Unconformities and Deep Time in the Jemez

This view is well known to residents of San Diego Canyon, as it looms above the village of Jemez Springs below Cat Mesa. This is a geological "unconformity," where 1.25- to 1.61-million-year-old Bandelier Tuff from great explosions of the Valles Caldera overlies the orange and red 272- to 300-million-year-old Yeso and Abo sandstone/mudstone. In contrast with the missing one billion+ years in the Great Unconformity, a mere 270 million years of sediments are missing here.

If you study history you know that there are gaps. The record of the past is almost always incomplete in detail and in time. Historical geologists call gaps in the stratigraphic record "unconformities." The first rule of geology is that younger rocks sit on top of older rocks. But this doesn't guarantee that all of the rock layers that formed in the past will be present in any given exposure, such as in the descending walls of the Grand Canyon, or in the rising west face of the Sandia Mountains.

In fact, there is an enormous gap in these rock exposures that is known as the "Great Unconformity." It is near-global in extent.[1] The big gap in the Grand Canyon occurs just above the 1.84 billion-year-old basement rocks exposed along the Colorado River. These are among the oldest rocks visible on Earth. They were the foundations of mountains that completely eroded away over vast stretches of time. The next layer above them, the

[1] A very informative summary of Sandia Mountains and New Mexico geology, including discussion and illustrations of the Great unconformity, is in Dirk Van Hart's 2023 book "New Mexico's Magnificent Sandia Mountain, The Complete Geological Story," Sunstone Press, Santa Fe, 453 pgs.

Tapeats Sandstone, was deposited along coastlines of shallow seas 508 million years ago. So, what happened to the missing 1.33 billion years of rock layers in between?

No one knows for sure, but the inevitable conclusion is that the ancient mountains were eroded away by the slow-but-steady forces of rain, snow, ice, and wind over eons of time.[2] What happened to all of the eroded sediments is also a continuing mystery, but some may have been recycled by the conveyor belts of tectonic plates subducting into the magmatic crust. We are left with over a billion years of lost time, the Great Unconformity.

In contrast to the Grand Canyon where the big gap is near the bottom, in the Sandia Mountains it is near the top. The upper 500 feet or so of the Sandias is capped by 300 to 315 million-year-old Madera Limestone and Sandia Formation mudstone.[3] This ancient rock was formed by coral reefs and the accumulated shells of countless marine animals when an inland sea existed in what is now the Southwest. The limestone and mudstone sit on top of the 1.45 billion-year-old Sandia Granite. So, from Albuquerque and the surrounding landscape, you can see the Great Unconformity any time you want to just by looking up at Sandia Crest.

The great pluton of Precambrian granite and Paleozoic limestone of the Sandias was pushed up and tilted away from the Rio Grande Rift, a great spreading fissure in the continent. The emergence of ancient foundation rocks along fault lines occurred again in the Jemez Mountains.[4] Here, the Madera limestone shows up in San Diego Canyon, beginning about at the San José de los Jémez Mission (Jemez Historic Site), at the north end of Jemez Springs. The fossil beds there up to the Forest Service ranger station are among

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[2] Van Hart, ibid, page 116, says that "continental glaciations of global scale between 717 and 635 Ma [million years ago] deeply scoured the continental surfaces, lowering their elevation." This is potentially the mechanism of removal of the great mountain masses that sat upon the basement rocks that we see today where they emerge. Further, Van Hart says this erosion by massive glaciation created lower elevations which served as "accommodation space" on the continents where sediments accumulated over subsequent eons.

[3] Van Hart, ibid, pg. 114, notes that "unconformity" is the general geological term, and there are multiple different types of unconformities in geological strata. The Great Unconformity in the Grand Canyon, Sandias, and the Jemez is technically a "disconformity," i.e., a time gap, or hiatus, between layered rocks of significantly different ages <u>and</u> types (sedimentary atop igneous/metamorphic in these cases).

[4] Van Hart, ibid, pgs. 158-163, says that both the Jemez and Sandia plutons of Precambrian rock emerge at what is called "wrench-faults," i.e., two parallel faults moving in opposite directions which allow the less dense rock of the pluton to "pop up" between them. In the Jemez case, these are semi-parallel faults that are both part of the NE-SW-oriented Jemez Fault. He also says that it is possible that the Jemez and Sandia exposures of basement rocks have a common origin in a larger pluton that rose up from the mantle.

the richest in New Mexico. Crinoids, brachiopods, clams, bryozoans, and other mysterious fossils are embedded in the stone walls of the old mission church and scattered on the nearby slopes.

Just upstream of the ranger station and the fossil beds, a big block of reddish Precambrian rock juts up from the canyon floor, with the limestone and mudstone on top. The Jemez River cut through these rocks over the past 1 million years or so, forming a box canyon with Soda Dam at the northern end. The reason that 1.6 billion-year-old basement granite (gneiss)[5] shows up here is that the Jemez Fault, a major crack in the Earth extending down from the Valles Caldera, cuts diagonally across San Diego Canyon right at this point. Hot, mineral-laden waters descending from the Valles Caldera emerge here along the Fault to form Soda Dam. The Jemez Fault continues west and crosses the Rio Guadalupe drainage near the box canyon there (along with the Sierrita Fault). In the 1920s, railroad tunnels were blasted through the same ancient basement rocks so that loggers could access the timber up the Guadalupe and its tributaries.

Every time you drive up state road 4 past Soda Dam, or up through the tunnels in Guadalupe Box, you travel over the Great Unconformity, the 1.3 billion years of missing rock-time. A notable location of the Great Unconformity is right at the waterfall of Soda Dam as it comes through the eastern end. The waterfall flows over Precambrian rock, and the travertine domes of Soda Dam above it are probably less than 1,000 years old.

You may be wondering how we know these rocks are as old as they are. The answer is that geologists have used what is called “radiometric dating” to estimate the time since they were formed. Carbon-14 dating (C-14 or radiocarbon dating) is perhaps the best-known example of this method for dating long-dead plant or animal material, like wood or bones.

The basic idea comes from the knowledge that isotopes of some elements are “unstable,” or radioactive, and over time they lose electrons at a fixed rate from their atoms. When organisms are alive they have the same amount of radioactive C-14 isotopes in their tissues as in the atmosphere. After they die, no more C-14 is added, and it decays into nitrogen-14. So, the longer something has been dead, the lower the amount of carbon-14 is present relative to the stable isotopes of carbon 13 and 12. By measuring the ratios of

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[5] To my knowledge, the Precambrian rocks exposed in the Soda Dam Box have not been dated with radiometric methods yet. In the Geologic Map of Jemez Springs 7.5 – minute quadrangle, by Shari Kelly, Kirt A. Kempter, Fraser Goff, Mike Rampey, Bob Osburn, and Charles A. Ferguson, May 2003, New Mexico Bureau of Geology and Mineral Resources, they say that “Although no age data is available, the [Proterozoic granitic gneiss] is likely a 1.6 to 1.7 Ga [billion year old] rock since it is foliated.” The Proterozoic eon is the latter part of the Precambrian.

these three isotopes, and using the known decay rate of C-14, scientists can estimate how long ago the organism died.[6]

In the case of radiometric dating of rocks, isotopes of uranium, lead, potassium, argon, thorium, and other elements are commonly used. The amount of radioactive isotopes of these elements in rocks is set at the time they formed, and then it decreases at a constant rate afterwards, providing a clock-like mechanism for dating. These dating methods using unstable and stable isotope measurements and decay rates have also been checked against other dating methods. For example, ancient tree rings have been used to cross-check and calibrate radiocarbon dating.

Most trees form one ring each year, and also the ring widths correspond to climate variations. So, it is possible to count the tree rings and match ring-width patterns among trees to determine each ring's exact calendar year of formation. Carbon isotopes can then be measured in the exactly-dated tree rings, and then the two dating methods can be compared. One of the tests that established the accuracy of the radiocarbon dating method compared C-14 dating estimates with exactly dated, ancient giant sequoia tree rings, leading to a Nobel Prize in chemistry awarded to the discoverer (Willard Libby) in 1960.[7]

Finally, here's an interesting sidenote regarding both the Great Unconformity and ancient trees in New Mexico. Some years ago, my colleagues and I collected tree-ring samples from trees in the Sandias to study the history of temperature and rainfall variations.[8] We took pencil-sized core samples from some very gnarled and stunted limber

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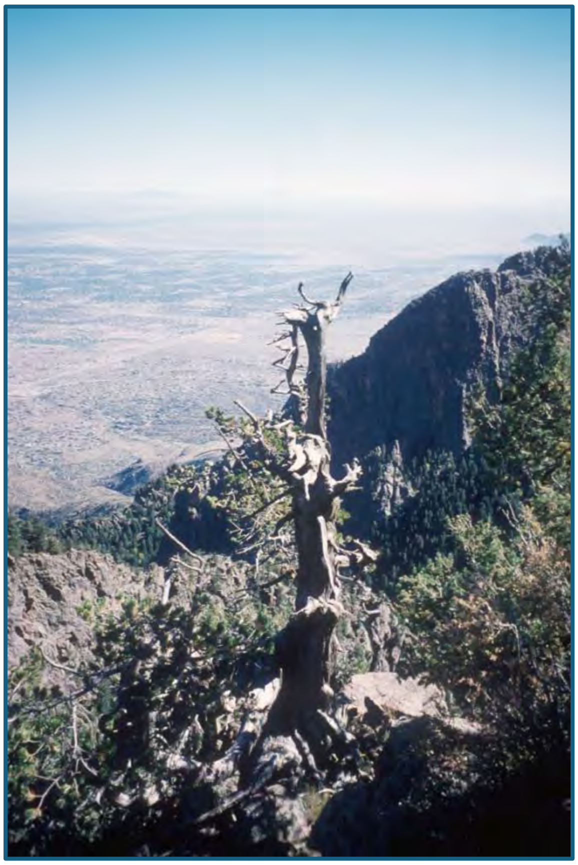
[6] The half-life of Carbon-14 is approximately 5,730 years. This means that it takes that long for one-half of the original amount of the unstable C-14 in bone or wood, etc., to decay into nitrogen-14. After about 50,000 years since the organism died (and stopped incorporating more C-14 in its tissues), there is virtually zero C-14 left. This puts a time limit on the usefulness of radiocarbon dating to periods less than 50,000 years. In comparison, the unstable potassium 40 isotope has a half-life of about 1.25 billion years. And Uranium-238 has a half-life of about 4.5 billion years. Hence, ratios of these isotopes and their decay products (lead, calcium, and argon isotopes), are useful for dating rocks that are up to billions of years old.

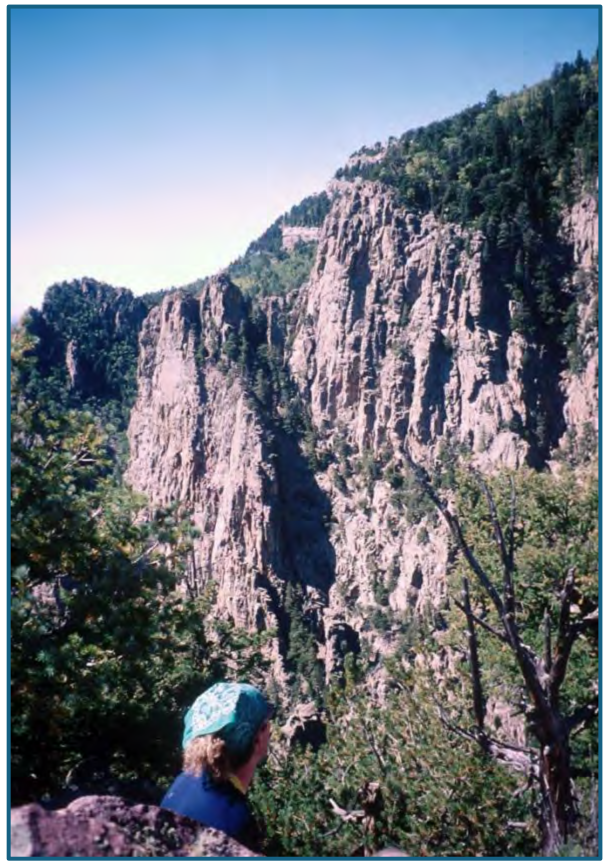
[7] Willard Libby's biography: https://en.wikipedia.org/wiki/Willard_Libby ; Exactly dated giant sequoia tree rings were provided by the Laboratory of Tree-Ring Research (LTRR), University of Arizona in the late 1940s to Libby for his testing of the radiocarbon dating technique. These tree-ring dated wood samples were part of what Libby called the "Curve of Knowns," which established the accuracy of radiocarbon dating. In subsequent decades, LTRR provided more that 9,000 years of exactly-dated bristlecone pine tree-ring samples for comparison and calibration of radiocarbon dating.

[8] In Figure 16 of a paper published in the Journal of Climate in 1998, we showed a time series of the millennia-long tree-ring growth of the Sandia Crest trees, and from five other sites in New Mexico and Arizona. Most of these sites are above 9,000 feet elevation. The time series extending to 1993

pine trees growing on the Sandia Granite, just below the Madera limestone and Sandia Formation mudstone. These trees are located spatially, but not temporally, within the Great Unconformity.

It turns out, they are among the oldest known living trees in New Mexico. We obtained a core sample from one tree that was hollow in the center, but there were more than 1,000 tree rings on the core sample. Undoubtedly, many millennium-plus-aged trees are growing near the summit of the Sandias. Of course, a millennium is a long time from our human perspective, but it is very short compared to the more than one million millenniums of the Great Unconformity.





Millennia-aged limber pine (*Pinus flexilis*) at left, in the Sandia Mountains above Albuquerque, growing on the talus slope just above the 1.45 billion-year-old Sandia Granite. Other limber pines are visible on the right, with the Sandia Granite and Madera Limestone cliffs visible at the center and upper right.

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show that the most recent decade had much higher-than-average ring growth. We speculated that warming temperatures may have favored growth of trees at these sites where summer season length and warmth is important to ring-width growth. Swetnam, T.W., and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate* 11:3128-3147.