

THE NATURE-BUILT LANDSCAPE: GEOLOGICAL UNDERPINNINGS OF BUTTE

Richard I. Gibson

*Consulting Geologist, Butte, Montana, and
Butte Citizens for Preservation & Revitalization
rigibson@earthlink.net*

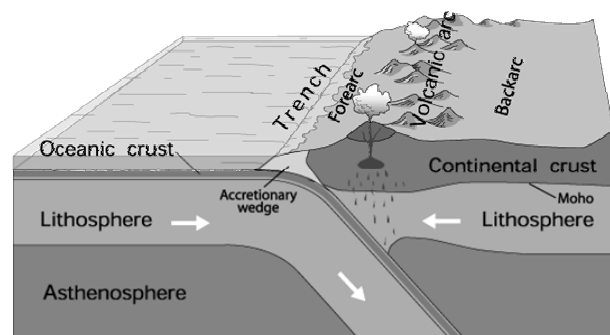
Seventy-five or eighty million years ago, volcanoes dotted the western edge of North America, which was located here in western Montana and in Idaho. The plains to the east, stretching into the Dakotas and south to Colorado, were mud flats laced with sandy rivers. Dinosaurs grazed, preyed, and scavenged over this wide, lush panorama during a geologic time called the Cretaceous Period.

Butte's metallic future was evolving deep beneath the surface, in the roots of the volcanoes. A gigantic lava lamp, now petrified, lay beneath what is now Butte. Huge blobs of molten rock many miles in diameter were rising buoyantly from a depth of about 100 km (60 miles) as a result of earth's recycling process—subduction.

Subduction results from density differences in the earth's crust. Oceanic crust is denser than continental crust, so when the two meet—driven together by huge, slow movements called convection currents—oceanic crust usually dives under continental crust. The place where this happens is a busy location, tectoni-

cally—earthquakes, volcanoes, oceanic trenches, and mountain ranges all form at such zones of collision.

The subducting slab of oceanic crust plunges to greater and greater depths. Eventually things get hot enough for water to be driven off, rising into the overlying rock where it reduces the melting point and generates the blobs of magma (molten rock) that rise toward the surface as if they were part of that giant lava lamp.



Subduction produces mountain ranges and volcanoes at continental margins. Southwest Montana was something like this about 78 million years ago. Image from U.S. Geological Survey.

Near the surface, where temperatures and pressures are lower, molten magma begins to solidify and even crack as it cools. The cracks form conduits for the last subterranean hot water and bits of molten rock, which often carry the good stuff—copper, silver, gold and the wealth of other minerals that made Butte so rich. When that last material solidifies, it becomes ore veins sought by prospectors and miners.

Insulated by overlying rock, the granite in the blobs of magma can take hundreds of thousands of years to completely solidify. If it does reach the surface, it may erupt through a volcano—and such volcanoes were present in this area during the Cretaceous Period. Their remnants are the Elkhorn Mountains about forty miles northeast of Butte.

Blobs of magma—as many as 16 of them—coalesced to form a huge mass of granite called the Boulder Batholith, which extends from the Highland Mountains south of Butte almost to Helena, making the batholith (a word that means “deep rock”) seventy miles long and forty miles wide. The Boulder Batholith is small as batholiths go—California’s Sierra Nevada Batholith is close to 500 miles long.

Big Butte, the town’s namesake, is also the resistant remnant of a volcano’s core, but 25 million years younger than the Butte granite. That still makes it 50 million years old.

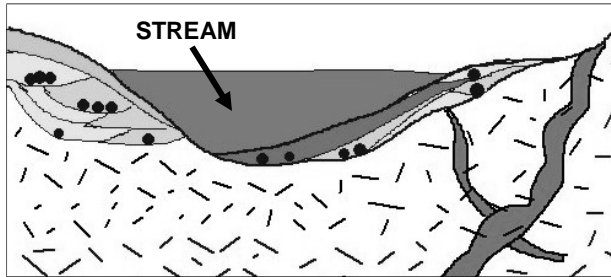
Forcing magmas into the surrounding rock produced some uplift of the whole region. Southwest Montana was also uplifted by the thousand-mile-long collision western North America was undergoing. Uplift meant that most of this area was above sea level after about 70 million years ago, and that in turn meant that erosion was taking place.

Millions of years of erosion removed the overlying rock, as well as any volcanoes (if present) associated with the deep Butte granite. Erosion reached down into the granite, but not too far—the presence of Big Butte’s rocks, which cooled relatively close to the former surface of the earth, indicates this, even though the upper parts (probably at least three miles) of the Big Butte volcano—25 million years younger than the granite—have also eroded away. Erosion proceeded just far enough to expose the granite’s cracks and veins filled with rich metallic ores—a lucky chance.

As the edges of ore veins eroded away, broken pieces of rock and ore washed into rivers—a process that continues today. Water winnowed the fragments, separating the denser, heavier chunks that could not be carried as far, and deposited them in low spots in the river, or along meanders where the river flowed more slowly. These concentrations of dense minerals (often including gold) are called *placers*, usually the easiest gold to discover and separate using a simple gold pan or sluice box.



Placer miner with a gold pan.

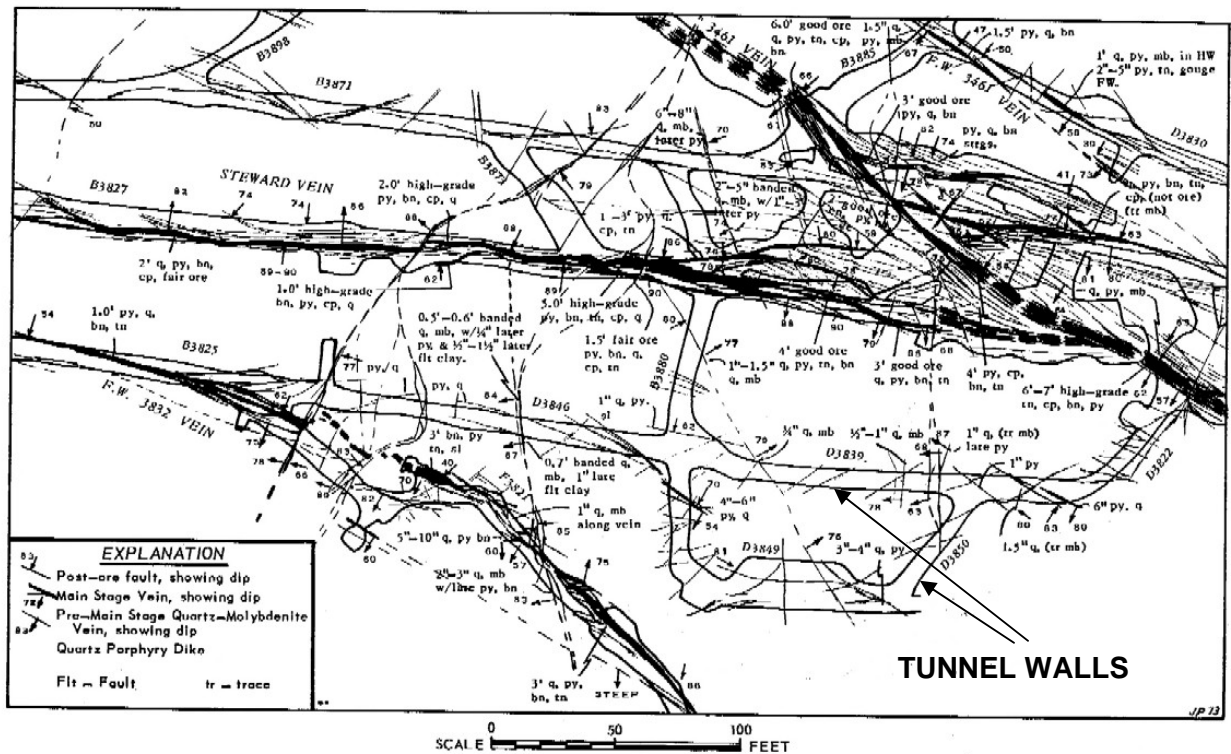


Placer deposits (black dots) form at selected locations along stream courses. Bedrock containing gold and other ores is indicated by the random dash pattern, with an intrusion of different rock at right.

Even before the easy-to-find gold in placers played out, miners were scouring the Butte Hill for outcrops of ore veins. Underground miners chased these veins and ultimately created more than 10,000 miles of underground workings—drifts, stopes, crosscuts, and shafts—beneath about five square miles of Butte’s land. The initial 1860s boom was

driven by gold exploration, and resulted in a population in the vicinity of Butte estimated variously at 500 to 1500. By 1874, however, Butte’s population had dropped to an estimated 50 or 60 relatively desperate miners. Discovery of abundant hidden silver in 1875 saved Butte, and the geology of the ore deposit controlled how the mines and neighborhoods developed.

The minerals of Butte are arranged in concentric zones, like a big irregular onion, sliced to give the appearance of a gigantic bull’s-eye. The outer zones, especially on the north and west sides, are richest in silver, lead, zinc, and manganese, so some of the older mines—the Orphan Girl (at the World Museum of Mining), Travona, and the Alice up north in Walkerville—started as silver mines. Walkerville grew up as one of the first neighborhoods (it



Map showing variability and complexity of underground vein system. This is at the 3800 level (3800 ft below surface) at the Steward Mine. The paired lines represent man-made tunnels (drifts and stopes). All other lines are veins. The Steward Vein, extending left-right just above center, was more than 10 feet thick in places. From Proffett (1978).

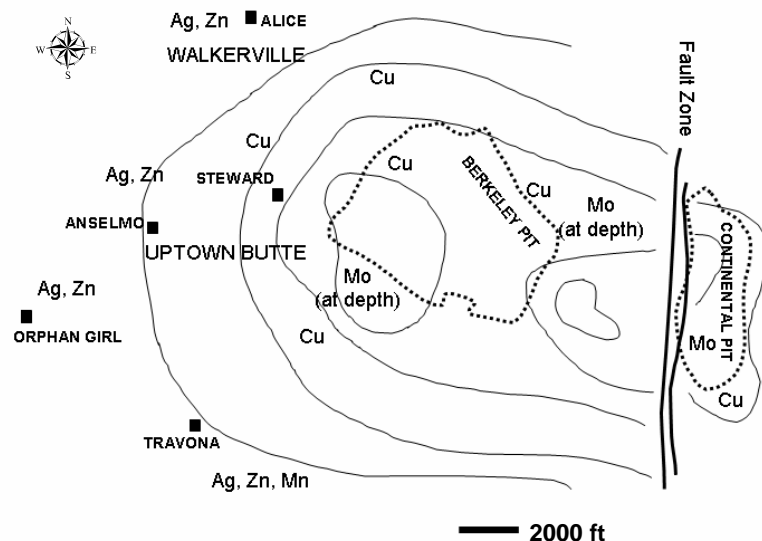
was, strictly speaking, a city in its own right, and is still independent of Butte), settled by Cornish miners and named for the mine's owners, the Walker brothers of Salt Lake City. They hired young Marcus Daly, an Irishman fresh from the Comstock Silver Lode in Nevada, to manage their mine. His experience and earnings allowed him to prosper and acquire the Anaconda mine in the middle of the district—the zone that was not silver-rich, but which contained some of the thickest, richest copper veins known on the planet.

Daly's discovery of the Anaconda copper vein in 1882 was timely. The invention of the telephone (1876) and electric light (1879) created huge demand for copper for wiring. Butte's population grew from about 3,300 in 1880 to 23,000 in 1890 and to an estimated 85,000 to 100,000 in 1917. (Butte's population today is about 32,000.) Mining development of the central zone, rich in copper, expanded with the population, until in the early part of the 20th century Butte was supplying nearly a third of all the copper produced in the world. Butte's copper was the most important single factor in electrifying North America. Following the silver crisis of 1893, many silver camps ceased operations. Butte was impacted, but by that time copper was already at the forefront of the mineral treasures here, and silver remained a valuable byproduct—enough so that Butte is the second largest producer of silver in the United States (after Coeur d'Alene, Idaho) and likely in the top five silver producers in the world.

Another important mineral zone lies about 2800 to 4000 feet beneath most of Butte. The molybdenum, or moly, zone was known and small amounts were

produced in the early 20th century as steel alloys with moly were found to add strength and corrosion resistance to engine parts and other commodities. This zone came into its own in the middle 1980s, and remains important today with molybdenum the primary byproduct (and at times, the most valuable product) at the Montana Resources Continental Pit, east of the Berkeley Pit. Most of Butte's molybdenum has come from the Continental Pit in the past 20 years. The east wall of the Continental Pit is visible beneath the East Ridge, viewed east along Broadway Street. Molybdenum can be mined in the relatively shallow Continental Pit because the zone was uplifted by as much as 4000 feet along faults that lie between the Berkeley and Continental Pits.

During the century of underground mining, from about 1875 to 1975, the richness of the ore varied from vein to vein, but copper values ranging from 5% to 10% were common, especially in the early years. One vein in the Anaconda Mine was more than five feet thick and assayed at 55% copper. For several years



Generalized map of mineral zonation for Butte area. Modified from Czehura (2006) and other sources. Ag = silver, Zn = zinc, Mn = manganese, Cu = copper, Mo = molybdenum.

in the early 1880s, ore averaged 45% copper, rich enough to make it highly profitable despite shipping it all to Swansea, Wales, for processing. Even silver was occasionally produced at rates exceeding 1,000 ounces per ton. In contrast, the Berkeley and Continental Pits extracted much lower grades of ore. Today, the Continental Pit's copper grade is about 0.3% (three-tenths of one percent), yielding about 6 pounds of copper per ton of ore, together with not quite one pound of molybdenum per ton. At the peak in 1915-1918, about 16,000 men were employed underground. Today the Continental Pit employs about 350.

The billions of pounds of copper produced from Butte represent enough to pave the Interstate from Butte to beyond Salt Lake City—450 miles—with pure copper four inches thick.

Arizona, Utah, New Mexico, Nevada, and Montana (in decreasing order) account for 99% of domestic copper production, but despite more than a million metric tons extracted from US mines, in 2007 the US was dependent on copper imports for 37% of its needs. The building construction industry consumes just over half of the copper used today. Electronics account for another 19% with consumer and general products at 11%; transportation equipment, 10%; and industrial machinery and equipment, 9%.

More than 80% of moly consumption goes to steel alloys, in applications where the steel needs to have strength at high temperatures and pressures, as in airplane engines. Moly steels are corrosion resistant and are used in water and gas transmission systems and hospital and food-handling equipment. The US is a net exporter of molybdenum, one of only a few mineral commodities for which this is the case.

RICHEST HILL ON EARTH

Is Butte really “The Richest Hill on Earth”? The US Geological Survey has estimated the value of Butte's total mineral production and reserves at \$162 billion in 1987 dollars, well ahead of US #2 Bingham Canyon, Utah, at \$128 billion. In the world, however, it is likely that the vast deposits of copper in Chile as well as the gold mines of South Africa have produced and/or contain mineral wealth of greater value, and this may also be true of a few other mining districts elsewhere in the world. Butte is not about to change its nickname, though!

The Landscape

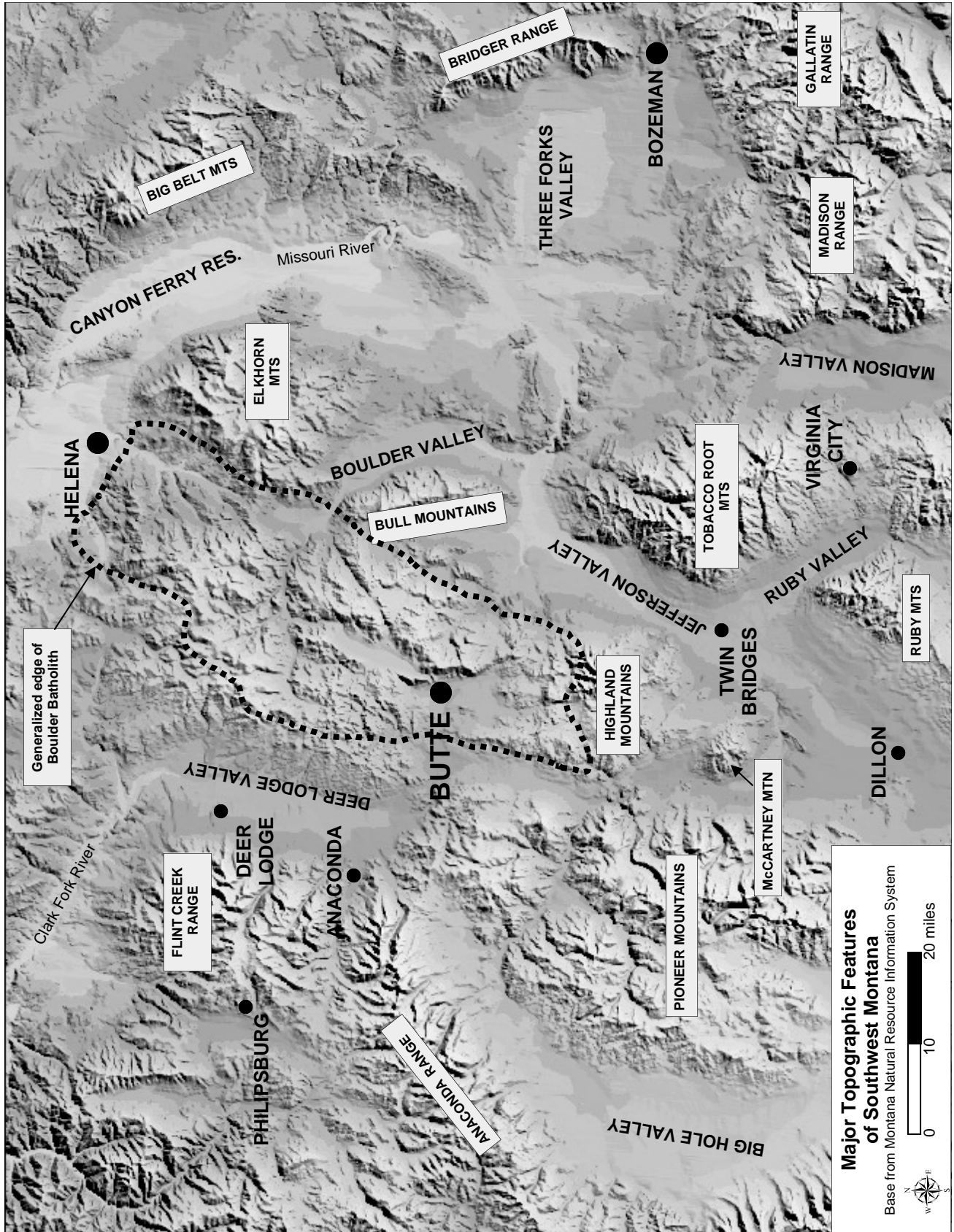
Southwest Montana is a land of fertile but semi-arid valleys separated by relatively small but high mountain ranges. This general topography is the result of the most recent geologic activity in the region. (Map, page 6.)

BUTTE MINERAL PRODUCTION

1880 through 2000
with ranks in US by US Geological Survey

Copper: Butte #2 in production, #1 in produced + reserves
Silver: Butte #2 in production, #1 in produced + reserves
Zinc: Butte #6 in production, #4 in produced + reserves
Manganese: Butte probably #1 in production

COPPER	21,479,571,676 pounds
ZINC	4,909,202,540 pounds
MANGANESE	3,702,787,341 pounds
LEAD	854,797,405 pounds
MOLYBDENUM	183,128,294 pounds
SILVER	714,643,005 troy oz
GOLD	2,922,446 troy ounces
CADMIUM	4,306,156 pounds
BISMUTH	4,042,663 pounds
SELENIUM	316,855 pounds
TELLURIUM	237,256 pounds



Although the underlying geologic structures of Butte and vicinity resulted from great tectonic collisions, the present-day framework is the result of relaxation and pulling apart. Much of western North America is like almost-solid peanut brittle being tugged at by fighting children, with the result that many areas—most of Nevada, western Utah, southeast Idaho, and southwest Montana—are breaking apart.

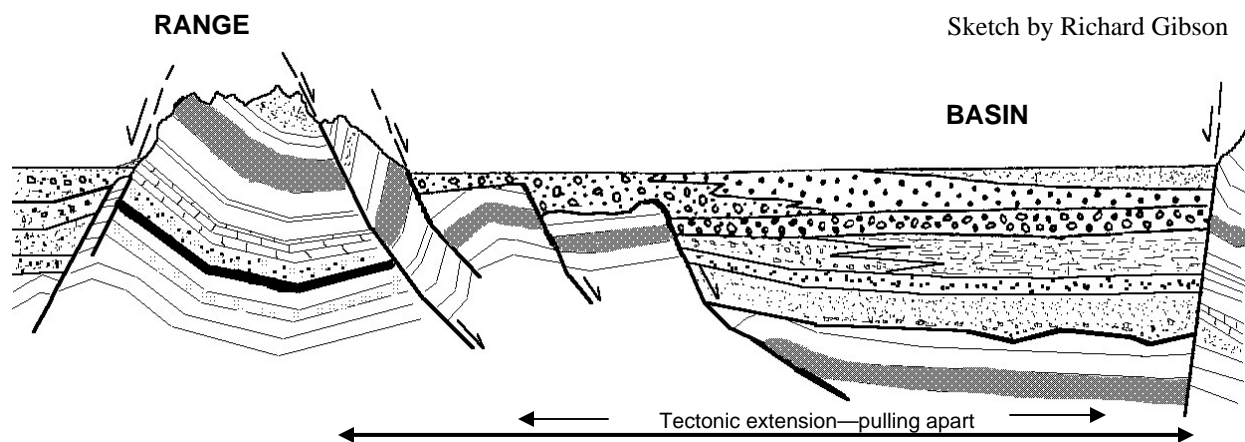
When rocks break along faults, one side goes up or down with respect to the other (or sometimes sideways). Gigantic blocks dropped down along normal faults develop as a result of pulling apart, like the keystone at the top of an arch. A down-dropped basin formed in this way is called a graben, and many of the modern river basins in the region formed in this way, with fault lines along mountain fronts. The Jefferson, Madison, and Bitterroot valleys are among the best examples in western Montana of this origin. The Deer Lodge Valley is similar, but with only a single large fault bounding the basin on one side, making it a half-graben. It contains as much as 10,000 feet of sediment (including lake beds, river sediments, and glacial deposits) eroded from the adjacent highlands over the past 50 million years.

Over time, this basin-and-range landscape has been modified by erosion. At times, southwest

Montana was much more humid than at present, resulting in greater erosion. Today, the semi-arid environment means that most weathering is simple mechanical destruction of rocks by freezing and thawing, and by flowing water when it does rain.

During the most recent ice age (from about 2,000,000 to 14,000 years ago), glaciers were not present at Butte. But in the high mountains nearby, small ice caps formed, and many valleys bore thick valley glaciers. To the west, much of today's Clark Fork River valley was occupied by Glacial Lake Missoula that formed on the ice margin when an ice dam developed in Idaho. The lake did not reach Butte; the furthest up the Clark Fork the lake extended was the vicinity of Drummond, about 75 miles downstream (northwest) of Butte. During glacial times, Butte uplands likely saw lots of rain and snow, but no glacial ice and no large, persistent lake.

The physical landscape today, apart from human-induced changes including vegetation patterns and mining, is much the same as it was when Lewis and Clark just missed Pipestone Pass and the headwaters of the Clark Fork River in 1805, a route that would have saved them much hardship.



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Flora and Fauna

The mountains of western Montana contain abundant large mammals, diverse birds, and fish. This section describes the setting in and near Butte and Anaconda.

Moose have been seen infrequently in Butte, mostly in the relatively open spaces a few blocks off Harrison Avenue on the Flats, and in the area around Big Butte. Deer are common, and in some disused fields prairie dogs are found. Foxes frequent the Big Butte Open Space and are sometimes seen in town, along with their common prey—jackrabbits and cottontails.

Mountain bluebirds, ravens, goldfinches, magpies, and occasionally seagulls, hawks, and owls fly Butte's airspace, along with common sparrows, finches, and many other summer residents. Watery areas are avian gathering spots—watch for Canada geese and other waterfowl, especially along Blacktail Creek.

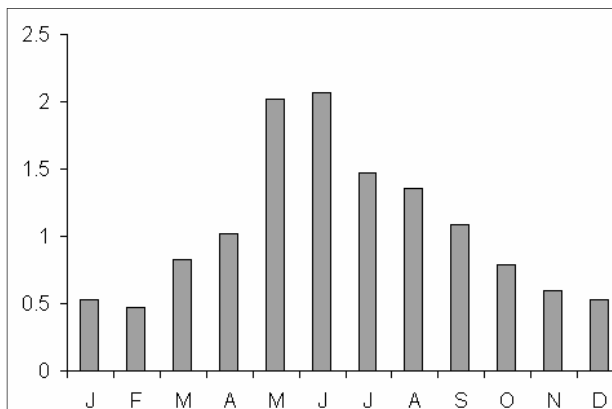
The long winter and semi-arid urban environment restricts the abundance of reptiles and amphibians, but garter snakes are found, as well as frogs and toads near watercourses.

Climate

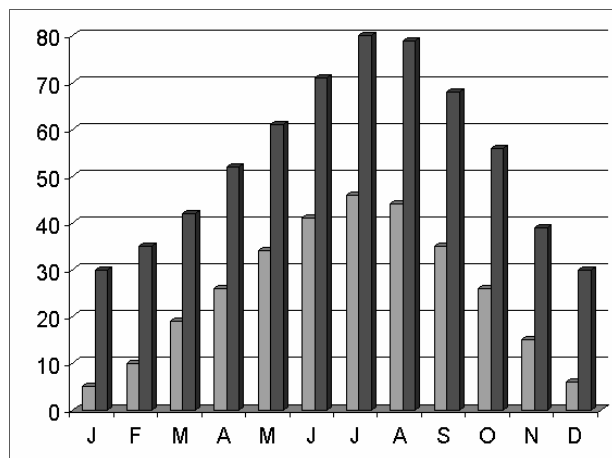
The high mountains and low valleys in western Montana produce a wide range of microclimates, ranging from boreal rain forests at lower elevations west of the Continental Divide to high alpine deserts. Winters in Butte are long, with short periods colder than 30° below zero (F) common. Spring is wet and cool, and summers are dry (with occasional, intense thunderstorms) and warm, with cool nights.

Ranching in nearby lower elevation valleys is restricted more by the arid climate than by a

short growing season. About 20% of Montana's work force is employed in the agricultural sector, but agriculture's \$850 million in revenue only accounts for about 3% of the gross state product. The mining sector – including oil and gas—fluctuates significantly with the world economy and the prices of commodities, but in 2007 amounted to about 7% of the gross state product. (Sources: Bureau of Economic Analysis of the U.S. Department of Commerce and Montana Office of Economic Development.)



Average monthly precipitation in Butte, in inches. April and May are the snowiest months, but snow is possible in any month of the year. Summer rains usually come in brief, intense thundershowers. Butte's annual total precipitation of just under 13 inches makes its climate semi-arid. Data from NOAA.



Average high and low temperatures at the Butte airport in degrees Fahrenheit. On "The Hill" in Uptown Butte, temperatures are commonly about 5° warmer in winter and 5° cooler in summer than on the Flats.

Environmental Concerns

Butte is a cautionary tale in environmental mismanagement—and a success story of environmental restoration. A century of irresponsible mining practices, hidden away in remote Montana, all but killed the upper Clark Fork River, destroyed the utility of subterranean aquifers forever, and contaminated vast areas of soil. Butte and areas downstream for 120 miles became the largest Superfund site in the United States.

Like its namesake, the Anaconda Company squeezed its competition in the Wars of the Copper Kings, killed the Gibraltar of Unionism during the turbulence of 1914-1920, and throughout its tenure generally did what it wanted to in the name of "getting the ore in the box." Problems were not limited to the immediate vicinity of the mines in Butte. For decades, the smelter in Anaconda spewed acidic arsenic-laden smoke into the Deer Lodge valley. Among the first lawsuits (1900-1920) brought against the Anaconda Company were those of ranchers downwind from the smelter, where livestock was dying as were many square miles of trees in the National Forest. The latter allowed the Federal government to participate—but corporate pressure resulted in a change in the boundary of the National Forest, so that property of the United States was no longer damaged, and the Federal government no longer had standing in the cases. The battle—on the whole, a losing one—is documented in *Smoke Wars* by Donald MacMillan (Montana Historical Society Press, 2000).

The advent of environmental consciousness in the United States in the 1970s coincided with the end of Anaconda, as its assets in Chile were nationalized and the magnitude of its environmental liability became clear. By 1982, soon after the Anaconda Company was acquired by the oil company Atlantic Rich-

field (ARCO) in 1977, all mining and smelting operations in the Butte-Anaconda area ended. The ensuing economic catastrophe also resulted in a battle to remediate the environmental damage, but after decades of lawsuits, by 2008 most of the claims had been settled; one major consent decree was pending at this writing (April 2009). The State of Montana, and its partners Butte and Anaconda, have received many millions of dollars in settlements from ARCO and other potentially responsible parties.

In addition to the settlements awarded, ARCO has spent over \$1 billion in Butte, Anaconda, and the Clark Fork River watershed to clean up damage caused by past mining, milling, and smelting operations. In some cases this means removing hazardous material, covering the exposed land with clean soil, and monitoring contaminant levels. It meant building a water treatment plant at the Berkeley Pit. It means providing for replacement funds in circumstances where the damage is deemed to be forever, as is the case with Butte's underground aquifers—Butte's water supply must instead be pumped many miles, from the Big Hole River across the Continental Divide, and from uncontaminated reservoirs high in the mountains. This is nothing new; the Big Hole Pump Station is a National Register listed site whose construction began in 1899 to supply water to Butte's burgeoning population.

Through Montana's Natural Resource Damage Program, funded largely by ARCO, a unique educational program has been developed to inform school children of what happened and why, and to encourage them to become caring stewards of their land and waterways. The Clark Fork Watershed Education Project (www.cfwep.org) is a highly successful example of place-based education, reaching more than 7,000 students in its first three years. Students make careful measurements of both damaged and pristine stream reaches to

compare diversity of biota as an estimate of stream health. There is good news: the once-dead Silver Bow Creek and Upper Clark Fork River have come back to life and are clearly improving.

See also Quivik, this volume (p. 11).

Thanks to Dick Berg for a helpful review of this essay.



Students study Silver Bow Creek in Butte, formerly one of the most polluted tributaries of the Clark Fork River. (Photo courtesy Clark Fork Watershed Education Project)

SOME BUTTE MINERALS

Sulfur, producing sulfuric acid, and arsenic are the two greatest environmental problems.

- Bornite Cu_5FeS_4
(copper-iron sulfide) peacock ore
- Chalcocite Cu_2S (copper sulfide)
- Chalcopyrite CuFeS_2 (copper-iron sulfide)
- Covellite CuS (copper sulfide)
- Digenite Cu_9S_5 (copper sulfide)
- Enargite Cu_3AsS_4 (copper-arsenic sulfide)
- Molybdenite MoS_2 (molybdenum sulfide)
important ore of molybdenum
- Pyrite FeS_2 (iron sulfide)
usually part of the waste rock
- Rhodochrosite MnCO_3
(manganese carbonate)
- Sphalerite ZnS (zinc sulfide)
- Galena PbS (lead sulfide)