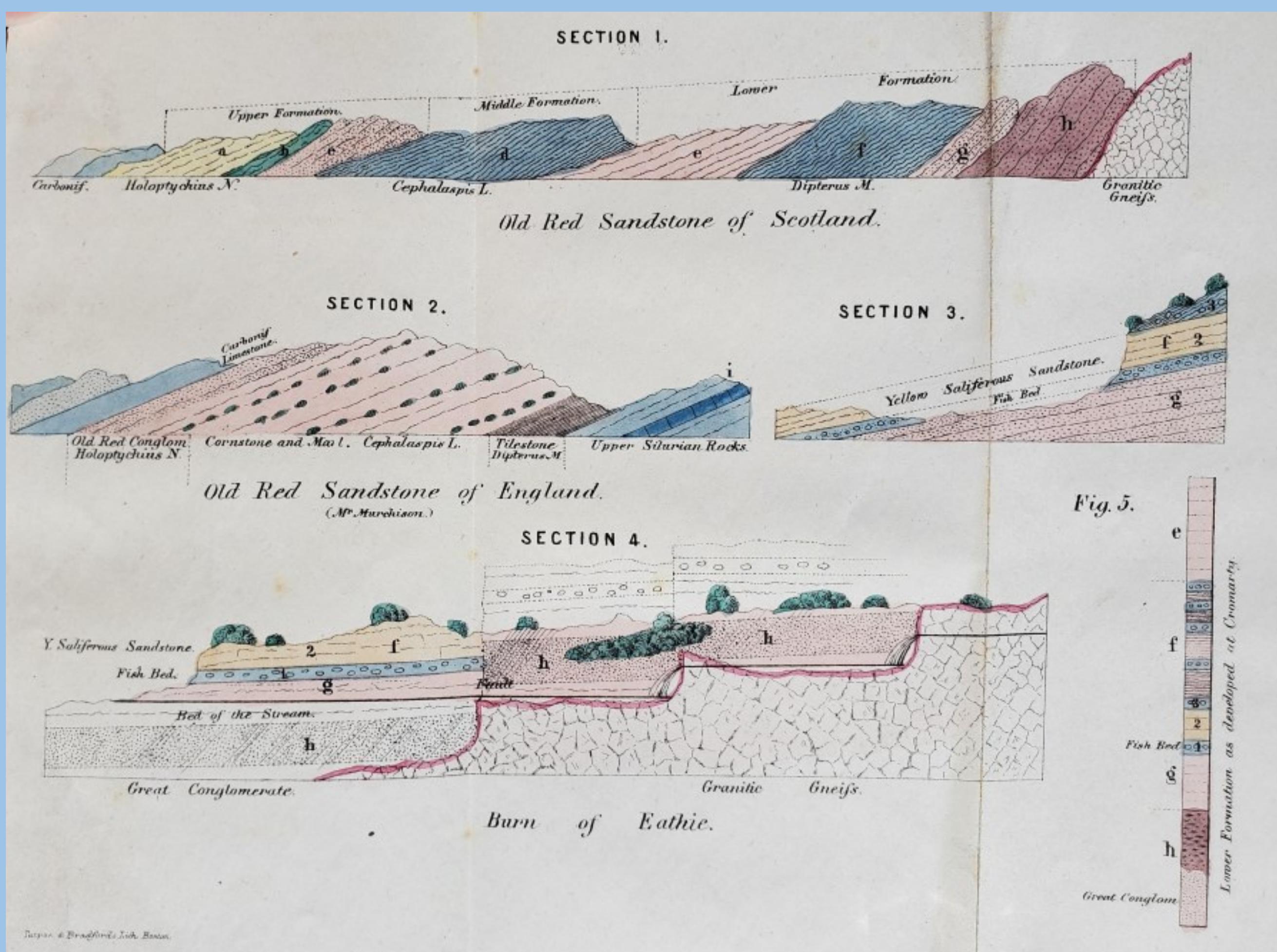
POSTINGS

ON THE

HISTORY OF GEOLOGY



BY RICHARD I. GIBSON

POSTINGS

ON THE

HISTORY OF GEOLOGY

BY RICHARD I. GIBSON

These essays comprise a compilation of posts on Facebook that I did mostly from about 2016 to 2022. They appeared on my personal Facebook page as well as the History of the Earth page. They are little modified from the original posts, and include my personal observations about the items in my collections on which the posts are based as well as notes about my learning experience in researching them. Consequently, this is a highly personalized and subjective look at the subject, derived from things I actually have.

The old photos and maps are in the public domain. A few photos, such as those I made of mineral specimens, are mine, and the texts are © 2022 by Richard I. Gibson. I encourage sharing of the entire document, but request that you not copy the texts directly without permission or attribution. Thanks for your interest!

—Dick Gibson, Butte, Montana, 2022. rigibson@earthlink.net

Cover: Cross-sections from the frontispiece of Hugh Miller's Old Red Sandstone, 1851 (First American Edition).

CONTENTS

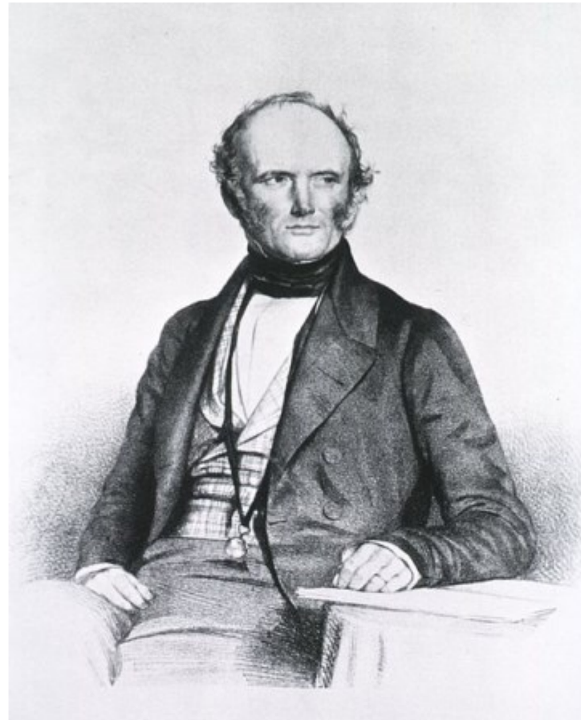
Lyell in Spain

The print here of the volcanoes at Olot, Catalonia, in far northeast Spain about 90 km north of Barcelona, serves as a frontispiece for Volume IV of Charles Lyell's *Principles of Geology* (my copy is the fifth London edition, published in 1837). It was based on a sketch by Lyell himself while he was at Olot in early August 1830. The printed plate was hand-colored with watercolors by an unknown artist; every copy of this illustration published in the *Principles* was hand-painted individually, and the clouds are entirely the work of the watercolor artist – they vary from copy to copy of this print. Lyell himself boasted vaingloriously of his press runs to colleagues, and the first edition was a run of 1,500 versus a more typical 800. Likely the publisher hired a small army of artists to do the watercolors, of which there are more than one, each an original, in each of the four volumes.

Having read that people in Olot recalled eruptions, Lyell sought original sources because he didn't think the flows were that recent. He wrote to a colleague, "As to historical dates, that is all a fudge. I found out the man who provided Maclure with all his antiquarian information, and after reading it, I can assure you that there never was an eruption within memory of man." He observed volcanic cones with craters, but also "perhaps twenty points of eruption without craters. In all cases they burst through secondary limestone and sandstone." Today, we'd probably call these eruptions without craters fissure eruptions, and Lyell's “secondary” refers to the Mesozoic, part of a naming system that survives in the names Tertiary and Quaternary.

Vulcanism began in this area about 700,000 years ago, and the most recent activity is around 11,000 years old. The volcanoes are considered dormant rather than extinct, and the region is seismically active – earthquakes in Catalonia in 1427 and 1428 killed many hundreds of people and pretty much destroyed the town of Olot.

Iberia (Spain and Portugal) is a cratonic block that has operated as a semi-independent microcontinent (something like the island of Madagascar today) for much of its recent geologic history. When Gondwana collided with Laurentia (North America) to form Pangaea, Iberia was adjacent to the Grand Banks offshore present-day Newfoundland. After the North Atlantic began to open, Iberia was probably more or less locked with present-day Africa, but it broke off around 40 million years ago.



Sir Charles Lyell (1797—1875)

As it moved and rotated, Iberia collided with the southern edge of Europe (then in present-day France) to begin uplifting the Pyrenees, and contemporaneously the rotational rift that’s now beneath the Bay of Biscay began to form. The tectonic history of the Mediterranean is really complicated, but the volcanism here might be related to another rift that began forming on the east side of Iberia about 15 million years ago, between Iberia and the Balearic Islands, the Balearic Sea today. That pull-apart probably broke the crust at the eastern end of the Pyrenees (in Catalonia) allowing the volcanoes to develop, or it may have to do with a slight subduction of Iberia beneath the edge of Eurasia. I don’t pretend to understand the tectonics of this area. But in any case, today, Iberia is pretty much locked (albeit imperfectly) with Eurasia, and the plate boundary runs about through the Strait of Gibraltar.

Lyell expanded James Hutton’s idea that processes observable on earth today could produce all the things we see in earth history, given enough time. Lyell was an ardent proponent of this gradual change and his ideas significantly shaped Darwin’s thinking about evolution, but “uniformitarianism,” the word to describe this perpetual change over many millions of years, was actually coined by William Whewell, who also invented the word “scientist,” and for whom a painfully common kidney stone mineral is named. Today we recognize uniformitarian aspects of geologic processes, but punctuations in the form of catastrophes as well as other short, intense geological developments are also seen to have roles in earth history.

Lyell’s *Principles of Geology* ultimately went through 12 editions, the last in 1875, and the work had a long-lasting impact on geological thought.

The stone to make this 1837 illustration of the Catalonian volcanoes was 14 x 21 cm (it’s a fold-out in the book). It’s almost certainly a painted lithograph, although other plates in the volumes (typically fossils) are clearly engravings (steel- or copperplate), with the names of the delineator and the engraver appended. The 4-volume set of the *Principles of Geology* cost 24 shillings in 1837, which had a buying power equivalent to about five days of a skilled workman’s labor, and equates to about 75 pounds sterling (US $97) today. For the Director of the Geological Survey of England and Wales, who was paid 500 pounds (10,000 shillings) per year in the late 1830s, the books were affordable. For a clerk earning 10 shillings a week at a time when a loaf of bread cost him a half a day’s pay, they were not.

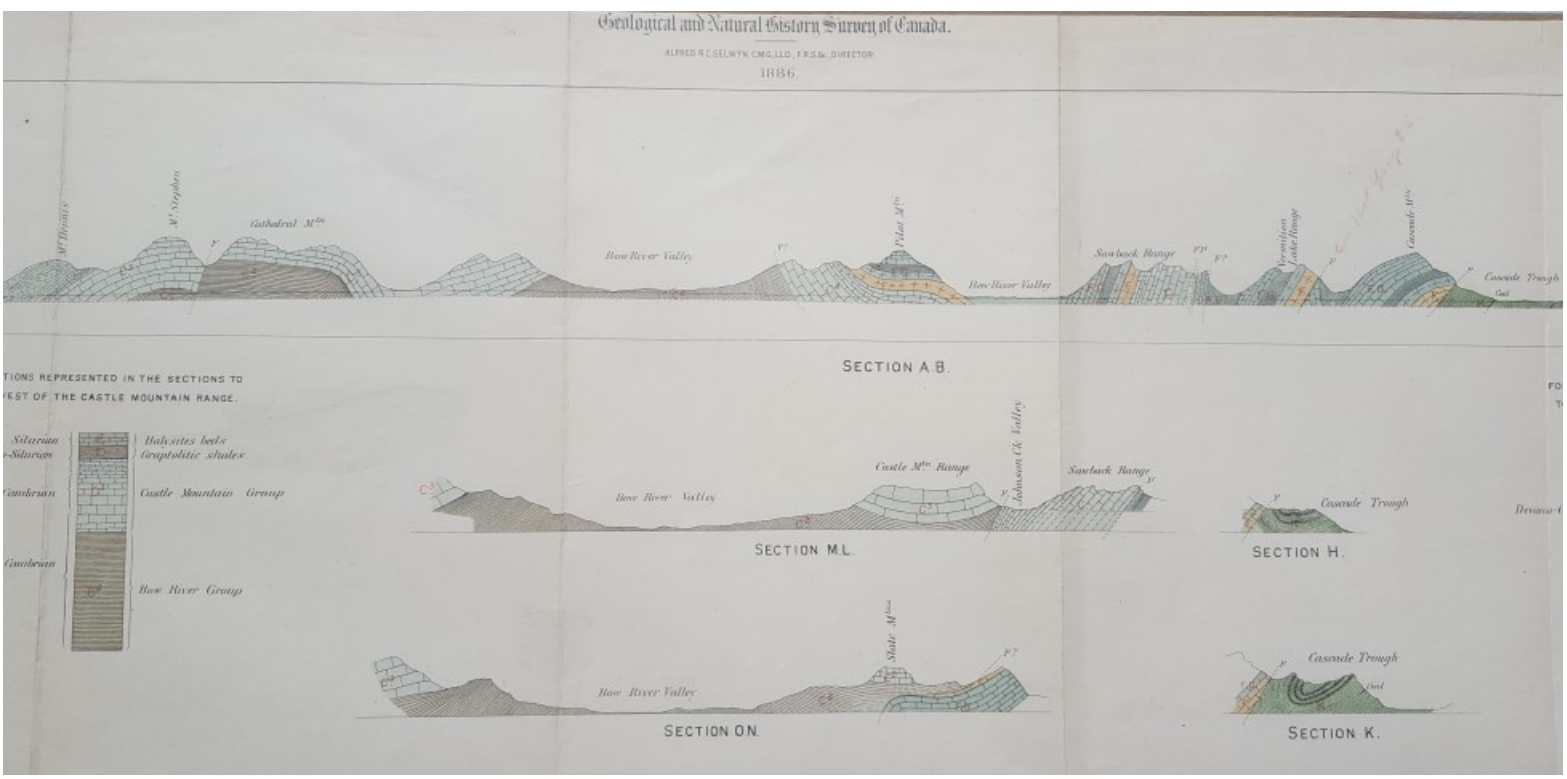
Overthrusts in Canada

"The thrust producing these crustal movements and dislocations came from the west, and must have been highly energetic in its action, as some of the breaks are of huge proportions, and are accompanied by displacements of many thousands of feet. The faulted region is now about twenty-five miles wide, but a rough estimate places its original width at over fifty miles, the difference indicating the amount of compression it has suffered."

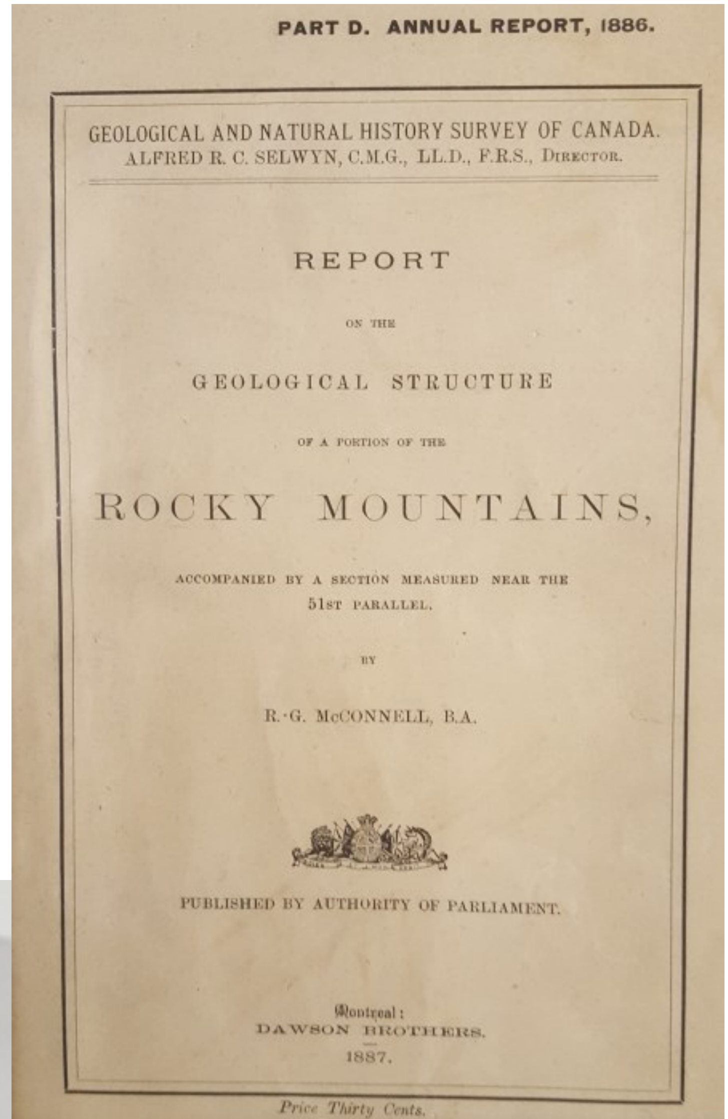
With these words, R. G. McConnell was the first geologist to report the interpretation of low-angle thrust faults with significant throw in the western Cordillera of North America. McConnell's study, entitled *Report on the Geological Structure of a portion of the Rocky Mountains*, was published in 1887 by the Geological and Natural History Survey of Canada. These cross-sections, near the 51st Parallel, accompanied the report. They document work during the field season of 1886, which was primarily spent in compiling a general geologic section along the line of the Canadian Pacific Railway.

The section begins on the right at Devil's Gap, east of Devil's Lake (now Lake Minnewanka) and extends westward toward Banff. Cascade Mountain, labeled on the section, is just north of Banff and rises to 9836 feet above sea level. The profile then approximately follows the railway up the valley of the Bow River, past Laggan (now the community of Lake Louise), and over the Continental Divide at Kicking Horse Pass. Cathedral Mountain (10,464 ft) and Mount Stephen, shown on the section, are just west of Kicking Horse Pass. The Burgess Shale, classic locality for soft-bodied Cambrian fossils, was discovered in 1909 by Chares D. Wolcott about three miles north of the summit of Mt. Stephen.

When later geologists defined the continuity of individual thrust faults in the Canadian Rockies, one of the major thrusts was named for McConnell. The photo of the Geological Survey Camp, used as the frontispiece of this report, was actually taken during Dawson's surveys a few years later. Dawson's work was generally in country to the south of that described by McConnell.



When I found this report in a used book store, it was falling apart – covers off, pages torn, and the edges of the loose, folded cross-section were severely damaged. Unfolded, the plate with the cross-sections is 10”x38” and it is hand-colored. The middle portion is shown here (previous page), along with the cover and frontis-piece.



PART D. ANNUAL REPORT, 1886.

GEOLOGICAL AND NATURAL HISTORY SURVEY OF CANADA.
ALFRED R. C. SELWYN, C.M.G., LL.D., F.R.S., DIRECTOR.

REPORT

ON THE

GEOLOGICAL STRUCTURE

OF A PORTION OF THE

ROCKY MOUNTAINS,

ACCOMPANIED BY A SECTION MEASURED NEAR THE
51ST PARALLEL,

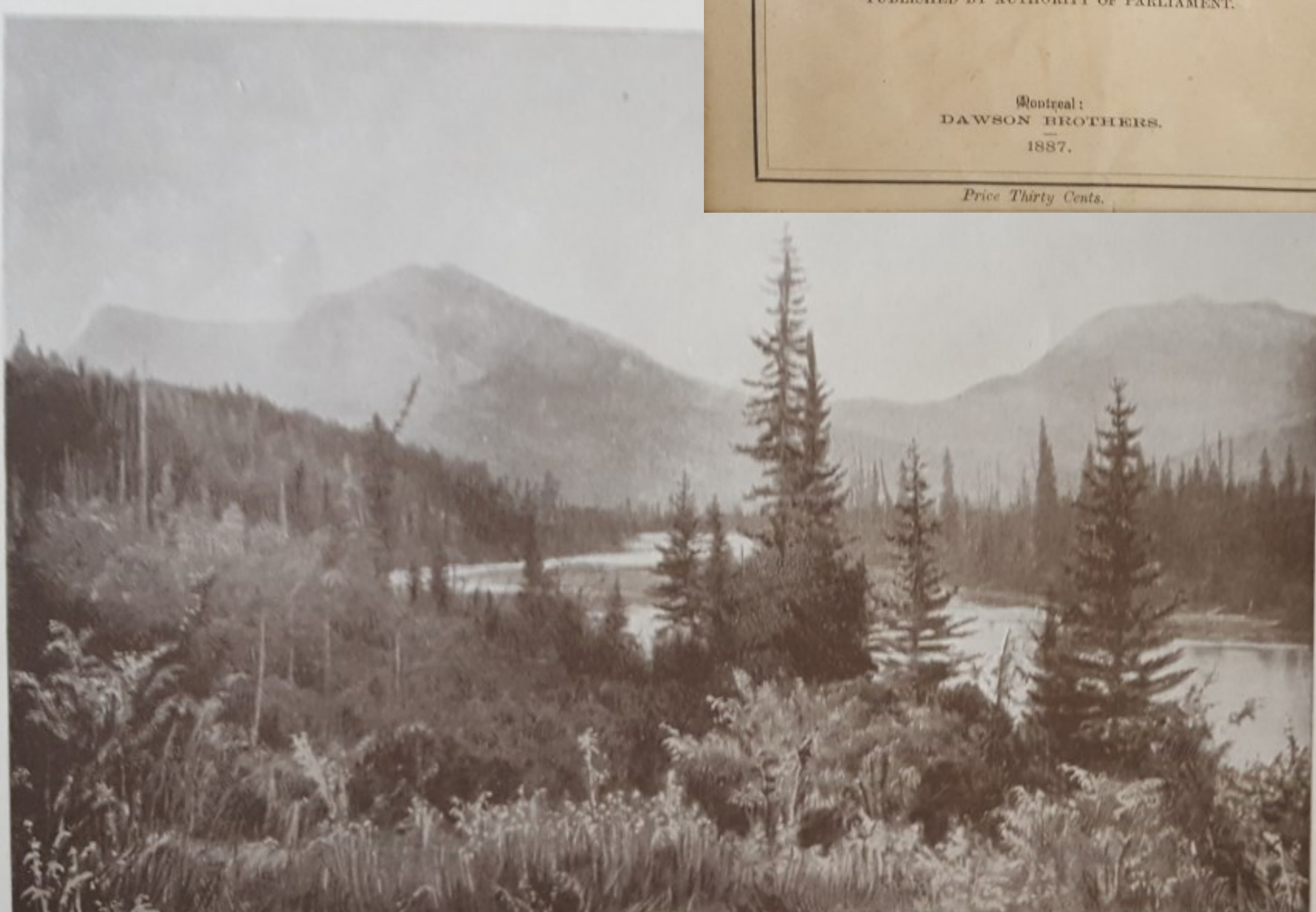
BY

R. G. McCONNELL, B.A.

PUBLISHED BY AUTHORITY OF PARLIAMENT.

Montreal:
DAWSON BROTHERS.
1887.

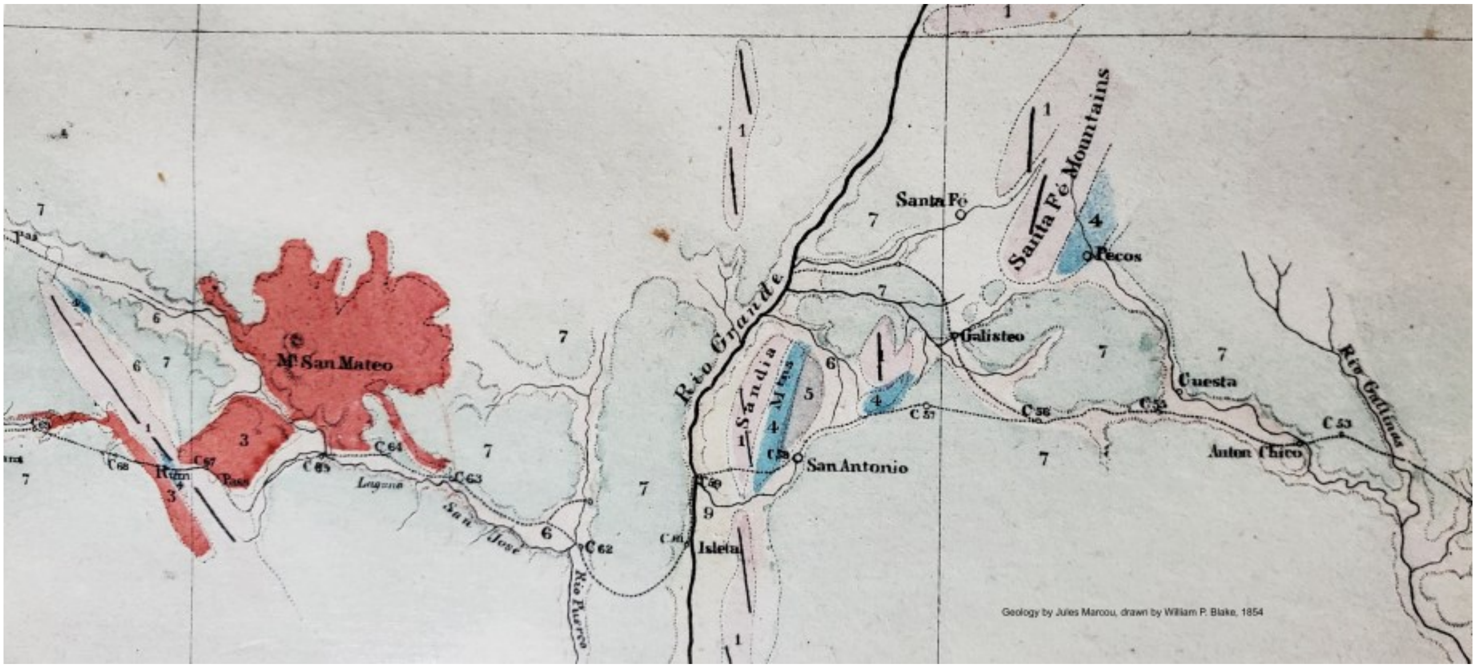
Price Thirty Cents.



G. W. DAWSON, PHOTO., 25TH AUG., 1881. IVES PROCESS | GEO. E. DESBARATS, MONTREAL.

VIEW LOOKING DOWN BOW-PASS, FROM GEOLOGICAL SURVEY CAMP.

The Whipple Survey



Following the US annexation of the Republic of Texas in 1845 and the ensuing Mexican-American War over boundary disputes and the United States' pursuit of Manifest Destiny, among other things, the Mexican Cession of 1848 (by treaty signed February 2) granted the United States the vast territory that now includes all or most of California, Nevada, Utah, and Arizona, together with about half of New Mexico, a quarter of Colorado, and the southwest corner of Wyoming. Although Texas claimed territory as far west as the Rio Grande in the middle of present-day New Mexico, the effective western limit of known and populated Texas was about the middle of the present state of Texas. From there west to the Pacific, the region was mostly unexplored by the US, although it had been explored and occupied by Native Americans and then by Spanish and Mexicans for centuries.

The discovery of gold in California in January 1848, just nine days before the Mexican Cession treaty was signed, created a huge impetus for understanding the topography and geology of the unknown territory, including potential routes to California for prospectors and ultimately for railroads.

The Whipple Survey of 1853-54 was commissioned by the US government to explore southern routes for possible railroads west, specifically more or less along the 35th parallel. The company mapped the region beginning at the mouth of the Arkansas River at the Mississippi, at Napoleon, Arkansas (a town since lost to shifting river courses). The survey corps went up the Arkansas and its tributary the Canadian River, across the Pecos River in West Texas, past the Sandia Mountains to the fort and small settlement on the Rio Grande at Albuquerque, which probably held fewer than 1500 residents in the early 1850s. Albuquerque is Camp 59 (C59) on the Rio Grande on this map.

After crossing the Rio Grande, the company continued west following the San Jose, Zuni, and Puerco Rivers and a segment of the Little Colorado. They passed the San Francisco Peaks in north-central Arizona, followed the Williams River to the Colorado, ascended it to a point above present-day Needles then followed the Mojave River west, ultimately reaching the Mexican settlement of Los Angeles, whose population in 1850 was just 1,610.

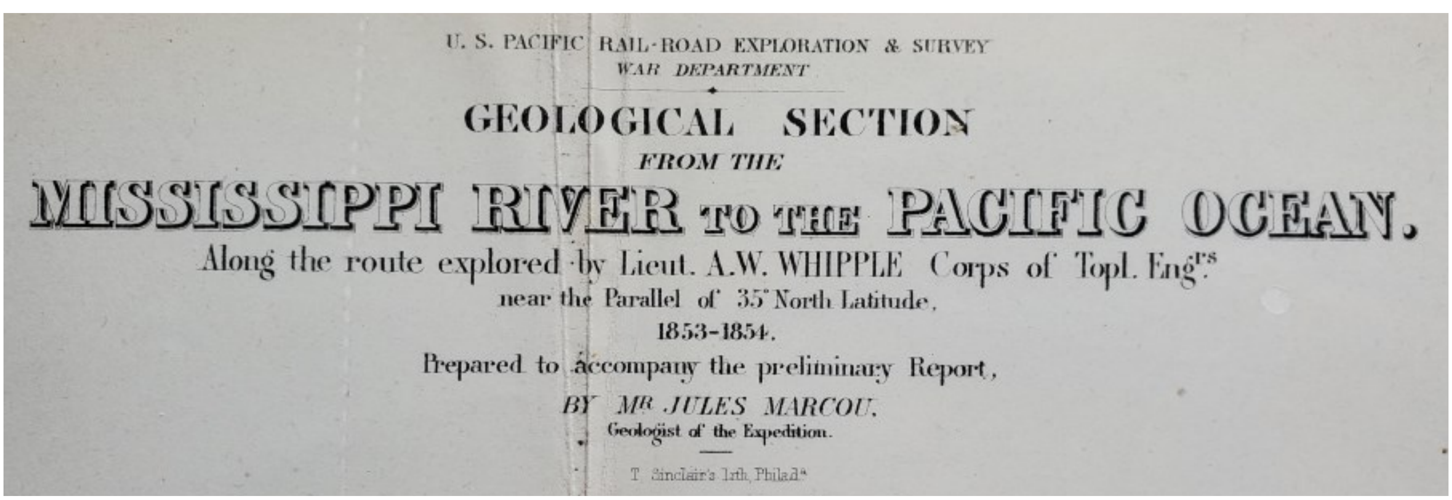
The Whipple Survey was one of five expeditions ultimately under the authorization of Secretary of War Jefferson Davis (who went on to other pursuits) and funded by a Congressional allocation totaling $150,000 for all five. The Whipple Survey covered the region and much of the specific route of the later Santa Fe Railroad, US highway 66, and Interstate 40.

A.W. Whipple was accompanied by Jules Marcou, a 29-year-old French geologist who is credited with compiling the first good, comprehensive geologic map of the United States and southern Canada from the Atlantic to the Pacific. As one of the first geologists to cross the US to the Pacific, he added considerable geologic knowledge to the otherwise blank areas of the Western US.

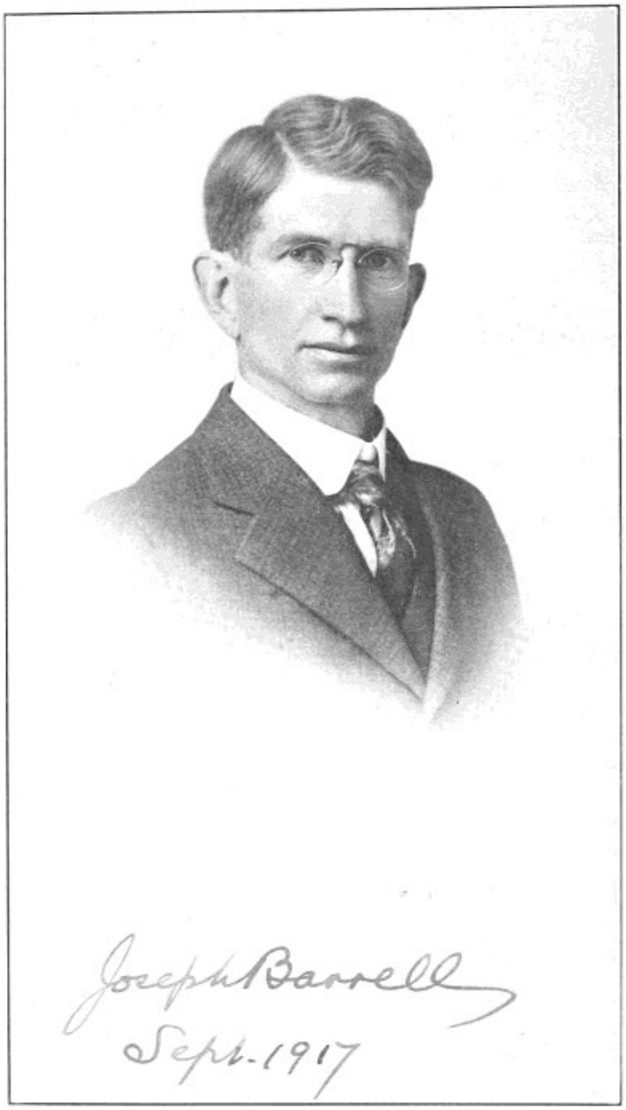
The map here is a snippet from a huge (100 cm by 28 cm) fold-out strip map in my collection of the route of the Whipple Survey from the Mississippi to the Pacific. It is hand-colored (watercolors) and shows the pink #6 “Gypsum Formation” (mostly the Permian Castile formation) as well as the gray “Carboniferous Sandstone” #5 and blue “Carboniferous Limestone” #4 (mostly the Madera and Sandia formations) in the Sandia Mountains east of Albuquerque, with pink #1, “granite and metamorphic” on the western flank of the range. Light blue “Cretaceous rocks” (#7) lie west of the Rio Grande as well as to the east, and the bright red patch around Mt. San Mateo is “extinct volcanoes and lava.” The volcanic rocks near San Mateo are mostly young, with some dated to 2 to 3 million years. They are probably related to the opening of the Rio Grande Rift through which the Rio Grande River flows. Although reconnaissance in nature, all this geologic mapping is quite accurate.

This map was drawn by William P. Blake using Marcou’s notes and sketches (and presumably his own as well) and published in 1854 by the Office of Pacific Railroad Exploration & Survey, War Department, printed as a lithograph by Sarony, Major, & Knapp of New York. Although Marcou brought the cachet of his name and fame to the expedition, Blake was arguably the workhorse geologist for the team. He was newly graduated from Yale when he joined the Whipple Survey as a mineralogist and geologist at age 27 and he went on to have a diverse and well-respected career. He was an emeritus professor at the University of Arizona and retired Arizona Territorial Geologist when he died in 1910.

The military leader of the survey, Amiel W. Whipple, died of wounds suffered as a brigadier general at the Battle of Chancellorsville in 1863.



Joseph Barrell



American geologist Joseph Barrell died in 1919 at age 49. He was most closely identified with his professorship in structural geology at Yale, but when he died, he was mourned as one of the most imaginative, thoughtful, and thorough geologists of his day. And much of his thinking, which contributed significantly to the idea of continental drift at a time when it was highly contested, was informed by his early work in Montana.

Barrell came to Butte in June 1897 to work as a mining geologist and civil engineer for the Butte & Boston and Boston & Montana companies, both owned by the Lewisohn brothers of New York. Those companies became the second largest producer of copper in Butte (and the US) after the Anaconda, and were merged into the Amalgamated (Anaconda) company in 1901. Barrell is only listed in one of Butte's city directories, for 1898, when he roomed at the Lenox Hotel, 132 West Granite (the parking lot between the Water Company and Carpenters' Union Hall today), but he was in Butte off and on from 1897 to at least 1901. Among other things derived from his time in Butte, he published on methods for keeping stope books and on dealing with errors in underground surveying.

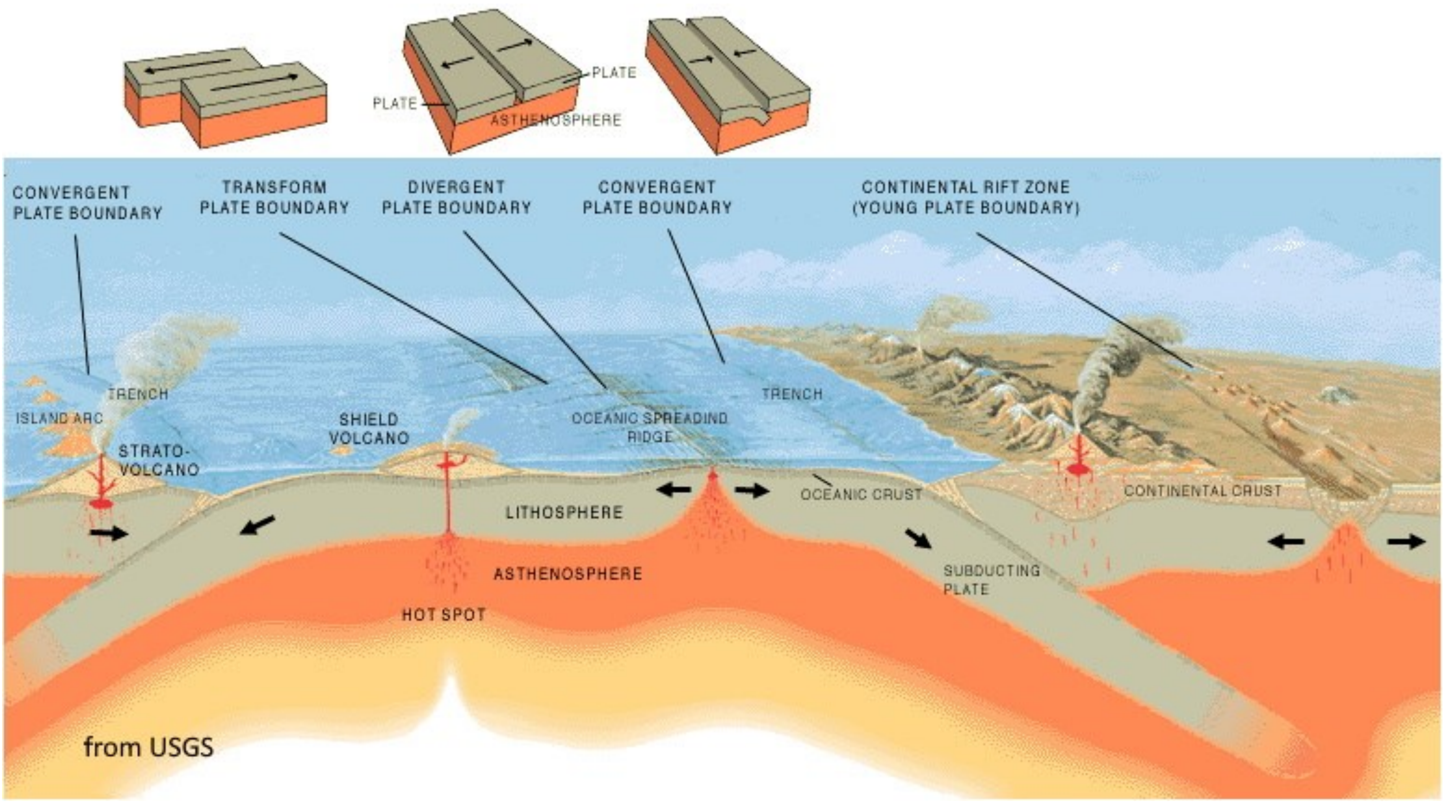
During the summer of 1899 he worked (mostly from horseback) with Walter Harvey Weed and the USGS on the first serious geological study of Montana's Elkhorn Mountains and the Elkhorn Mining District. Their report was published in 1901 in the 22nd USGS Annual Report and included a section by Barrell on the "microscopical petrography" of the Elkhorn Mining District. His work led to his doctoral dissertation at Yale and ultimately to his professorship there. It also led Barrell to seminal understanding of changes in mass and volume when rocks are metamorphosed, particularly in contact metamorphic situations. When Weed and Barrell worked at and around the town of Elkhorn, it was already in decline, but by 1900 the district had produced nearly 9 million ounces of silver.

Barrell was back in Montana in the summer of 1900, working at Butte and the Deer Lodge Valley. In 1901, he again worked with Weed, this time on the Marysville Mining District northwest of Helena, Montana. Barrell's report on Marysville was called one of the "classics of geology" in a contemporary review in the American Journal of Science, and "one of the most instructive works produced in modern times" on intrusions and related volcanism (as expressed by Edouard Suess, one of the most prominent geologists of the second half of the 19th century).

Barrell's work at Marysville (USGS Prof. Paper 57, 1907) led him to the concept of magmatic stoping, the idea that an igneous intrusion works its way up through overlying rocks by breaking them and partially melting and assimilating them. This is such a fundamental concept that it seems axiomatic today, but before Barrell (and separately and independently, Reginald A. Daly) found the field evidence and expressed it as a detailed, well-supported theory, most geologists felt that intrusions shouldered their way up, pushing overlying rocks aside. That happens too, but magmatic stoping is a critical and important aspect of intrusions and ore formation. For that alone, Barrell is a star among geologists of the early 20th century.

The ideas about stoping and mass and volume changes during intrusion and metamorphism drove Barrell to think about the strengths of rocks, and ultimately to the strength of the earth's crust. In the 1910s there were generally two schools of thought about the crust's strength: it was either strong and deformed brittlely, or weak and deformed plastically. Those two end members of the question were critical to evaluating the idea that continents had broken apart and drifted, a question that raged in the 1910s.

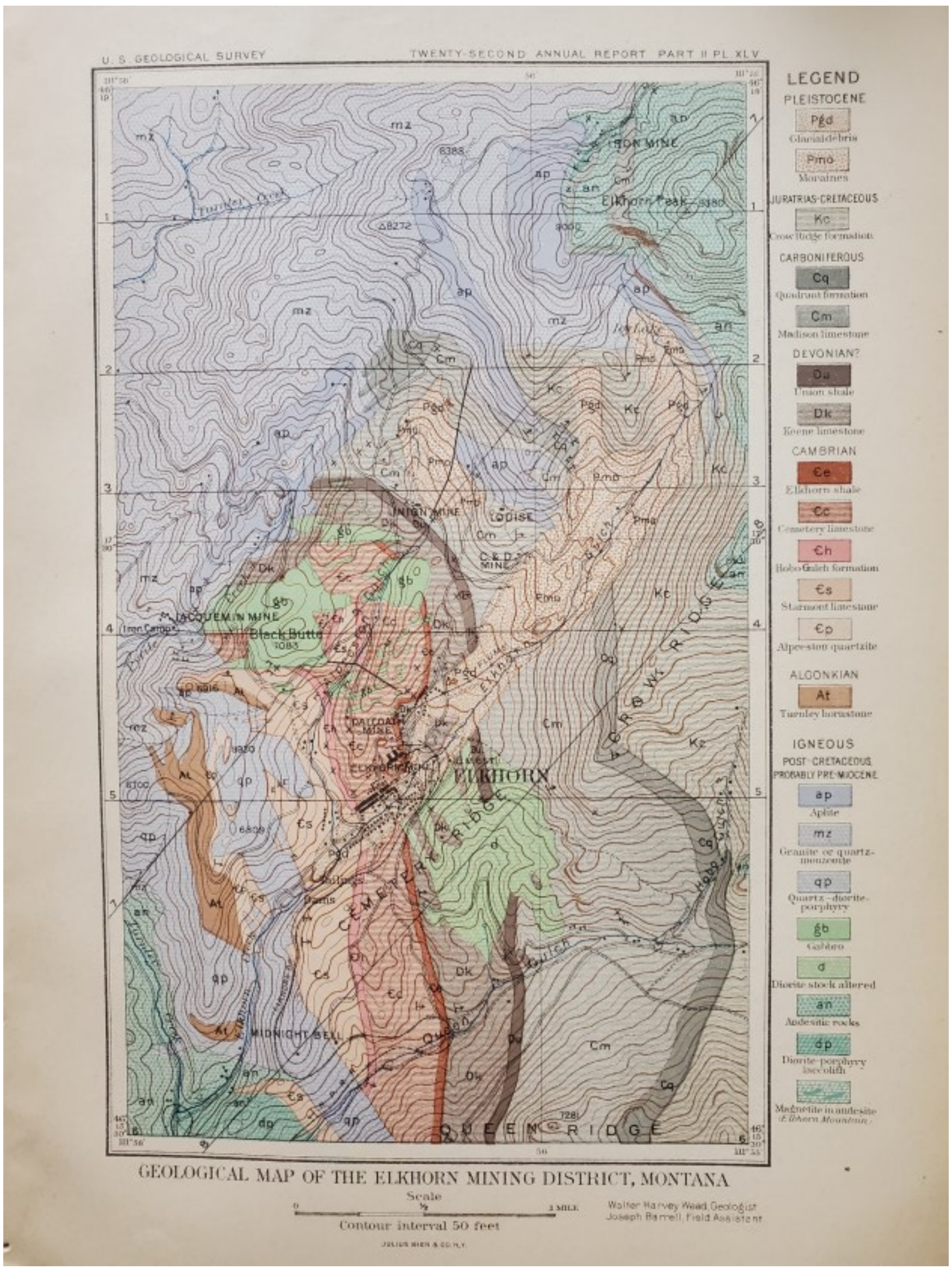
In 1914-15 Barrell published a series of eight papers in the Journal of Geology titled "The Strength of the Earth's Crust." The ideas he expressed there grew out of wide-ranging studies including the volumes and densities of sediments and the spaces they were eroded from and their relationship to isostasy (the state of equilibrium in the crust necessary for mountains to exist), together with his earlier work in Montana on magmatism, volcanism, contact metamorphism, and ore formation at Butte.



The series of papers constituted an exhaustive analysis, but one of the most significant aspects of the work was Barrell's idea that the crust was BOTH brittle and plastic, that there was an upper rigid layer that he called the lithosphere (litho = rock) and a deeper, weaker layer he called the asthenosphere (from Greek for "without strength"). My fellow geologists will recognize those terms: Joseph Barrell coined them, based in part on ideas he developed in Montana. Today those two layers are integral to the notion of Plate Tectonics; the asthenosphere is the viscous, weak, and ductile zone at the top of the mantle that makes plate tectonics possible. It's the orange zone in the USGS illustration of subduction.

When Barrell died young of spinal meningitis complicated by pneumonia, just days after he was elected to the National Academy of Sciences, his memorial by Charles Schuchert was effusive: "Had he lived longer he would have become the chief exponent in the subjects of geologic sedimentation, metamorphism, structural geology, the geologic bearings of isostasy, and the genesis of the earth. T. C. Chamberlin writes: "We had come to look upon him as one of the most promising leaders in the deeper problems of earth science"; Bailey Willis, that "there is unanimous recognition of the fact that Barrell was one of the strongest of the younger leaders and a man of great promise"; John M. Clarke, that Barrell's death "is a truly overwhelming disaster for American Geology.""

For me discovering that Joseph Barrell, such an important force in American geology in the 1910s, worked in Butte and lived just a few blocks from my house (built in 1898, the year he lived on Granite Street), was a big damn deal. And it won't surprise many of you to know that yes, I even have original copies of the 1914-15 Journal of Geology containing Barrell's papers on the strength of the crust in which he coined the words lithosphere and asthenosphere. I also have to admit to getting pleasure out of the fact that I've seen at least some of the outcrops and rocks Barrell studied at Elkhorn, rambling around up there with my friend Joel.



Geology of the Elkhorn Mining District, by Weed & Barrell, 1901

22nd USGS Annual Report

The 49th Parallel Survey

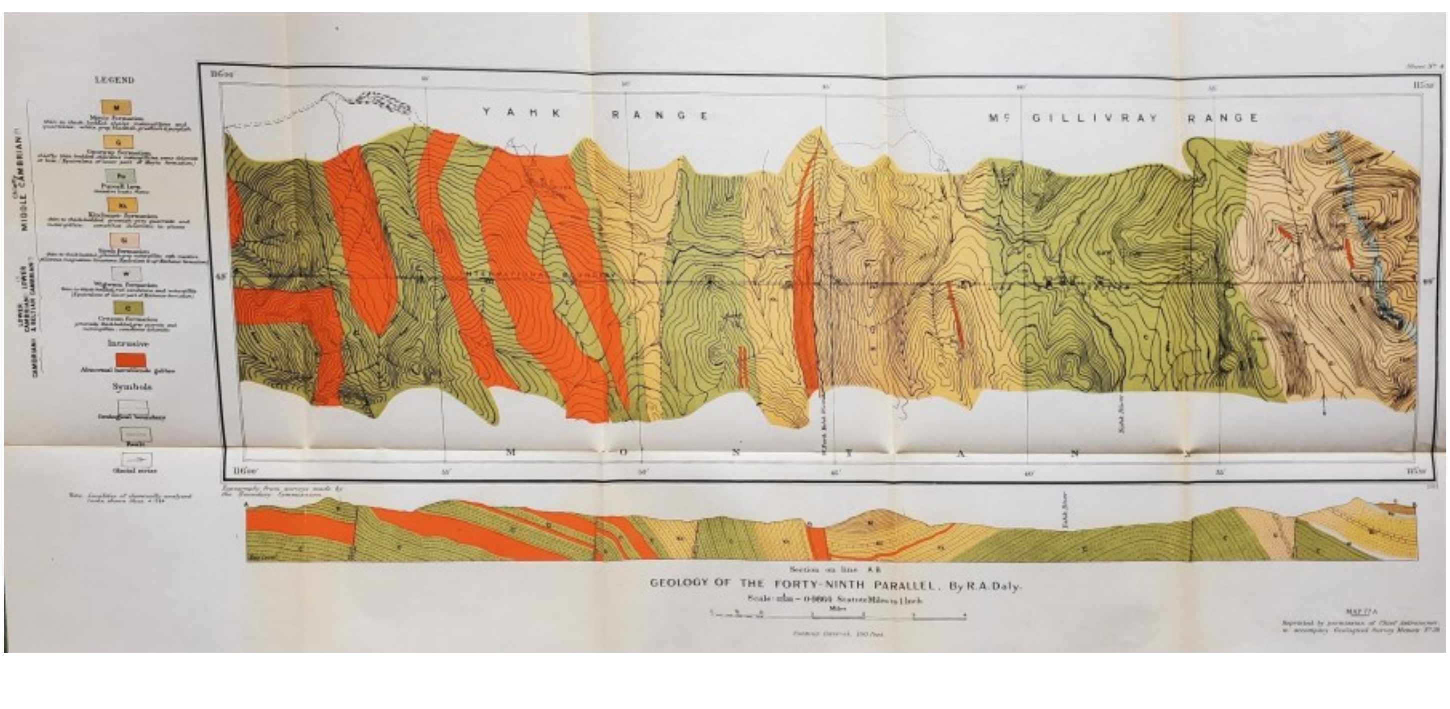
The treaty defining the 49th parallel as the boundary between the United States west of the Lake of the Woods in Minnesota and British North America was signed in 1846. “British North America” became Canada in 1867. It was not until 1901-1906 that the line was surveyed, both topographically and geologically.

For Canada, the geological survey was led by Reginald Aldworth Daly, with US counterparts Bailey Willis, F. Leslie Ransome, and George Otis Skinner. The Canadian report by Daly, published in 1912, contains a wealth of maps defining both sides of the 49th parallel. The map here is of the boundary in far northwestern Montana and adjacent British Columbia.

The map and cross section show rocks such as the Creston, Wigwam, Siyeh, and Kitchener formations, and the Purcell Lava. All these rocks were inferred to be of Cambrian age at the time (then, defined as 600 to 500 million years ago), but today we construe the entire package as part of the Belt Supergroup, whose age is about 1,400 to 1,500 million years. The folding and faulting, shown on the map and cross section, developed during the Laramide-Sevier Orogeny about 80 to 55 million years ago.

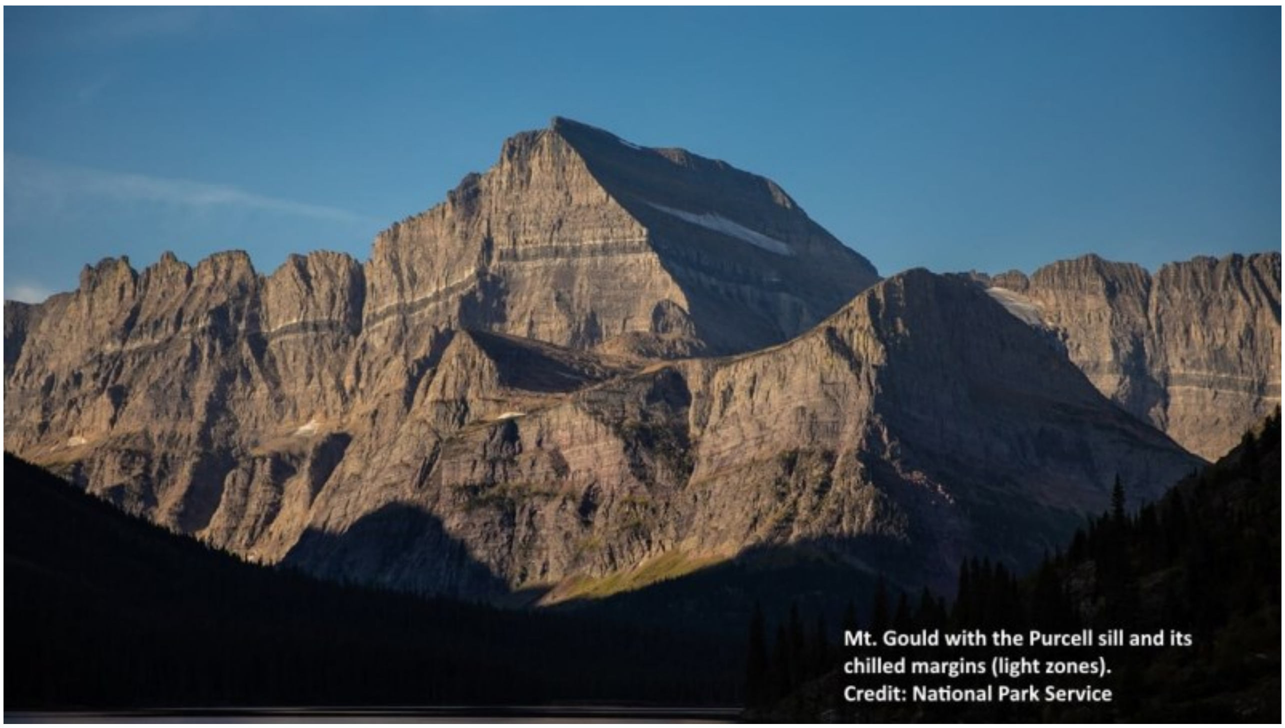
The Purcell Sill intruded concordantly into the Siyeh Formation, so it must be younger than the Siyeh. Radiometric age dates for sills in the Belt Supergroup (sometimes called the Purcell Supergroup in Canada) have a wide range, from about 1,420 million years, which would be near the end of Belt deposition, to about 750 million years, which would record the break-up of the supercontinent of Rodinia that would establish the long-lived passive margin of western North America (Pană and others, 2018, Geochronology of Selected Igneous Rocks in the Alberta Rocky Mountains, with an Overview of the Age Constraints on the Host Formations, AER/AGS Open File Report 2018-03). The Purcell Lava is the narrow blue zone at the far east (right) side of the map shown here from Daly’s 1912 report.

The bright orange-red zones in the western (left) part of Daly’s map are “abnormal hornblende gabbro.” They are also sills related to the more well-known Purcell sill in Glacier Park. Daly’s analysis showed them to be alkali-deficient quartz-bearing gabbros with hornblende as 60% of the rock. They are still mapped as parts of the Purcell intrusives (Harrison and others, 1992, Geologic map of the Kalispell 1 x 2 degree quadrangle, USGS map I-2267).

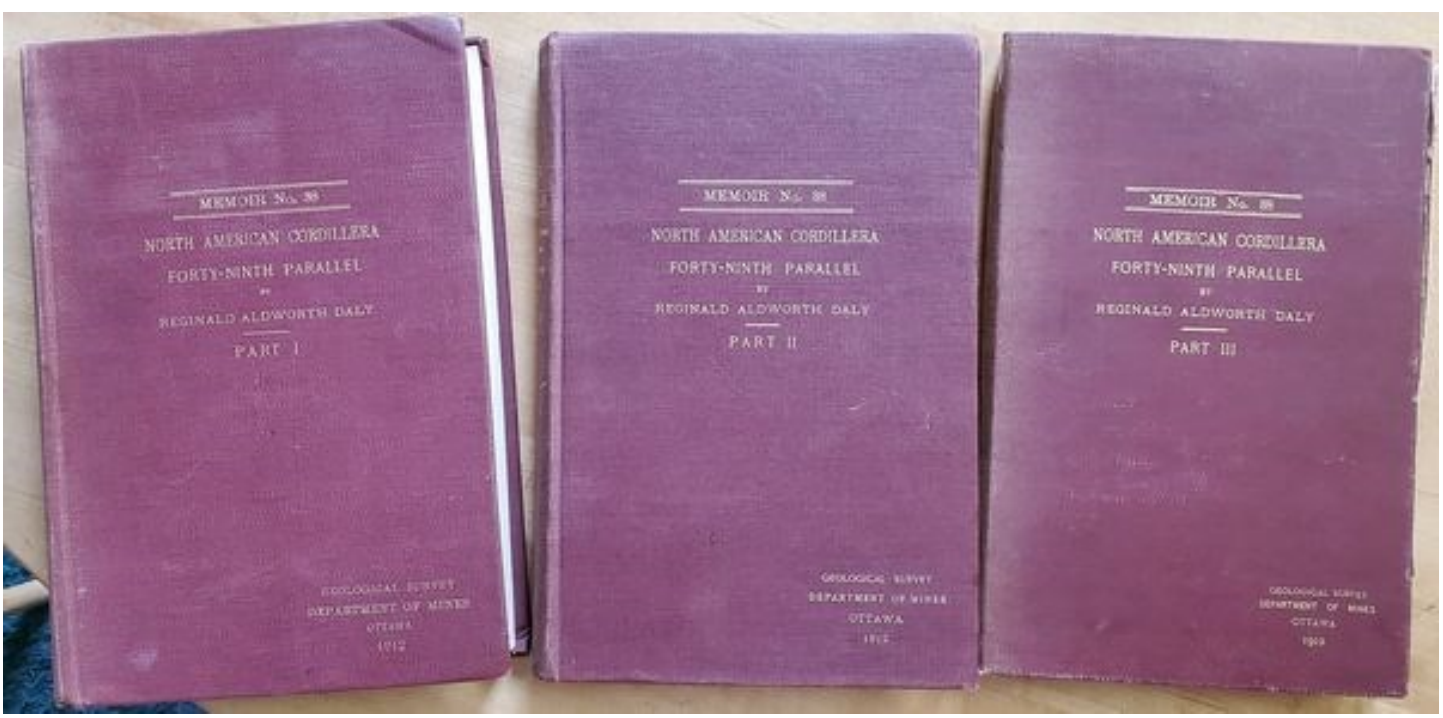


Daly, apparently without irony, described his work on the 49th parallel survey: “No geologically trained assistant was employed in any part of the field. The work was, therefore, slow.” Despite working alone or with an assistant for logistics only (i.e., someone to pack supplies and rocks), Daly (1871-1957) completed the mapping of the strip along the boundary from the Pacific to the Plains in six summer seasons. Analytical work included 960 thin sections he made himself. His 1912 Boundary Commission report, titled *North America Cordillera: Forty-Ninth Parallel*, appeared as a two-volume work totaling 857 pages with a separate map case. My copy lacks a couple of the maps. Among many other things, Daly was an early proponent of the theory of continental drift at a time when the concept was largely ridiculed in North America (it was generally accepted in Europe and South Africa from the 1920s onward).

Spelling of the Yaak River and Range is “Yahk” on this map, following Canadian usage. It means “arrow” or “bow” in the Kootenay language.



Mt. Gould with the Purcell sill and its chilled margins (light zones). Credit: National Park Service



Darwin's Petrified Forest

This fairly non-descript piece of petrified wood is connected to a lot of scientific history. Charles Darwin discovered the petrified forest this rock is from on a side trip during his travels on H.M.S. Beagle in 1835, although the upright petrified trees were possibly already known to indigenous people as well as European settlers in the Agua de la Zorra area, near Uspallata, Mendoza, Argentina.


Triassic petrified wood, Uspallata, Argentina
Potrerillos Formation, Cuyo Basin
55 mm long, inset FOV ~ 5 mm. R. Gibson photos
Cat. No. 470

Darwin traveled from Valparaiso, Chile, to Mendoza, Argentina and back from 12 March to 20 April 1835, crossing some of the highest passes of the Andes, including Portillo and Uspallata Passes where he sketched the cross-sections in the accompanying image. The latter pass is at 3810 m (12,500 ft) above sea level. The expedition was fundamentally geological and his observations on this trip cemented Darwin's support for the gradualist (as opposed to catastrophist) nature of earth history, a controversy that was raging at the time. Lyell, the champion of gradualism (also called uniformitarianism), focused on Darwin's letters from this tour in his Presidential address to the Geological Society in 1836, because he recognized Darwin's support and evidence. In passing, it also confirmed Darwin as a geologist of the first order in England.

The petrified trees Darwin observed were in growth position, but not vertical. Most were tilted about 20 degrees from vertical and were encased in fluvial, lacustrine, and volcanic sediments. Darwin described a veritable forest, 52 trunks several meters long and ranging from one to 1.5 meters in diameter. He collected his first petrified wood in the fossil forests on March 30, 1835.

Darwin thought the trees were Tertiary in age (probably less than 50 million years old, although Darwin did not have absolute age dates), and that the volcanic sediments were associated with the present-day volcanoes in the Andes. Analysis of the rocks and the fossils 150 years later assigns them to middle Triassic age, 235-240 million years ago, in the Paramillo Formation, equivalent to part of the Potrerillos Formation in the Cuyo Basin. Those layers were deposited in braided streams draining volcanic highlands, so the sediments were mostly volcanic in nature.

The volcanism and the fault-bounded Cuyo Basin itself are consequences of one major aspect of the assembly of the supercontinent of Gondwana. The Gondwana Orogeny was a collision between smaller terranes and the core of the continent, in eastern South America and Africa north of South Africa. Those two continents, as we know them today, did not develop until about 150 million years ago when the South Atlantic Ocean opened, but 280 to 230 million years ago, during the Permian to Middle Triassic, a collage of island arcs and small continental terranes was colliding with the southern margin of South America+Africa as well as with Antarctica and Australia, which were also attached parts of Gondwana.

Darwin as a young man.

Portrait by George Richmond.

The mountain belt that resulted from the Permian-Triassic collision, the Gondwana Orogeny, is dismembered today, but it is preserved in the Sierra de la Ventana in Argentina, the Cape Fold Belt in South Africa, the Ellsworth Mountains that cross Antarctica, and some of the hills of eastern Australia. Gondwana grew through the addition of Patagonia, the mostly submerged Falkland Plateau, the Antarctic Peninsula, and perhaps parts of Zealandia.

The Gondwana Orogeny collision did more than produce a mountain belt. Such collisions have complex expressions within continents and around their margins, and in this case, it translated into extension, oblique pulling apart, in the region that is northwestern Argentina today. The Cuyo Basin is a set of elongate troughs, fault-bounded pull-apart zones where sediments accumulated. The volcanism was probably the last stage of the magmatic cycle related to subduction of what is now Patagonia beneath the core of South America (Spalletti et al., 2008, Geologica Acta, Vol. 6, № 3, 267-283).

The Darwin forest has been estimated to contain 450 to 750 trees per hectare (Brea et al., 2008, Ecological reconstruction of a mixed Middle Triassic forest from Argentina, Alcheringa 32, 365–393. ISSN 0311-5518). (A hectare is about 2.5 acres.) Mariana Brea and her colleagues have identified the fossil tree wood as coming primarily from conifers and corystosperms, extinct fern-like woody plants that were abundant in the Triassic of Gondwana.

Corystosperms, a type of seed fern whose taxonomic affinities remain unclear today, were widespread across Gondwana and were used by South African geologist Alexander du Toit (in his 1937 book, Our Wandering Continents, of which I have a copy) to infer the existence of the Gondwana supercontinent at a time when the concept of continental drift was ridiculed in America for lack of a mechanism for it. The conifers were 16 to 20 meters tall (up to 65 feet), while the corystosperms reached 30 meters, 100 feet. These were big forests.

The sedimentary rocks that entomb the Darwin forests are thick muds, sands, conglomerates, and pyroclastic materials that were deposited very rapidly by high-energy sinuous rivers. The descriptions sound very much like lahars, volcanic-derived hot mud flows that often come off volcanoes with lots of water available, either in heavy rains, lakes, or glacial ice. The overall environment in which the wood grew was likely dry and subtropical (Brea et al., 2009, Darwin forest at Agua de la Zorra: the first in situ forest discovered in South America by Darwin in 1835, Revista de la Asociación Geológica Argentina 64 (1): 21 – 31. ISSN 0004-4822), but the source of the mudflows and volcanics might have been mountains high enough to support glaciers, though glaciers are not required for lahars ("lahar" is a Javanese word for these volcanic mudflows which occur frequently in Indonesia).

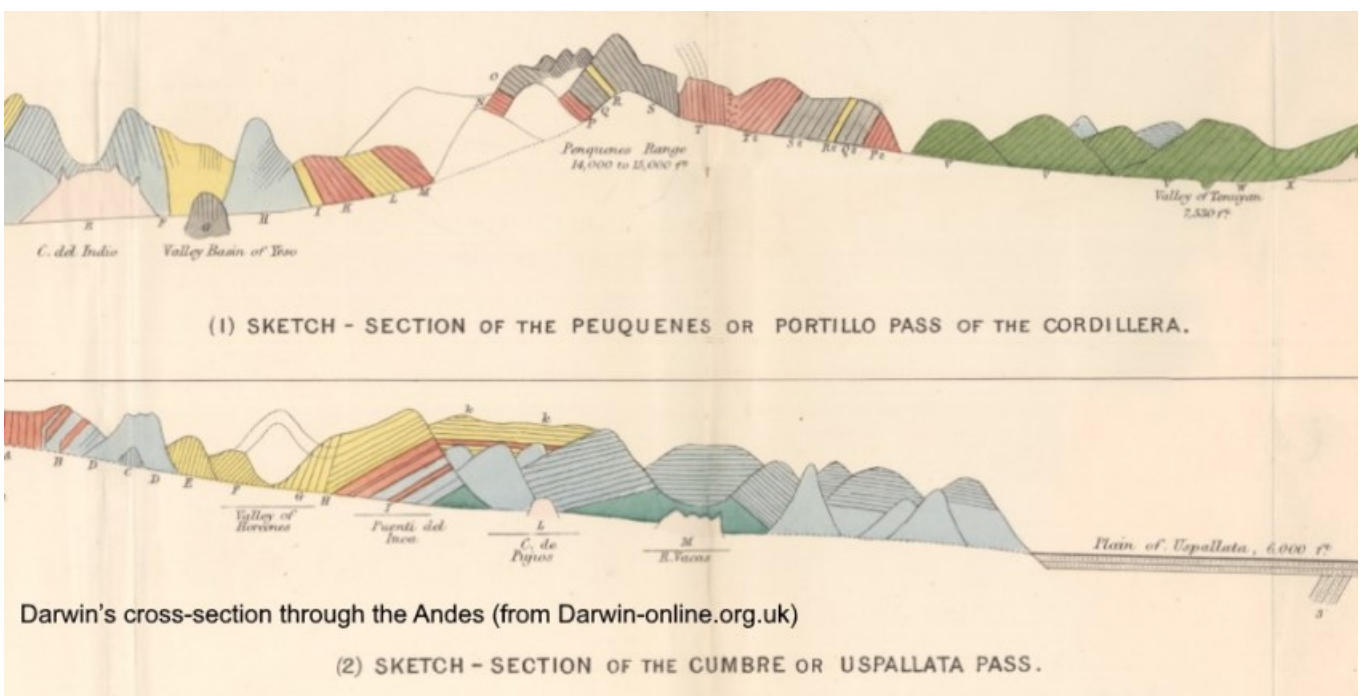
The tilting of the in-place tree trunks in the forests is probably a result of much later tectonic activity, probably the relatively recent uplift of the modern-day Andes in the past 50 million years. This uplift tilted the much older Triassic rocks (240 million years) together with the tree trunks in them.

This little piece of petrified wood, 55 x 5 mm, is silicified. I'm no paleobotanist, but the patterns in the surface (in the inset in the photo) are similar to those on Calamites, relatives of horsetails. Near the end of the Paleozoic Calamites (now extinct) and ferns typified the understory of lush forests, and ferns composed the understory of the Triassic Darwin forests as well. This rock probably preserves part of a large fern or perhaps a bit of one of the corystosperms.

I've only done a little work on the Cuyo Basin, when I interpreted the gravity map of South America for oil exploration. The 15 or so little oil fields are mostly related to uplifts along the normal faults that created the basin in Triassic time. Changing a down-dropped basin to an uplift is called structural inversion, and in this case it probably resulted from the much later squeezing imposed on the old basin by the uplift of the Andes – the same activity that tilted the strata with the fossil tree trunks. Geochemical data suggest that the oil in the Cuyo Basin was sourced from organic-rich sediments deposited in lakes on the valleys and flood plains where the trees and other plant life grew.

This specimen was a gift to me from Pat Dickerson, who got it when she was the geological study leader for a Smithsonian Journey in Patagonia. The lighter-colored parts of it display a nice orange-yellow fluorescence. I've paired it with a portion of Darwin's cross-section (below) through the Andes (from Darwin-online.org.uk), which he based on his sketches on the trip when he discovered the petrified forest.

The Darwin forests are only about 5 or 10 million years older than the famous Petrified Forest of Arizona.



Darwin's cross-section through the Andes (from Darwin-online.org.uk)

Anticline Theory of Oil Trapping

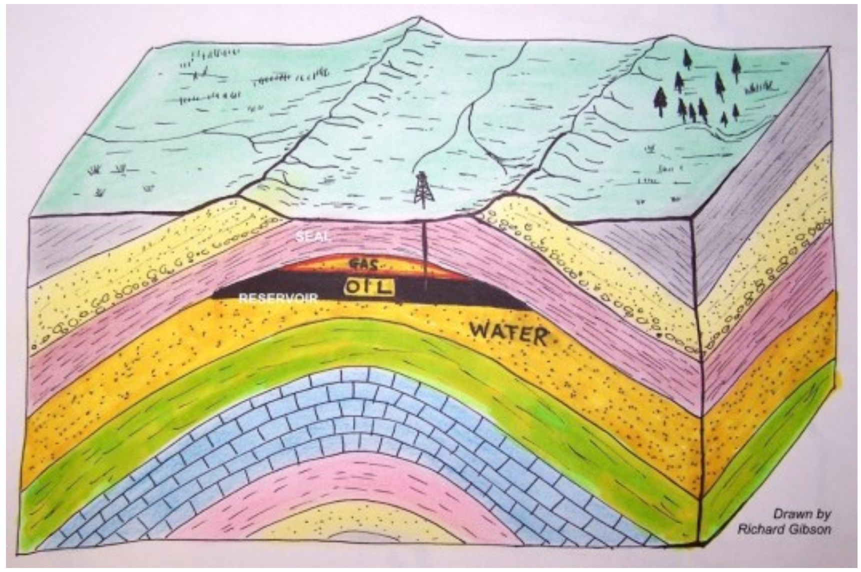
Anyone who knows me well knows I have a lot of stuff. One of those things is Memoir 50, Part 1, of the Geological Survey of India, published in 1912 and titled *The Oil-Fields of Burma*. It's a book I got at the Colorado School of Mines book sale around 1990, probably for $1.00 (the cost of a hardback book on Fridays of the sale).

The two-inch-thick book is full of fascinating fold-out maps, photographic plates, and line drawings, but it also includes this huge (5 feet by 2 feet) map of Yenangyaung Oil Field, in the photo at left. "Yenangyaung" means "stream of oil," and in Burma as elsewhere oil wells were first dug based on the presence of surface seeps and flows. People in central Burma had been doing that via hand-dug wells as long ago as 900 B.C.

Yenangyaung was actively worked by the 1750s using bamboo pipes and other methods. In 1855, Irish-born geologist Thomas Oldham, working for the Indian Geological Survey, recognized that the local drillers were focusing their efforts on the crest of an anticline exposed at the surface. You can see it in my photo of the map as the long, vertical white-beige oval surrounded by yellow, and the oil wells are concentrated in zones along the top (the axis) of the anticline. That's how anticlines work, they trap oil in the highest points the oil can migrate upward to, trapped beneath some impermeable rock that seals the oil from going further up. (see drawing on next page)

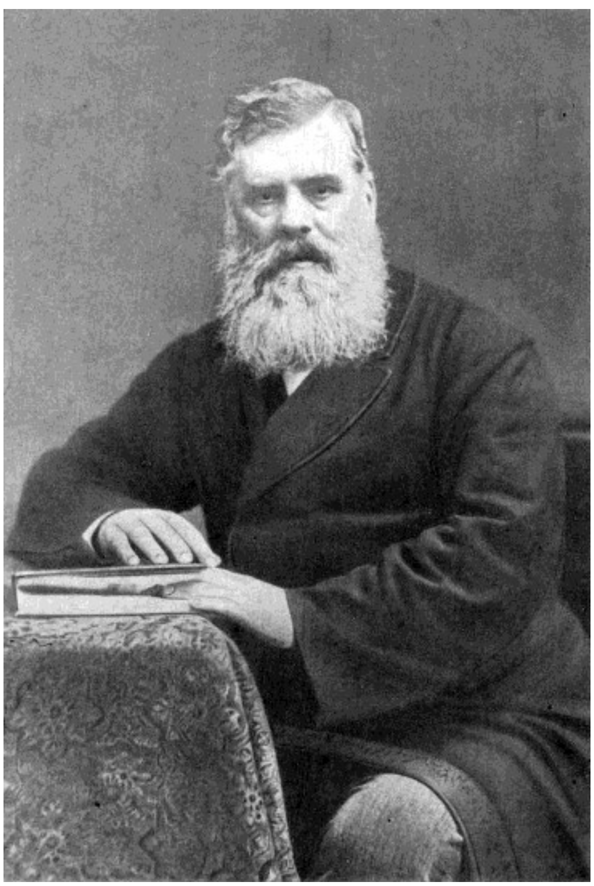
Oldham's correlation between the Yenangyaung anticline and a subsurface oil trap is generally considered to be the first recognition of that relationship. Other oil discoveries chased oil seeps, but were not usually based on sound theory; the first deliberate oil discovery in the United States, at Titusville, Pennsylvania, didn't come until 1859. Yenangyaung had been producing for more than 100 years then.

Burmah Oil Co. was established in Glasgow, Scotland, in 1886 to exploit the oil fields of Burma (at the time, part of British India), with Yenangyaung probably the most important single field. Even though local production dated to the 1750s, commercial-scale British drilling and production didn't begin until about 1889. The riches from Burma allowed Burmah Oil company to acquire rights to explore in Persia, creating the Anglo-Persian Oil Company as a subsidiary of Burmah Oil in 1909. The British government invested to become a 51% owner of Anglo-Persian, which became Anglo-Iranian Oil Company in 1935. In 1954 that company, whose heritage goes back to the oil in the anticline on this 1912 map, was renamed British Petroleum. In 2000 BP acquired ARCO, the oil company that had acquired the Anaconda Copper Company in 1977. BP still owns the environmental liability here in Butte and in most rankings is the 6th largest oil and gas company in the world.



Yenangyaung was central to Japanese strategy in southeast Asia during World War II. Besides the oil itself, Yenangyaung's location would be useful in Japan's attempts to cut the Burma Road that was the Allies' supply route from India to China.

Yenangyaung has been producing oil "officially" since 1889, with a cumulative total of about 200 million barrels. At its peak in 1918, the field produced 16,000 barrels a day, with single wells producing 1,000 barrels a day at times (for comparison, excellent wells in Saudi Arabia produce 4,000-6,000 barrels per day; in the US today, the average is about 12 barrels per day per well). Today, Yenangyaung still produces about 2,000 barrels a day from the whole field.



Thomas Oldham (1816-1878)

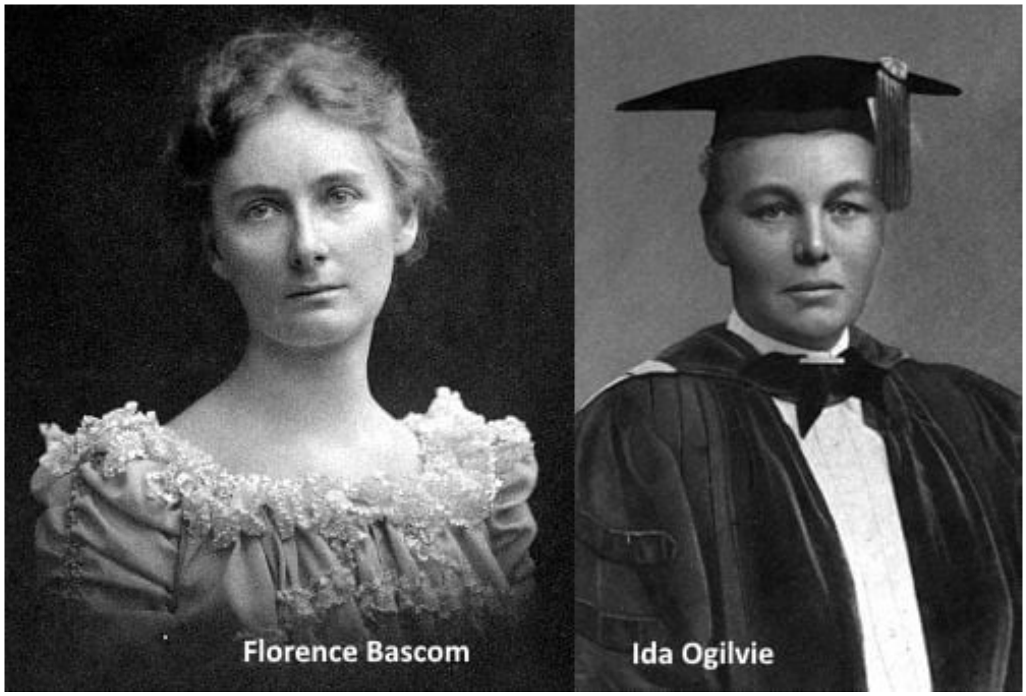
The oil reservoirs at Yenangyaung range from the middle Miocene Kyaukkok formation to the Eocene Padaung formation, 20 to 40 million years old. The anticline itself and the complex but generally north-south, linear fold belts of Burma, are a consequence of the collision of India with Eurasia. The collision is essentially squeezing tectonic blocks that were once in Tibet and other parts of South China into what is now Indochina and vicinity. Some of that squeezed stuff is pushed back to the west, where (in Burma, now named Myanmar) the rocks are rolling up and over the flank of the Indian tectonic plate, in a secondary squeeze that's more or less east-west-directed compression. That makes these long lines of folds in central Burma.

I didn't know that the anticline on my map in this photo was the very one that started the anticline theory of oil trapping. I didn't know about the strategic importance of this field in World War II. I knew about Burmah Oil as the ancestor to BP, but really hadn't made the connection to this particular field as essentially the start of Burmah Oil and therefore of BP. I consider learning all that to be well worth a dollar.

Florence Bascom

I'm pretty good at refraining from acquiring things, given the volume of stuff, especially books and rocks, already in my house. But that doesn't mean no acquisitions. I recently got a pair of U.S. Geological Survey Monographs, No. 43 on the Mesabi Iron Range in Minnesota (published in 1903) and No. 46 on the Menominee District of Michigan (1904). They're excellent publications and beautiful antique books.

But it is the story of the ownership of my copy of Monograph 43 that excites me.



The inside front cover contains a prominent bookplate indicating that the book belonged to Ida H. Ogilvie. No, I never heard of her – but she has her own Wikipedia page, because she's one of the earliest prominent female geologists in the United States.

She was born Feb. 12, 1874, and graduated in zoology and geology from Bryn Mawr College near Philadelphia in 1900. Her 1903 PhD from Columbia University was geologic mapping of a 15-minute quadrangle in the Adirondacks of New York, producing the first geologic quadrangle map published by the New York State Museum, the state's geological survey. She went on to teach at and start the geology department at Barnard College in her native New York City, and she died in 1963.

Ogilvie was one of the first students of Florence Bascom at Bryn Mawr, just as Bascom was establishing the Geology Department there, essentially the first such department in a women's college in the United States. And yes, I definitely have heard of Florence Bascom. Bascom (1862-1945) received the second PhD in geology granted to a woman in the U.S. and was the first woman to receive a PhD from Johns Hopkins (1893). She was the first woman professional hired by the USGS (1896; she continued with the USGS until 1936), and the first woman elected to the Geological Society of America (and the organization's first woman officer).

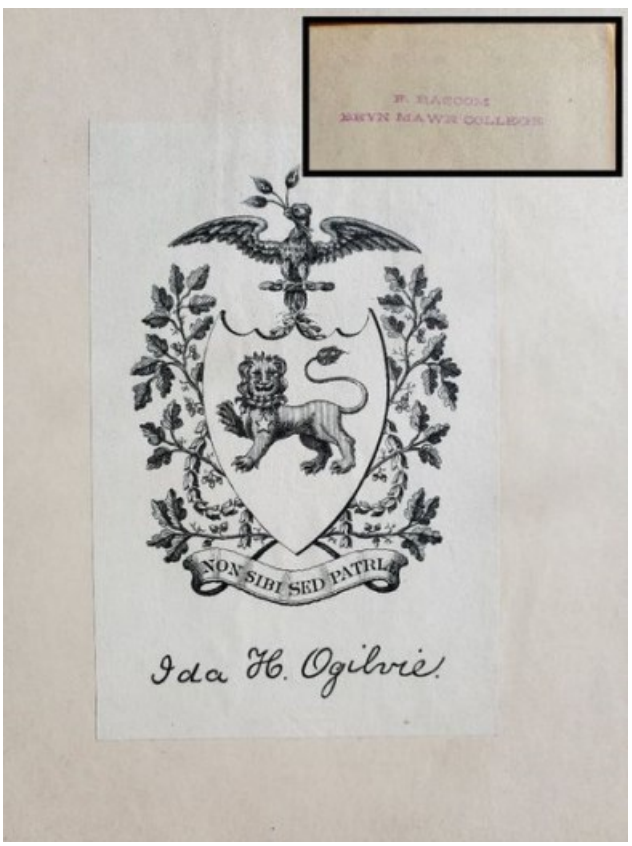
Bascom's Bryn Mawr Geology Department was one of the most rigorous in the country.

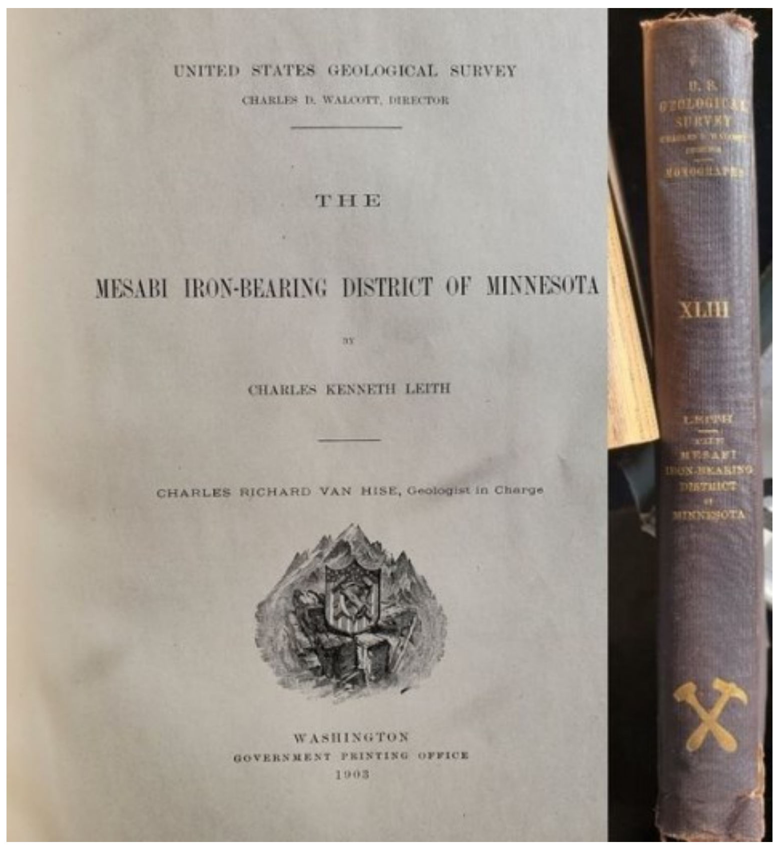
Bascom was a polymath in the geological world, with valuable work on volcanoes, geomorphology, petrology, crystallography, and water resources. Her mentors at the University of Wisconsin, where she did her Master's work on the Precambrian gabbros of the Lake Superior area, were Roland Duer Irving and Charles Van Hise, two of the most prominent students of the Precambrian of the Lake Superior region. They worked with Charles K. Lieth, the author of Monograph 43, and it is inconceivable that Bascom did not know him as well, although she was a few years ahead of him in grad school. At Johns Hopkins, Bascom worked with George H. Williams, the field geologist and petrologist whose beautifully artistic thin section drawings I've shared elsewhere in this compilation. Williams died at age 38 of typhoid fever.

There is a crater on Venus named for Bascom, along with an asteroid, a glacial lake, and the USGS geoscience center in Reston, Virginia. She is rightly considered to be the first female geologist in the U.S.

"The fascination of any search after truth lies not in the attainment, which at best is found to be very relative, but in the pursuit, where all the powers of the mind and character are brought into play and are absorbed by the task. One feels oneself in contact with something that is infinite and one finds joy that is beyond expression in sounding the abyss of science and the secrets of the infinite mind." — Florence Bascom

And guess what? On the page opposite the inside front cover with Ogilvie's prominent bookplate in my copy of Monograph 43, there's a small, subtle handstamp: "F. Bascom/ Bryn Mawr College." This book went from Florence Bascom to her student Ida Ogilvie, and now I have it. I can't prove it, but I like to think that the author, C.K. Lieth, gave this book to Bascom. All of this pleases me more than I can say.

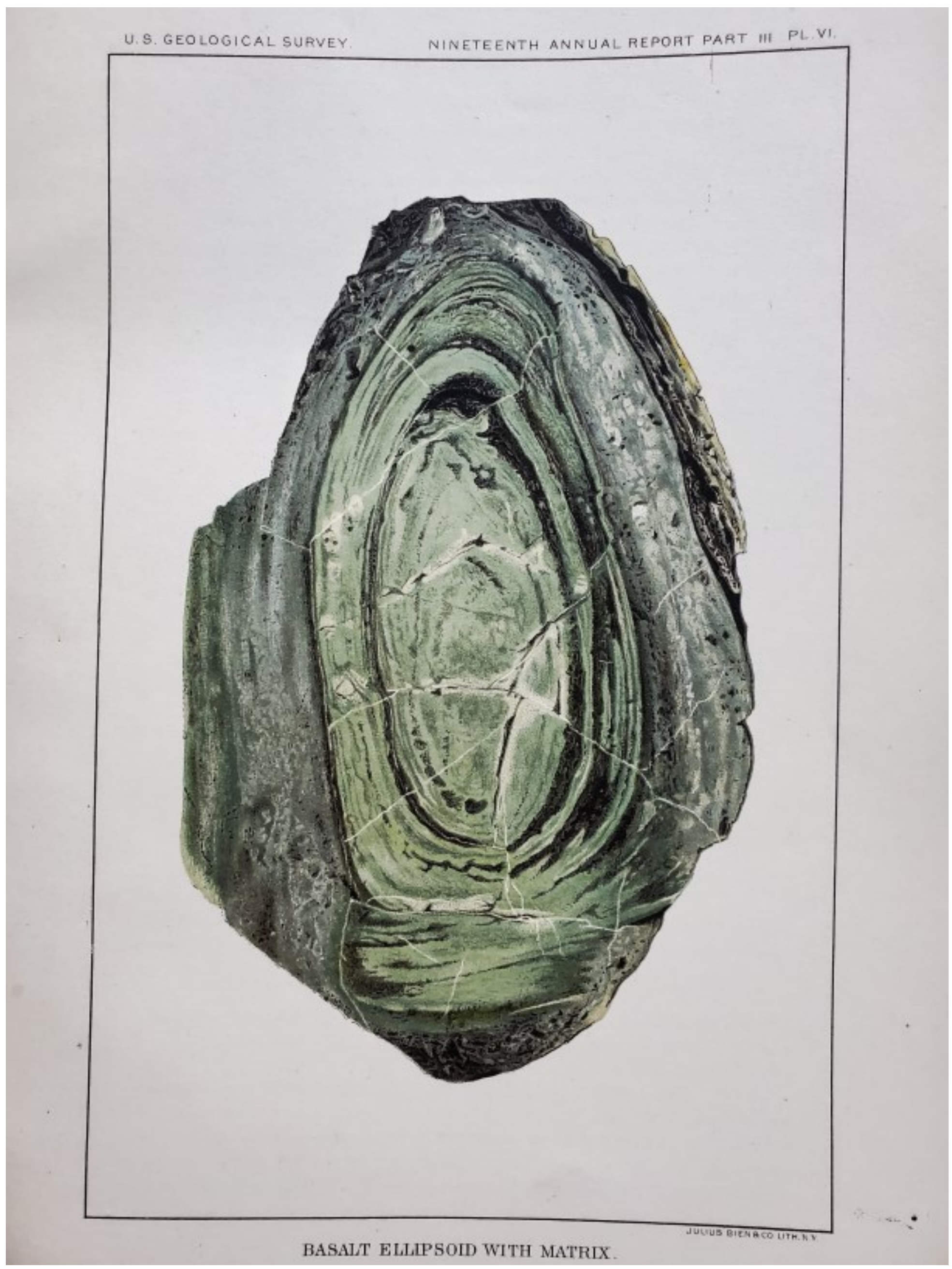




Pillow Basalt

This chromolithograph of a "basalt ellipsoid" was published in U.S. Geological Survey Annual Report 19, part 3, in 1899. The paper, "The Crystal Falls iron-bearing district of Michigan," by Clements and Smyth, was one of many such reports on the iron regions of Michigan, Wisconsin, and Minnesota in the 1890s and early 1900s.

Apart from my well-known appreciation for the artistry of both the image and its printing, I love this because it was on the same outcrops as those described in the report that I first saw and really learned what a "pillow lava" is, during a Flint Junior College geology field trip in 1967. Pillow lavas are not surprisingly bulbous ellipsoidal pillow-shaped bodies from a few inches to a few feet in diameter. They form when molten lava (usually basaltic) flows into water, usually at depth. Their modern formation has been filmed in Hawaii; the contact with water instantly crystallizes a flexible crust around the molten lava, which keeps squeezing in to "inflate" the encrusted shell like a balloon. This was a simple albeit still somewhat rare concept when I learned about it, so seeing a good example was fun.



But when this report was published in 1899, pillow lavas were more than novelties. Those near Crystal Falls, Michigan, were only the second occurrence to be described in North America, and how they formed was enigmatic. It wasn't until 15 years later that the idea of subaqueous lava flows was fully described and accepted (Lewis, 1914, Geol. Soc. Amer. Bull. 25:4, p. 639).

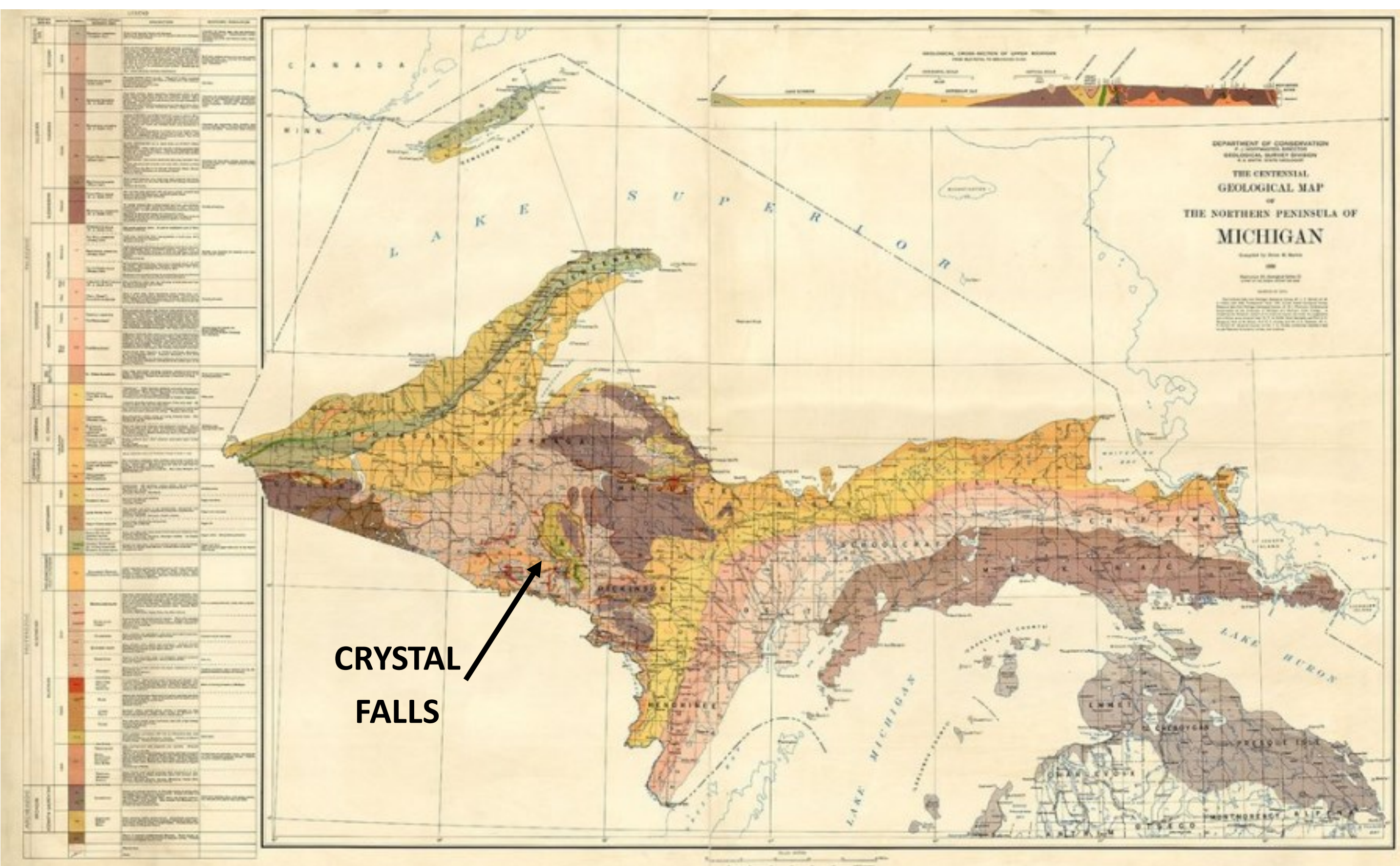
The basalt here is greenish because its constituents are altered by hydration and metamorphism and include abundant green minerals such as epidote, fibrous hornblende, chlorite, sericite, and uralite (not a mineral, but pseudomorphs of green amphiboles altering from pyroxenes). In the late 1890s, chromolithography was the only technique offering any level of mass-produced printing that displayed true natural colors in rocks.

The pillow basalt at Crystal Falls is called the Hemlock Formation and was formerly referred to the Lower Huronian period of the Algonkian Era. Today, we call the Algonkian Proterozoic, and Huronian refers to a group of rocks of Paleoproterozoic age, about 2.2 to 2.5 billion years old.

The Hemlock volcanics are now dated at 1.874 billion years (Schneider and others, 2002, Can. J. Earth Sci. 39: 999–1012). The entire package is estimated to have had an original thickness approaching 30,000 feet, a remarkably huge pile of basalt and other volcanic rocks. That's such a huge thickness that I bet there is some tectonic thickening in that estimate, although the Ontong Java Plateau in the southwest Pacific Ocean is a pile of igneous rocks of comparable or even greater thickness. Apparently, there is a reliable stratigraphic thickness for the Hemlock formation in places of 15,000 to 20,000 feet (Wier, 1967, USGS Bull. 1226). Clements and Smyth defined and named the Hemlock Formation in the report from which this chromolithograph comes, and today, the volcanic pile is thought to be a remnant of a continental or oceanic margin flood basalt like that in the Columbia Plateau of Washington and Oregon. The iron in the Hemlock formation may have been a source for the iron formations in later sedimentary deposits (Reference: Institute on Lake Superior Geology, 2018, proceedings volume 64).

Tectonically the Hemlock basalts probably represent volcanism associated with the Penokean Orogeny. The Penokean was a two-phase collision from about 1.88 to 1.83 billion years ago between first, an island arc and later, a microcontinent, with the southern margin of the Superior Province, which forms the largest Archaean core of North America. The Hemlock volcanics formed early in the Penokean cycle, possibly in an extensional back-arc setting. Modern back-arc basins that have related volcanism and may be somewhat analogous to the setting of the Hemlock basalts include the Lau Basin, behind the Tonga-Kermadec trench and magmatic arc in the southwestern Pacific, and the extensional Tyrrhenian Sea back-arc basin offshore Italy.

I wish I had a photo from my 1967 visit to the glacially polished outcrops of the Hemlock formation pillow basalts in upper Michigan. But I don't. The 1899 report was a new acquisition in January 2021. The original specimen in the chromolithograph is about 15 cm (6 inches) top to bottom.



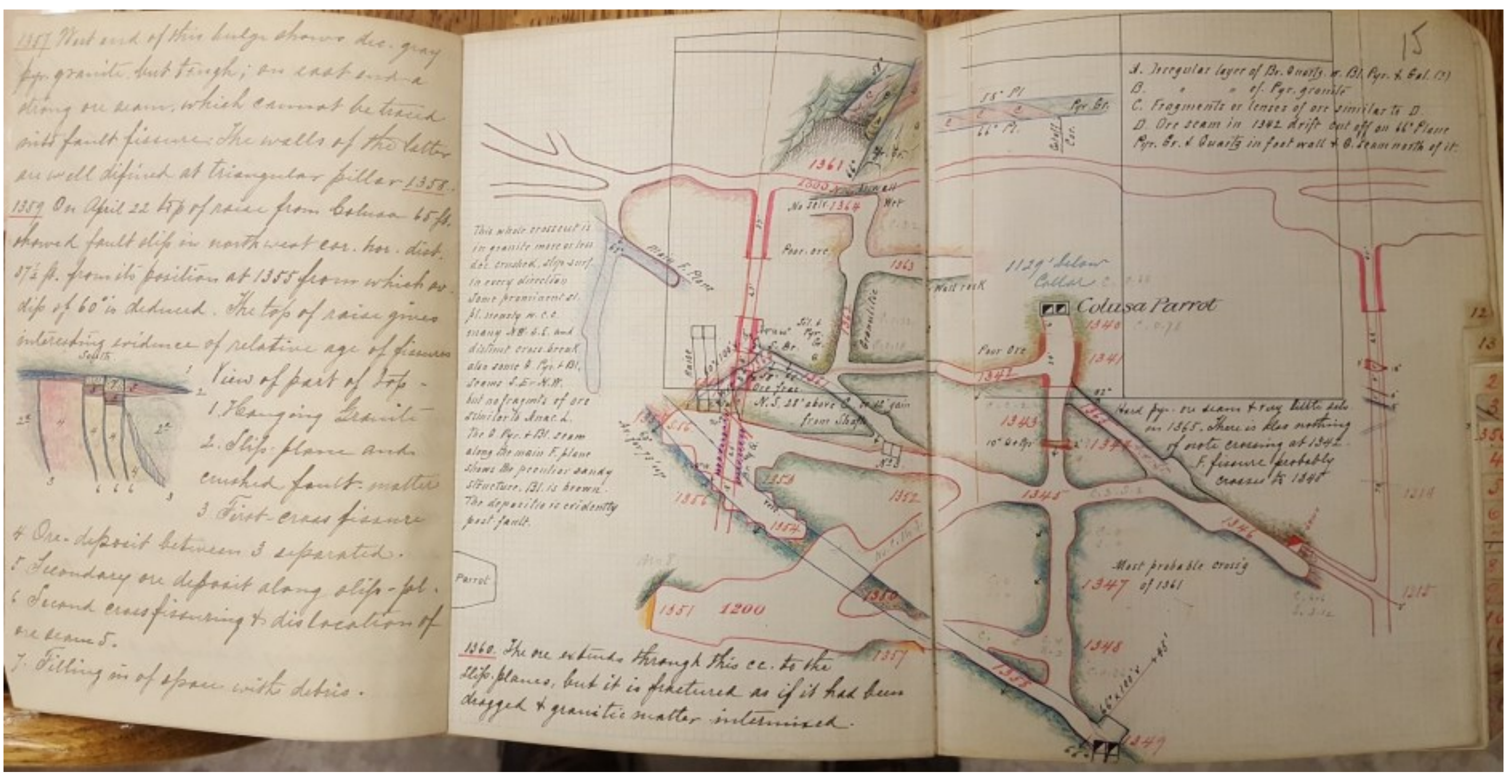
Underground Mapping at Butte

David Armstrong, a volunteer at the Butte Archives, invited me to see the books recently donated by Montana Resources to the Archives. They are the Pocket Notebooks used for underground mapping by Anaconda Company geologists. The Anaconda Company's first geologists.

David Brunton (who invented the pocket transit, or Brunton compass known to most geologists) hired Horace V. Winchell to work with him in Butte beginning in 1898. Together they devised the approach to mapping in underground mines still recognized as usually the best way to attack such a challenging problem, and still used today as the "Anaconda Method." Winchell organized the company Geological Department in 1900, and hired Reno Sales, whose name is more closely associated with the expansion and popularization of the Brunton-Winchell method.

The collection David Armstrong is working to catalog, document, and transcribe contains more than 100 of these books of maps and information. The image shown here is by Winchell himself, a beautiful work of art apart from its scientific value. Every color and texture means something, enhanced by Winchell's hand-written notes.

This is a treasure trove of not just Butte mining history, but of the history of science in mining in general.



Whipple Survey: Part 2

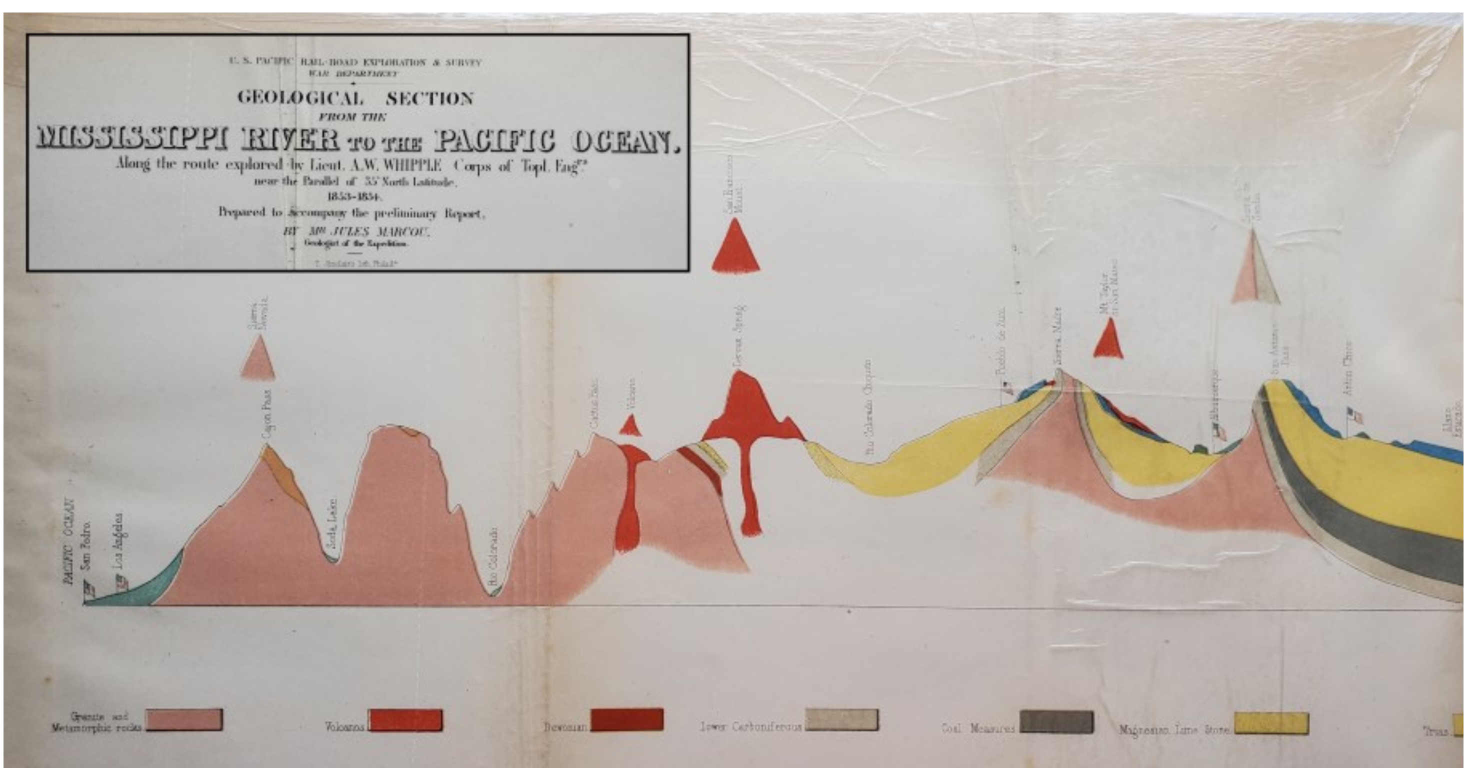
This cross section extends from the Llano Estacado in what is now West Texas to the Pacific Ocean. It is part of a 3-foot-long geological cross section (the other half is folded over on the back of this part) from the Mississippi River in Arkansas to the Pacific, drawn as part of a report of the Whipple Survey that explored possible railroad routes to the west in 1853-54 (published in 1856). That survey was driven by the discovery of gold in California, which had been recently ceded to the United States as a result of the Mexican War.

There appears to be a LOT of vertical exaggeration in the drawing, so the canyons and other topography appear to be vastly steeper than they are in reality. Nonetheless, the section conveys a basic geologic and tectonic interpretation of the rocks. On the right side of the section Albuquerque (population at the time about 1500) sits in the low Rio Grande Valley, a tectonic rift, and to the east of Albuquerque the section shows the Precambrian rocks of the Sandia Range (light red color mostly in the subsurface) with overlying tilted layers (tan, black-brown, yellow, blue) which today are mostly mapped as the Pennsylvania Madera Group, including coal (black-brown layer) and carbonates (yellow).

The volcanic rocks of the San Francisco Mountains north of present-day Flagstaff (an 1881 settlement that did not exist at the time of this survey) are shown in bright red near the center of the image. Proceeding west the survey crossed the Rio Colorado and entered California in the Mojave Desert, which is quite complex geologically. The team showed the rocks there as mostly light red, signifying granite and metamorphic rocks.

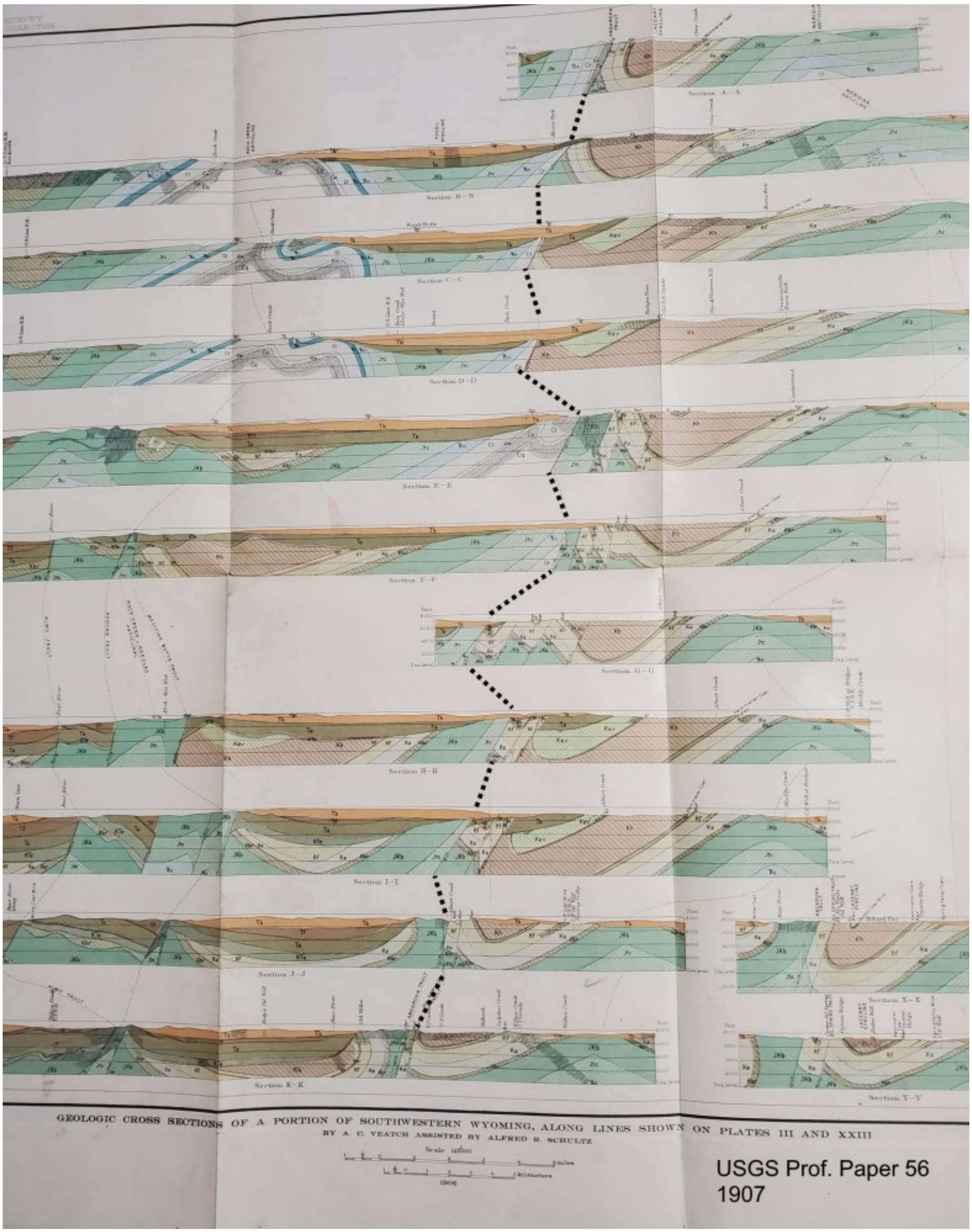
The Geologist for the Expedition, Jules Marcou (1824-1898) is credited with making the first comprehensive and detailed geologic map of the United States and Canada, and in his role with the Whipple Survey he became the first geologist to travel and map the US in a traverse from the Atlantic to the Pacific, at age 29-30.

This cross section and the accompanying strip map were the first serious geological look at the US southwest. Colors are watercolors, hand-painted. I got these items in an antique mall in Golden, Colorado, about 1990.



Overthrusts in Wyoming

There's a huge amount of work represented in this set of cross sections, by A.C. Veatch assisted by Albert Schultz. Published in 1907 as part of USGS Professional Paper #56, this is one of the early representations of the Wyoming Thrust Belt in the western part of the state.



In the Rockies, the concept of low-angle thrust faults with large displacement had been first described in Canada (the second essay in this compilation shows cross sections from 1885 that I believe to be the very first such recognition in print), but the idea was still rather unusual by 1906 when Veatch was mapping in Wyoming. His focus then was actually on coal and oil resources; in the late 1900s and early 1910s demand for oil for gasoline was surging along with the development of cheap automobiles, and coal was still king in terms of heating and steam and electricity generation.

Each of the cross sections is correlated with the next one, arranged here from north (at top) to south, spanning about 60 miles. The obvious break near the center is the Absaroka Thrust, one of the largest faults in the belt. I've enhanced Veatch's correlation lines for that fault between sections. Veatch recognized the drag typical of these faults that produced a syncline on the lower plate (to right of the faults) and an anticline on the upper plate, to the left and less evident in most of the sections. He knew the faults were reverse faults because they juxtapose older over younger rocks.

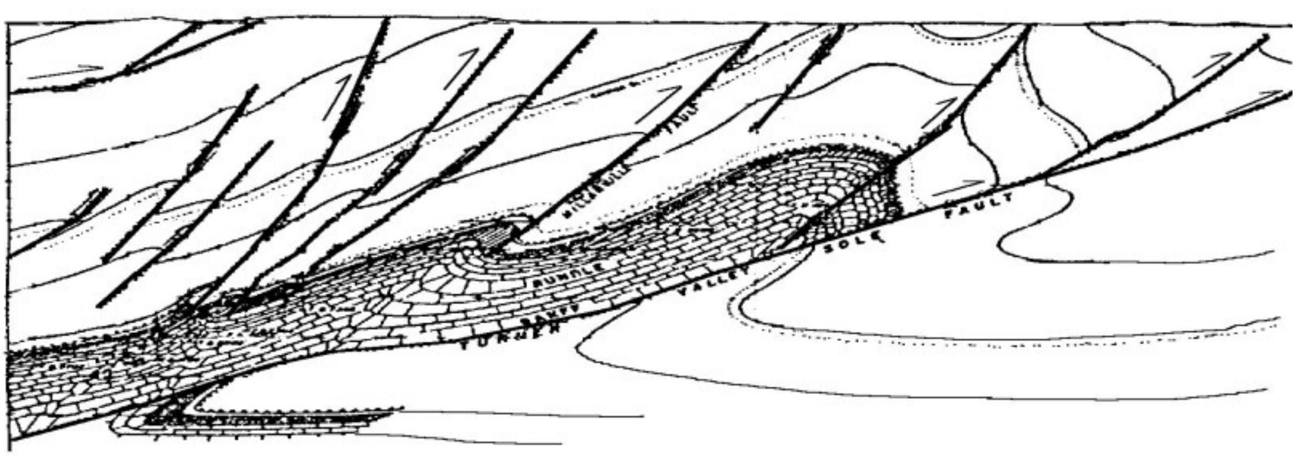
Today we'd probably curve Veatch's faults a little more, recognizing that they change from medium-steep near the surface to a flatter angle at depth. Veatch's interpretive cross sections extend to about 7,000 to 8,000 feet below the surface, which is deep enough for that change to be shown as we know the subsurface today. I used gravity data back in the mid-1980s to try to help unravel some of the subtleties – I wish I could share but it was a proprietary project for an oil company.

These faults are part of what is called the Sevier Orogeny that resulted from collisions among island arcs, other small isolated and diverse terranes, and western North America, pushing rocks eastward and ultimately breaking them in places, as here in western Wyoming. That happened in this area mostly about 60 to 70 million years ago.

My copy of Professional Paper 56 was well used by its previous owners, although it is still in pretty good shape. The first owner (he wrote his name on the cover) was probably C.A. Fisher, a contemporary at the USGS with Veatch. Fisher was also a coal geologist who worked on the Great Falls Coal Field, among other things, during his USGS career from at least 1903-1909. A later owner, A.B. Fields of Wheat Ridge, Colorado, wrote his name in the book February 23, 1964, but I haven't found out anything else about him.

Arthur Veatch himself had a distinguished career. He was educated as a geologist at Indiana University (as was I), Cornell, and the University of Wisconsin. He was with the USGS from 1902 to 1910, but then switched to the oil business, working in Venezuela, Trinidad, London, and New York. He was chief exploration geologist for Sinclair Oil from 1919-1928. He died in 1938 at age 60.

I got the 178-page 1907 Professional Paper "Geography and geology of a portion of southwestern Wyoming" and the supplementary plates at the Colorado School of Mines book sale about 1990, probably for 50 cents.



Chromolithographs

This illustration published in 1890 in USGS Bulletin 62 was drawn by geologist George Huntington Williams. The rock is greenstone schist from Lighthouse Point at Marquette, Michigan. The green radial sheaf-like crystals are hornblende and the rest of the rock is mostly albite (feldspar) and quartz, with some chlorite, epidote, and ilmenite grains.

The rock is highly metamorphosed and was originally either a basaltic flow or (as Williams thought) a basaltic-composition ash-fall tuff. Either way, the original material was very old already when it was metamorphosed around 1.8 billion years ago.

I share this not so much for the science, but for the art. Williams probably made the drawing using his microscope and a camera lucida, a technique for tracing views seen through the microscope. The field of view of this thin slice of the rock is about two millimeters across, and it is in ordinary light (not polarized). The printed illustration is 6 cm wide.

In 1890 there were few satisfactory ways of reproducing true colors for mass publication. You could literally paint each copy (usually with watercolors) but that was impractical for more than a few copies, although it was sometimes done for hundreds of prints. This image was created by chromolithography, the process where multiple lithographic stones would be engraved with the line drawing, then coated with the appropriate ink. In order to achieve true natural colors, it might require a dozen engraved stones and/or multiple passes with various inks. That was still a laborious and costly process, but the results were both accurate and reproducible, and often beautiful. You can imagine the difficulties of properly registering the multiple print runs to make one single copy.

I don't know the initial press runs for USGS Bulletins in 1890, but I speculate it would be fairly small – on the order of 200 or so. The demand for "The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan: A Contribution to the Subject of Dynamic Metamorphism in Eruptive Rocks" was likely not very great.

George Huntington Williams

It wasn't until the early 1900s that cheaper and quicker color reproduction became possible. I do appreciate the irony of this historic image being captured by the amazing camera on my cell phone and now being viewed by you on a display screen that contains elements that hadn't even been isolated in 1890 (e.g., europium). (Indium, one of the main components of touch screen displays, was however discovered in 1863.)

George Huntington Williams died in Utica, New York, of typhoid fever in July 1894, four years after this USGS Bulletin was published. He was 38 years old, and left his wife and three children, the eldest age seven. For my geology friends and others who love jargon, Williams coined the term "poikilitic," a word for a texture in igneous rocks where larger crystals enclose smaller crystals of other minerals within them, from a Greek word for 'variegated.'

Bulletin 62 is part of my collection of old geology books. It contains 18 beautiful chromolithographs similar to this one.

* * *

The next page shows another historical thin section drawn by George H. Williams, this one published in USGS Bulletin #28, "The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Maryland," in 1886.

This particular chromolithograph shows brown cores of hypersthene, a magnesium-iron silicate in the enstatite (magnesium) to ferrosilite (iron) series of pyroxenes; the name hypersthene is now discredited but has a long and frequent use historically.

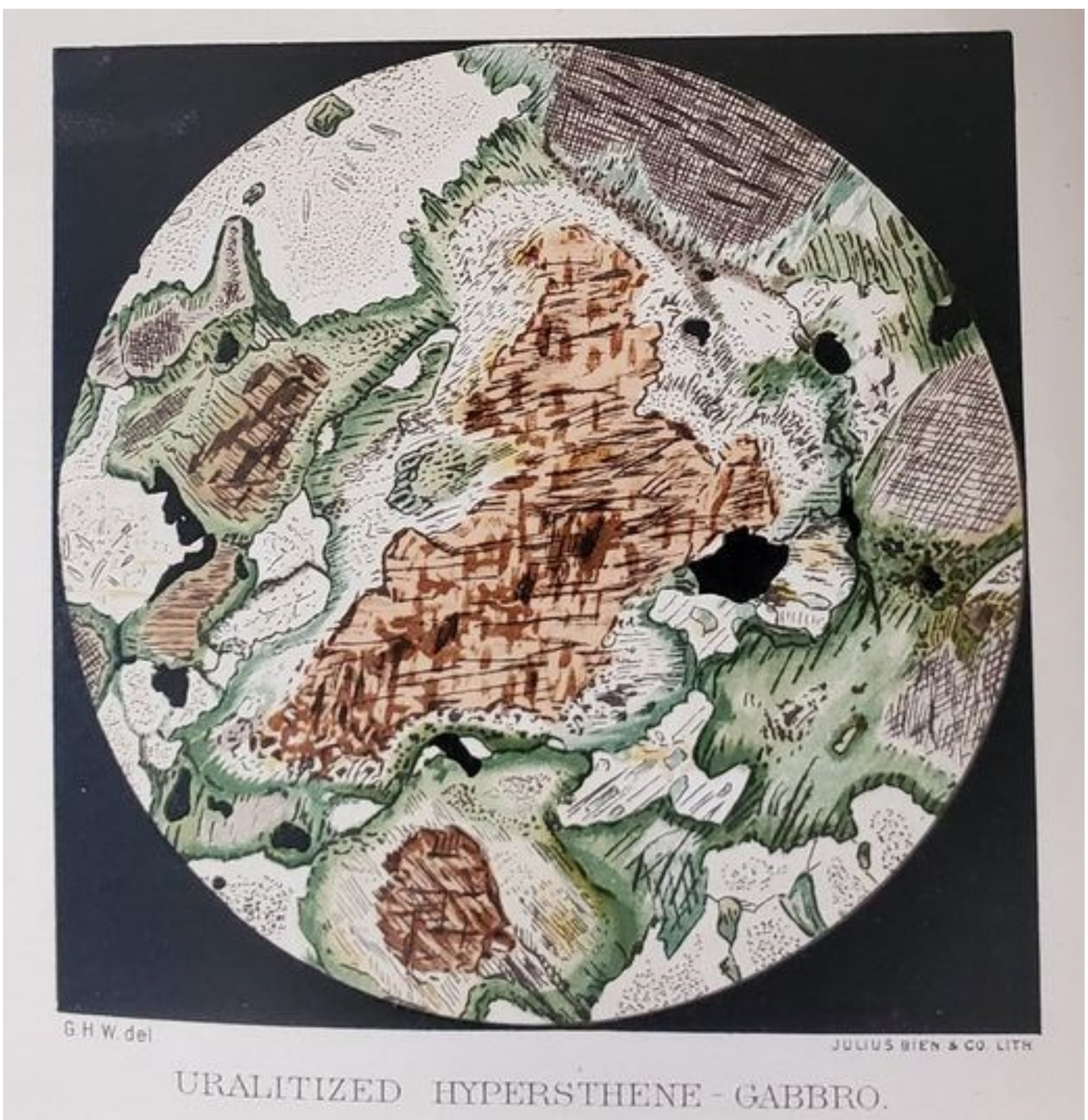
The brown hypersthene is surrounded by rims of colorless to green hornblende, a catch-all term for minerals in a calcium-magnesium-iron-aluminosilicate amphibole group. The change from pyroxene cores to amphibole rims occurred through a process called "uralitization," a type of alteration in which the original mineral changes its structure and sometimes its chemistry during cooling of a magma, or during low-temperature metamorphism. So in effect, the outer parts of the crystals are pseudomorphs of hornblende after hypersthene. When well-formed, such crystals are sometimes called 'uralite,' which is not a mineral itself, but a name for crystals that show that pseudomorphism. "Uralite" is from occurrences in the Ural Mountains, Russia. "Hypersthene" is from words meaning "exceeding" and "strength," because it is stronger than hornblende; "hornblende" comes from words meaning "horn," referring to a crystal projection, and "blende," to blind, in the sense of "dazzle," implying it deceives, since it was a common dark mineral that contained no metallic ores.

The rock here is from near Pikeville, Maryland, northwest of the city of Baltimore, where it was found in a zone of metamorphosed gabbro, the coarse-grained equivalent of basalt. Both are dark, iron- and magnesium-rich rocks, but fine-grained basalt crystalized relatively quickly, while coarse gabbro took longer to cool so its crystals grew larger. The origin of the word “gabbro” is from an occurrence near the village of Gabbro, Tuscany, Italy.

The gabbro is part of the Piedmont Province, a linear zone of Precambrian to early Paleozoic rocks that comprise the eastern part of the Appalachians from Alabama to New Jersey (and perhaps as far as Newfoundland). The tectonic history is complex, but most of the Piedmont near Baltimore probably formed during collisions about 470 to 440 million years ago as part of the Taconic Orogeny (named for rocks in the Taconic Mountains of eastern New York and western New England). The Taconic Orogeny (mountain-building episode) represents the collisions between ancestral eastern North America and large volcanic island arcs, together with other terranes including probable back-arc basin sediments and possible oceanic crust.

The Piedmont and its rolling hills are the roots of the high mountains that were here 440 million years ago.

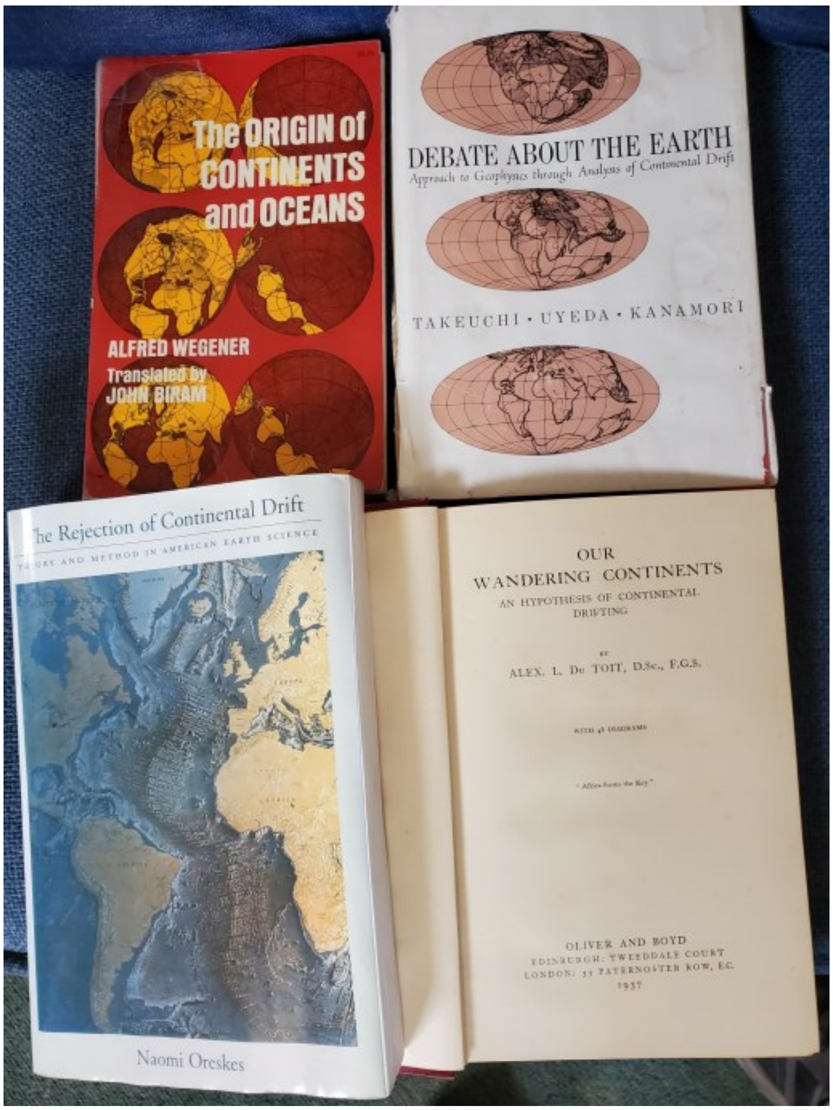
The field of view of this section is about 3 millimeters across. Standard thin sections are slices of rock cut and ground to a thickness of 30 microns, or three hundredths of a millimeter. My copy of this Bulletin is bound together with USGS Bulletins 25-30, but the plates for Bulletin 28 are by far the prettiest. You can tell this was drawn by Williams from the label in the lower left corner: “G.H.W. del.” — where “del.” means delineator.



URALITIZED HYPERSTHENE - GABBRO.

Continental Drift

These four books don't tell the whole story of plate tectonics, but they are important to it. Wegener's "Origin of Continents and Oceans" (my copy is a 1966 translation of the original 1929 German 4th edition, based largely on ideas Wegener began to develop about 1912) set out the radical idea that continents had drifted, moved apart. The idea was largely ignored or ridiculed at the time, but in Europe, South Africa, and South America, increasing and diverse evidence in the 1920s and 1930s began to provide significant support for the concept, if not quite for an acceptable mechanism.



Alexander du Toit was a South African geologist who also lectured at the University of Glasgow and worked in South America. His book, "Our Wandering Continents," provided a comprehensive review of the large volume of petrologic, tectonic, stratigraphic, and paleontological evidence supporting the fact of continental drift, much of it based on his own work. He offered various theoretical mechanisms, including the idea of convection currents in the mantle (largely echoing Arthur Homes and others from the 1920s). His book summarized what was already largely a fait accompli for European and South African geologists (and a very few Americans) in 1937. My copy is an original, published in 1937 in Edinburgh. It was previously owned by G.F. Kaufmann, a 1921 graduate of the Colorado School of Mines who worked as a petroleum exploration geologist, retiring from Standard Vacuum Oil Co. in 1959. Stan-Vac was a joint venture of Standard of New Jersey (later Exxon) and Socony-Vacuum (later Mobil) for operations in the Far East. Stan-Vac essentially started the oil industry in China.

Du Toit and others who argued for continental drift continued to be largely ridiculed (albeit with a degree of professional politeness, at least sometimes) in the United States. Naomi Oreskes' 1999 book, "The Rejection of Continental Drift," is a review of how that rejection developed and continued in America after European and South African scientists had generally embraced the idea. She points out that although it is common to say that American geologists rejected it for lack of a mechanism, in reality it was more complicated.

The rejection happened "because it [continental drift] seemed to conflict with the basic standards of practice in American geology." Oreskes' thesis is that it was not for lack of evidence (which was abundant), nor for lack of a theoretical mechanism (in fact, geologists routinely accept phenomena without knowing their causes, and anyway, convection current theory dates to the 1920s or earlier), nor because those proposing it were crackpots or obscure (they weren't). She contends that American scientists could not accept it because American geoscience in the 1920s to 1950s was so ingrained in observational method and existing theory, and some of its practitioners so intransigent, so parochial, that many of them were intellectually unable to even start to believe the idea of continental drift, which went from theory to observations to prove or disprove it, not the "normal" (American) way, which started from collecting facts that then led inductively to promulgating a theory.


Alfred Wegener

From conflicting 19th century theories of the Earth, European geologists inherited the premise that change was pervasive, while Americans were saddled with ideas that centered, erroneously, on permanence. Influential American geologists such as William Bowie, T.C. Chamberlain, and Charles Schuchert rejected continental drift for diverse reasons, including its conflicts with Pratt's theory of isostasy, its violation of the method of multiple working hypotheses, and a perceived violation of uniformitarianism, all of which were good ideas, just not the end all and be all of geoscience practice. But geology, like other sciences in the first half of the 20th century, was strongly driven by strong personalities, so their approaches and beliefs carried significant weight in the debate about continental drift.

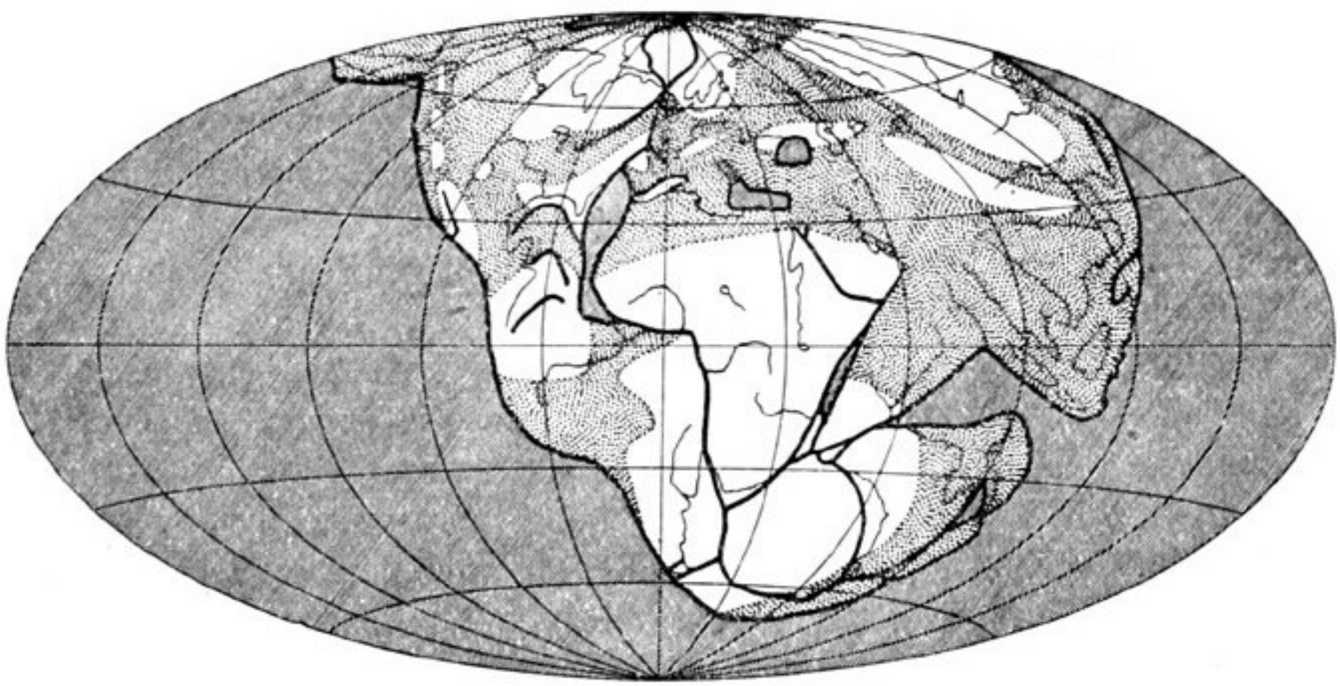
In their defense, American geologists used their methodological, observational, fact-collecting approach because it usually worked at least locally and regionally (and their inductive geology was certainly good science), but it left them challenged to accept a global theory based on other approaches such as those espoused by Wegener and du Toit. It's more complicated than THAT, too, but I'm not smart enough to summarize it better. Read Oreskes' book if you want more; she took 318 pages to elucidate what I tried to outline in a few hundred words here.

"Debate about the Earth," by Takeuchi, Uyeda, and Kanamori, geophysicists at the University of Tokyo, was published in the U.S. in 1967, and I got my copy the same year as a gift from geology profs at Flint Junior College, when I was 19 years old. The book summarized the new information, largely from geophysics, that came out mostly in the mid-1960s to revolutionize thought about this idea (at least in the U.S.; it was hardly a revolution for the rest of the geologic community, even though the new data gave the concept compelling strength). In a single decade, American geologists went from skeptics at best and downright detractors of "continental drift," to some of the most ardent advocates.

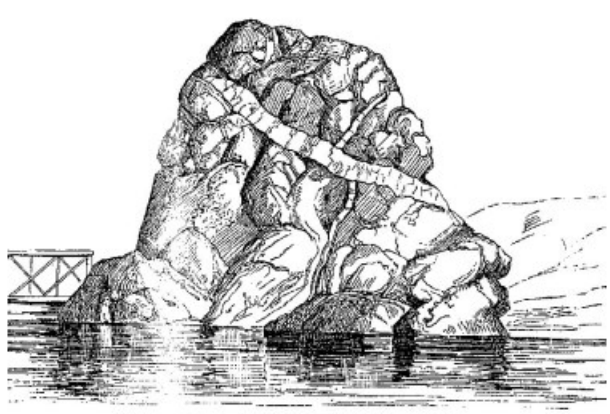
What it amounts to is that the evidence became so overwhelming, and from so many seemingly unconnected directions, that the unbelievers simply had no more legs to stand on, scientific or emotional; and to some extent, the new geophysical data were perceived as less subjective than even overwhelming but purely geological information. Enough details that were inherent in the theory arose to provide predictable, testable hypotheses, which worked. (It should be acknowledged that the shifts in American geological thinking had begun by the late 1930s with new discoveries, such as gravity data in the ocean basins, sloping zones of seismicity, and the fact that the magnetic field had reversed; World War II slowed the 'revolution' down, delaying comprehensive data acquisition and synthesis until well into the 1950s and 1960s.)

"Continental drift" became "plate tectonics" in short order, and it also subsumed the term "sea-floor spreading," which more or less expressed the mechanism at the earth's surface. The phrase Plate Tectonics was probably first used by J. Tuzo Wilson (U. of Toronto), but because theory and practice and evidence were changing so quickly in the 1960s, it's unreasonable to assign the term to any particular person or date. Suffice it to say that in North America in 1960 or thereabouts, continental drift and plate tectonics were still largely rejected (or at best not fully accepted), but by 1970, the concept was largely embraced wholeheartedly, and today it is truly a 'grand unifying theory' with cogent applications in every area of geoscience.

For me personally, in college studying geology from 1966-73, it was an incredibly heady time to be a student. My historical geology textbook (Historical Geology, by Carl Dunbar, 2nd Ed. 1960, purchased in 1966), contains but one short paragraph on continental drift, ending with the sentence, "But this premise itself is still in the realm of speculation!" In 1967, just one year after I bought that book, the concept was almost a household word in college geology departments, at least, and geologists were excitedly beginning the long process of dotting the i's and crossing the t's.



Wegener's Pangea



Charleston Earthquake

William John McGee of the U.S. Geological Survey inspecting a fissure near a wrecked brick house on Tradd Street in Charleston. Photo by John Karl Hillers, USGS (public domain).

On August 31, 1886, a strong earthquake struck a very unexpected place – Charleston, South Carolina. The magnitude is estimated at 6.9 to 7.3 – huge by any estimation. It was felt as far away as Boston, where the shaking rang church bells. Almost every building in Charleston was severely damaged or destroyed, and at least 60 people were killed.

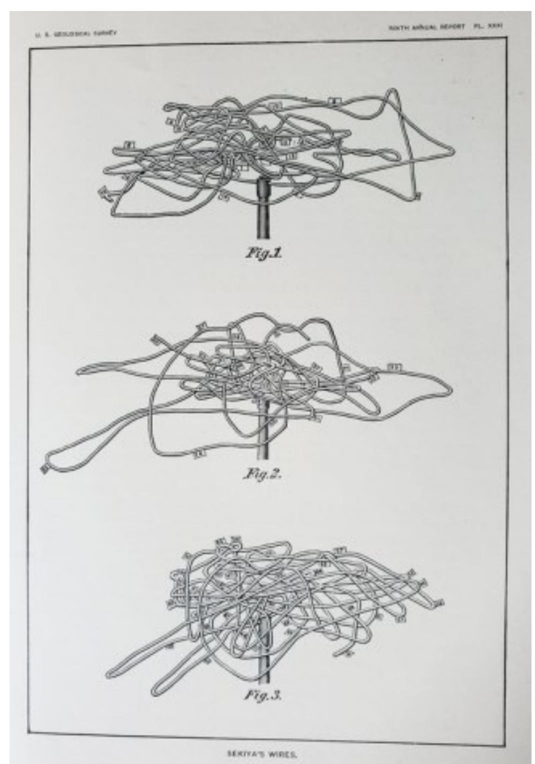
The area had a long history of low-level seismic activity, just as it does today. But why is there any seismicity at all? Charleston is thousands of kilometers from plate margins and volcanic zones. It's really challenging to explain these earthquakes that occur far from areas of active fault motion, but I think the current explanation for the Charleston quake is that there was significant faulting in this area when the Atlantic Ocean's opening initiated during the Jurassic (about 175 million years ago), and that the 1886 quake was a rejuvenation of that faulting related to the ongoing pull-apart of the Atlantic.

That sort of begs the question of why aren't there a lot more significant earthquakes along the US East Coast, because there are plenty of places with faulting inherited from the Atlantic opening. The location at Charleston probably relates to the specifics of stress build-up in the present-day Atlantic extension, but the ultimate explicit cause remains under study. Intraplate seismic activity in general is an area of active research.

In the Ninth Annual Report of the United States Geological Survey, 1887-88, Clarence Dutton presented a comprehensive report on the Charleston earthquake. Among other things, Dutton brought to bear the latest advances in seismology, which was in its infancy at the time.

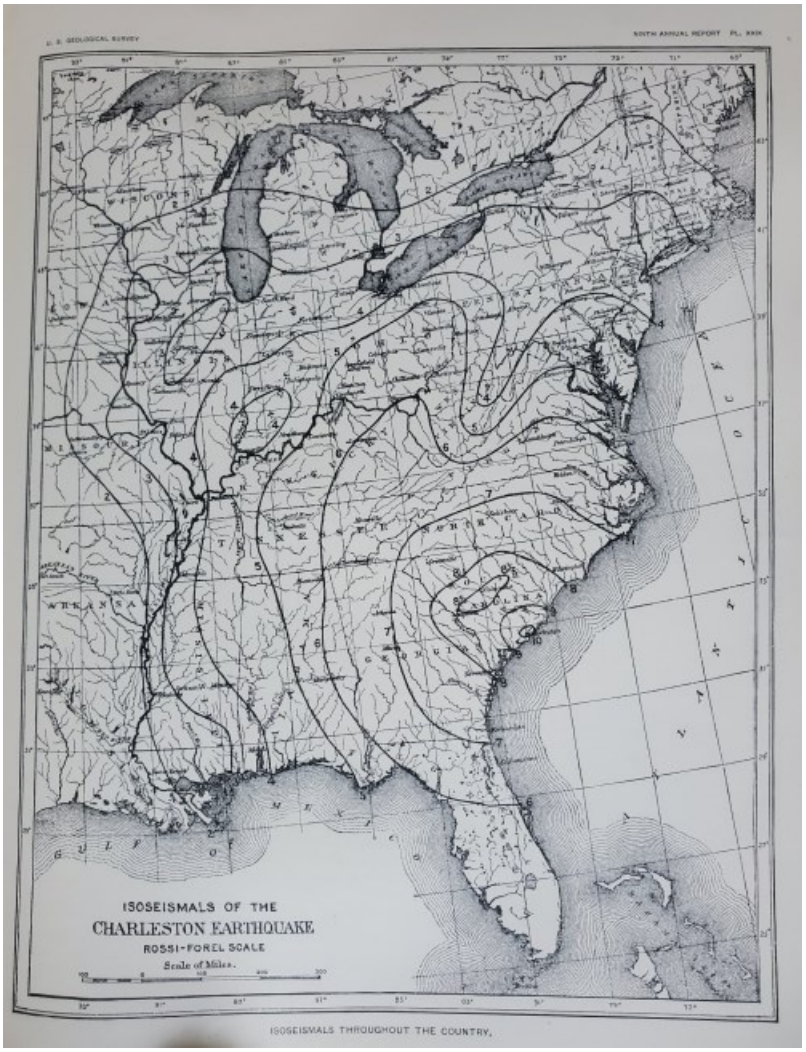
Japanese geologist Sekiya Seikei, considered by many to be the first scientific seismologist, had recently developed a technique for understanding the movement of materials during earthquakes, using a revolving plate which measured the three components (two horizontal, relative to north-south-east-west directions, and one vertical) of earthquake motion. He used those measurements to construct a three-dimensional representation of the motion of a point on the ground.

The final product of Sekiya's efforts was wire models of earth motion. The drawing here, from the 1888 USGS Ninth Annual Report, shows motions from the first 20 seconds (top), from the 20th to 40th second (middle) and from the 40th to the 72nd second of earthquake movement (bottom).

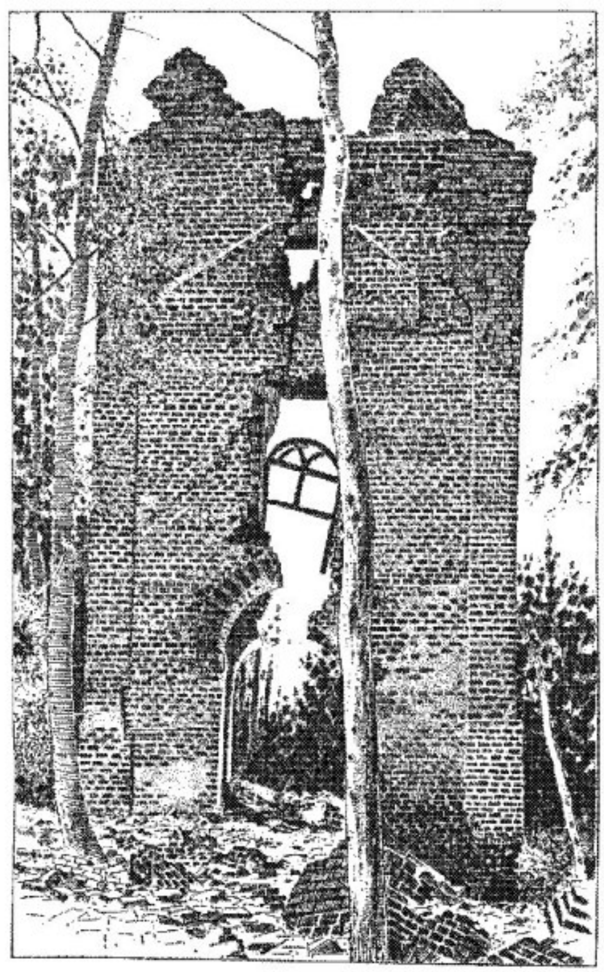


The chaotic nature of Sekiya's wires was informative in itself, but careful analysis showed the relationships among main shocks and smaller aftershocks. This was an early quantification of earthquake magnitudes. The wires in the drawing are from a quake in Japan, but Dutton considered it to be similar to the Charleston quake.

Sekiya died in 1896 at age 40. Dutton contributed prolifically to the USGS, including significant work in the Grand Canyon, on Hawaiian volcanoes, and at Crater Lake. He coined the term "isostasy," the state of balance (or imbalance) in the earth's crust depending on the density of the rocks present. He died in 1912.



Isoseismals, shown on the map at left from the 1888 report, are lines indicating positions where earthquake intensity is felt equally. It's subjective but was a step on the way to quantifying earthquake strength and magnitude. Isoseismal maps are really about the same as today's "Did you feel it?" maps from the USGS. The outermost line on the map, Intensity 2, delimits the area over which the quake was felt.



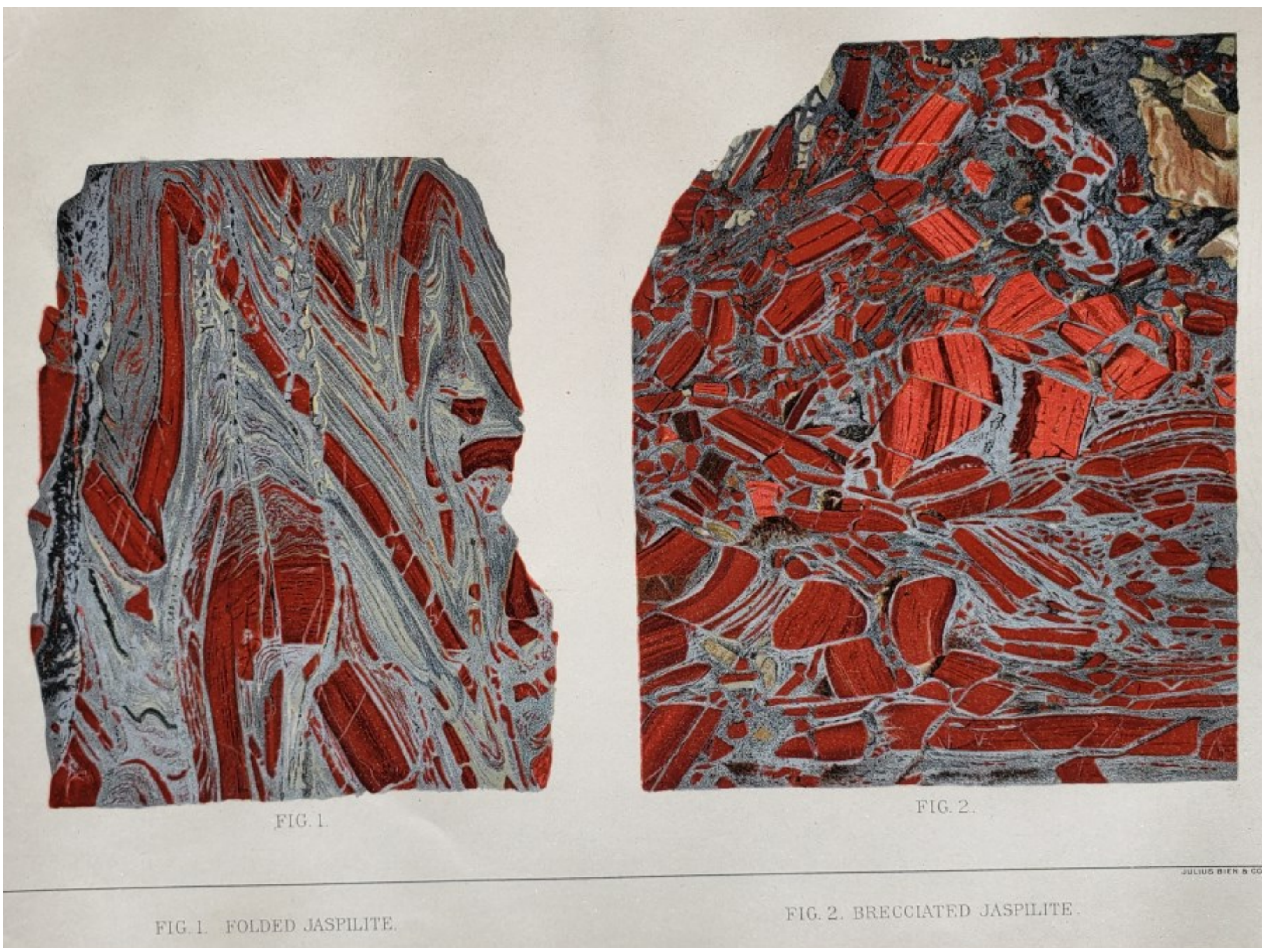
Damage at Charleston

Silver Ink as Specular Hematite

These prints, from USGS Monograph 28, The Marquette Iron-Bearing District of Michigan (Van Hise and Bayley, 1897), are among the most spectacular achievements of scientific printing of the 19th Century. They accurately depict the appearance of metallic iron ores 2.1 billion years old.

The prints portray primarily two kinds of materials. The red is iron-rich chert, microcrystalline quartz, called jasper. The silvery bands are hematite, iron oxide, called specular hematite for its flashy, mirror-like nature. “Speculum” in Latin means “a mirror.” The rocks are so old they have been metamorphosed (“changed form”) by heat and pressure multiple times, so that the original hematite, which is essentially the same as rust, has recrystallized to bright shiny flakes.

All the iron in these rocks from Negaunee in the Upper Peninsula of Michigan represents a time in Earth history when the most significant forms of life were algae, cyanobacteria, which were producing oxygen so prolifically that the iron in the environment precipitated as this iron oxide. Once most of the iron had combined



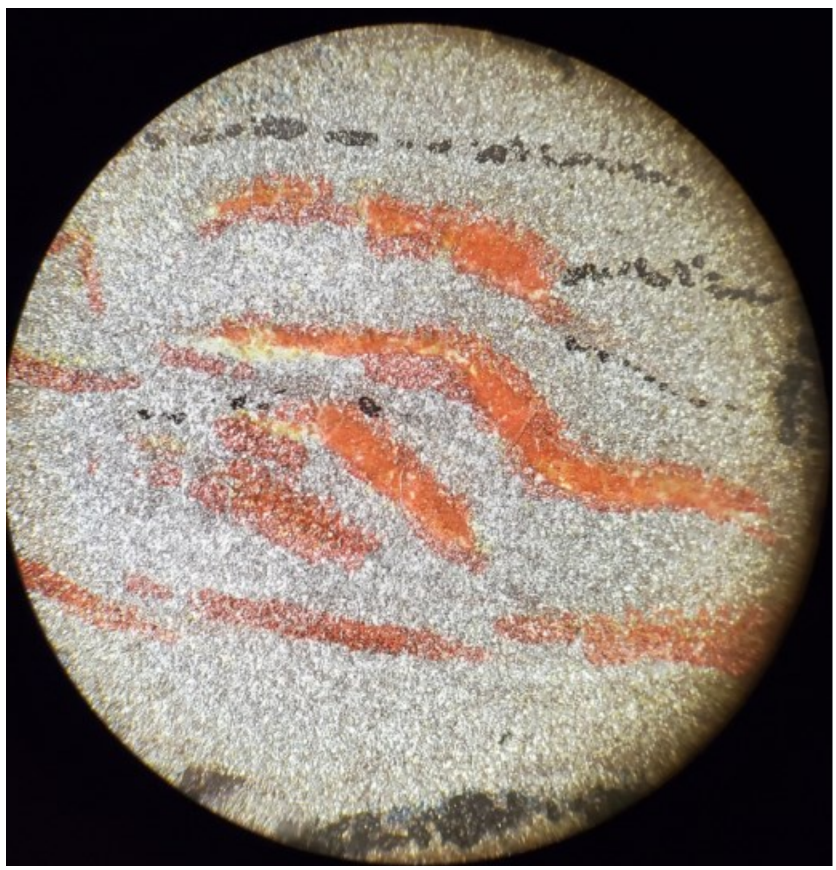
with free oxygen, ongoing oxygen production began to change Earth's atmosphere to the oxygen-rich conditions we have today. It took hundreds of millions of years for enough oxygen to enter the atmosphere for it to support the kinds of life prevalent on the surface today.

These prints were made in a variation of standard chromolithography, in which colored inks are applied to engraved lithographic stones to produce the desired colors.

The red colors, true to natural hues, were probably made with standard red inks, mostly derived from iron oxides, so the print uses the same material as it illustrates.

The silvery material, highly reflective in the original prints, was depicted in a slightly different way. True metallic inks barely existed in the 1890s, so effects like this were created by applying a glue selectively to the lithographic stone, precisely in the positions where the silvery appearance was desired. Then the paper was printed, transferring the glue to the paper just as the red ink was transferred, but that was followed by another step: metallic flakes in powder form were spread on the glue-covered paper, so that they adhered to the paper in the proper manner for the image.

This metallic powdering process is called "bronzing" in printing, even though it really has little to do with bronze, except that for some coppery metallic images flakes of bronze might be used. For these silvery prints, the choices for the powder are either aluminum or silver. Aluminum was so costly to produce in the mid-19th century that until a cheaper process was developed in the 1880s, it cost significantly more than silver—25 times more in the 1850s, and aluminum and silver both cost about $1 per ounce in the 1880s.

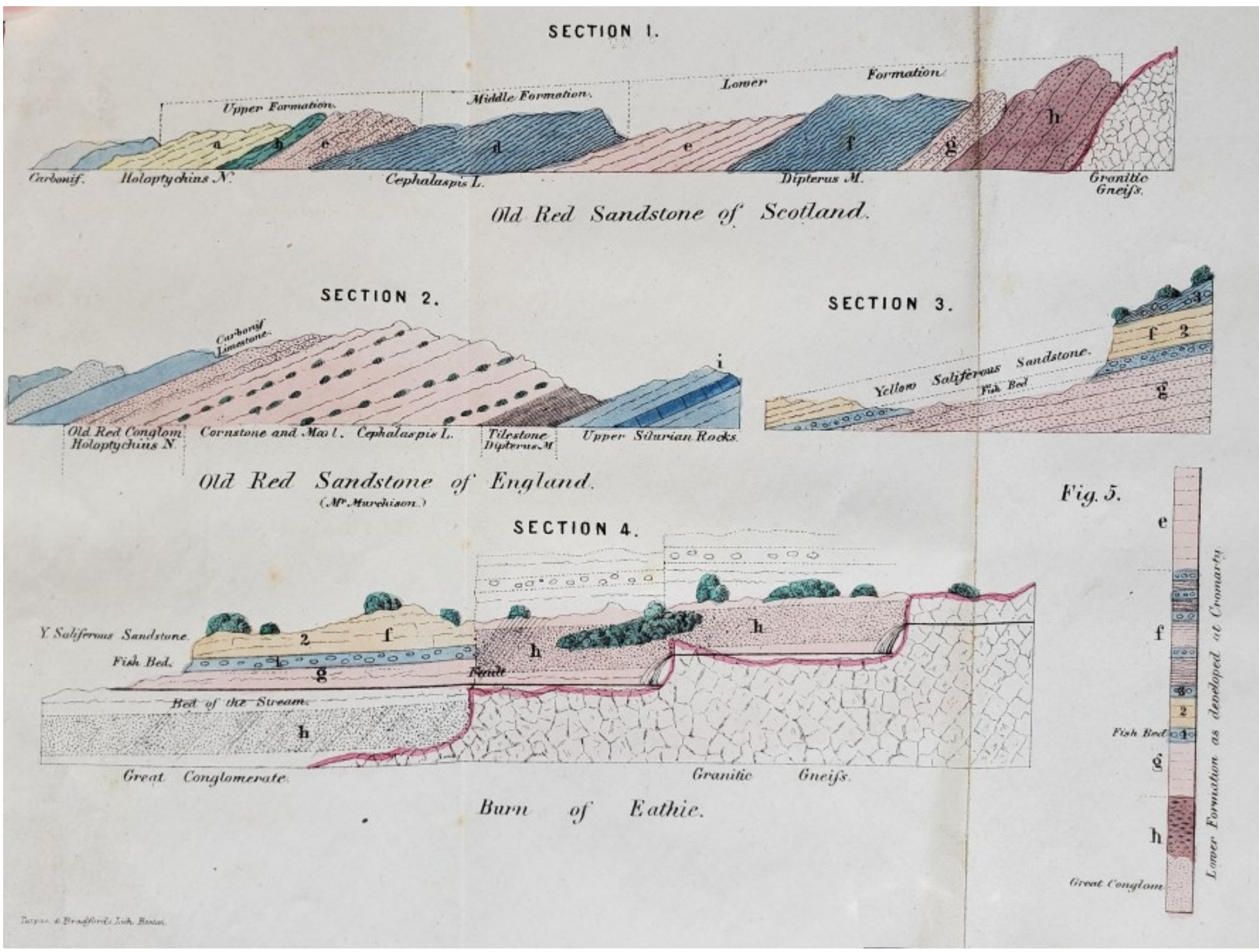


By the 1890s when these prints were made, the price of aluminum had fallen considerably, to about half the cost of silver, but it was still hard to make and in short supply, while silver, despite the cost, was abundant. It's most likely that these prints were produced using coatings of powder in the form of microscopic flakes of silver, which gives a dramatic reflective sheen to the originals as printed in the USGS book. Each print is slightly different microscopically owing to slight differences in the distribution of the adhesive, and the individual flakes of silver can be readily seen under the microscope as well. The photomicrograph showing both the silver powder and red ink is about 8 mm across.

The Old Red Sandstone

Hugh Miller's 1841 book, *The Old Red Sandstone: Or, New Walks in an Old Field*, was an early scientific work on the rocks of Britain that made geology accessible to laymen. This frontispiece, from my copy of the first American edition published in 1851 in Boston, shows cross sections that helped people understand the relationships among tilted and deformed strata.

The Devonian Old Red Sandstone was deposited in fault-bounded troughs formed late in the Caledonian Orogeny when sediments were eroded from the high Caledonian Mountains about 370 to 390 million years ago. At that time, a 300-mile-long (480 km) transform (strike-slip) fault developed in what is now Scotland (where it is called the Great Glen Fault), Newfoundland (as the Cabot Fault), and Cape Breton Island Nova Scotia (the Aspy Fault) which were attached to each other then as parts of the elongate microcontinent/island arc of Avalonia.



The big transform fault, similar to the San Andreas or even more so to the Alpine Fault in New Zealand, resulted from parts of the amalgamated terranes sliding past each other and also from faulting breaking into the older rocks they collided with in the ancient core of North America (Laurentia). Ongoing movement eventually tilted the Old Red Sandstone beds. That was probably mostly related to the Carboniferous collisions that formed Pangaea about 335 million years ago when the Great Glen Fault was rejuvenated. There may have been some additional movement when Pangaea broke apart and the North Atlantic Ocean formed about 180 to 160 million years ago.

Today, the Great Glen Fault localizes Loch Ness, a long, very narrow lake. The fault continues offshore north-eastern Scotland, just a few miles east of Cromarty and the Burn of Eathie where Hugh Miller made his observations, and whose rocks are shown in his cross sections in the frontispiece to his book.

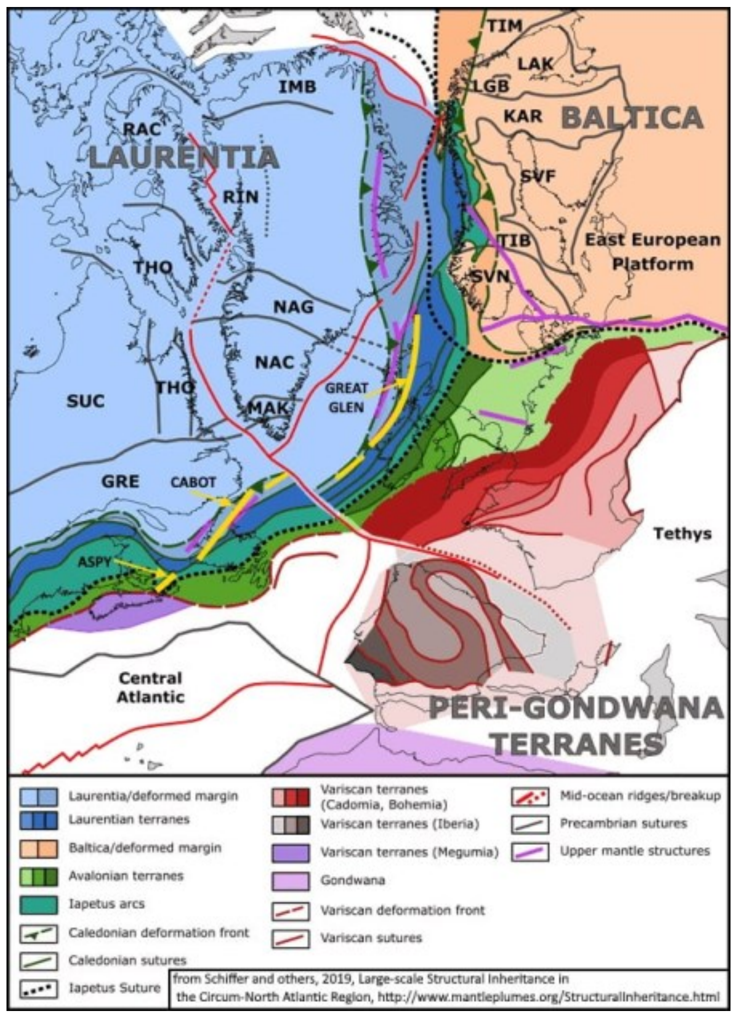
According to Piccardi (2014, Mem. Descr. Carta Geol. d'Italia, XCVI, pp. 431-446) the origin of seismic activity (with rare earthquakes as large as magnitude 5) on the Great Glen Fault today is ambiguous and may be related to ongoing spreading of the North Atlantic Ocean or to glacial rebound or both. There is also good anecdotal evidence that the modern belief in the Loch Ness Monster correlates with periods of seismic activity on the Great Glen Fault that probably produced "violent commotion of the water and anomalous wave-wakes," particularly in an earthquake swarm in 1934. Seismic sounds and other phenomena near the Great Glen Fault are also reported in the stories of St. Columba, the 6th-century Irish priest who brought Christianity to Scotland and in whose legends the Loch Ness Monster is first mentioned.

Until chromolithography became relatively cheap in the 1870s, the only effective method for producing color in mass-produced items like books was hand-painting. Each instance of this color illustration would have been individually hand painted with watercolors on sheets engraved or lithographed with the outline of the drawing. The press run was probably on the order of 800 copies, and for larger runs publishers employed small armies of painters to color their illustrations.

Watercolors here include shades of red, blue, green, and yellow, all probably derived from mineral-based pigments. Reds come from various iron oxides and the blue may be Prussian blue, a pigment made of iron cyanide, or it might be the newer (1802) cobalt blue. Chrome green was developed in 1809 and cadmium yellow became available in 1817.

Even with such varied pigments, accurate natural colors were challenging to reproduce cheaply in printing until the advent of chromolithography.

Hugh Miller's house in Cromarty, Scotland, was built in 1800 and still stands. The Devonian rocks Miller described are called the "Old Red" to distinguish them from similar but much younger red sandstones of Permian to Triassic age – the New Red Sandstone.

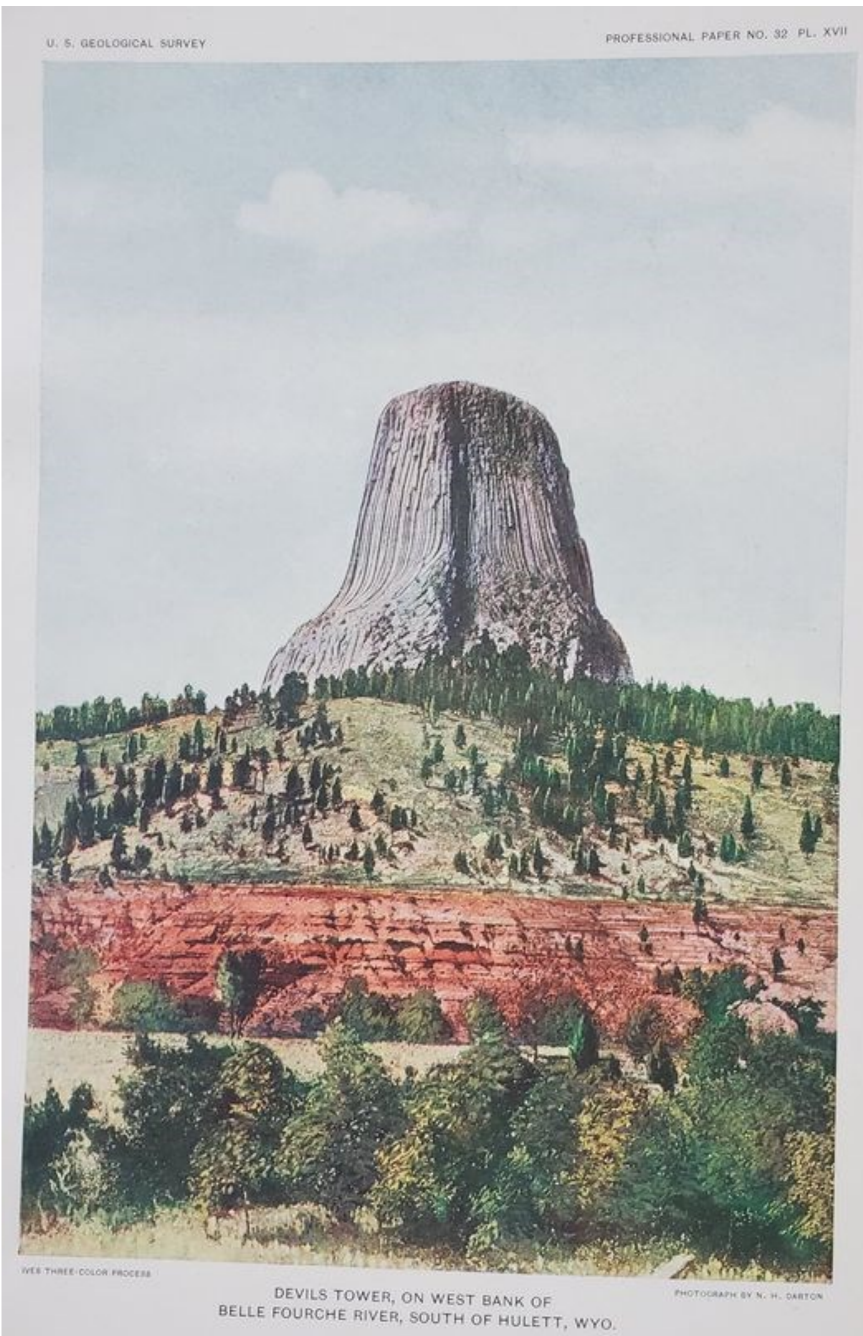


Map above (with fault names added by me) from Schiffer and others, 2019, Large-scale Structural Inheritance in the Circum-North Atlantic Region, http://www.mantleplumes.org/StructuralInheritance.html

Devil's Tower

Chromolithographs began to be supplanted by other printing technologies for color by the early 1900s. This photo of Devil's Tower, Wyoming, by geologist N.H. Darton, appeared in 1905 in US Geological Survey Professional Paper #32, "Preliminary report on the geology and underground water resources of the central Great Plains." It was printed using the Ives Three-Color Process.

The photographic process invented by Frederic Ives was commercially available about 1898. To make a photograph, three separate black and white images were made of the subject, shot through red, green, and blue filters. To create a color print, a three-phase halftone process was used. "Halftone" printing represents gradational shades with various sized dots that the eye perceives as continuous toning. For color, three prints were combined. This was an exacting and costly process, but less so than detailed chromolithography, and the US Geological Survey used it for a few years for natural-color mass-produced printing as for this photo of Devil's Tower. The color is good but a bit unrealistic in its saturation, a consequence of the process.



The rock at Devil's Tower is phonolite porphyry, an igneous (formerly molten) rock of intermediate composition with low silica content. Consequently it has little quartz in it, and it is dominated by sodium and potassium feldspars, usually with things like nepheline. Those are all silicates, but they form in preference to quartz as an expression of the chemistry of the original magma.

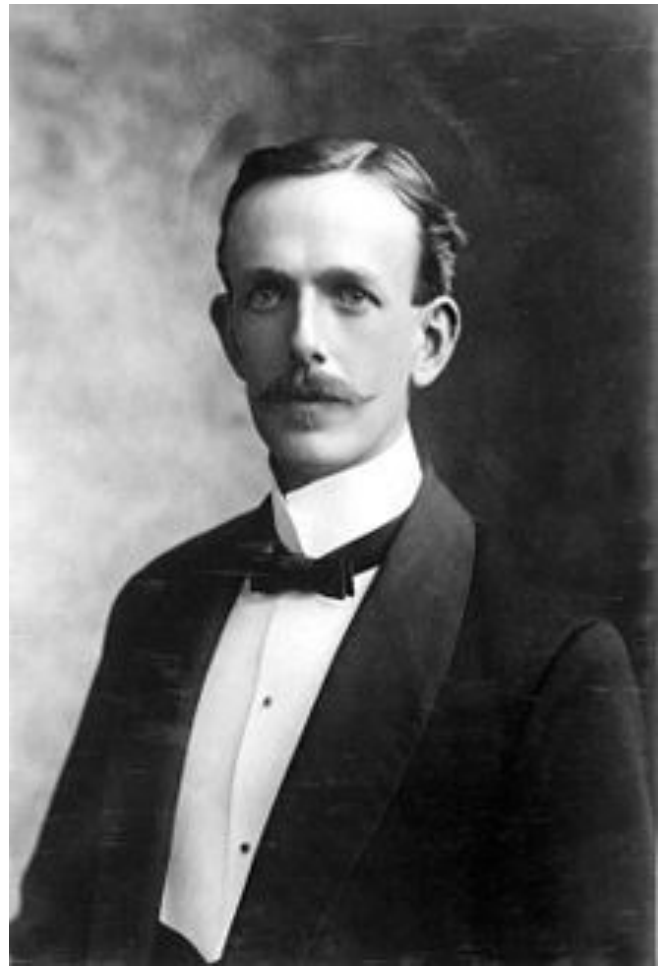
The columnar jointing in Devil's Tower is one of the best examples in the world. The joints (cracks) result from cooling of the magma, and they form long polygonal columns because that's the most efficient geometry for the shrinking, solidifying material to take. The magma body was probably essentially a volcanic neck, but it may have been part of a wider body of molten material in the subsurface. Whatever its original form, the tower is the result of erosion of surrounding, less resistant rocks; the tower was NOT forced up into open air.

Devil's Tower is one of several such intrusive bodies that formed in the northern Black Hills in South Dakota and Wyoming around 40 million years ago. The erosion that revealed the rocks in the tower is probably no more than one or two million years old or less.

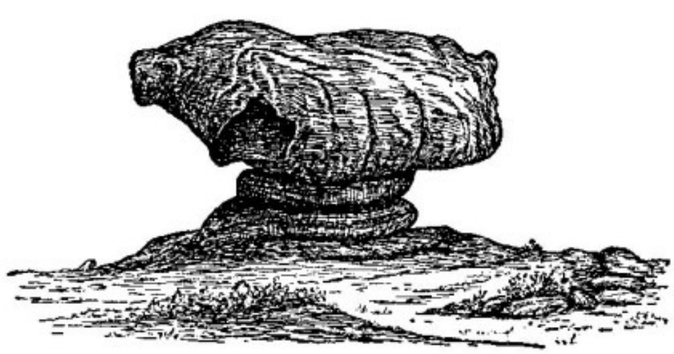
The 40-million-year-old igneous activity probably contributed the gold that has been mined at Homestake, South Dakota, the largest and deepest gold mine in North America when it closed in 2002. It produced nearly 44 million ounces of gold; compare Butte at not quite 3 million ounces of gold.

The tectonic setting that generated igneous activity in the Black Hills about 40-50 million years ago is poorly understood. The overall uplift of the Black Hills is related to the same crustal breaking that produced the Wind River, Big Horn, and other ranges in Wyoming about 50-70 million years ago (the Laramide Orogeny), and the magma that created Devil's Tower and the other intrusions might have risen through deep crustal cracks related to that, and to the deep position of the subducting crust beneath this part of the North American Craton.

I got the copy of Darton's USGS Professional Paper #32 that includes this image at the Colorado School of Mines book sale about 1993.



Nelson Horatio Darton (1865-1948)

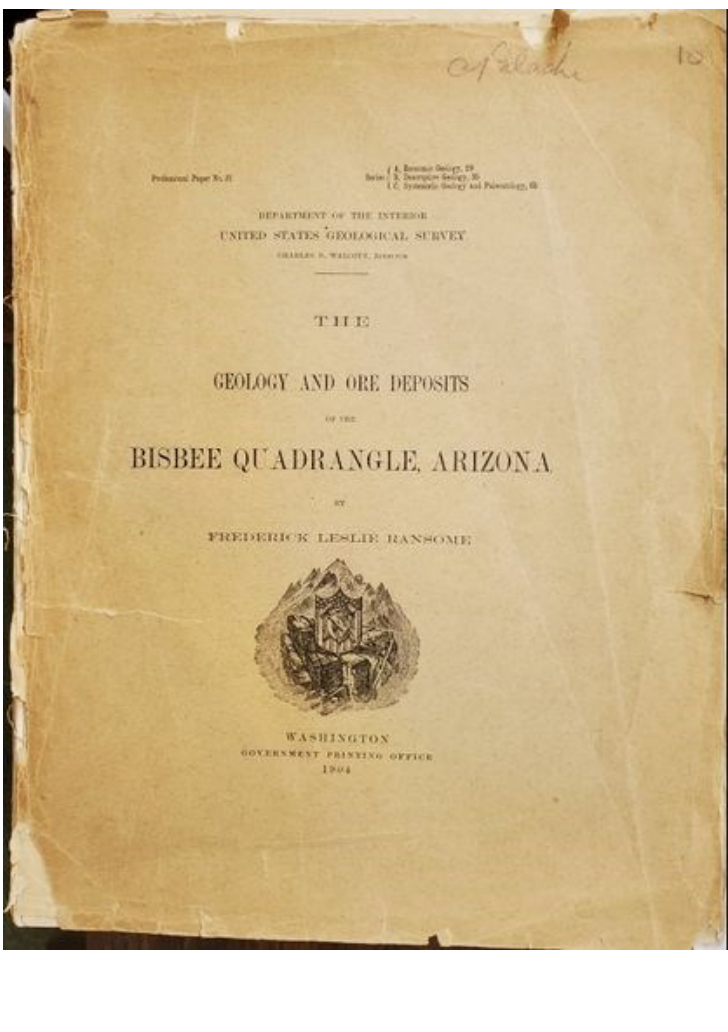


Bisbee & Charles Palache

Bisbee, Arizona, USA is renowned for its beautiful secondary copper minerals, including especially blue azurite and green malachite. Both are copper carbonates, representing the different valence states of copper. The mineralization is a porphyry copper deposit similar to that at Butte, but at Bisbee the host rocks are mostly Paleozoic (Devonian to Pennsylvanian) limestones rather than Butte's granite, and the intrusive granite that carried the minerals in solution is about 180 million years old (Jurassic) rather than 76 million years old (Late Cretaceous) as at Butte. The abundance of carbonate minerals at Bisbee versus Butte probably reflects those limestone (carbonate) host rocks.

I happen to have two copies of the 1904 USGS Professional Paper (#21) on Bisbee. Both are in pretty ratty condition from the "collectible" point of view, but they remain very cool to my eye, illustrated with colored maps, mine charts, and photos. But possibly the coolest thing about the copy whose cover is shown here is its previous owner, who penciled his name in the upper right.

Charles Palache was arguably the most influential American mineralogist and crystallographer of the 20th century, at least for the first half of it. Most of his career was at Harvard, and he led the revision of Dana's System of Mineralogy – the ultimate "bible" for mineralogy – to produce the 7th edition beginning in 1944 (Palache, Berman, and Frondel). I only have Volume 1 of that edition, 834 pages of information about elements, sulfides, sulfosalts, and oxides. That copy came to me in 1986 from my mineralogy professor Carl Beck (who likely got it new in the late 1940s; Beck did his graduate work (Masters and Ph.D.) in mineralogy at Harvard in the mid-1940s where he certainly knew Charles Palache) by way of his earlier student, Ralph Steven-



Azurite, malachite
Bisbee, Arizona
2.7 cm vertically
R. Gibson, cat. no. 10.

son, who received it from Beck in 1963. Palache dated his preface to that book April 1944, ten years before he died at age 85.

Palache was a founder and president of the Mineralogical Society of America, president of the Geological Society of America, and a member of the National Academy of Sciences. He described many minerals, and two were named for him: charlesite and palacheite, although the latter mineral was shown to be identical with botryogen, a name that was older and had precedence, so the name palacheite is not used.

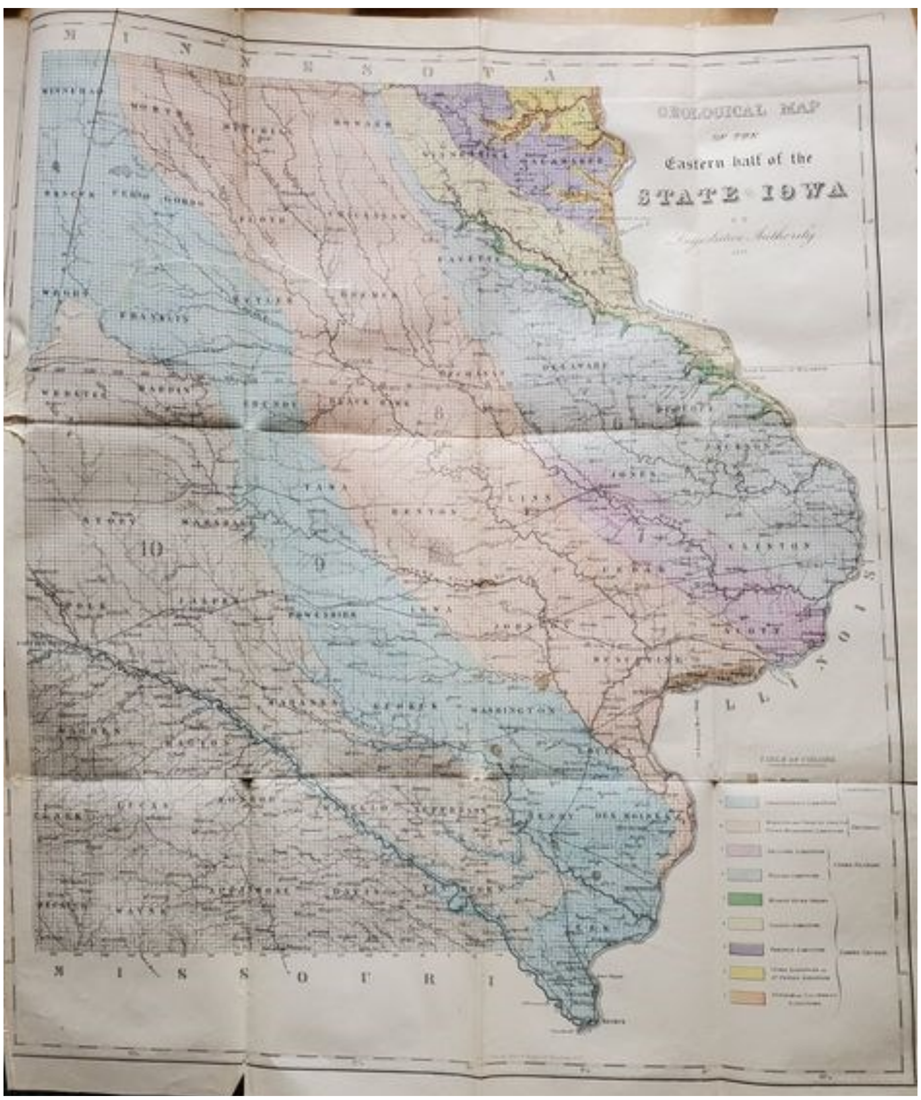
And I have Palache's copy of USGS Professional Paper #21. (My other copy was owned by Bruce Curtis, for 26 years a professor at the University of Colorado in Boulder, exploration manager for Continental Oil Co., and a president of the Rocky Mountain Association of Geologists.)

Charles Palache (1869-1954).
Photo from Franklin-Ogdensburg
Mineralogical Society.

Iowa 1858

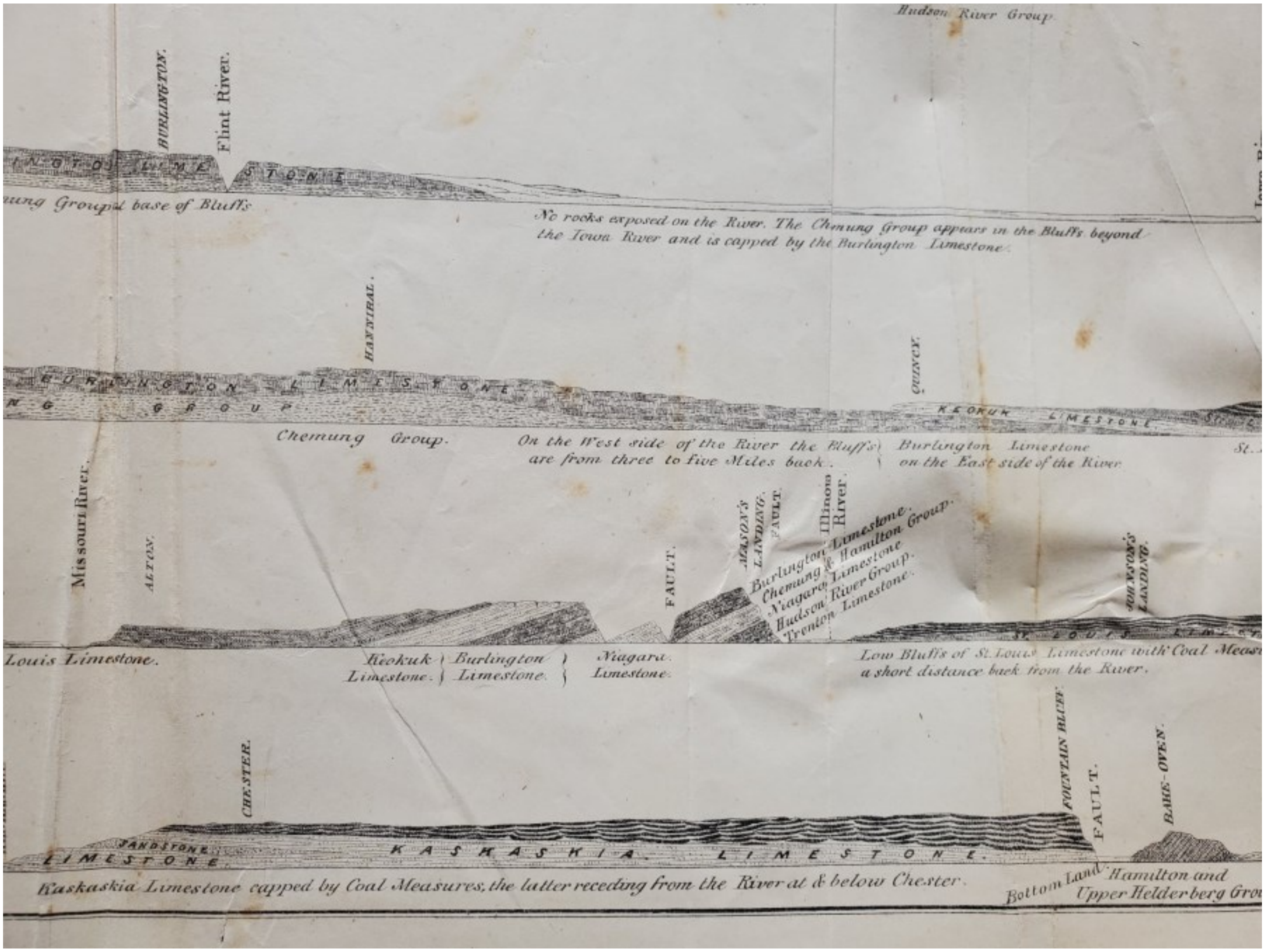
Although my interests in geology are catholic (small "c", in the original Greek sense meaning "according to the whole," often taken [not quite correctly, etymologically] to imply "universal"), I admit that the surface rocks of Iowa are less interesting to me than say, the faulted, folded, and metamorphosed Paleoproterozoic rocks of Montana's mountains.

Nonetheless that didn't stop me from getting this 1858 report by James Hall, a comprehensive report on the geology of Iowa. Especially given that it just cost $1.00, at the Colorado School of Mines book sale sometime in the 1990s. I enjoy the historical development of geology as well as the artistry of the maps and illustrations, and hey, there's also a certain satisfaction just from owning a book that was printed 163 years ago.



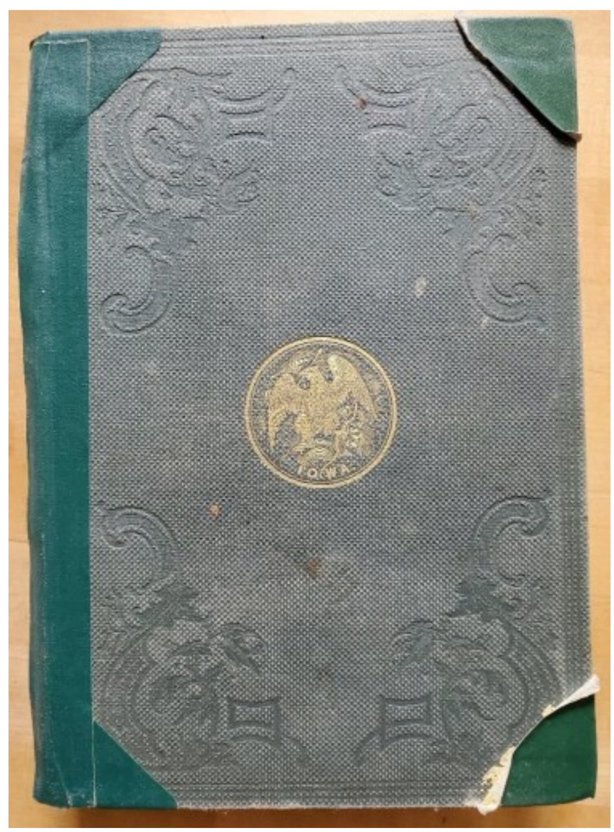
The fold-out maps and cross-sections at the back of this 500-page book are in bad shape, but you can still see the regional tilt in the mostly Paleozoic sedimentary rocks that cover most of Iowa. The strata in eastern Iowa tilt gently from older Ordovician rocks in the northeast corner of the state to younger Carboniferous rocks in the southwest. That's a regional expression of a broad basinal downwarp between high-standing Precambrian rocks in Wisconsin and Minnesota to the north and northeast, and a similar high in the Ozarks of Missouri to the south. The map is hand-painted water colors.

Those uplifts and basins (including the Michigan and Illinois Basins and the Cincinnati Arch-Nashville Dome) are part of the general warping of this region that was probably a consequence of intense collisions closer to the East Coast, where episodically for around 200 million years (from Ordovician to Permian time) island arcs, elongate slices of continental material, and finally, the main mass of Gondwana (in what is now northwest Africa) and Baltica (the core craton of northern Europe) amalgamated themselves with North America. When it was all done, North America, most of Eurasia, and Gondwana (Africa + South America + Antarctica + India + Australia) were together in Pangaea ("all earth"). The Appalachians from the US to Maritime Canada to Scotland, and the Urals in Russia are the remnants of the collisions.



James Hall (1811-1898), the primary author of this report (in which he often makes statements in the first person, since much of the work was done by him alone), is most closely connected to New York state where he was State Paleontologist at age 30 and eventually, State Geologist at age 82. Between those New York end points, Hall worked extensively in the Midwest including Michigan, and he served as the State Geologist of Iowa and then of Wisconsin. He participated in a geological expedition to the Ural Mountains of Russia when he was 85 years old, two years before his death. Hall Hall, a dormitory at Rensselaer Polytechnic Institute in Troy, New York, is named for him.

Hall's co-author, Josiah Dwight Whitney (1819-1896), was Iowa's State Chemist & Mineralogist in the 1850s, but he made his name in California where he was State Geologist from 1860 to 1875. Mt. Whitney, the highest point in the conterminous 48 states, is named for him.



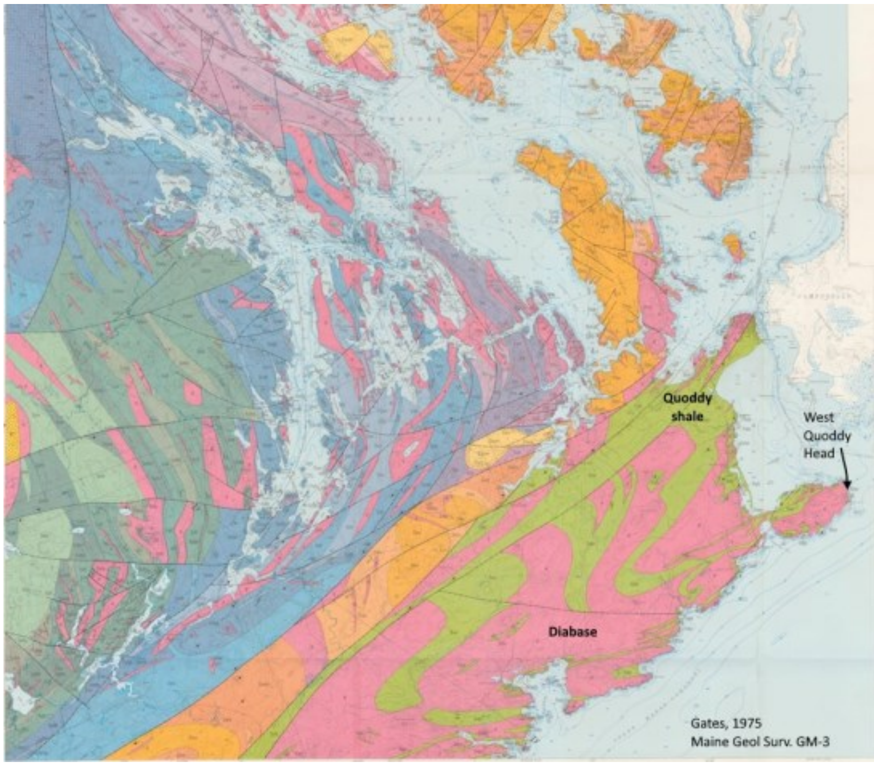
Folios: Eastport, Maine

The Folios of the US Geological Survey are big (18 x 22 inches) and were intended to provide comprehensive information about quadrangles across the US. They typically include several maps plus text, and often have big plates showing fossils or structural features. 227 Folios were published between 1894 and 1945 (but only 5 appeared after 1929). They were superseded by the GQ (Geologic Quadrangle) map series.

The 1914 Eastport (Maine) Folio by Edson Bastin and Henry Williams includes the easternmost point in the US, the ironically named West Quoddy Head. (I'm ignoring semantic arguments that would claim that some of the Aleutian Islands, west of the 180th meridian, are farthest east.) The 1914 folio shows that point just below right center in my photo of part of the geologic map, and it is mapped mostly as Silurian diabase (pink) with some bits of Silurian Quoddy Shale (purple lined pattern).

The map didn't change much in that area when it was re-mapped by Gates (1975, Maine Geol. Surv. GM-3), but a few areas of Quoddy Shale were added. On the mainland west of the Quoddy Head Peninsula, Gates identified larger areas of Quoddy Shale (in green on the 1975 map) and mapped them to imply that the intrusive diabase and gabbros were broadly sill-like (concordant with the bedding in the shale) in nature. Gabbro is the intrusive equivalent of basalt, and diabase is a rock of similar composition but a texture intermediate between coarse gabbro and fine-grained basalt.

This area of eastern Maine is usually inferred to be part of the Avalonian microcontinent, a narrow strip of continental crust that rifted from Gondwana (Africa + South America + more) in Cambrian to Ordovician time, 500 to 450 million years ago. By the Silurian Period (about 440 to 420 million years ago) Avalonia began to interact with the edge of North America and Baltica (Europe) which



were already attached to each other. Avalonia is now dismembered by the opening of the Atlantic Ocean, but parts of it lie in what are now the Avalon Peninsula of Newfoundland, Nova Scotia, New Brunswick, New England as far south as Connecticut, the Carolinas (probably), southern Ireland and southern Great Britain, and parts of northwestern Germany.

The rocks of the Quoddy Formation include a lot of deep-water shale containing graptolite fossils that date it to the Llandovery Epoch of the Silurian, 443 to 434 million years ago. There are some volcanic ash layers in the Quoddy Formation that probably record the first igneous activity related to subduction generated by the Avalonian collision. The shale probably represents a deep-sea basin on the flank of the encroaching Avalonian microcontinent along the edge of North America.

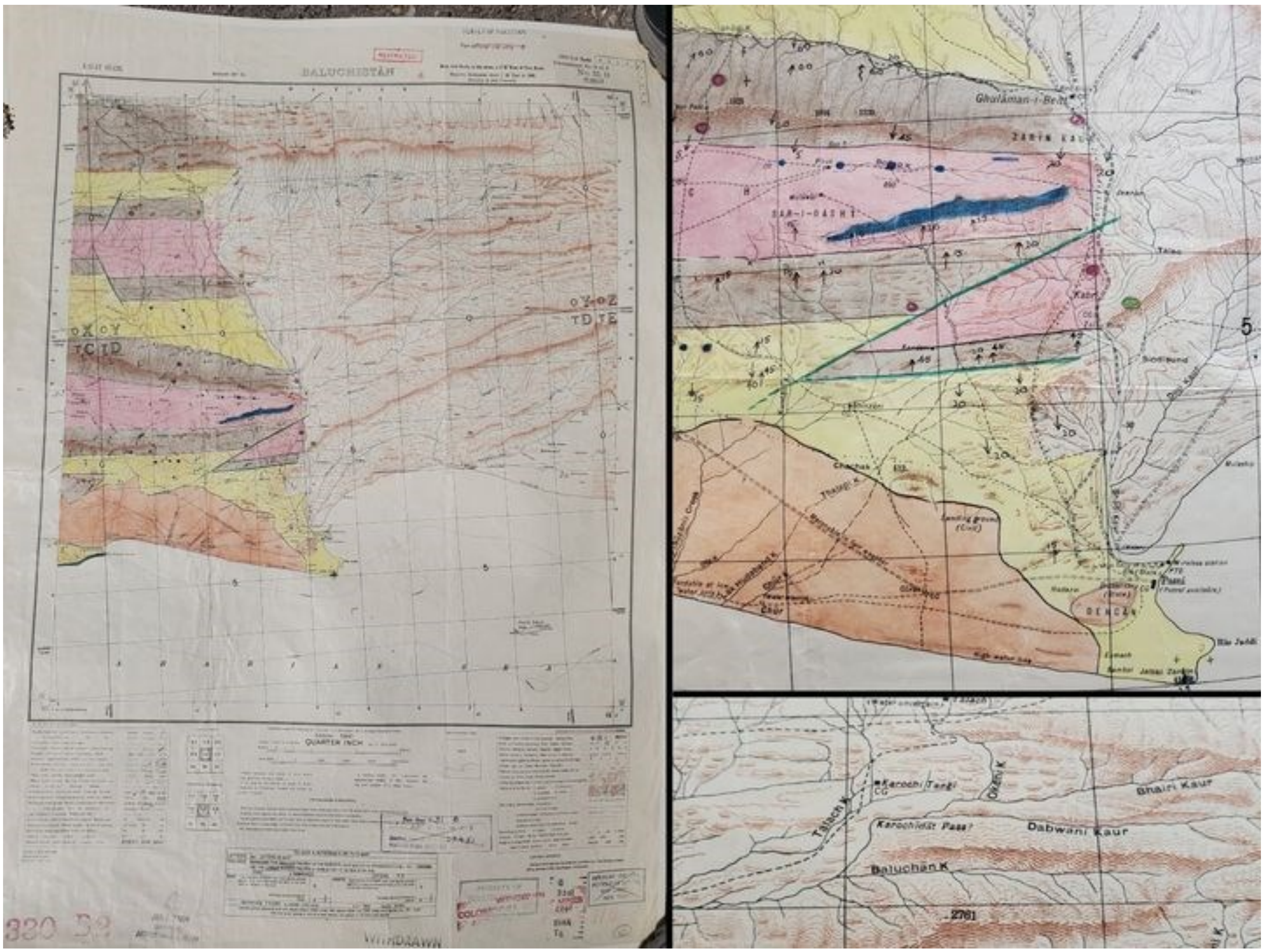
Igneous activity increased as the intensity of the collision proceeded, resulting in the diabase and gabbro intrusions (probably around 420 to 410 million years ago) into the Quoddy Formation.

The third photo here shows a page of fossils from the Eastport Folio, another 18-by-22-inch sheet.

Names containing “quoddy” derive from "Passamaquoddy," an anglicization of the Passamaquoddy word peskotomuhkati, which is the autonym (the name they use for themselves) of the Passamaquoddy First Nations people who live in Maine and New Brunswick. The name ultimately means “pollock-spearer,” an indication of the importance of the pollock fish to those people.

Baluchistan

If you know me, you know I like maps, especially old maps, especially old maps of distant areas with demonstrable interesting chains of ownership, especially old maps of distant areas with demonstrable interesting chains of ownership that were printed by some obscure printing process, especially beautiful old maps of distant areas with demonstrable interesting chains of ownership that were printed by some obscure printing process and have hand-drawn and hand-colored geology on them, especially when that map cost me ten cents.



This map of part of Kelat State, Baluchistan (now rendered “Balochistan”), at the time part of British India, was surveyed topographically in 1890-92, with bathymetry from 1874 corrected to 1926. The first edition was made in 1914, second in 1939, “interim” in 1941, and reprinted (this copy) in April 1943 by the Survey of India office in Murree (now in Pakistan). The print was zincographed, a process like lithography but using a zinc plate and complex chemical processing. You can see the resulting detail in the lower right image. Today the area covered by the map is in far southwestern Pakistan, with Pasni on the coast and Turbat in the northwest corner of the map as the main towns. “Kaur” and its abbreviation “K” mean “river” in the Balochi language. Balochi is (probably – its history is uncertain) an ancestral Indo-European language with more than 7 million native speakers today.

Sometime after the partition of India and Pakistan in August 1947, this map was stamped "Survey of Pakistan" for the national mapping and surveying agency of the new nation. On September 27, 1951, according to the imprint and handwritten information, this particular sheet was received from the Survey of Pakistan ("S. of P.") by the Geological Survey of Pakistan. The history of the sheet after that is unclear, but it was once owned by American Overseas Petroleum Limited Map Library, New York. Amoseas was a joint venture of Socal (that is, Standard Oil of California, now known as Chevron) and Texaco that later became part of Caltex Pacific, one of the international operations of the two companies in partnership, with a focus today mostly on marketing in Africa and Asia. It was also at some time in the Princeton University Library, and it had been held by but was withdrawn from the Arthur Lakes Library of the Colorado School of Mines, at whose book sale I purchased the map for the aforementioned ten cents about 1990 (along with 99 other maps at ten cents each at that particular sale).

The geologic mapping in color on the west side of the map is by hand, with annotations of orientation (strike and dip or something similar), faulting, and contacts. The colors represent various rock strata, with colored circles (red, blue, green) representing something I don't know. The colors were applied by hand (quite uniformly) using some wet medium, either watercolors or a water-based ink. Unfortunately, neither authorship nor geological explanation is included, nor do I know when it was done other than after the 1943 printing. Modern maps indicate that the strata mapped are mostly Cenozoic clastic rocks (sandstones, siltstones, shales, and mudstones) in multiple thrust faults that push those rocks to the south.

Southwest Pakistan on this map and adjacent Iran to the west comprise the Makran, a thick wedge of sedimentary rocks in imbricate thrust faults that result from the collision of Arabia on the south with a small strong buttressing microcontinent in what is now Afghanistan to the north. In some ways the Makran is like a miniature Himalaya fold-thrust belt, one that in a few tens of millions of years may be considerably more greatly uplifted as the collision between continents continues. The Persian Gulf, Strait of Hormuz, and the northwestern arm of the Arabian Sea between Oman and Pakistan will close as waterways, and the region will become even more complexly folded and faulted than it is today.

The two legend blocks below show some of the amazing detail that was included on these maps. Because the area of this map is largely desert, many of these features are not present; the legend would have been generic for probably all of British India.