'disharmonic' folding (outlined by white lines) in a migmatitic (partially melted) gneiss located in the east couloir on Hilgard Peak. Common minerals in each band are indicated. Chris Kussmaul for scale.

of Beehive Basin and the Taylor-Hilgard unit of the Madison Range (Figure 1). These metamorphic rocks form the 'basement' for all other rocks later deposited in the region.

Soon after, nearly all the continental crust on Earth had been stitched together through subsequent collisions to form a supercontinent called Columbia, in which Siberia or Australia was likely attached to western Montana. But no good thing lasts forever—processes under this enormous landmass, deep within Earth's interior mantle, eventually caused rifting and fragmentation. As the supercontinent fell apart in the Mesoproterozoic Era (1,600–1,000 Ma, million years ago), a deep sea opened. This sea formed the Belt Basin, parts of which were filled with more than 12 miles of sediment. A skier dropping into the west side of the Bridgers may now marvel at this exquisitely persevered record of Mesoproterozoic Earth.

Around a billion years ago, Earth's continents once again organized themselves into an enormous landmass. Not to be outdone, this supercontinent—known as Rodinia—was likely even larger than its predecessor. The high topography generated by this supercontinent caused the erosion of almost all sedimentary rocks (with the notable exception of rocks of the Belt Basin) from Earth's continents, effectively erasing much of Earth's early history from the rock record. A global glaciation known as 'Snowball Earth' froze nearly all of Earth's ocean during this time. This may have enabled a coveted ski traverse of the equator.

The sedimentary record in Montana resumes as Rodinia rifted apart. Western Montana became a continental margin, likely resembling the modern Atlantic margin of North America. This region was cyclically flooded and drained with the rise and fall of sea level. These cycles deposited stacks of sediment along this margin as eroded detritus was supplied from the continent. This sediment was compacted and 'lithified', creating a layer-cake of mud and limestone now preserved in the Paleozoic age (~541-252 Ma) rocks of Montana. Shales, highly friable mud rocks, were deposited during periods of high sea level. These weak rocks erode easily, forming many of the couloirs of the Bridger Range. Carbonate mud and the shells of marine organisms were deposited in shallow tropical seas during lower sea level to form limestones, such as the prominent Mississippian (~359–323 Ma) Madison Group forming the crest of the Bridger Ridge (Figure 2).

Moving Mountains

As a tranquil beach scene occupied southwestern Montana, Earth's most recent supercontinent, Pangea, was forming. Though its creation was relatively tectonically boring in Montana, its rifting caused all hell to break loose. A mighty ancient oceanic plate, called the Farallon Plate, was forced under the western margin of North America. The once quiet marine environments of Montana were uplifted as an impressive wedge of mountains began to develop. Island arcs, similar to modern-day Japan, began slamming into North America. These island arcs behaved much like a 120 mm waisted DPS ski in Sierra Cement—they didn't want to sink.

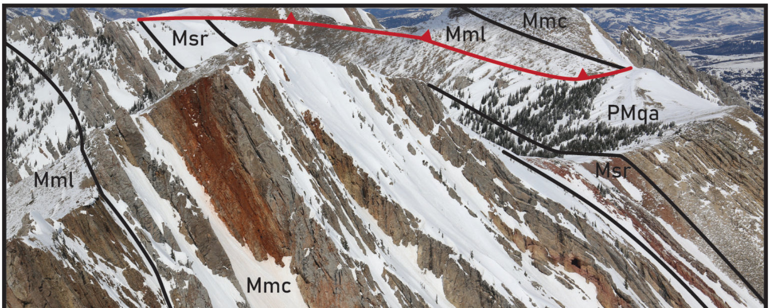

Figure 2: Tilted Paleozoic rocks seen looking north past Hollywood wall. Black lines define units. Barbed red line is a thrust fault. Mml–Lodgepole Limestone; Mmc–Mission Canyon Limestone; Msr–Snowy Range Group; PMqa–Quadrant and Amsden formations.

As a result, the snowplow-like wedge of deformed rock, called the Sevier Fold and Thrust Belt, grew increasingly large—likely becoming even more impressive than the modern Andes Mountains. Volcanoes formed along the western margin of the continent, with their roots preserved in locations such as the monolithic walls of the Sierra Nevada Mountains.

The Farallon Plate subducting under the western margin of North America flattened to a much shallower angle in the Cretaceous Period (145–66 Ma). This resulted in volcanism migrating more than 300 miles inland and deformation following suit. This 'flat slab subduction' was likely responsible for many of the most dramatic ranges of the Rockies, including the Madison, Beartooth, Tobacco Root, and southern Gallatin and Bridger ranges (Figure 3), as old basement rocks were forced above younger rocks along steep contractional 'thrust faults'. Related magmatism formed the extensive Boulder batholith and nearby igneous bodies, including Hollowtop Mountain and Granite Peak in the Tobacco Roots. Meanwhile, dinosaurs roamed the region without much pause for their hostile geography; their bones, eggs, and even their turds—known as coprolites—are commonly found persevered in formations of this age.

In the Eocene Epoch (~56–34 Ma), the Farallon plate began to roll back in a motion analogous to the peeling of a climbing skin. Hot material from the underlying mantle welled up in this vacated space, triggering an intense period of volcanism. These eruptions formed the Crazy Mountains, southern Montana Absarokas, and the northern Gallatin Range—including rocks found in Hyalite Canyon. The volcanic peaks which comprised this province have long since been eroded, but the andesitic dikes and sills which fed them and the debris-flows which cascaded off their flanks are preserved, testifying to the once-great volcanoes of Montana.

They All Fall Down

The roll-back of the Farallon plate was accompanied by the beginnings of the collapse of the mountain belt. The thick, gravitationally unstable crust began to expand along low-angle extensional faults. This formed low-lying valleys, such as the Gallatin Valley, which filled with over a mile of sediment. By about 10 million years ago, the Farallon plate had been nearly consumed by subduction underneath the North American continent. This caused our metaphorical snowplow to be put into reverse. The immense stack of rocks it pushed began to undergo rapid extension along steep extensional structures called normal faults. These faults modified the mountains into something a modern Montanan may recognize, bounding many modern river valleys and creating the 'basin-and-range' topography now characteristic of this portion of the state. Many of these faults remain active today and are responsible for earthquake activity. One such example is the 1959 magnitude 7.2 earthquake on the Madison

Figure 3: The author hop-turning down the Sphinxter. The Sphinx Conglomerate is comprised of clasts (chucks of rock) recycled out of uplifted and eroded rocks during the formation of the modern Madison, Gravelly, and Gallatin Ranges. Large clasts are highlighted.

Valley fault, which caused a landslide creating Quake Lake and killing those in the campground below—the namesake of the Night of Terrors Turnout at the start of the Taylor-Hilgard traverse.

During this time, a hot rising 'plume' of material from the mantle—the Yellowstone hotspot— began melting the crust and trigging explosive volcanism. As North America moved westward atop this stationary feature, a series of super-eruptions created a chain of enormous

Figure 4: Geologic time scale with stratigraphic (rock) column of notable formations in SW Montana. Arrows indicate time period spanned by important events. Colors follow USGS standards for time designations and are keyed to geologic units in Figure 5. Ma–Million years ago; Ga–Billion years ago; Fm–Formation.

Eon/ Era	Period	Notable Rocks (Map Legend)	Ski Areas Where Exposed	Important Events
CENOZOIC	Neogene	Glacial Deposits	These deposits are found in vallies in all ranges. A thick ice cap once flowed into Paradise Valley, blanketing the Absarokas and carving their dramatic topography. The trailhead for Pine Lake lies on an ancient glacial moraine.	Last Glacial Maximum; Yellowstone Volcanism
		Yellowstone Volcanics	The Huckleberry Ridge Tuff, comprising >530 cubic miles of erupted material from Yellowstone's largest eruption at 2.1 Ma, is exposed near Electric Peak and the turn off to Big Sky.	
	Paleogene	Eocene Volcanics	These rocks are regionally abundant. Good exposures include Hyalite Canyon, Emigrant Peak, and the Crazy Mountains. Striking columnar jointing occurs in lava flows as a result of contraction during cooling. Look for mineralization of beautiful hyalite opals within fractures and pockets!	Eocene Volcanic Flare-Up; Tectonic Extension
66 Ma				
MESOZOIC	Cretaceous	Synorogenic Conglomerates	The Sphinx conglomerate forms Sphinx Mountain and is comprised of clast recycled during the rise of nearby ranges.	Thrust Faulting; Farallon Subduction
		Createaceous Intrusives	These are solidified magma chambers, comprising Hollowtop and Granite Peak in the eastern Tobacco Roots.	
	Jurassic	Foreland Basin Deposits	These Jurassic–Cretaceous units, including the Morrison and Kootenai Formations, hosts fantastic dinosaur digs. They're well exposed on the way in to Fairy Lake.	
	Triassic	Dinwoody Fm.	This deep red-colored formation forms the "Devil's Slide" near Gardiner, which has reportedly seen several ski descents.	
252 Ma				
PALEOZOIC	Permian	Phosphoria Fm.	This thick sucession is well exposed in the Bridger Range where it's been steeply tilted and faulted during uplift. Keep a look out for abundant fossils of a wide variety of marine organisms, like those of the extict order of horn-shaped rugose coral. Take a sniff of the Jefferson Dolomite to examine the 'fetid' odor of oil trapped in these rocks—"smells like money!", the oil geologists say.	Continental Margin Deposition; Supercontinent Pangea
	Pennsylvanian	Amsden Formation		
	Mississippian	Madison Group Limestone		
	Devonian	Jefferson Dolomite		
	Silurian/ Ordovician	Big Horn Dolomite	Elephanthead Mountain is formed by a 'dip slope', or bedding-parralel surface, of this formation.	
	Cambrian	Flathead Sandstone	The Flathead marks the end of the "Great Unconformity", an extensive period from which few rocks are preserved globally.	
541 Ma				
PROTEROZOIC		Belt Supergroup	These rocks form the east side of the northern Bridgers. They record an elusive period of Earth's early history for which much of the sedimentary record has been erased by erosion. The LaHood Formation often contains car-sized boulders of gneiss shed from steep faults associated with the down-dropping of this basin. Looks for stromatolites—biogenic mounds created by cyanobacteria and some of Earth's oldest fossils.	Supercont. Rodinia; Belt Basin Deposition; Supercont. Columbia
2.5 Ga				
ARCHEAN		Deformed and metamorphosed basement rocks	Dominatly composed of 'gneiss', these rocks form the monolithic walls of the western Tobacco Roots, Spanish Peaks, Taylor-Hilgard, and northern Absarokas. These rocks were brought to the surface along steep thrust faults in the Cretaceous and Paleocene.	Continental Crust Formation

volcanic calderas which blasted the mountains flat, creating the Snake River plain. There is evidence that, prior to the intervening mountains being destroyed by this hotspot, the faults and possibly the topography of the Teton Range may have extended northward as far as southwest Montana. Although you may rest assured that this lurking beast is exceedingly unlikely to erupt explosively during our lifetimes, evidence of its tumultuous past is displayed in volcanic tufts present in the southern Absaroka, Madison, and Gallatin ranges.

Geologic Time Includes Now

During the Pleistocene Epoch (~2.6–0.01 Ma), glaciation pervaded Montana. The skiing was likely excellent. The high topography associated with the Yellowstone hotspot facilitated a positive feedback loop of glaciation, culminating in an ice cap up to 4,000 feet thick. This ice cap encroached into the Gallatin, Madison, Absaroka, and Beartooth Ranges carving their dramatic faces. Elsewhere, smaller glaciers left their mark. These are responsible for the modern cirques and 'U-shaped' valleys in many ranges.

As Edward Abbey mused, "geologic time includes now." Tectonic and geomorphic processes in Montana march onward in the present. Sea levels continue to rise and fall with the cyclic coming and going of glaciations (the latter with some help from humans) and the tectonic plates continue their dance of supercontinent cycles. Many of southwest Montana's mountain ranges continue to grow with progressive slip along normal faults. At the same time, erosional processes compete to reduce them to flat-lying heaps of rubble. Through this dance of deep time, the next great Montana ski line may be only a few million years away.

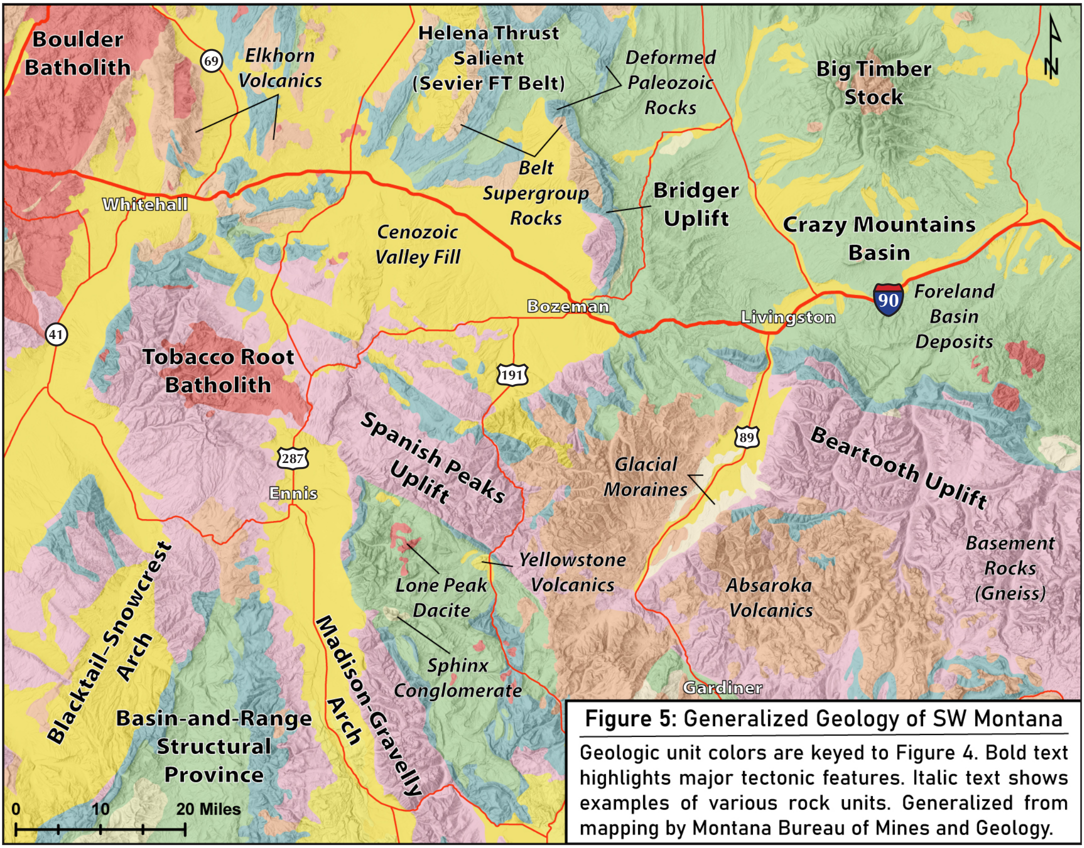

Figure 5: Generalized Geology of SW Montana

Geologic unit colors are keyed to Figure 4. Bold text highlights major tectonic features. Italic text shows examples of various rock units. Generalized from mapping by Montana Bureau of Mines and Geology.