A Slice Through Time

the Santa Catalina Mountains

A Calendar for the Ages

To understand Earth's geologic history, scientists have devised a chart called a geologic column to represent the phases of the planet's development.

On the bottom edge of these panels, we've turned the column on its side. So starting at the left, you can see that Earth's earliest phase, the **Precambrian**, has also been the longest—by billions of years. The Precambrian began when Earth coalesced, about 4.5 billion years ago, and lasted until the start of the **Paleozoic Era**, 542 million years ago (mya). To put that in perspective, if Earth's history spanned a single calendar year, the Precambrian would stretch from January 1 until November 18.

The Paleozoic Era, when multi-cellular life began to flourish, lasted until 251 mya, or from November 18 to December 12.

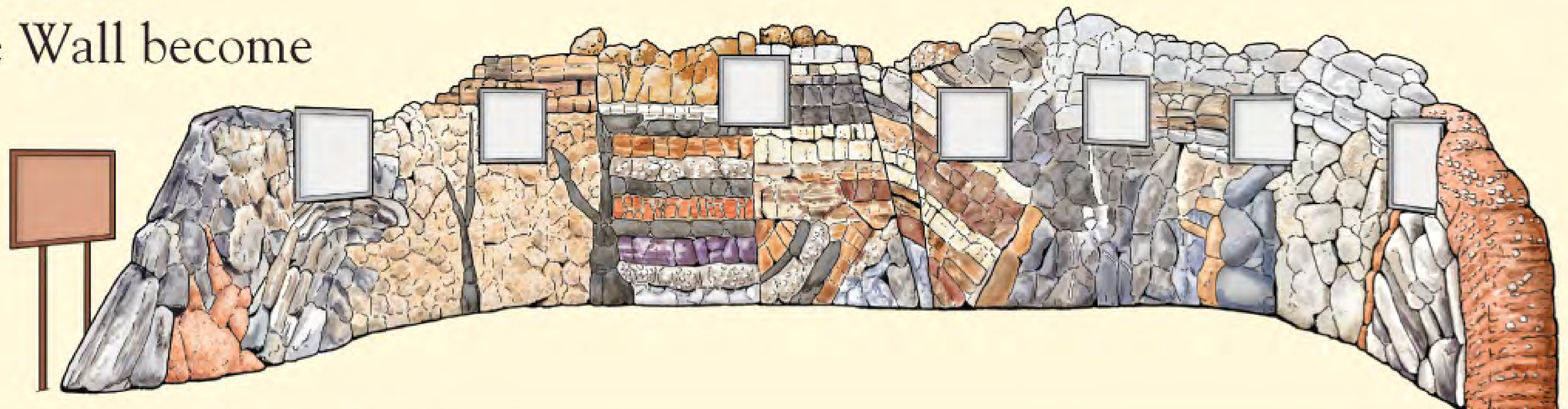
The **Mesozoic Era**, known as the Age of Reptiles, lasted until about 65 mya, or December 12–26.

We live in the most recent Era, the **Cenozoic**, which began on December 26, so to speak. The Cenozoic is the age of "new life," when mammals came into their own—modern humans have been around since only about 11:48 pm on December 31.

Walk along our Geology Wall, from one end to the other, and you'll stroll through nearly two billion years of Earth's history. The Wall represents a slice of geologic time cut from Tucson's Santa Catalina Mountains—and the geologic story of Southern Arizona. You would have to hike more than 30 miles through the Catalinas to see the same rock formations you'll see here.

In general, the rocks of the Santa Catalina Mountains and the Wall become younger as you walk south. The oldest rocks, displayed on the Wall's left end, are found about 39 miles north of Tucson near the town of Oracle; they are about 1.8 billion years old. Tucson is built on the youngest sediments, displayed on the Wall's far right; they are only 10 to 20 million years old.

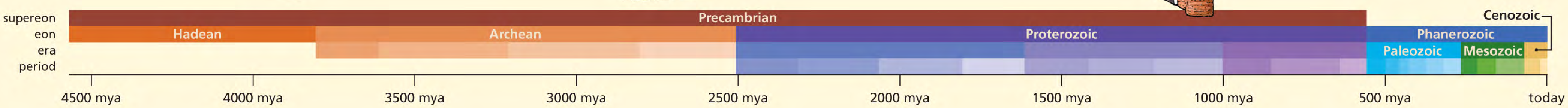
As you move along the wall, refer to the graphic locator on each panel to see where you are in the exhibit, and check the timeline at the bottom of each panel to see where you are in geologic time.



Building Blocks

Tohono Chul Park's Geology Wall, the vision of Park founder Richard Wilson, a University of Arizona geology professor, was inspired by the geologic formation fireplace in the Bright Angel Lodge at the Grand Canyon. Designed by Mary Jane Colter, the fireplace represents the geology of the Canyon from rim to river.

Completed in 1985, our 55-foot semi-circular Geology Wall was designed and built by geologist Doug Shakel, with the help of Toby Wright. It consists of several-hundred rock specimens collected from more than two-dozen geologic formations in the Santa Catalina Mountains, which are visible just over the top of the Wall. Shakel and Wright spent three years gathering the specimens and building the Wall.



The Geology Wall signage has been made possible by generous donations from . . .

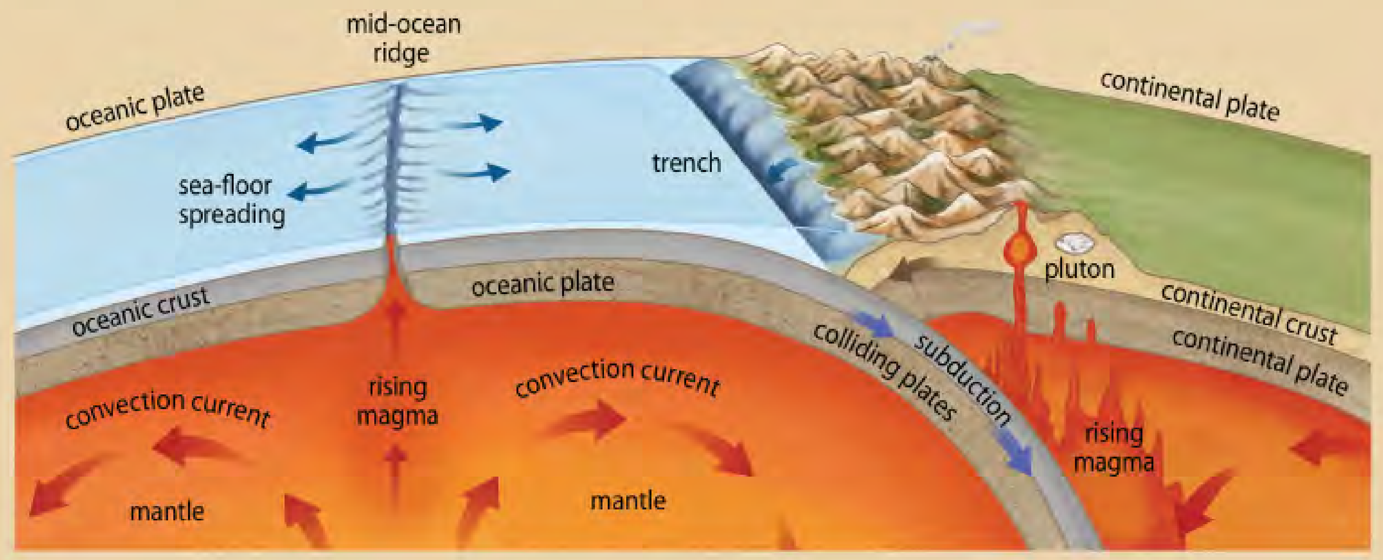
Ancient Roots in the Basement

230 mya

A partially-submerged Arizona from about 230 mya. At this point in geologic time, the continents we know today have not yet split from the supercontinent Pangea and Arizona is only slightly north of the equator.

Land in Motion

You may not notice, but the ground beneath you is moving. At a snail's pace, the position of the continents has changed throughout geologic history. For example, between 200 and 250 mya (mid-December on our calendar), the landmass including what is now Arizona was much closer to the equator than it is today. At the rate of less than an inch a year, it took our state more than 200 million years to get where it is now; and the movement continues.



Earth's crust, which varies from 9 to 124 miles thick, is made up of interlocking tectonic plates, like pieces of a puzzle. These continental and oceanic plates float like rafts on the planet's mantle. Convection currents in the mantle, like those in a pot of boiling water, keep the plates shifting, causing them to collide or separate. Colliding continental and oceanic plates often result in the subduction (downward movement) of the oceanic plate. As the oceanic crust slides below the continental crust, friction causes rock to melt. Molten rock (magma) either cools below the surface to form plutonic rock (such as granite) or rises to the surface to form volcanoes and volcanic rock.

mantle: 1,800 mile layer of slow-moving rock material between earth's crust and core where temperatures range from 932 to 7230° F (500 to 4000° C)

Intense compression and squeezing produced the Santa Catalina Mountains' oldest rocks, the basement foundation—**Pinal Schist (A)** and **Oracle Granite (B)**, which you can see surrounding this panel. These rocks are the exposed roots of an ancient mountain range that stretched across much of what is now the American Southwest. The range was uplifted by colliding plates during the Precambrian, about 1800 mya ago (late summer on our calendar), and later eroded away to the schist and granite roots that remain today.

Pinal Schist, a shiny metamorphic rock present in small areas in the northern Catalinas, forms most of the Pinal Mountains south of Globe. It likely correlates to the famous Vishnu Schist found in the deepest gorges of the Grand Canyon. The pinkish Oracle Granite to the right of this panel is plutonic igneous rock formed 1450 mya (September) when magma intruded into the Schist. Near the town of Oracle, exposed Oracle Granite is visible at surface-level.

Oracle granite in Oracle State Park

uplift: to cause (a portion of the earth's surface) to rise above adjacent areas

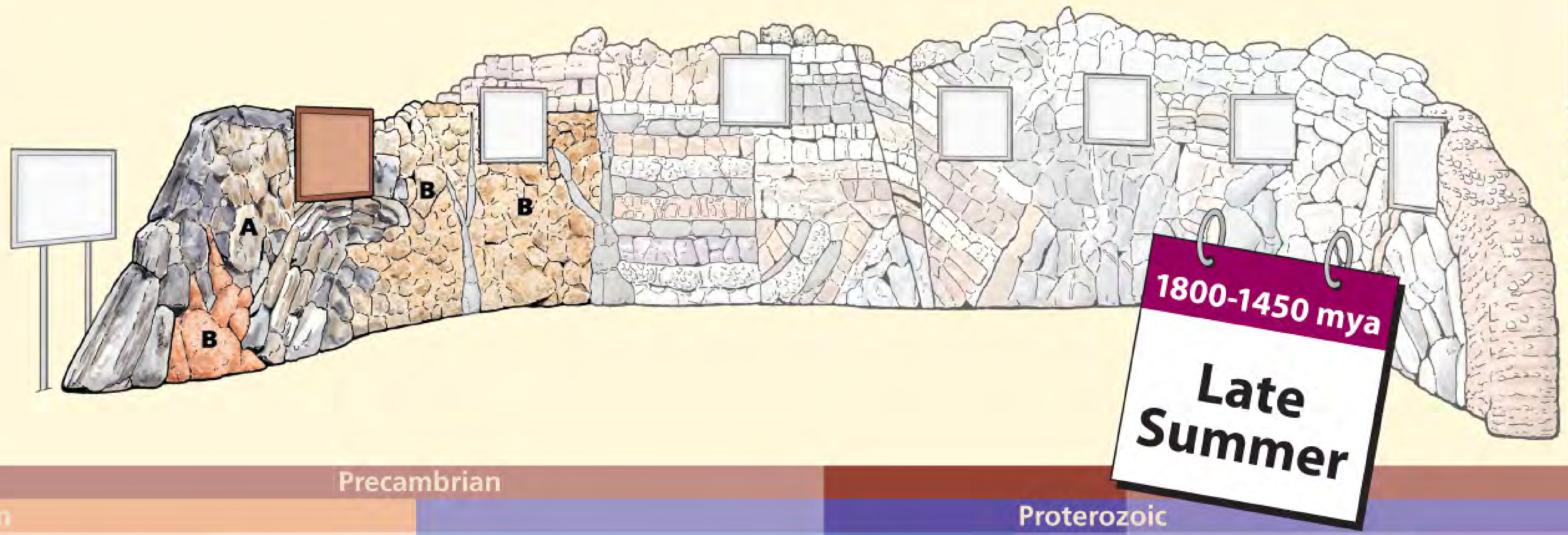
plutonic rock: rock formed by solidification of magma deep within the earth and crystalline throughout

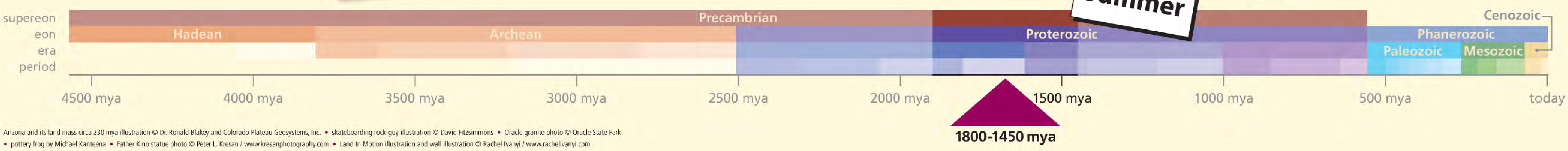
igneous rock: any of the major rocks that have crystallized from a high-temperature molten liquid or magma

Lofty By Any Name

17th century explorer, missionary, and cartographer Father Kino is credited with naming Tucson's most prominent mountain range in honor of Saint Catherine—Sierra de la Santa Catarina—which became, over time, the Santa Catalinas. To the Tohono O'odham, the native people of this region, the 9,000-foot peaks have always been Babad Do'ag or Frog Mountain.

pre-Columbian pottery frog replica; statue of Father Kino in central Tucson





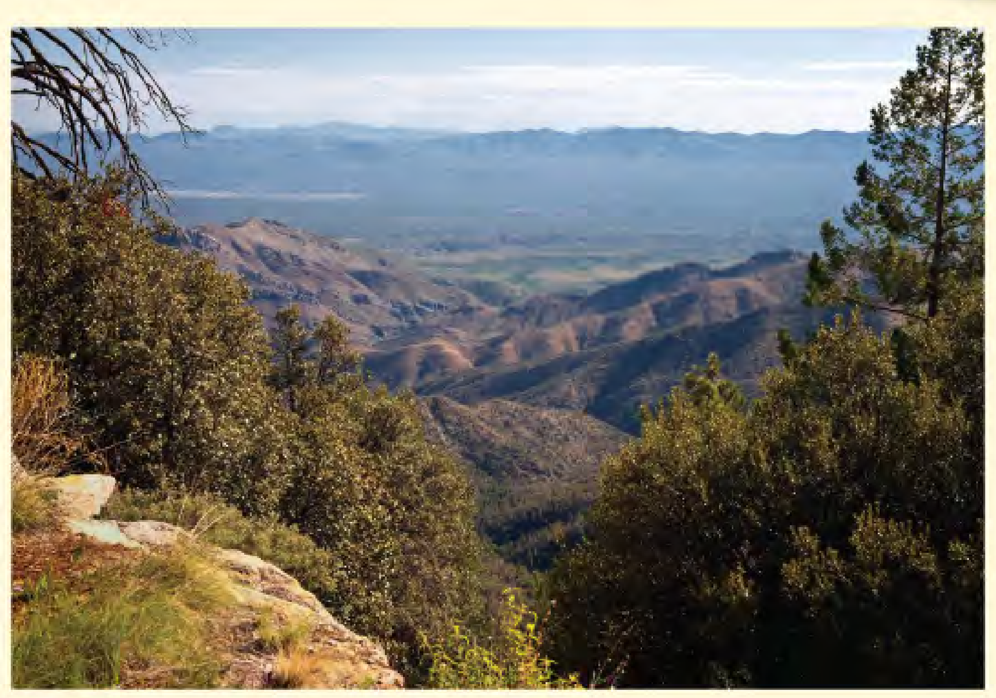
A Work In Progress

As geologic time creeps along, Earth's crust continues to change in both subtle and monumental ways. From 1400–800 mya (September–October), the towering mountains that once dominated the landscape were worn away to a flat and featureless plain during a long period of erosion. Shallow seas advanced and receded over this lowland, depositing gravel, sand and mud, which would in turn result in layers of new rocks **(D)**.

About 1275 mya, Earth's crust was on the move, great blocks shifted along fault lines that later filled with magma which cooled to form a dark igneous rock called **diabase** **(C)**. Where the magma followed vertical faults, the resulting intrusion is called a **dike** **(C1)**; where it flowed in spaces parallel to sedimentary layering, it is called a **sill** **(C2)**, as seen in the layers of the **Apache Group (D)** rocks beyond the dike to the right. As the Precambrian drew to a close, the landscape was again worn down by erosion, allowing oceans to cover the land. On and on, the cycle has repeated, and continues to do so.

A dike running next to Shiprock, in New Mexico

conglomerate: composed of rounded rock particles shaped by moving currents and later cemented together by silica or calcium carbonate



Rocks from the Apache Group are visible from the San Pedro Outlook on the Mt. Lemmon Highway as you look down on the hilltops below.

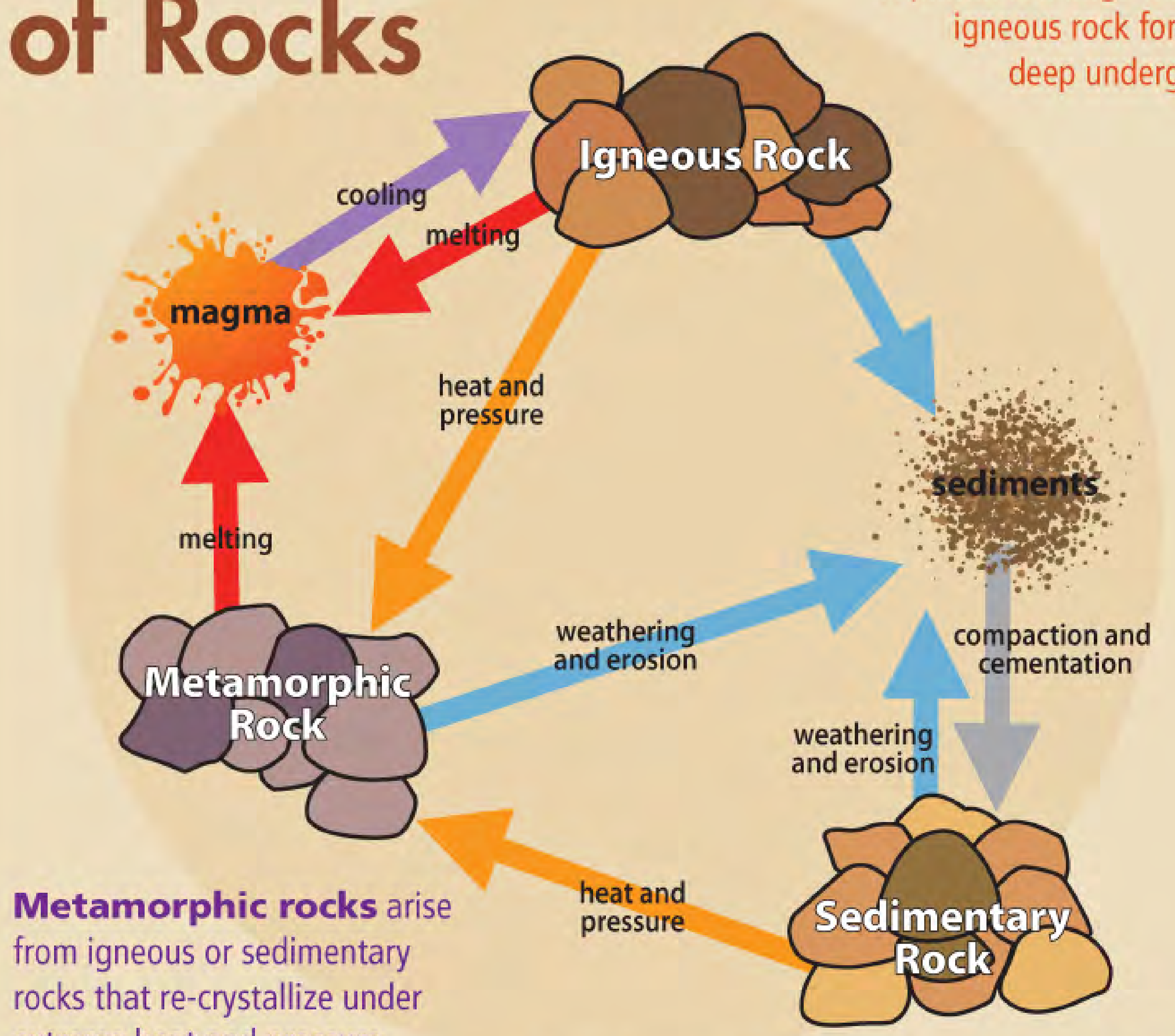
Missing Links

When prolonged erosion wipes out a portion of the geologic record like pages torn from a history book, the gap is called an "**unconformity**." An example can be seen at the line of contact **(U)** between the sequence of much younger sedimentary rocks in the **Apache Group (D)**, above this panel, and the much older **Oracle Granite (B)** below it. This **Scanlan Conglomerate**, one rock in the Apache Group, was deposited directly onto the older, weathered Oracle Granite. This uncormformity represents perhaps 200 million of years of missing rock history!

Mountains, and the rocks they are made of, may appear to last forever, but they are being created, altered and destroyed in a continuous cycle of transformation, posing the question of which came first? All three main types of rocks are found in the Catalinas.

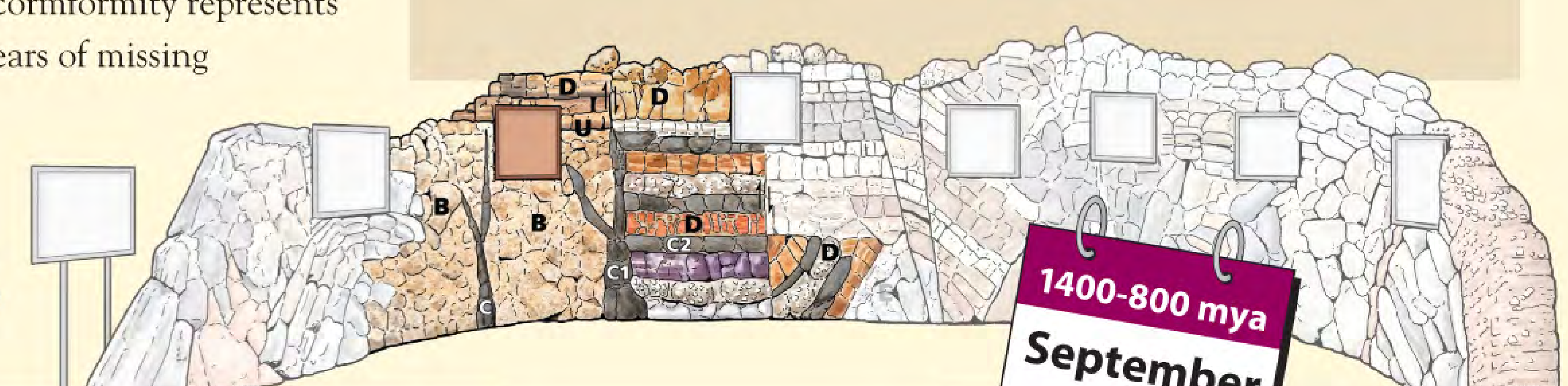
The Circle of Rocks

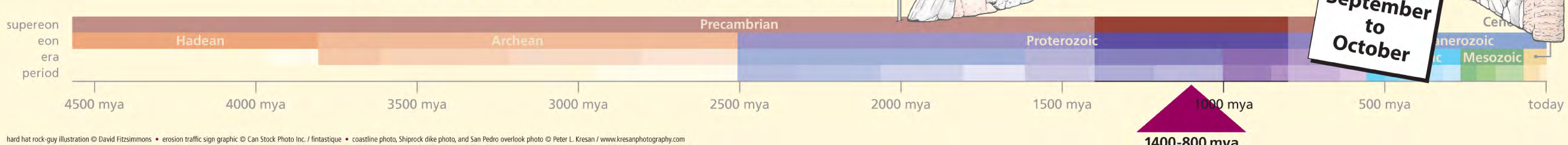
Igneous rocks are produced by molten magma that cools slowly, deep below Earth's surface, creating crystalline plutonic rocks like granite, OR magma that erupts onto the surface as lava to cool rapidly and form volcanic rocks such as basalt. A pluton is a large mass of igneous rock formed deep underground.



Metamorphic rocks arise from igneous or sedimentary rocks that re-crystallize under extreme heat and pressure, just short of melting back into magma. Metamorphic rocks often show banded or lineated structures, such as schist and gneiss.

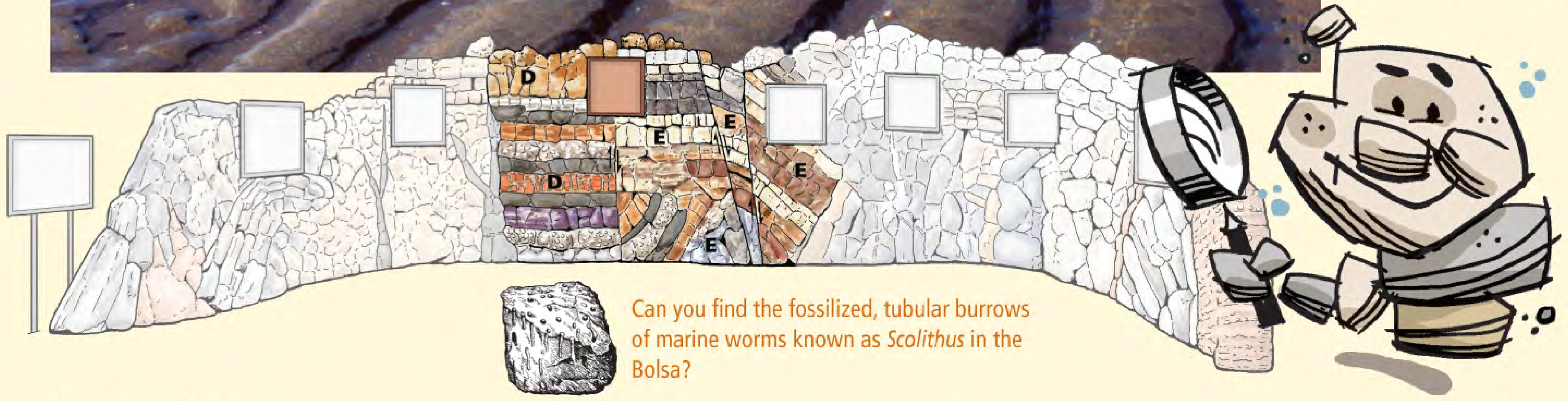
Rocks exposed at the surface are subject to weathering by water, wind and gravity. Over time, eroded rock fragments settle into layered deposits or sediments. The intense pressure of accumulated layers creates **sedimentary rocks** such as sandstone and shale. Another sedimentary rock, limestone, forms in shallow seas from the remains of shells, coral and other sea invertebrates.





Oceanfront Property (in Arizona!)

Arizona 370 mya and 318 mya



Can you find the fossilized, tubular burrows of marine worms known as *Scolithus* in the Bolsa?

Lemmon Herbarium and its occupants, Oakland, California, 1895. Image courtesy of the University and Jepson Herbaria Archives, University of California, Berkeley.

During the Paleozoic Era, 542–251 mya (mid-November to mid-December), seas repeatedly advanced and withdrew as the relative elevations of land and water changed, leaving sedimentary deposits in the form of sandy beaches, and mudflats and limey deposits of marine organisms where the waters were deeper. Oceanfront property was easy to come by in what would become southern Arizona. The mudflats and limey organic deposits laid down early in the Paleozoic Era are now the erosion resistant shales and limestones of the **Abrigo Formation**. Noted for distinctive flat pebble conglomerates, the Abrigo strata are the result of ripped up layers of mudflats, the work of ancient ocean storms. The sands of long ago beaches that covered nearly all of western North America are preserved as Bolsa Quartzite. **Abrigo** and **Bolsa (E)** are the lowest horizontal layers below this panel and to the right.

Layers of Time

During the middle to late Paleozoic, 416–251 mya, the oceans continued to come and go, but there was little or no crustal disturbance, resulting in a long period of relative stability and the laying down of successive layers of sediments. These limestone deposits, commonly several hundred feet deep, are the layers in which important cave systems such as Kartchner Caverns are found.

Kartchner Caverns, 50 miles south of Tucson

Starting with the earliest deposits at the bottom of the layers and working our way up is the:

- **Martin Formation** (Devonian Period, 416–359 mya), is overlain by
- **Escabrosa Limestone** (Mississippian Epoch, 359–318 mya), then the
- **Naco Group**, comprised of the **Earp, Horquilla** and **Colina Formations** (Pennsylvanian Epoch and Permian Period, 318–251 mya).

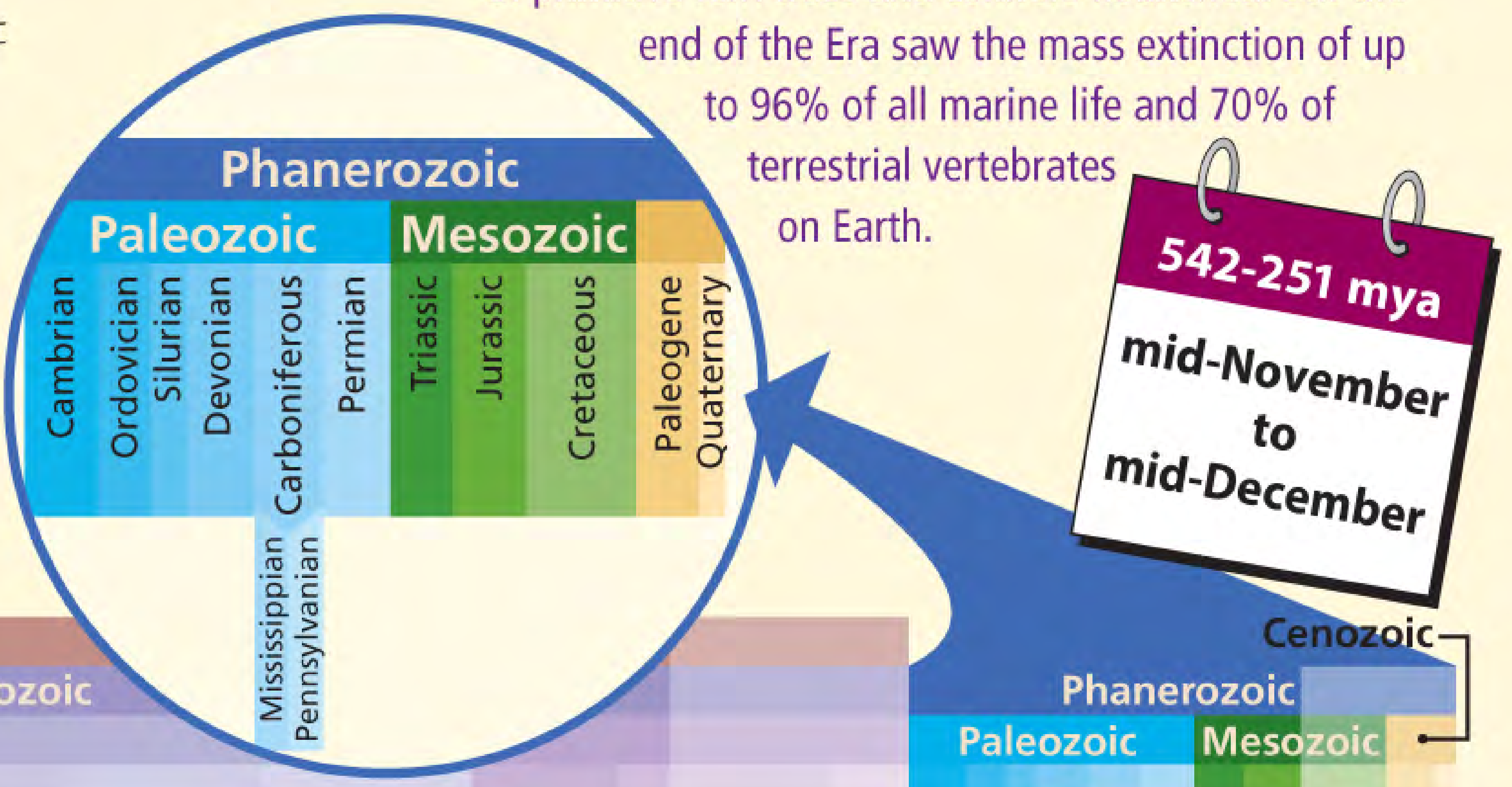
The layers can be seen in horizontal bands to the right of this panel **(E)** and also in the tilted section further to the right. The faulting, tilting and metamorphism came later. The younger or Paleozoic sediments **(E)** originally overlaid the Precambrian layers **(D)**, but now they rest side by side.

Lady Mountain

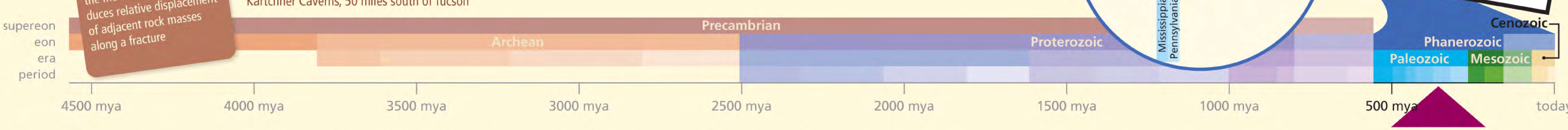
The highest point in the Catalinas, Mount Lemmon (9,157 ft), is named not for the fruit, but for Sarah Plummer Lemmon (1836-1923) an amateur botanist who, on her honeymoon in 1881, hiked to the top on foot and by mule to catalog the plants of southern Arizona.

An Era of Firsts

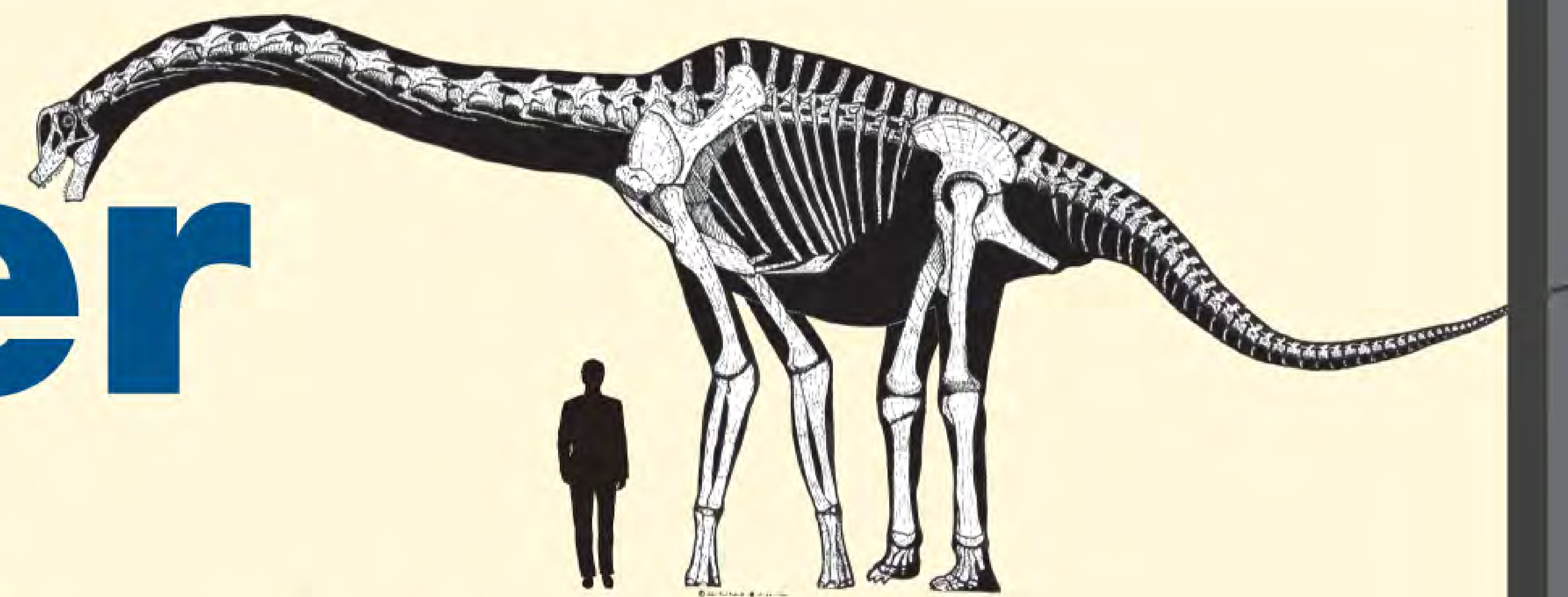
The Paleozoic is an Era of firsts—from the first vertbrates (fish) to the first land plants, from the first insects to the first amphibians, and from the first plants with seeds (ferns) to the first reptiles. Coal swamps characterized much of the land, and the first forests of primitive fern trees and conifers flourished. But the end of the Era saw the mass extinction of up to 96% of all marine life and 70% of terrestrial vertebrates on Earth.



faulting: the movement which produces relative displacement of adjacent rock masses along a fracture



Out of the Water




stromatolite mounds, Shark Bay, Australia

Fossilized Oxygen Machines

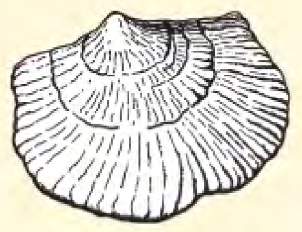
Some of the oldest fossils on Earth, and the earliest fossils represented in the Wall, are stromatolites—literally, "layered rocks." Dating to as much as 3.5 billion years ago (March 20), they are the accreted remains of single-celled organisms that are the oldest form of life on the planet—the blue-green algae, or cyanobacteria, responsible for the accumulation of oxygen in Earth's atmosphere. In the beginning, free oxygen didn't exist in the atmosphere, which was likely composed mostly of hydrogen and carbon dioxide. Through the process of photosynthesis, the single-celled algae metabolized carbon dioxide and released free oxygen. Over the course of millions of years this process dramatically changed Earth's atmosphere and facilitated the later development of more complex forms of life. These stromatolites are still alive today in certain parts of the world, especially in Western Australia; to see ancient fossil remains, look to the left of the fourth panel, near the top of the Wall, in the **Apache Group** limestone. **(D)**

Most of Earth was covered by water throughout the Paleozoic Era and marine species dominated the planet. During the Paleozoic's Cambrian Period, 542–488 mya (mid to late November), an explosion of new life was made possible by the development of complex, multi-cellular life forms that could respond to the diverse demands of their watery environments—burrowing into bottom sediments, living on ocean floors, or swimming through open seas.

Mostly invertebrates, the fauna of the Cambrian included trilobites, brachiopods and mollusks. Later came fish and other vertebrates. By November 21 (488–444 mya), life was no longer confined to the seas and plants moved onto land, followed by invertebrates November 27–29 (444–416 mya). By December 2 (416–359 mya), amphibian-like vertebrates walked dry ground, eventually followed by reptiles at the end of the Paleozoic Era, while primitive conifers, cycads and ferns covered the landscape.

Fossils found in the gray Paleozoic limestones **(E)** near this panel:

- **foraminifera**, commonly referred to as forams (to the left and above) are tiny one-celled animals whose fossilized shells look like wheat grains



- bivalved, meaning two-shelled, **brachiopods** (below)

- bases of solitary **"horn" corals** (below) with a unique horn-shaped chamber that looks like an ice cream cone

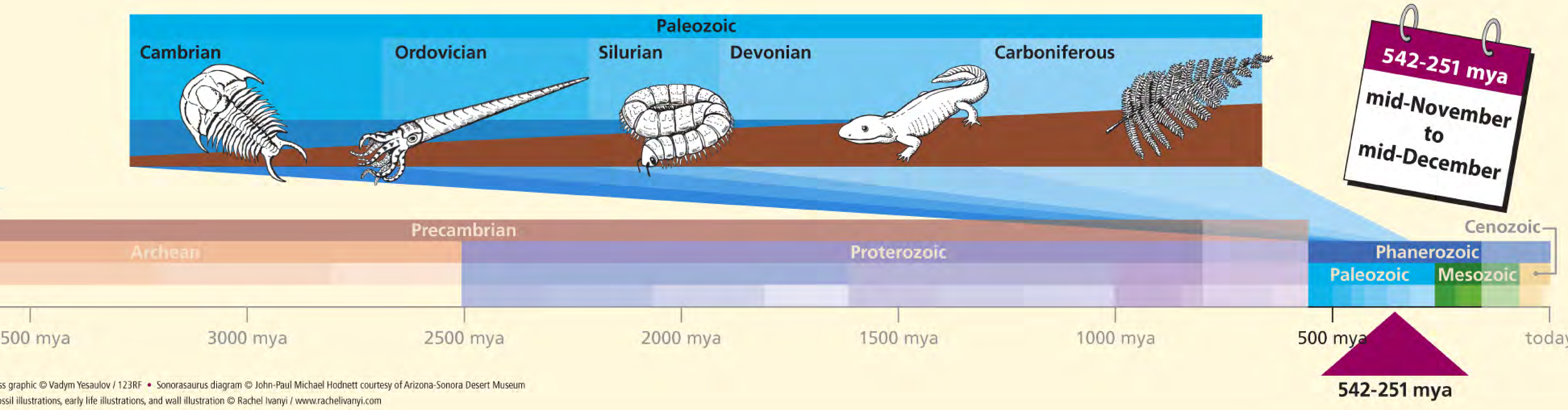
- round stem fragments or "buttons" of anchored animals called **crinoids** (to the left)

What about Dinosaurs?

More recent Mesozoic Era (251–65 mya, or mid-December) sedimentary rocks containing fossils of dinosaurs are not found in the Catalinas. The carnivorous Albertosaurus has been found in the Santa Rita Mountains south of Tucson and herbivorous sauropod Sonorasaurus was excavated from a remote canyon about 40 miles southeast of Tucson. Fossilized dinosaur bones and footprints are also found in Northern Arizona in rock formations of the Colorado Plateau.

Pusch Ridge

Rising from the western end of the Catalinas, Pusch Ridge is visible just beyond the Wall. It was named for German pioneer George Pusch (1847–1921), who built Steam Pump Ranch near the base of the ridge, on the Cañada del Oro, in 1874. Pusch Ridge was home to one of the last populations of Desert Bighorn Sheep in Arizona; none have been seen since 2005.



Squeeze Play

King Copper

Copper has played a major economic role throughout Arizona's history. First discovered in the Middle East, it has been used for 10,000 years, initially for jewelry and then for weapons. Today, its physical properties make it an excellent choice to conduct electricity and heat, make wire for communications technologies and computers, and pipes to transport water and gas.

Around 70 million years ago, when the Rocky Mountains were formed, igneous intrusions caused by faulting and volcanic activity created porphyry and secondary copper ores. The latter include turquoise, prized through the ages for jewelry-making, and the minerals azurite and malachite that you can see on the copper boulder near the Overlook. Other metal ores, such as lead, zinc, titanium, molybdenum, silver and gold, are also associated with **Arizona's porphyry (G)** copper deposits. Today, Arizona is the largest copper producer in the United States, and second largest in the world after Chile.

orogeny: the process of mountain formation especially by folding of the earth's crust

porphyry: a medium- or fine-grained igneous rock containing numerous well-developed crystals

igneous: formed by the solidification of magma

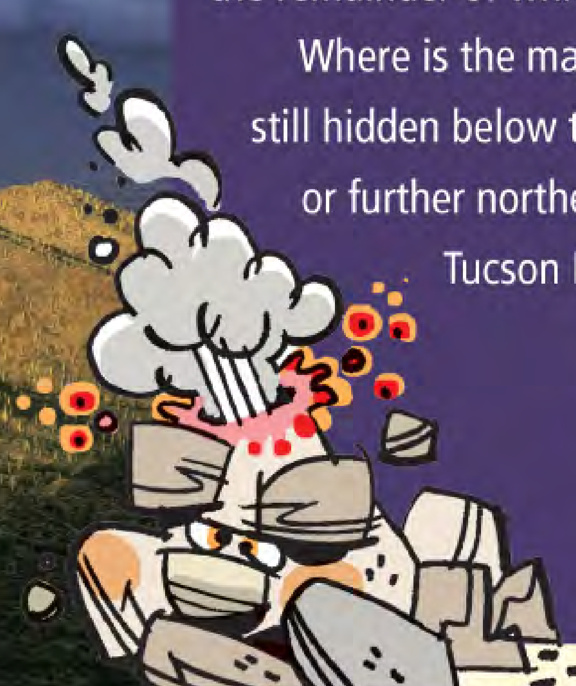
100 mya and 60 mya

In the late Mesozoic and Early **Cenozoic** Eras, 145–40 mya (December 20–26), colliding plates and subduction caused another period of intense crustal compression, resulting in uplift, igneous intrusions and metamorphism. Magmas formed from super-heated subducted oceanic crust, rose up into the overlying continental crust, and created metamorphic marble and quartzite from pre-existing Paleozoic sedimentaries. Some magmas crystallized below the surface and formed plutonic rocks such as granite, others reached the surface and formed volcanoes.

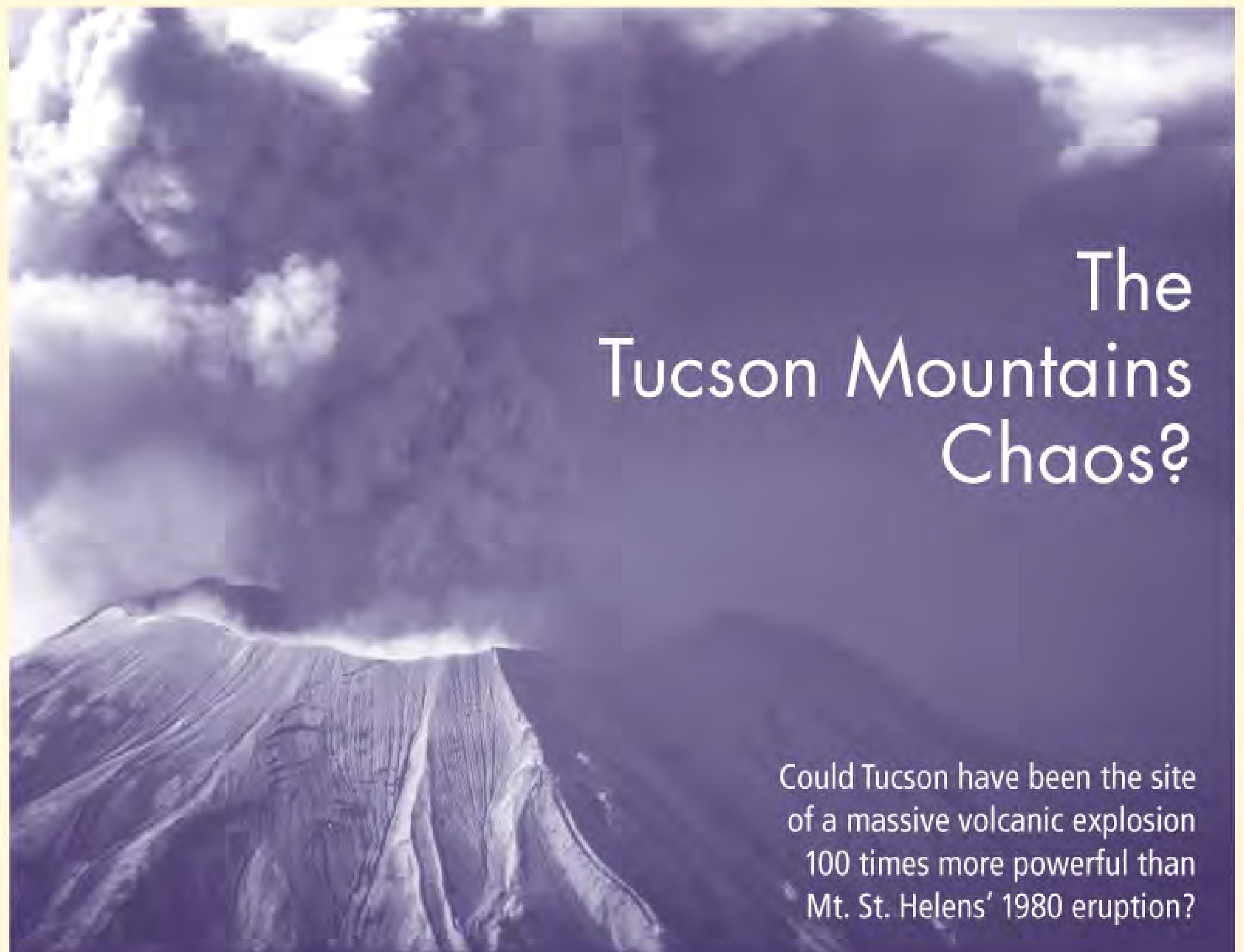
Rocks in the Catalinas from this time period reflect this mix of igneous and metamorphic processes. Near where Mt. Lemmon is today, the granitic **Leatherwood Suite (F)** surrounding this panel was intruded into older rocks at great depth, likely beneath a massive volcano on the surface. These intrusive granites formed during the **Laramide Orogeny** of the late **Cretaceous** and early **Paleogene** Periods about 70–35 mya (December 26–28). The Orogeny, a series of mountain-building events that impacted much of what is now western North America, crafted mountain ranges from the Black Hills to the Rockies.

Garnet-bearing **Wilderness Suite** granites (50–44 mya) **(H)** and **Catalina Granite** (29–25 mya) **(H1)** were emplaced as the crustal and oceanic plates began to pull apart.

Looking beyond the Tucson Mountains to Pusch Ridge in the Catalinas



The Tucson Mountains Chaos?



Could Tucson have been the site of a massive volcanic explosion 100 times more powerful than Mt. St. Helens' 1980 eruption?

The origin of the Tucson Mountains is subject to geologic debate. One theory holds that they were formed when the collapsed crater or caldera of a large volcano, which sat for millions of years over what is now the Santa Catalina Mountains, "slid off" the rising Catalinas toward the southwest as the result of a detachment fault triggered by crustal stretching 25 mya.

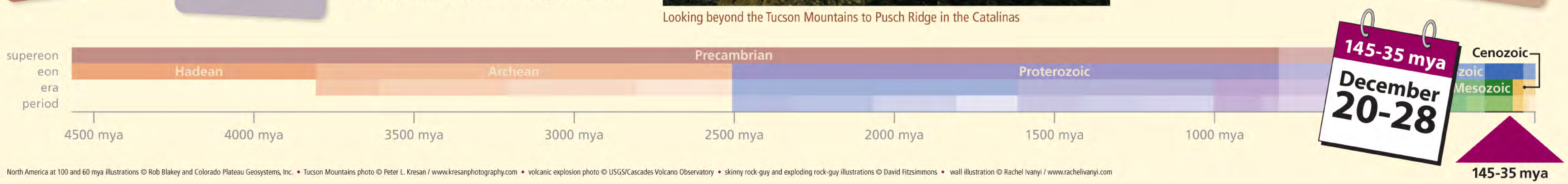
Unlike the Catalinas, which contain only minor Cenozoic (Tertiary) volcanic rocks and none associated with the Mesozoic and Cenozoic intrusions, the Tucson Mountains contain primarily Cretaceous and Tertiary volcanic rocks. Volcanic rocks exposed in the Tucson Mountains were formed by quiescent lava flows, explosive ash deposits and the collapse of calderas, possibly the result of an eruption over the Catalinas.

On the contrary, say other geologists, the volcano erupted where the Tucson Mountains sit now — they are the east half of the volcano's caldera, the remainder of which is buried somewhere in the Altar Valley.

Where is the magma chamber that created these volcanics? It's still hidden below the surface — either under the Tucson Mountains, or further northeast, possibly in the vicinity of Pusch Ridge, if the Tucson Mountains did indeed slide off the rising Catalinas.

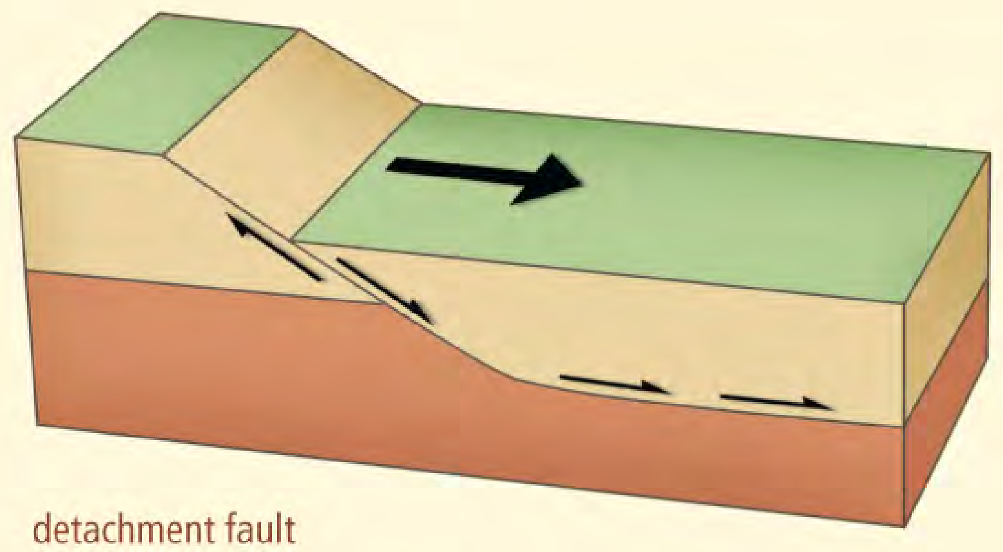
metamorphic: changed into a more compact form by the action of pressure, heat, and water

caldera: a volcanic crater that is formed by collapse of the central part of a volcano or by explosions of extraordinary violence



The Stretch

During the Middle and Late Cenozoic, 50–25 mya (December 26), rocks in this area were subjected to crustal extension as continental and oceanic plates began interacting in new ways. This stretching of Earth's crust caused the formation of nearly horizontal detachment faults at a depth of 6 to 8 miles, and stretched granitic rock as the continental crust ripped apart.

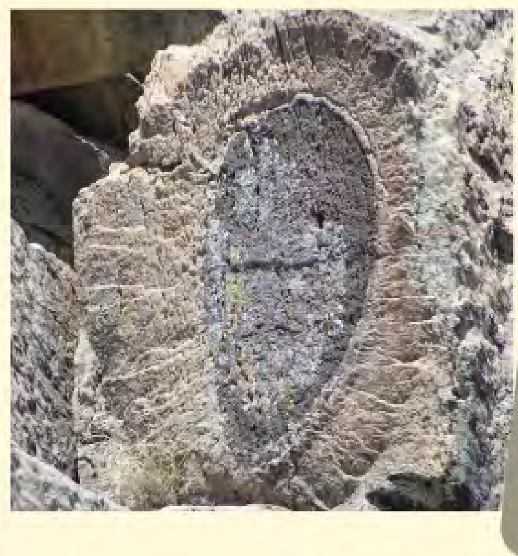


detachment fault

One more period of geologic mayhem and mountain building, the **Mid-Tertiary Orogeny**, 20–30 mya (December 28), added masses of igneous rock to the Catalinas, partly in the form of **Catalina Granite (H1)**, with its inclusions of older rocks or xenoliths that had been caught in up-swells of magma. In appearance, Catalina Granite looks much like Precambrian Oracle Granite, but it is almost 1.6 million years younger!

At the same time, nearly all of the southern part of the Santa Catalina range was converted to **Catalina Gneiss** (pronounced "nice") **(I)**, a greatly deformed rock that is banded or layered as a result of crustal stretching much like a taffy pull.

The intense stretching created a nearly horizontal detachment fault deep below the surface and Catalina Gneiss formed along the fault. In the Tucson area, rocks along this fault may have been transported from 6 to 20 miles apart in a NE-SW direction. As the fault movement was occurring, thinning crust allowed lighter weight granites to rise upward. Concurrently, weathering and erosion removed vast amounts of older rocks that were previously at the surface. Paleozoic sediments were transported off the top and into the crumpled and folded limestone and other rocks found near Colossal Cave and Oracle. The deep metamorphic cores of both the Catalina and Rincon Mountains were eventually exposed at Earth's surface by rock weathering and erosion processes.



xenolith: an intrusion of older rock in a plutonic (igneous) rock

Of Gneiss and Rubies

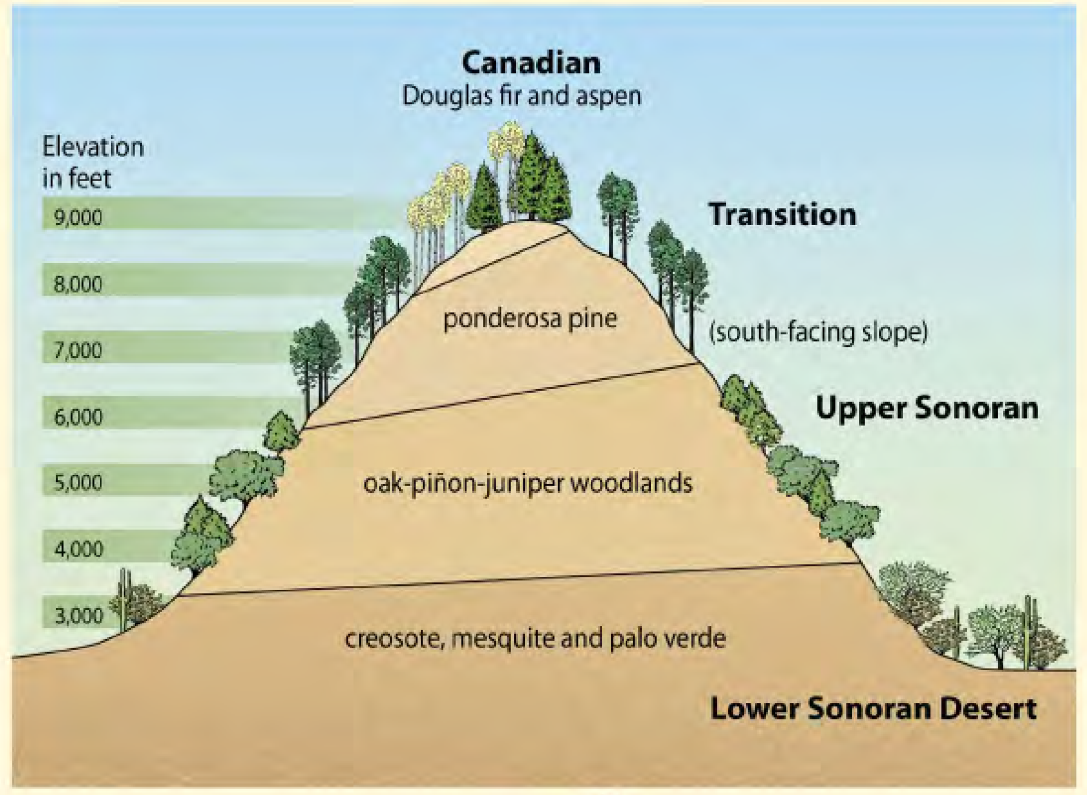
Many layers of Catalina Gneiss **(I)** contain small garnet crystals, "sand rubies," which, once exposed by erosion, can be found in foothill washes. Look for Gneiss here in the upper portions of the Wall, at and above the top level of this panel, extending toward your right, to near to the Wall's right end.

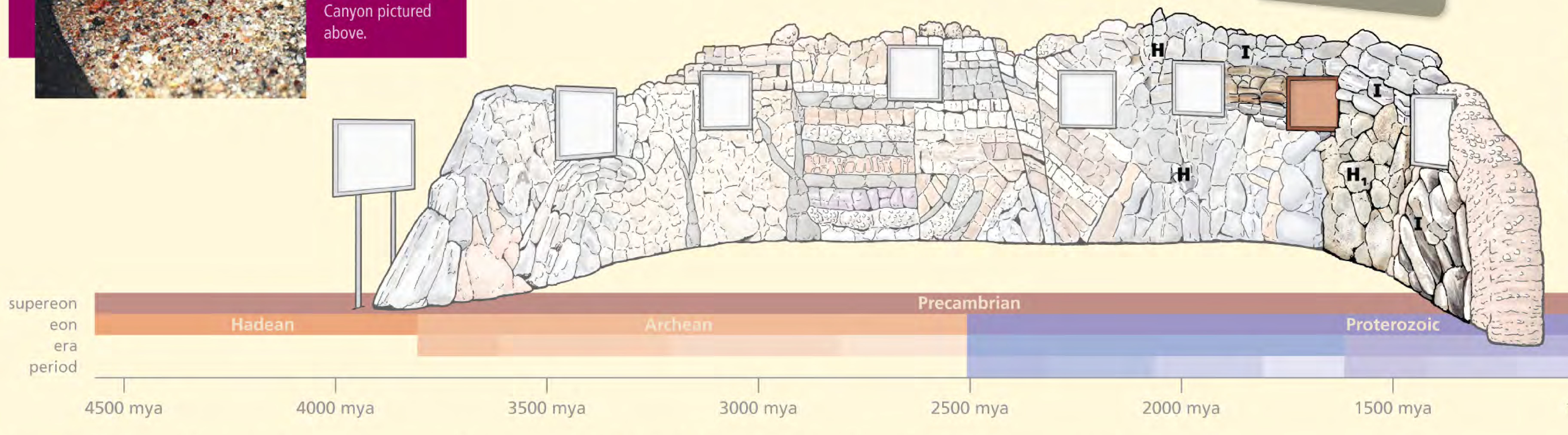
"Sand rubies" can be found in foothill washes like Sabino Canyon pictured above.

Life Zones

In 1889, C. Hart Merriam studied the relationship between climate and distribution of flora and fauna and observed that changes in plant communities at increasing latitudes were similar to changes seen at rising elevations, even though the latitude remained constant. He called these belts "Life Zones" and described six distinct zones that correlated to latitudinal vegetation belts ranging from Sonora, Mexico, to the Arctic coast of Canada.

Drive up the Mt. Lemmon Highway and in just one hour you'll travel from the Lower Sonoran Desert of creosote, mesquite and palo verde to the Canadian zone with its forests of Douglas fir and stands of aspen.





Breaking Up Is...

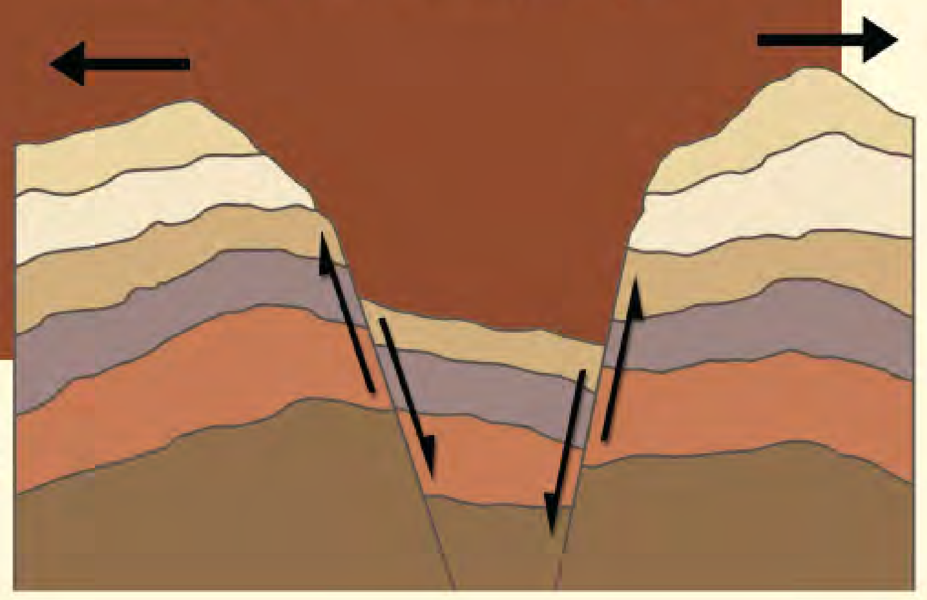
Where the Faults Lie

Numerous earthquakes affected this area as adjacent mountain and valley blocks moved into new positions along their edges. The abrupt western and southern boundaries of the Catalinas are manifestations of two such faults—the Pirate Fault along the western front of mountains, and the Catalina Frontal Fault, which forms the southern boundary. The Pirate Fault is visible today in the steep cliff face of Pusch Ridge.

In modern times, the most famous earthquake to affect Arizona occurred in 1887 when a magnitude 7.4 quake originating 190 miles southeast of Tucson did significant damage across southeastern Arizona. While the state continues to be impacted by movement of the San Andreas Fault in California, and other faults, the San Francisco volcanic field around Flagstaff warrants close attention. The most seismically active region in the state, it has been active for 6 million years, with the last eruption, Sunset Crater, less than 1,000 years ago!

Sunset Crater near Flagstaff, AZ

Many fault zones contain angular debris broken off adjacent fault walls. Aggregates of these broken fragments are called fault breccias. The fault breccias that developed in Catalina Gneiss and Catalina Granite during the powerful geologic activity of the Mid-Tertiary Orogeny typically have a resistant matrix formed of blood-red silica **(J)**; see samples of the breccia below this panel.



alternating uplifted fault-block mountains and valley

The Pirate Fault can be seen at the base of Pusch Ridge on the west side of the Catalinas.

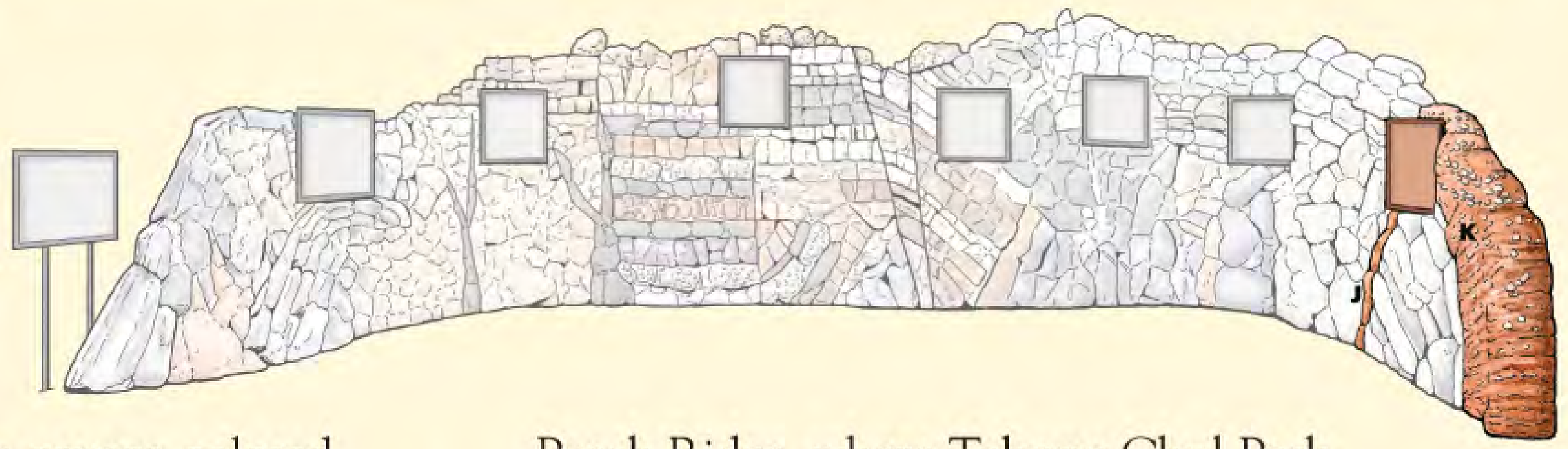
Sky Islands

The block-faulting and uplifting that created our Basin and Range topography had another effect as well. The resulting mountains, separated one from another by wide alluvial basins, were "landlocked." These Sky Island mountain ranges tower over a sea of desert and grassland. At the end of the last ice age, forests and woodlands pushed out by gradual warming retreated to these islands, which remain bastions of unparalleled biotic diversity.

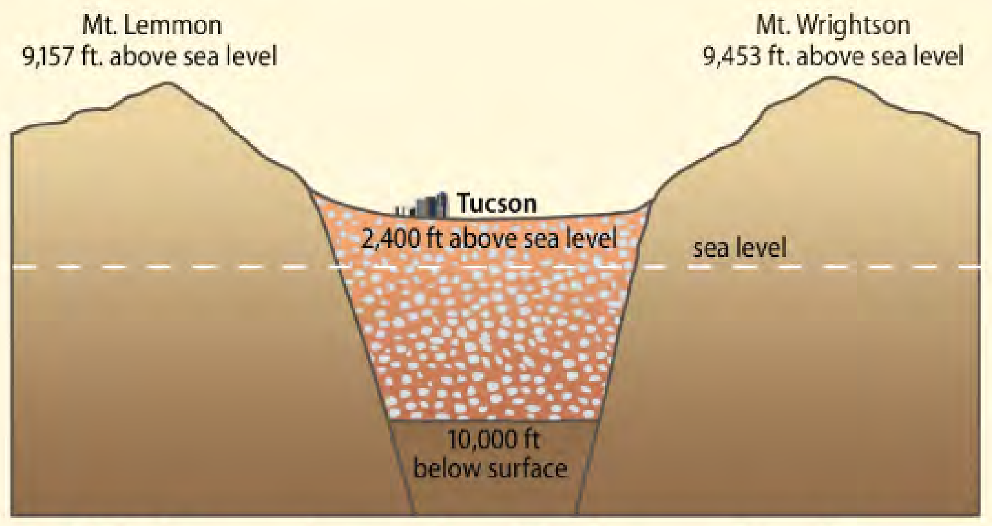
During the late Cenozoic, between 13 and 6 mya (December 31), continued crustal extension in an East-West direction resulted in a series of faults trending North-South. These faults, in turn, formed alternating uplifted fault-block mountains and valleys in the Southwest's Basin and Range Province. The faulted blocks had even less resistance to the rising granites, and as the basins dropped, the difference between basin floor and mountaintop increased, allowing the Catalinas to reach their present height.

Even as the mountain ranges rose over the basins below, they were attacked by weathering and erosion processes. Debris that washed or slid off the peaks softened the slopes and filled the basins with thousands of feet of coarse gravel, sand and silt—the porous sediments destined to become an extensive underground aquifer.

The youngest gravels on which most of Tucson sits consist almost exclusively of cobbles of gray Catalina Gneiss in an orange-colored sand and silt matrix known as the **Fort Lowell Formation (K)**. Found in the alluvial fan of



Pusch Ridge, where Tohono Chul Park rests, you can also see samples at the right edge of the Wall.



Fault-block mountains and the valleys between have huge vertical displacements, up to 15,000-20,000 vertical feet. Today, the depth of bedrock in the deepest parts of the Tucson Basin is more than 10,000 feet below the surface, while the crest of the Catalinas at Mt. Lemmon is 9,157 feet above sea level.

Where Do We Go From Here?

The final act has not yet played out for the Santa Catalina Mountains. Their promontories, canyons and other geologic features continue to weather and erode, sending pieces downhill to fill the Tucson Basin. The Mountains we see today are the sum of two billion years of geologic time; they may look the same from year to year, but they really are on the move.