New Mexico EARTH MATTERS

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MYSTERIES OF THE GREAT UNCONFORMITY, A JOURNEY IN DEEP GEOLOGIC TIME

One of the more challenging aspects of the Earth Sciences, for non-specialists and specialists alike, is the concept of deep time—that Earth history spans immense periods of time. As a species, we humans are accustomed to time in the near term, measured as days, months, years, lifetimes (centuries), and millennia (history/ archeology). We have little personal connection to time periods measured in millions or billions of years. For many, the concept of deep time is too abstract to comprehend. As we ponder the vastness of time, it is helpful to consider a simple exercise to illustrate very large numbers. As children we learned to count to one hundred. At one number per second, this exercise took less than 2 minutes. However, counting to one million would take over 277 hours, or over 11 days! No sleeping or eating, just counting. One billion is a 1,000 times larger than one million, far beyond our ability to count. To count to one billion would take over 11,574 days, almost 32 years!

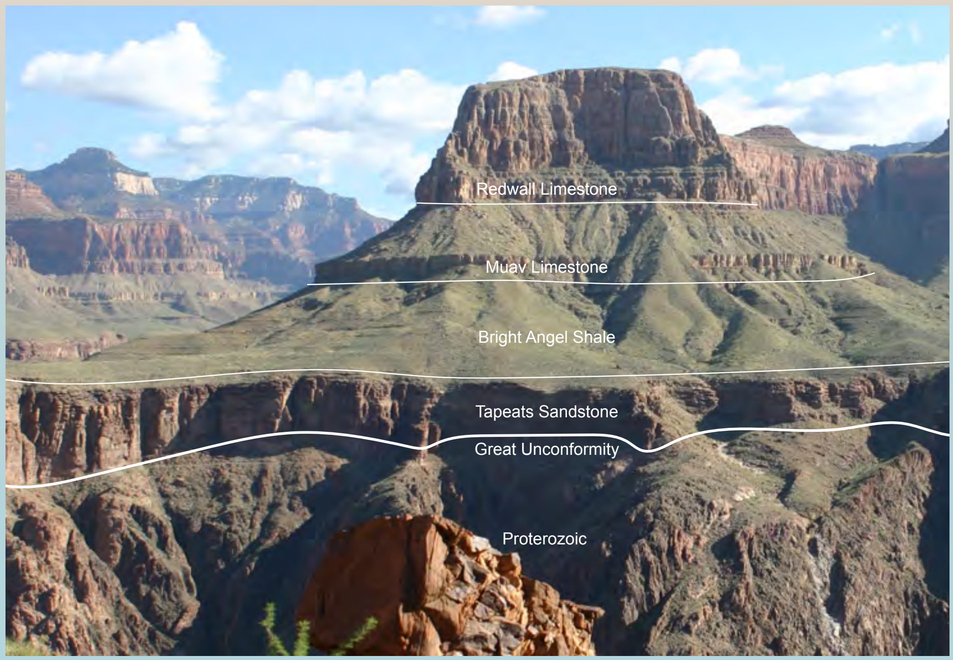


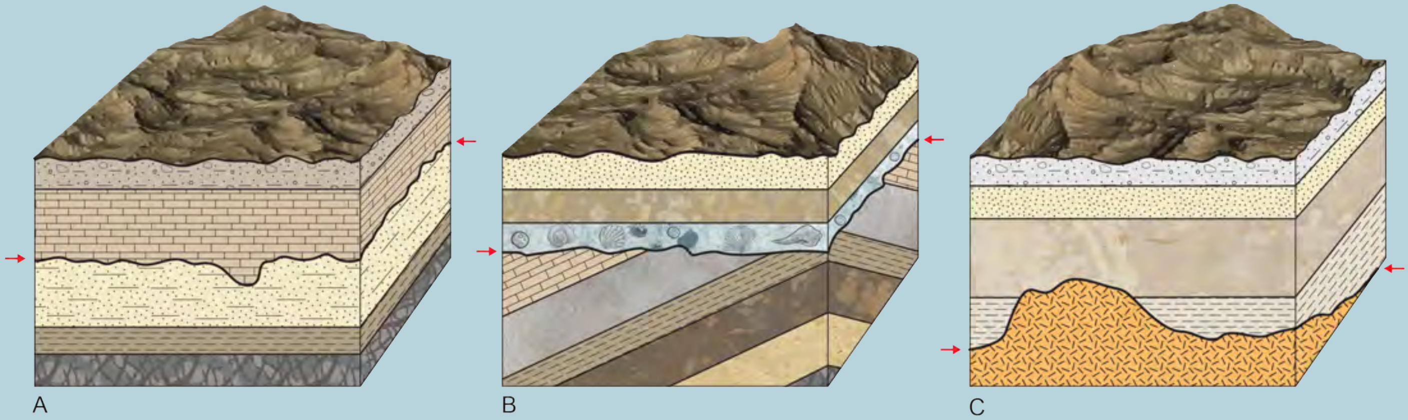
Photo of the Great Unconformity of Grand Canyon. Here, 500 million-year-old sedimentary strata of Cambrian age were deposited on 1,750 million-year-old metamorphic rock of the Granite Gorge, representing a 1,250 million-year break in the rock record. Photo by Peter Scholle.

As impossibly large as these numbers seem to be, Earth itself has been reliably dated at about 4.56 billion years old. This age was determined by dating the best-known material from which our planet formed, chondritic meteorites. This material formed as the inner planets coalesced during the formation of the early solar system. The oldest dates derived from Earth minerals are a bit younger than these meteorites. Because Earth is a dynamic planet that is constantly recycling crust through plate tectonics, the rock record becomes sparser the farther back in time one explores. In order to better understand Earth's geologic history and our place in that history, our task as geologists is to scour the planet and look for every available geologic record. Because our society lives and thrives by using geologic materials, the more we understand this history the better we will understand Earth's resources, their inherent limitations, and environmental consequences of their extraction and use.

Geologic puzzles and missing time

As geologists, we read the history of planet Earth as written in rocks, but that history is written in thousands of "books" that are scattered around the globe. And, within any single "book," there are missing "pages," even "chapters." The missing pages and chapters represent periods of geologic time that are not recorded in each regional storyline. Each bit of missing time represents a gap in the geologic history, which geologists call an unconformity. How can we unravel the events that may have occurred within each missing period of time? You might consult another book from another library or from another part of the globe. This other book may describe the same story but from another character's point of view. The story is clearly the same, but the descriptions are a bit different, and the gaps in the story occur over different intervals. If we're clever, and with the benefit of international scientific collaboration, we can combine the two (or more) books to create a complete story.

If you have traveled much around New Mexico, the region, or across the globe, you have seen excellent outcrops that



Block diagrams illustrating the three main types of regional scale unconformities. Each unconformity, indicated by red arrows, represents a break in the rock record where time is unrepresented. Each type of unconformity requires a different set of geologic events to explain the resulting geologic relationships, although erosion is a common thread.

record Earth's rich geologic history, but you may not have known how the story from place to place fits into a coherent record of Earth's geologic past. This is the job for geologists—to understand the geology of Earth from region to region, and correlate each regional history into a cohesive global geologic history. The students and professionals of the geological sciences have been unravelling this mystery for over 100 years, and each generation of scientists brings new techniques and insights into play.

Armed with an understanding of deep time, and using the natural radioactive decay of some key minerals, we can now explore geologic mysteries in our own backyard. Our first task is to get acquainted with unconformities—those missing sections in geologic time—and learn how to recognize them in the real world. Because unconformities most commonly represent a period of erosion, one might look for evidence of erosion.

There are three common types of regional-scale unconformities; all represent erosional surfaces marking the contact between rocks below and above the contact, as illustrated in the block diagrams above. The most common, is the disconformity (block A above), which is found between layered sedimentary rocks. The contact can be recognized by an abrupt change in the composition, age, or depositional setting of the layered sedimentary rocks across the unconformable boundary, although the strata may appear continuous. On the block diagram, the boundary is marked by a heavy black line that represents an irregular, eroded contact between two different sedimentary rocks. After deposition of the lower/older layers, there was a period of non-deposition and/or erosion (perhaps from a drop in sea level) that was followed by deposition of another sedimentary unit (perhaps due to rising seas). Disconformities may be difficult to identify, especially if there is little evidence for erosion at the contact. If so, other evidence must be brought to bear to verify the gap in the rock record. Before geologists could directly date geologic material using radiometric dating techniques, we had to rely on the succession of fossils in the rock layers. An abrupt change in fossil assemblages between two layers would indicate that some period of time was missing (a disconformity!).

Real examples of disconformities are abundant within the state, but may seem unremarkable without the context of geologic time. Most any stack of layered sedimentary rocks in New Mexico is likely to contain one or more disconformities. For instance, driving north along I-25 approaching Las Vegas, NM, several noteworthy disconformities are exposed among the steeply tilted and colorful sedimentary rock layers cut by the highway. Within this interval, Permian Period limestone, sandstone, and mudstone that formed in an ocean 300–251 million years ago are overlain by Triassic Period sandstones and mudstones that were deposited by ancient river systems at 251–200 million years ago. In this case, the contact between them is a disconformity representing about 30 million years of missing time. The ancient river deposits are in turn overlain by Cretaceous Period sandstones and mudstones that represent another period of ocean inundation between 145 and 66 million years ago and another disconformable gap of about 40 million years. The same sequences of rocks and their accompanying unconformities are also exposed in other parts of the state, such as in the bluffs and mesas along the I-40 corridor from the Rio Puerco drainage west of Albuquerque to Grants.

The next type of unconformity, called an angular unconformity, is easily recognizable in the field (block B above). The lower strata are typically tilted more steeply than the overlying strata. Special geologic circumstances are needed to create an angular unconformity. After a package of layered sedimentary or volcanic rocks is deposited, the rocks are deformed by faulting or folding to tilt the layered bedrock. After tilting of the strata, the rocks then undergo erosion that bevels or planes off exposed portions of the deformed bedrock. The eroded surface is then covered by new layered rock deposits. The time gap represented by angular unconformities can span short or long periods of geologic time, but the exciting implication is that there has been a time of deformation or upheaval recorded in the rock record by the tilting and beveling of the lower layers.

In New Mexico, the Rio Grande follows the Rio Grande rift, which represents a relatively young (less than 30 million years old) chapter in the geologic story of New Mexico, and represents a zone of faulting due to thinning of the continental crust (see the summer, 2012 Earth Matters for more details). Along the axis of the rift, from southern Colorado to the Texas–Mexico border, basins formed by progressive spreading of the crust and consequent faulting over millions of years and filling of the rift basins by sedimentary rocks of the Santa Fe Group. In such a complex geologic setting where faulting,

San Lorenzo Canyon near Socorro, New Mexico showing an angular unconformity between older, tilted strata and younger near-horizontal strata. The older rocks must have been tilted by faulting and beveled by erosion prior to deposition of the younger rocks. Photo by Peter Scholle..

tilting, and continued deposition are happening in close association, angular unconformities are common. North of Socorro, near San Lorenzo Canyon, a spectacular angular unconformity records part of this rifting history. At this locality, 10–7 million-year-old sedimentary rocks of sandstone, mudstone, and conglomerates are preserved as tilted beds that are unconformably overlain by nearly horizontal 0.2 million-year-old conglomerates and sandstones (photo above). At this locality, over a relatively brief geologic interval, initially flat-lying sedimentary rocks were uplifted, tilted by faulting, and eroded. The eroded rocks were then buried by younger deposits of the rift. By carefully studying such features, and by applying high-precision dating techniques to the rocks, geologists have pieced together the geologic history of deposition, deformation, and erosion through time in the Rio Grande rift.

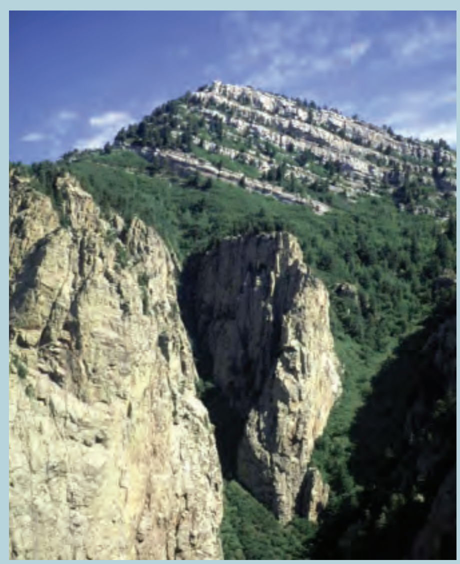
The final type of unconformity, the most recognizable of the three, is called a nonconformity, in which sedimentary rocks directly overlie crystalline metamorphic or igneous rocks that were formed deep within Earth's crust (block C on page 2). These unconformities mark a more substantial time break in the rock record as rocks that formed deep within Earth's crust (some 10–20 kilometers deep in the Southwest) must have been exhumed to the surface by deformation and uplift, and then beveled by erosion before sedimentary rocks could be deposited on them.

Nonconformities are plentiful in New Mexico, and happen to be exposed along much of the Rio Grande rift. These nonconformities were not created by faulting along the Rio Grande rift, as the unconformities themselves are much older than the rift. Instead, these features have only been exposed by the deformation and erosion of the rift-flank uplifts and by the general erosion of the Southwestern U.S. in the last 30 million years. New Mexico's most iconic nonconformity is easily visible at the top of the Sandia Mountains, east of Albuquerque (photo bottom right). In fact, it's responsible for the namesake of the mountain range. Sandia means "watermelon" in Spanish. The green, tree-covered rind of the watermelon is the thin layer of sedimentary rock that forms the crest of the Sandia Mountains, whereas the pulp of the watermelon is the pink Sandia Granite. The contact between the granite and the limestone is a spectacular nonconformity. By determining the ages of these two rocks using the fossil assemblages of the sedimentary rocks and direct dating of the Sandia Granite, we now know the time gap represented by this unconformity. In this case, the amount of time is truly staggering as the sedimentary rocks are about 300 million years old and the underlying Sandia Granite is 1,450 million years old. The nonconformity thus represents a 1,100 million (1.1 billion) year break—equivalent to nearly one quarter of Earth history! So profound a geologic feature is this, that even the first geologists of the late 19th century, like John Wesley Powell, recognized it over much of the western U.S. It is believed that Powell was the first to coin the phrase 'Great Unconformity' for this nonconformity, though he had no idea about the magnitude of missing time, or the age of planet Earth.

The Great Unconformity

An unconformity of this scale is generally recognizable over vast geographic areas. The most spectacular views of the Great Unconformity are arguably in Grand Canyon, where deeply incised canyons of the Colorado River contain fantastic exposures of the Great Unconformity. Grand Canyon is unique on our planet, as few places display the pages of our geologic story in such breathtaking views. The Great Unconformity is marked by the contact of 1,750 million-year-old metamorphic rocks directly overlain by the 500 million-year-old Tapeats Sandstone (photo on page 1). As in the Sandia Mountains, this monumental break accounts for nearly one quarter of Earth's geologic time! The Great Unconformity in Grand Canyon leaves us with a mystery on some important events in Earth history, including the assembly and breakup of the ancient supercontinent of Rodinia (the ancestor to the more familiar supercontinent of Pangea). Also concealed within this time gap are the emergence of most of the animal and plant kingdom lineages, and the "Snowball Earth" hypothesis, a series of global climate events thought to be periods of extreme glaciation at equatorial latitudes.

Why do the gaps in the rock record not match between the Great Unconformities of New Mexico and Grand Canyon? The answer is found in an understanding that such unconformities mainly represent erosion of the rock record, and erosion that did not occur evenly over the entirety of the geographic area that records the time gap. Rather, the net erosion in a massive unconformity represents periods of erosion and deposition, with the cumulative effects of the erosion destroying any record of deposition. So how does one understand



View of the Sandia Mountains, from La Luz Trail, showing the Great Unconformity, a classic nonconformity. The Sandia Granite crystallized from magma deep within Earth's crust and was later exhumed by tectonic forces and erosion. The younger sedimentary rocks of the Grey Mesa Limestone were directly deposited on the eroded granite in a warm, shallow Pennsylvanian-age sea. Photo courtesy of Mark Nohl, New Mexico Magazine.

Earth's history absent from the Great Unconformity, and the missing chapters of time from many regions of the world?

Fortunately for geologists, planet Earth has always been a dynamic place! While one part of the world was losing its geologic record through erosion of the landscape, another area was likely creating a geologic record through sedimentation. If we are lucky enough, ample clues will be preserved to allow geologists to fill in the gaps. Such is the case in Grand Canyon, where sedimentary rocks called the Grand Canyon Supergroup preserve some the geologic history that is missing in the Great Unconformity.

The Grand Canyon Supergroup is a nearly 12,000-foot-thick section of tilted layers of limestones, sandstones, and mudstones that can be divided into two main groups of rocks. The older (lower) Mesoproterozoic Unkar Group has been dated between 1,250 million years ago and 1,100 million years ago, whereas the younger (upper) Neoproterozoic Chuar Group has been dated between about 780 million years and 729 million years ago (diagram on this page). Each group records unique snapshots of the geologic history from within the Great Unconformity. For the Unkar Group, the sedimentary rocks and faulting record a period of deposition in the Grand Canyon region. Deposition occurred from erosion of a massive mountain range that extended from present-day Nova Scotia to west Texas. This mountain range, long since eroded, represents a suture between multiple continental plates during the formation of the supercontinent Rodinia a little over a billion years ago. A mountain range of this scale must have left an impressive sedimentary record, yet very little of these ancient deposits is preserved, with the notable exception of a few localities like Grand Canyon. After deposition of the Unkar Group, time passed, and the rocks were partially tilted and eroded.

About 300 million years after the Unkar Group, sediment was again blanketing the Grand Canyon region. The geologic history of these Chuar Group sediments suggests that basins were forming along the western margin of North America in response to the breakup of the supercontinent Rodinia. Coincident with the rifting of the western margin of North America, the biologic diversity of Earth was undergoing sweeping changes. A combination of extreme global climatic changes (Snowball Earth) and developing marine environments along the margins of the faltering supercontinent led to much of the great biological diversity we observe today. The first heterotrophic organisms (those that derive their energy from consuming other organisms) are found in the Grand Canyon rock record. Once again, following deposition of the Chuar Group, the region underwent erosion on a massive scale, such that remnants of these ancient basins are preserved in widely scattered outcrops from Grand Canyon to Alaska.

Although the geologic record from the Great Unconformity is fragmentary and widely dispersed across the continent, geologic investigations continue to fill in the gaps. The Great Unconformity is clearly a composite feature that conceals multiple periods of deposition, deformation, and erosion. The diagram on this page shows that the geologic record has many missing gaps in the rock record and that the Great Unconformity in Grand Canyon is really the net effect of a nonconformity, at least two angular unconformities, and several disconformities. Although the Grand Canyon is the planet's premiere geologic laboratory for illustrating fundamental deep time concepts such as unconformities, New Mexico has many fine examples as well.

As geologists piece together the fragmentary geologic record, new insights are revealed about the amazing complexity of what happened over 4.56 billion years of Earth history. In some important ways, by studying deep geologic time, we get a better understanding of our own history.

As impressive and enduring the geology of Grand Canyon or the Sandia Mountains appears to be, there is more missing record (as represented by time) than there is actual rock record. This makes the task of geologists all the more challenging. However, each generation of geologists, armed with new analytical techniques and better understanding of natural processes, will continue to unravel the mysteries of deep time and the geologic history of planet Earth.

—*J. Michael Timmons*

Mike Timmons is the Deputy Director at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) and manages the bureau's Geologic Mapping Program. His graduate work focused on the Late Proterozoic rocks of the Grand Canyon.

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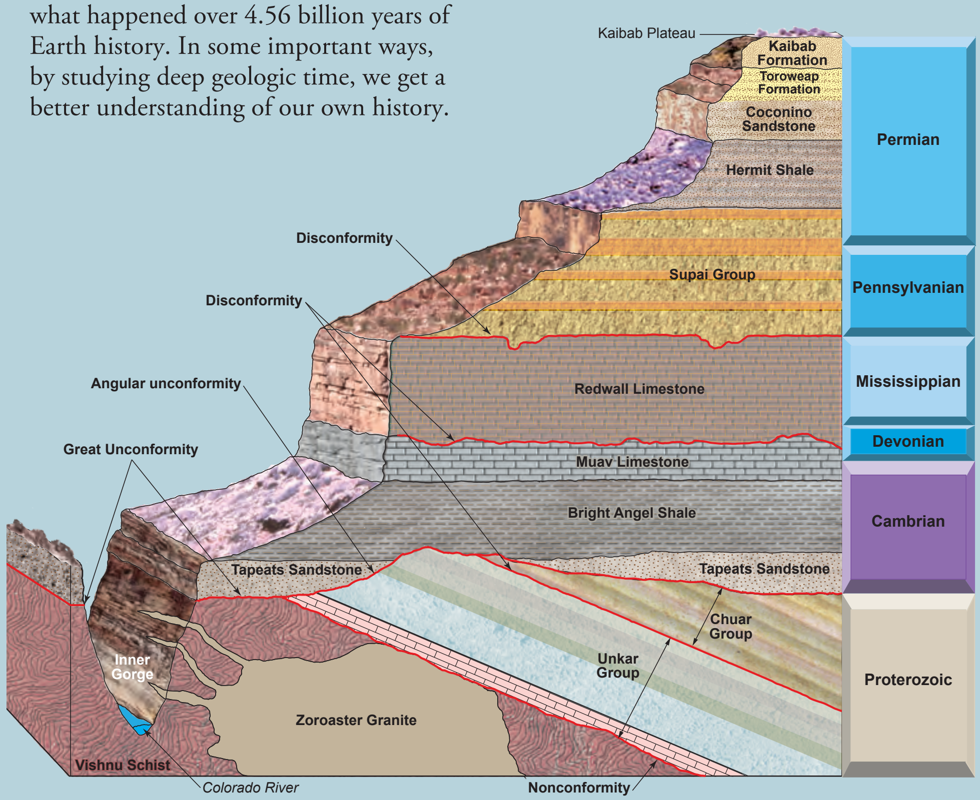

Stratigraphic diagram showing where unconformities exist in the rock record of Grand Canyon. Of particular interest is the composite nature of the Great Unconformity, as it represents the net erosion of multiple unconformities.

From left to right, Peggy Barroll, Andrew Core, Dr. Chuck Chapin, and Dr. Shari Kelley.

2017 New Mexico Earth Science Achievement Awards

On February 28th of this year the New Mexico Earth Science Achievement Awards were presented to Dr. Charles E. Chapin, for outstanding contributions advancing the role of earth science in areas of applied science and education, and to Andrew Core for outstanding contributions advancing the role of earth science in areas of public service and public policy. The presentation took place in the rotunda of the state capitol building on Tuesday, February 28th, during the legistlative session in conjunction with Earth Science Day.

Among Dr. Charles "Chuck" E. Chapin's numerous accomplishments are his definition of the Rio Grande rift and his detailed work on ash-flow tuffs in the northeastern Mogollon–Datil and central Colorado volcanic fields. Chapin was heavily involved in the establishment of the world-class geochronology center at the Bureau at New Mexico Tech.

Chuck's academic teaching career began at the University of Tulsa, but he soon moved to New Mexico Tech in Socorro, where he taught for five years and served as department chairman for two years. He started working for the NM Bureau of Geology in 1970, where he served as Director and State Geologist from 1991 until his retirement in 1999. Lite Geology, the Bureau's publication that is aimed at providing geologic information to earth science teachers, was conceived in 1992 while Chuck was director.

During Chapin's 34-year tenure in Socorro, he supervised 14 Ph.D. candidates and 31 Master's students. After retirement, he has continued to write notable, integrative, scientific papers about the geology of the southwestern United States. Since 2008, he has authored or co-authored four papers that have appeared in the international, peer-reviewed journal Geosphere on topics ranging from the effects of oceans and paleoclimate on sedimentation in the southwestern United States to the origin of the Colorado Mineral Belt.

Andrew "Andy" Core is one of those exceptional New Mexico geologists who mastered both the science of water and the art of water. When he retired from state government in 2014, he had contributed more than 25 years of technical and management experience to the state, much of which was spent working on water issues within the Office of the State Engineer.

From 2006 to 2014, he served as a Hearing Examiner within the Water Rights Hearing Unit. In that role, he scheduled and conducted administrative conferences and water rights hearings related to denied, protested, or disputed water rights applications. He also served as a designee of the State Engineer on the N.M. Coal Surface Mining Commission and the Hard Rock Mining Commission.

Prior to his appointment in the litigation unit, he was a senior hydrologist within the Hydrology Bureau of the OSE from 1990 to 2006.

Dr. Nelia Dunbar named Bureau Director and State Geologist

Dr. Nelia Dunbar has been named as Director of the NM Bureau of Geology and Mineral Resources and State Geologist by New Mexico Tech President Stephen Wells. Dr. Dunbar is the first female director of the Bureau and 15th overall in its nearly 90-year history. Dr. Dunbar has had a long and distinguished career at the bureau as a geochemist and volcanologist and as manager of the bureau's Electron Microprobe Laboratory. She completed both her M.S. in Geology (1985) and Ph.D. in Geochemistry (1989) at New Mexico Tech, and still serves as an adjunct professor in the department. She has done fieldwork not only throughout New Mexico, but also around the world, including extensive work in New Zealand and Antarctica.

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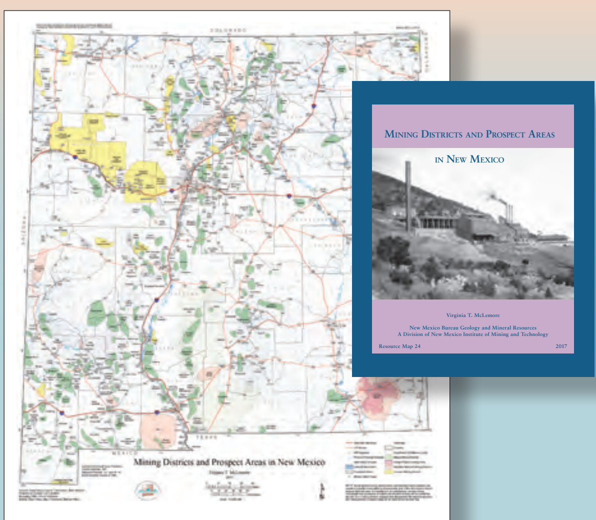
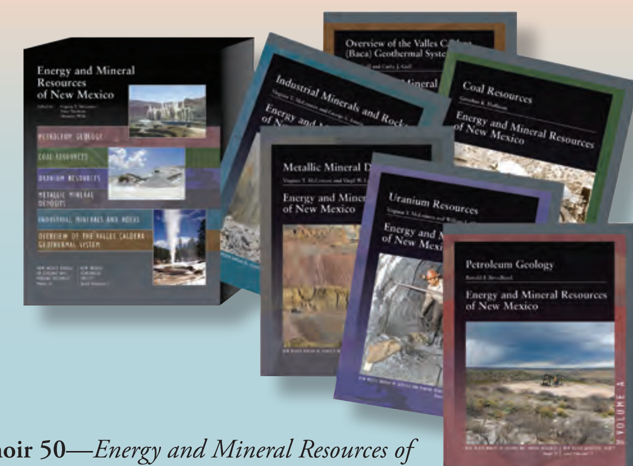


Resource Map 24—*Mining Districts and Prospect Areas of New Mexico*, New Mexico Bureau of Geology and Mineral Resources, by Virginia T. McLemore, Shari Kelley editor. *In press*, preorders available now.



Memoir 50—*Energy and Mineral Resources of New Mexico,* New Mexico Bureau of Geology and Mineral Resources and the New Mexico Geological Society, edited by Virginia T. McLemore, Stacy Timmons, Maureen Wilks. Available summer 2017.

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