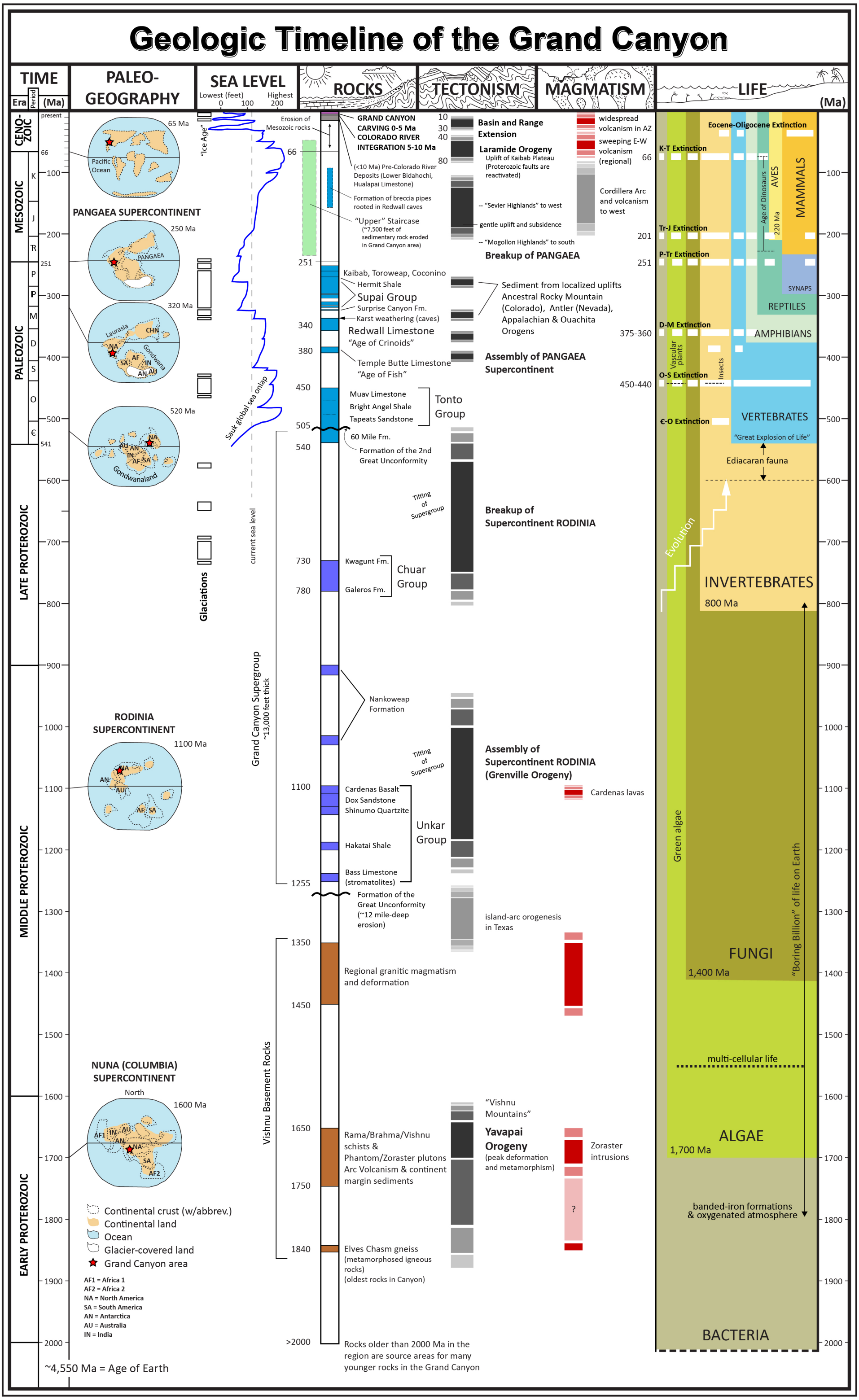
Geologic Timeline of the Grand Canyon



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HOW TO USE

This geologic timeline is designed to be used as a one-piece visual aid that illustrates the geologic history of the Grand Canyon region. The purpose of the timeline is to show relationships between land mass, sea level, erosion, deposition, tectonism, magmatism, and evolution of life unique to the Grand Canyon region. The timeline can be used while hiking in the Grand Canyon, alongside a book describing geology of the region, or while walking the Trail of Time on the South Rim of the Grand Canyon. This handout is intended for print at 11 by 17 inches, and can be folded into halves, quarters, and eighth's for stuffing into your pocket or book.

There are several ways to read the timeline. You can study an individual geologic process or feature over time or compare individual columns. You can fold the top or bottom of the handout to a point in time and see more clearly where all events line up and how they compare. For example, you can go to ~320 Ma and see that the Grand Canyon region lies near the warm equator with a fluctuating sea level. The marine Redwall Limestone is exposed to karst weathering where caves are forming. Nearby tectonism was present, free of any volcanism in the region. The world may still be recovering from a recent mass extinction 375 Ma. Invertebrate animals, plants and fungi still dominate. These relationships between geologic time and grandiose events can be especially impressive if one is sitting on the rim of the Grand Canyon or inside a cave within the Redwall Limestone.

COLUMNS: GEOLOGIC FEATURES & PROCESSES

This geologic timeline of the Grand Canyon region represents a generalized compilation of the geologic events, both global and local, as they relate to rocks and landscape we see today.

TIME - The geologic timeline is organized in millions of years or mega annum (Ma). The oldest rocks in the Grand Canyon are 1,830 Ma old (1.8 billion). To visualize this I often use a piece of paper to represent one million years, thus, the oldest rocks in the canyon are "1,830 pages thick". In a stack of papers ~4,550 pages thick (the age of the Earth), you would flip to page "1,830" to read about the formation of Elves Chasm gneiss being formed and deformed. Rocks found in and around the Canyon formed over the last ~2,000 Ma. However, the Grand Canyon itself is thought to have formed over the last 6 Ma. Geologic time is organized into Eras (Paleozoic) and Periods (Permian), nomenclature often used describe a geologic formation (e.g. Permian Kaibab Limestone).

PALEOGEOGRAPHY - The next column, Paleogeography, displays known positions of the continents to each other and general latitude. For much of its geologic history the Grand Canyon region has been uniquely positioned on the continental margin of North America and thus sensitive to changes in sea level. This margin of N.A. has also experienced mountain-building events, called orogenies, related to at least two supercontinents (Pangea and Rodinia) and many smaller tectonic "episodes".

SEA LEVEL - Sea-level change has affected most rocks in the region, either directly or indirectly. The Grand Canyon region has been situated on the margin of North America, subject to sea-level change throughout nearly its entire history. A combination of tectonic and climatic changes have a significant effect on sea level and on deposition of terrestrial and marine sediments along the continental margin. Changes in worldwide glaciation have had a significant effect on land mass, deposition of sediment, and marine and terrestrial life.

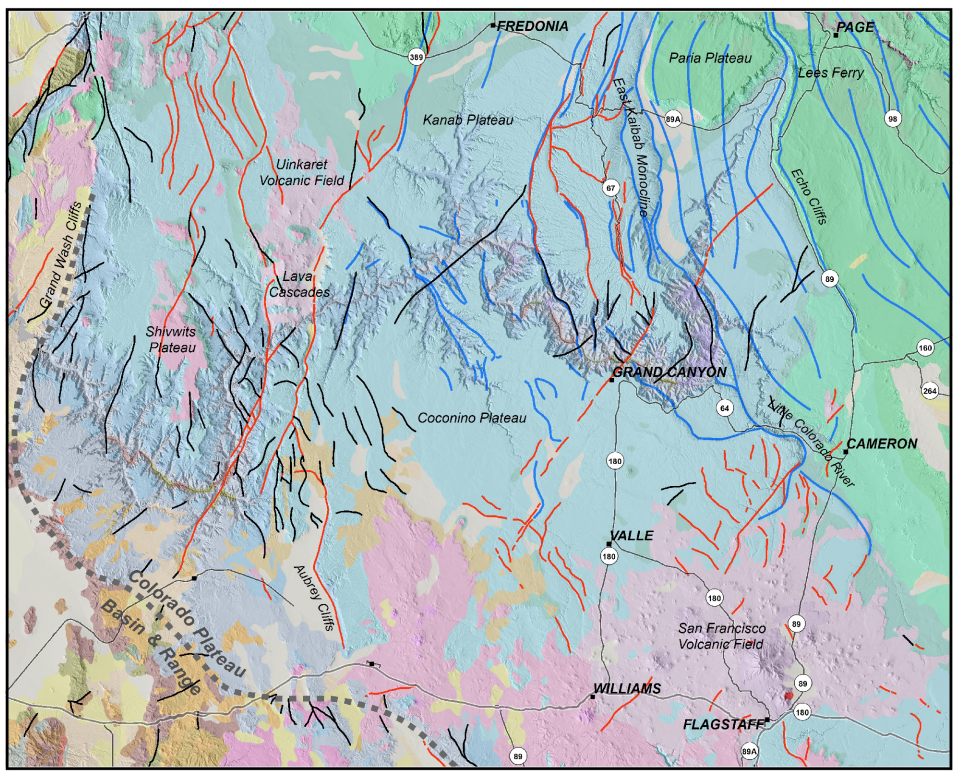
ROCKS - Rocks in the next column are rocks found in the Grand Canyon region. Separating rock formations are gaps of missing time in the rock record called unconformities (much like missing pages in a book). Nearly 70% of geologic time in the Grand Canyon region is missing or not preserved in the rocks we see. The 1st Great Unconformity (see geologic cross-section below) separates ~1,700 Ma old Proterozoic schist and granite from the overlying ~550 Ma old Cambrian Tapeats Sandstone, a gap of nearly 1,200 Ma of missing rock record, one of the iconic unconformities in the Grand Canyon and on Earth.

Major sequences of rocks in the Grand Canyon region include, from old to young, the igneous and metamorphic Vishnu/Zoroaster complex (referred to as "basement"), ~12,000 to 15,000 feet-thick Late Proterozoic sedimentary rocks of the Grand Canyon Supergroup, ~5,000 feet-thick Paleozoic sedimentary rocks, ~7,500 feet-thick Mesozoic rocks of the Grand Staircase and Black Mesa areas (missing in the Grand Canyon area), and relatively young Cenozoic rocks found in sedimentary basins and capping the landscape surround the Grand Canyon area.

TECTONISM - Tectonism refers to deformation of rocks related to plate tectonics. During tectonism, rocks can undergo forces such as uplift, burial, compression, and extension. Under such forces rocks can be cracked or jointed, tilted, faulted, and folded, and in some cases be subjected to intrusions of magma or metamorphism. A term associated with the process of deformation in a region of Earth's crust as a result of compression is called an orogeny. Orogenies typically start slowly, increase in intensity, and last for millions or 10s of millions of years. For example, the Laramide Orogeny lasted from about 80 to 40 million years and deformed rocks older than about 80 Ma over a large region of western North America. In some areas rocks were only deformed into closley-spaced, parallel cracks called joints, a "fingerprint" of the Laramide Orogeny. In other areas of the crust, rocks were faulted and folded, creating large folds called monoclines with thousands of feet of structural relief. During a tectonic event, deposition of sediment usually ceases and erosion takes over, creating an unconformity. Joints seen criss-crossing the rocks are a good example of a tectonic "braille or palimpsest" left over from an earlier tectonic event, and thus may point to an unconformity in the rock record.

MAGMATISM - Magmatism and volcanism refer to the process of molten rock, called magma, either being intruded into older rocks or magma being extruded at the surface as lava to form volcanic rocks. Magma usually navigates in the crust through faults or jointed systems. Magmatism usually occurs during tectonic events, especially on the margin of tectonic plates. However, the Grand Canyon and Colorado Plateau areas have been relatively shielded from more complex and abundant magmatism to the west and south. The most visible effects of volcanism are present in western Grand Canyon where Vulcan's Throne erupted and spilled into the Grand Canyon less than 1 Ma. Nearly 700 volcanoes define the San Francisco Volcanic Field in the Flagstaff area. From Desert View on the eastern South Rim the 1,100 Ma Cardenas lava flows form prominent cliffs near the Colorado River.

LIFE - Like paleogeography of the continents, this column of life represents important context to the significance of rocks found in the Grand Canyon. Life in these rocks span ~2,000 Ma from single- to multi-cellular life and record global "explosions" and extinctions of life. The Great Cambrian explosion or radiation of life occurred during deposition of the Cambrian Tapeats Sandstone, while the largest extinction in history follows deposition of the Kaibab Limestone at the Canyon's rim.



Generalized geologic map of the Grand Canyon region illustrating colors of major rock ages used in cross-section and timeline (blue = Paleozoic rocks, green = Mesozoic rocks, and pinks = Tertiary volcanic rocks). Dark lines are faults (red = active, black = inactive, blue = monocline folds). Proterozoic rocks not visible at this scale. Modified from Richard et al, 2000.

GEOLOGIC HISTORY

Nearly 40% of Earth's history is spanned by the age of rocks in Grand Canyon. Rocks in the Canyon are the product of collisions that assembled and brokeup two, perhaps three supercontinents, not to mention countless smaller localized tectonic "episodes". The first known orogen in the region, the Yavapai Orogeny, created voluminous volcanism related to a volcanic-arc system caught up in a collision course with another continent. Construction of North American continent was intruded by voluminous granites in the region around 1,400 Ma. By ~1,350 Ma the region was uplifted and deeply eroded, where rocks once ~12 miles deep lay exposed to erosion at the surface. By 1,255 Ma, the 1st Great Unconformity was blanketed by the Bass Limestone, the beginning of a sequence of sedimentary marine and terrestrial rocks that make up the Grand Canyon Supergroup. By ~1,200 Ma, a new supercontinent was being assembled, Rodinia, where nearly 15,000 ft of marine and terrestrial sediment accumulated in the area of Grand Canyon. Assembly of Rodinia caused periodic uplift and tilting of rocks that created many erosional unconformities. By 700 Ma, Rodinia was being broken up, faulted, tilted, and exhumed at the surface to create the 2nd Great Unconformity around 550 Ma.

By 550 Ma, global sea level and the Cambrian "explosion of life" were on the rise. North America was inundated by shallow, warm seas, and vertebrate life took hold, radiated and diversified worldwide. Over the next ~300 Ma, the Grand Canyon Paleozoic sequence would pile up nearly 5,000 ft of sand, mud, and lime that would eventually turn to stone. Supercontinent Pangaea was assembled by about 300 Ma, connected by extensive mountain belts, major river systems, and large land masses. The Paleozoic Era ("Age of the Invertebrates") would succumb to a massive extinction event at 251 Ma, the Great Permian Extinction. Evolution continued from the remaining life and initiated the beginning of the Mesozoic Era, dominate by reptiles, mammals, and birds found in rocks ~7,500 ft thick. Mesozoic rocks covered the Canyon region, but are eroded back some distance from the Grand Canyon rims.

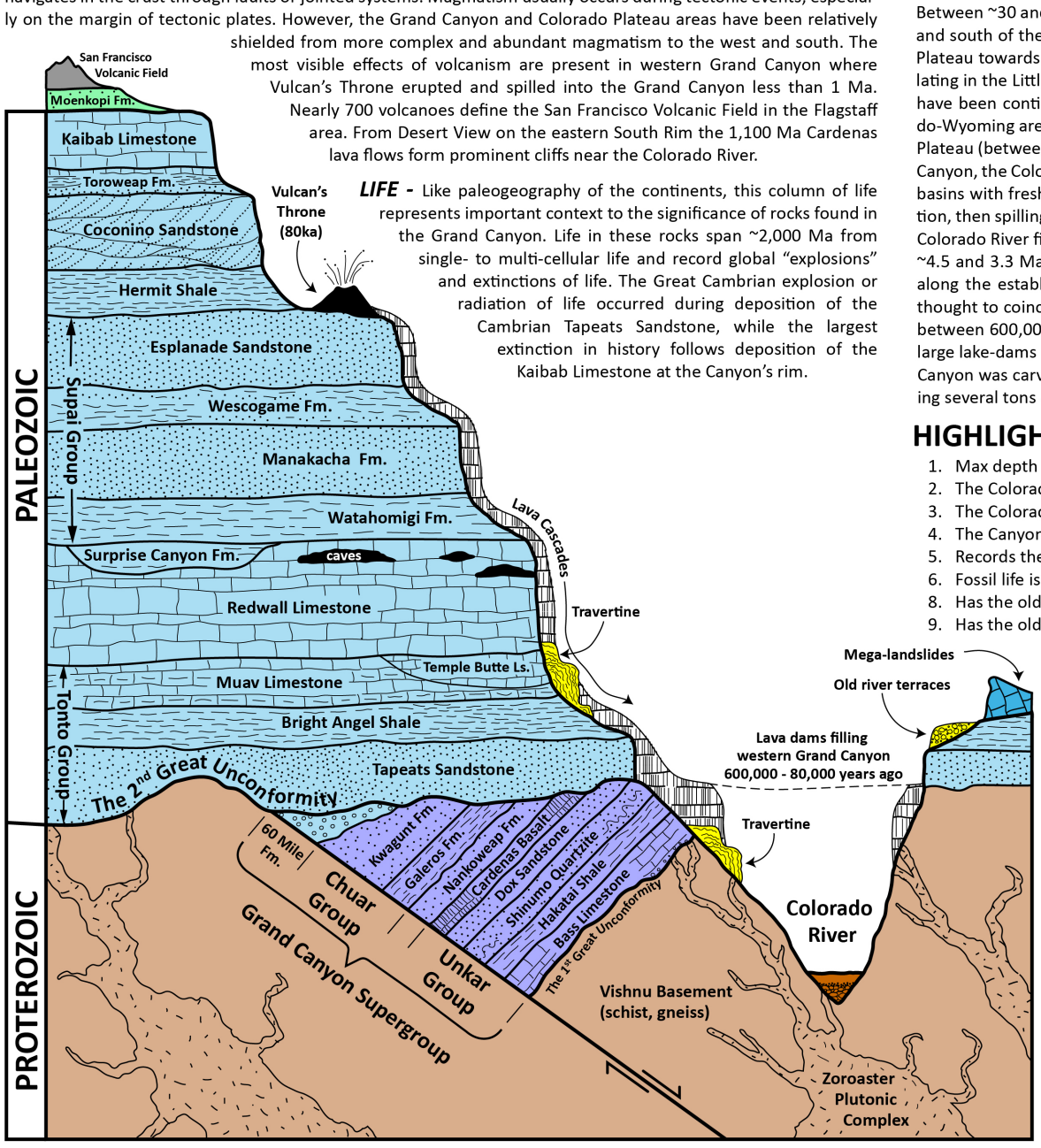
By ~80 Ma, the Grand Canyon region would be deformed again by another mountain-building orogeny, the Laramide Orogeny. At this time the Grand Canyon region was set farther back inland. Many of the same faults active during the assembly and breakup of Rodina were reactivated again during the Laramide event, displacing rock strata several 1,000 vertical feet, many in the opposite direction. Rocks older than ~80 Ma were faulted and and folded into half-folded "wrinkles" called monoclines, an iconic feature of the Colorado Plateau. The Rocky Mountains were formed during this event as well. By ~40 Ma the Laramide Orogeny had deformed (faulted and folded) and uplifted the region, and created the Colorado Plateau. To the south and southwest the "Mogollon Highlands" drained western, central, and southern Arizona towards the north and northeast onto the Plateau. The location of rivers and basins during this time remains poorly understood. Between ~30 and 15 Ma the Basin and Range tectonic event stretched and thinned the crust northwest, west, and south of the Colorado Plateau. East of Kaibab Plateau up to 1 km of Mesozoic rocks were eroded off the Plateau towards Gulf of Mexico until ~16 Ma, after which the Bidahochi Formation sediment began accumulating in the Little Colorado closed basin. Passive sedimentation in low-lying basins on the Plateau appears to have been continuous between ~20 to 10 Ma when the Colorado River started its course from the Colorado-Wyoming area towards lower land. The mechanism by which the Colorado River made it across the Kaibab Plateau (between the North and South Rim) remains controversial and extensively studied. West of the Grand Canyon, the Colorado River arrived with a relatively mature Colorado River drainage system, filling large desert basins with fresh water that formed saline terrestrial lakes fed by a river delta, depositing the Bouse Formation, then spilling over into each basin along its path between Grand Wash Cliffs and the Gulf of California. The Colorado River finally reached the Pacific Ocean in the northern Gulf of California by ~4.8 to 4.6 Ma. Between ~4.5 and 3.3 Ma, a thick sequence of river sand and gravel, referred to as the Bullhead Alluvium, aggraded along the established course of the Colorado River between Grand Wash Cliffs and the Gulf of California, thought to coincide with carving and erosion of the Grand Canyon. Some faults conveyed lava to the surface between 600,000 and 80,000 years ago, filling Grand Canyon with thousands of vertical feet of lava creating large lake-dams behind them. Several mega-landslides slid into river and some side canyons after much of the Canyon was carved. The Grand Canyon continues to issue many fresh and carbonated springs, some depositing several tons of travertine rock every day.

HIGHLIGHTS

1. Max depth of Canyon is 6,000 feet, averages ~4,000 ft deep over 277 miles, and ranges 10-18 mi wide.
2. The Colorado Plateau is one of the highest plateaus in the world, averaging ~7,000 ft above sea level.
3. The Colorado River is a drainage anomaly that carved across the Kaibab Plateau.
4. The Canyon includes 3 of the 4 eras of geologic time recorded in its rocks (40% of Earth's history).
5. Records the Great Explosion of Life ~540 Ma and the greatest extinction on Earth ~251 Ma.
6. Fossil life is found in 21 of 26 rock formations in the Canyon, spanning 1.2 billion years (1,200 Ma).
8. Has the oldest limestone in North America, the Bass Limestone, 1,255 Ma.
9. Has the oldest rock in the Southwest, the Elves Chasm gneiss, dated at 1,840 Ma.

Abbreviations

Ma = millions of years, ka = thousand years, ~ = approximately, mi = miles, m = meters.



Generalized geologic cross-section of the Grand Canyon. Colors are similar to Figure 1 and timeline on reverse side.

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Supplemental document with information used to create this timeline are found at repository.azgs.az.gov

This publication coincides with the 100th anniversary of the Grand Canyon National Park, created in 1919, and the 150th anniversary of geologist John Wesley Powell's 1869 expedition on the Colorado River through the Grand Canyon.