EARTHQUAKE
e-Newsletter about what's movin' and shakin' at the Earth Science Museum

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March 2026
Volume 15, Issue 3

ESM OUTREACH UPDATE
Mardy Zimmermann Outreach Coordinator

Lynne & Terry Dyer attended a science fair the last week of February at Knox Gifted Academy in Chandler.

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You may have heard that throwing rocks, sticks, or other items in hot springs in Yellowstone is a bad idea (and also illegal), but have you ever wondered what it takes to remove them?

Yellowstone Caldera Chronicles
March 16, 2026

Yellowstone Caldera Chronicles is a weekly column written by scientists and collaborators of the Yellowstone Volcano Observatory. This week's contribution is from Tara Cross and Jeff Cross, researchers with the Geyser Observation and Study Association (GOSA), and Margery Price, Physical Scientist with the Yellowstone National Park Geology Program.

Since Yellowstone National Park was established in 1872, park managers have worked to prevent and repair the damage caused by heavy visitation. Hats, gum wrappers, and tissues blown away on windy days, and rocks and sticks thrown into hot springs, all spoil the natural beauty of the Park. Keeping Yellowstone's hot springs clean requires constant effort!

Damage from vandalism can be substantial. Minute Geyser, which once erupted as high as 60 feet in Norris Geyser Basin, stopped erupting in 1947 when a rock was thrown into its vent and could not be dislodged. Visitors have tossed countless coins, rocks, sticks, and other debris into Morning Glory Pool, one of Yellowstone's most popular features. Morning Glory has since cooled and changed color, probably because of this damage. Microbes now grow in the crater, dulling the delicate blue color that made it famous. To date, more than 6,574 coins have been removed from Morning Glory. Handkerchief Pool, in Black Sand Basin, also suffered severe damage. Early visitors learned that the spring's circulating waters could carry dropped handkerchiefs deep into the vent, then quickly return them. Following decades of people dropping their linen in the feature, Handkerchief stopped working in 1927, and it was 20 years before the spring recovered.

Rangers attempting to clean trash out of Morning Glory Pool in September 1975. National Park Service photograph Dan Ing. *Public Domain*.

George Marler, Yellowstone National Park geologist, recognized in the 1940s that rocks, logs, and other rubble had been thrown by visitors into hot springs, filling some features to their rims. A cleaning

project initiated by Marler in 1942 removed so much debris from the hot springs that pickup trucks were sometimes needed to cart it all away! Marler pointed out that many visitors to Yellowstone stay for only a day or two before moving on, and the time available to educate them on park laws is limited. Today, over 4 million visitors must be educated every year—a demanding task for park personnel!

Today, Yellowstone National Park's Geology Program cleans the hot springs. The team passes through the geyser basins with special tools, collecting debris and remediating vandalism (including carvings into bacterial mats) and other damage. One small hot spring near the Grand Prismatic Overlook was found in 2025 to be filled to its rim with sticks and rocks thrown in by visitors. The feature had been remediated in 2020, meaning that it only took five years for debris to fill the spring back up. In summer 2025, Geology Program team members removed over 6,000 items (mostly rocks, sticks, and chunks of old asphalt) from the feature. After the remediation, the spring's water flow and temperature increased—both signs that the debris removed had been blocking the vent and damaging the spring.

Hot spring located along the trail to the Grand Prismatic Spring overlook shown before and after the Yellowstone National Park Geology Program team cleaned the feature of sticks and rocks that were thrown in by visitors. National Park Service photos by Margery Price, July and September 2025.

There are other stories of success, too. A cleaning project at Solitary Geyser in 2021 removed at least 15 logs, the heaviest weighing up to 90 pounds, as well as rocks the size of basketballs and hundreds of smaller pieces of debris. Much of this material was cemented in place by silica sinter and required special effort to remove. Other hot springs cleaned in 2021 yielded 16 entire trees, 5 tree stumps, and thousands of other objects thrown in by visitors, including religious figurines, a crystal ball, a football, and an unopened bottle of beer.

Logs and debris removed from Solitary Geyser, near Old Faithful, during remediation work in 2021. Photo by Jeff Cross.

Cleaning hot springs is hard work! Some remediations, like the Grand Prismatic Overlook trail spring, require shovels, strainers, and grabber tools. The cleaning of Solitary Geyser, however, required a hook with a 16-foot extendable handle to remove large objects within the interior parts of the pool and hand rakes to collect the hundreds of wood splinters that had been thrown into the splash basins around the pool margin.

Yellowstone's stunning and unique landscapes contain more than 10,000 hydrothermal features, many of them near boardwalks and trails for us all to enjoy. What can park visitors do to help keep these

beautiful features healthy? Leave rocks and sticks where they are, throw trash into trash cans, and never throw anything into a hot spring or geyser.

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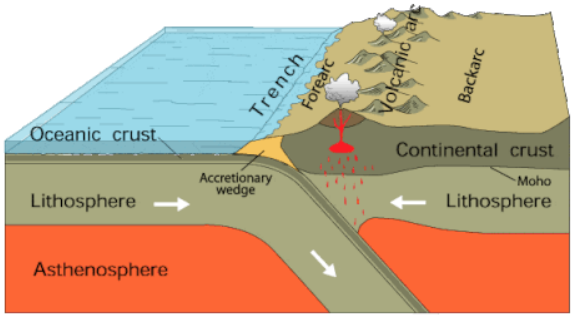
Continental Mantle Earthquakes

By Harvey Jong

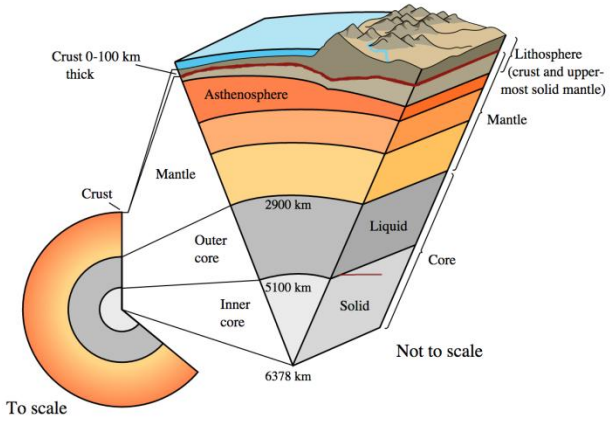
Earthquakes may occur in the crust or upper mantle at depths ranging from 0-700 km (0-435 mi). Based on the depth of focus (where a quake's fracturing begins and slippage occurs), earthquakes may be classified into three categories:

1. Shallow focus (0-70 km, 0-43.5 mi): These earthquakes occur mainly within the crust and include about 70% of all earthquakes. They also produce a majority of earthquake-related damage.
2. Intermediate focus (70-300 km, 43.5-186.4 mi): These earthquakes occur in subduction zones within the down going oceanic plate where the slab is heating and dehydrating. Intermediate-focus quakes may be felt over large areas, but involve less intense shaking than shallow earthquakes. Approximately 22% of global earthquakes have an intermediate focus.
3. Deep focus (300-700 km, 186.4-435 mi): These earthquakes are also associated with subduction zones, involving the deepest portion of the subducting slab. The deepest recorded earthquakes happened at approximately 700 km (435 mi) – near the boundary of the upper and lower mantle. Deep-focus earthquakes account for about 8% of global earthquakes.



Cross Section of a Subduction Zone
R.W. Saltus and A. Barnett/USGS diagram, - PD, via Wikimedia Commons

Continental mantle earthquakes (CMEs) represent a rare and somewhat controversial form of intermediate- and deep-focus earthquakes. Geoscientists have debated whether such seismic events could occur given the properties of the mantle (being more ductile than brittle). But in 2013, a magnitude 4.8 earthquake in the Wind River Mountains in central Wyoming provided the first confirmation of a CME (Wang et al., 2016). This quake, which occurred away from any convergent plate boundary, was determined to have a focal depth of 75 km ± 8 km (46.6 mi ± 5 mi). Since the crustal thickness around the site does not exceed 55 km (34.2 mi), the event happened within the lithospheric mantle below the Mohorovičić discontinuity or Moho.



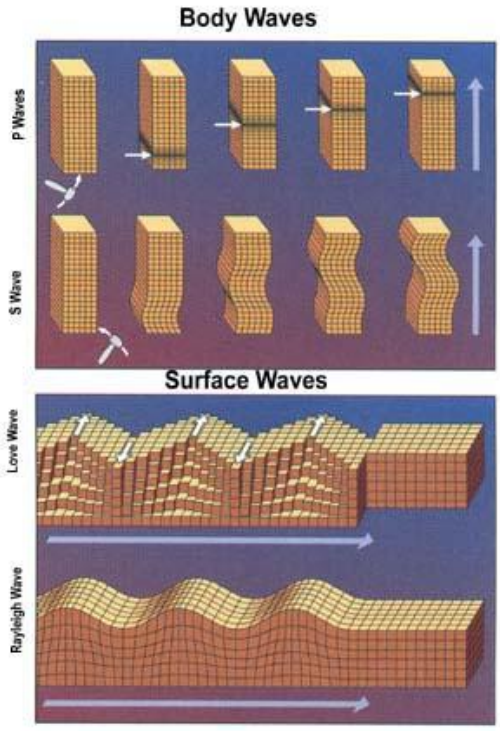
Earth's Internal Structure and the Moho
Volcano Hazard Program/USGS diagram, - PD, via usgs.gov

The red line in this diagram indicates the location of the Moho. This discontinuity represents the boundary between the crust and lithospheric mantle. It is characterized by a distinct change in the velocity of seismic waves as they pass through rocks with different composition and density. The Moho is located 5 to 10 km (3.1 to 6.2 mi) below the ocean floor and 20 to 90 km (12.4 to 55.9 mi) below continental crust with an average of around 35 km (21.7 mi).

Identifying Continental Mantle Earthquakes

With a confirmed CME observation, researchers started developing a method to identify similar quakes using seismic waveform data (Chen et al., 2021). Seismic waves generated by an earthquake can be grouped into the following categories and types:

- Body waves: travel through the Earth's interior and include two types:
  - Primary or compressional waves (P waves) – the faster of the two types of body waves. The name refers to the first waves detected at seismic stations. P waves can travel through solids or liquids.
  - Secondary or shear waves (S waves) – body waves that travel at about 60% of the speed of P waves. The propagation of S waves is limited to solids.
- Surface waves: propagate along the crust and include two types:
  - Love – named after British mathematician A. E. H. Love (1863-1940), who developed the mathematical model for this surface wave which involves entirely horizontal motion. The wave has the largest amplitude at the surface that diminishes with depth.
  - Rayleigh – named for British physicist John William Strutt (1842-1919), also known as Lord Rayleigh, who predicted the existence of this kind of surface wave in 1885. The wave rolls along the ground similar to an ocean wave with a complex motion where the ground moves up and down and forward and backward. Most of the shaking of an earthquake is due to Rayleigh waves.



Comparison of Body and Surface Waves
USGS diagram, - PD, via Wikimedia Commons
This diagram shows how particles move relative to the direction that a wave travels.

To identify CME's, geoscientists focused on comparing two prominent seismic wave phases that are preferentially excited in either the crust or mantle:

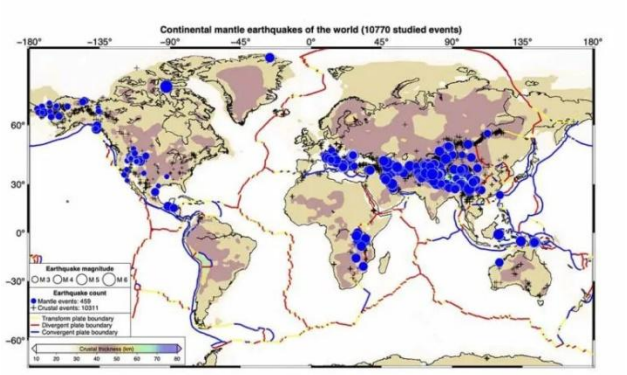
- The Lg phase is a guided surface wave with a velocity around 3.1-3.6 km per second (1.9-2.2 mi per second) and a frequency of 0.5-5 hertz.

- The Sn phase is a high frequency guided body wave that travels in the uppermost mantle below the Moho with frequency of 1 to 4 hertz or more. A typical Sn velocity in stable continental and oceanic lithosphere is around 4.7 km per second (2.9 mi per second).

Mantle earthquakes can be distinguished from those occurring in the crust by analyzing the ratio of the amplitudes of Sn and Lg (Sn/Lg) waves. A high Sn/Lg value corresponds to mantle earthquakes, while a low Sn/Lg ratio is associated with crustal quakes.

Distribution of Continental Mantle Earthquakes

In a recent paper, Stanford University scientists reported analyzing a USGS dataset of 46,616 earthquakes recorded from January 1, 1990 to April 10, 2024 to identify potential CMEs (Wang and Klemperer, 2026). Earthquakes with a minimum magnitude of 2.5 and occurring in areas with local crustal thicknesses of > 30 km (18.6 mi) and at least 50 km (31.1 mi) away from the boundaries of major subduction zones were selected for the study. These events were narrowed down to 10,770 potential candidates based on focal depths no more than 10 km (6.2 mi) above the local Moho depth and no deeper than 120 km (74.6 mi) along with the availability of nearby earthquakes at any depth to serve as a quality control for the analysis. Seismic ratios were applied to confirm the origin of the quakes. A global map of CMEs was constructed which shows the distribution and frequency of the estimated 459 deep earthquakes.



Global Distribution of Continental Mantle Earthquakes
Fig. 1 from (Wang and Klemperer, 2026), from https://phys.org/news/2026-02-global-rare-continental-mantle-earthquakes.html, accessed March 12, 2026
This map shows significant groupings of CMEs beneath the Himalayas in southern Asia and near the Bering Strait between Asia and North America, south of the Arctic Circle.

Significance of Continental Mantle Earthquakes

Given their uncommon occurrence and great depth, CMEs typically do not cause significant impact at the surface. These quakes, however, can provide insights into the characteristics of the upper mantle and the inner workings our planet.

References

Chen, B., S. Wang, K. Espinal, and S.L. Klemperer (2021) Above or below the Moho? Depth analysis of continental U.S. earthquakes using Sn/Lg ratio. *TechRxiv*. January 08, 2021.

Wang, S. and S.L. Klemperer (2026) Continental mantle earthquakes of the world. *Science*, 395(6785): 611-615.

Wang, X., D. Zhoa, and J. Li (2016) The 2013 Wyoming upper mantle earthquakes: tomography and tectonic implications. *Journal of Geophysical Research: Solid Earth*, 121(9): 6273-6987.

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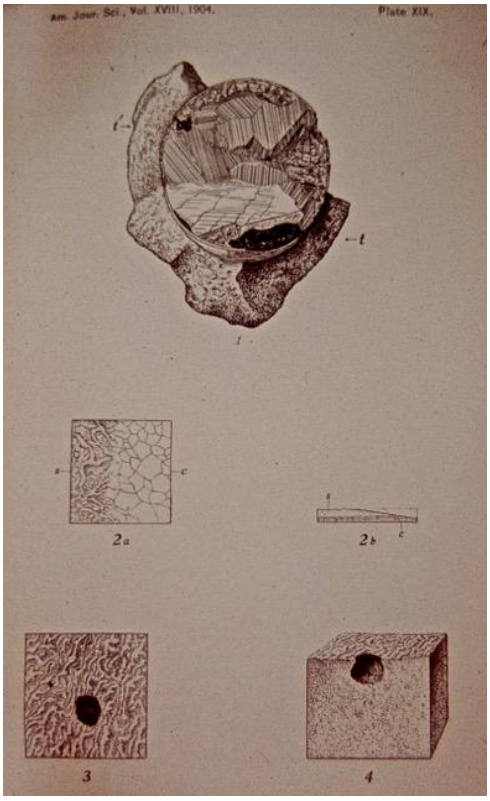
Arizona Rocks 154

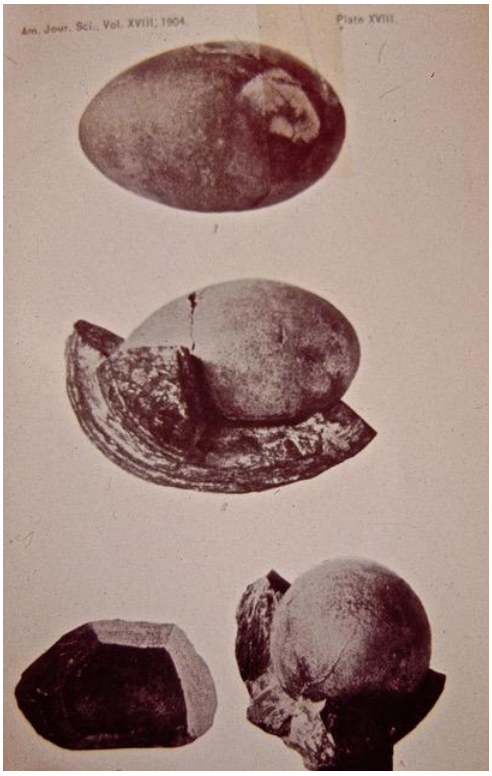
Text by Ray Grant
photographs from the American Journal of Science

Here is the story of Arizona's most unusual fossil specimen. I would not believe it was real, just a collector's tall tale, except there are photographs of it. It is a fossil egg filled with "crystallized colemanite and a tarry material resembling natural asphalts". Colemanite is calcium borate. The reference describing the specimen is Morgan, W. C., and Tallmon, M. C., 1904, A peculiar occurrence of bitumen and evidence as to its origin: Amer. Jour. Sci., v. 18, p. 363-377.

The specimen is described as "forming the center of a rounded mass of hard calcareous rock, which may be called the capsule or matrix. Its appearance is that of an ordinary irregularly shaped river pebble about 3.5x4x5 inches in dimensions. It is well worn by the action of water." The egg "separated readily and exposed what appears externally to be a typical egg in all respects. By comparison with eggs of birds of the present time, it is found to correspond closely with the type of egg laid by the cormorant. The egg was filled with "beautifully crystalline colorless colemanite."

It was supposed to been found by a prospector in gravels some distance above the present level of the Gila River. In the Mineralogy of Arizona it is placed in Maricopa County and one reference has it on the Gila River Indian Reservation north of Gila Bend and another reference has it in Yuma County north of Dateland. But I can find no real reason in any of the references for these locations. The article says it belonged to Mr. G. A. Helmore of San Francisco, California. I wonder where it is today?





Pinal Museum and Society News

351 N. Arizona Blvd., Coolidge, AZ

Pinal Geology and Mineral Society next meeting

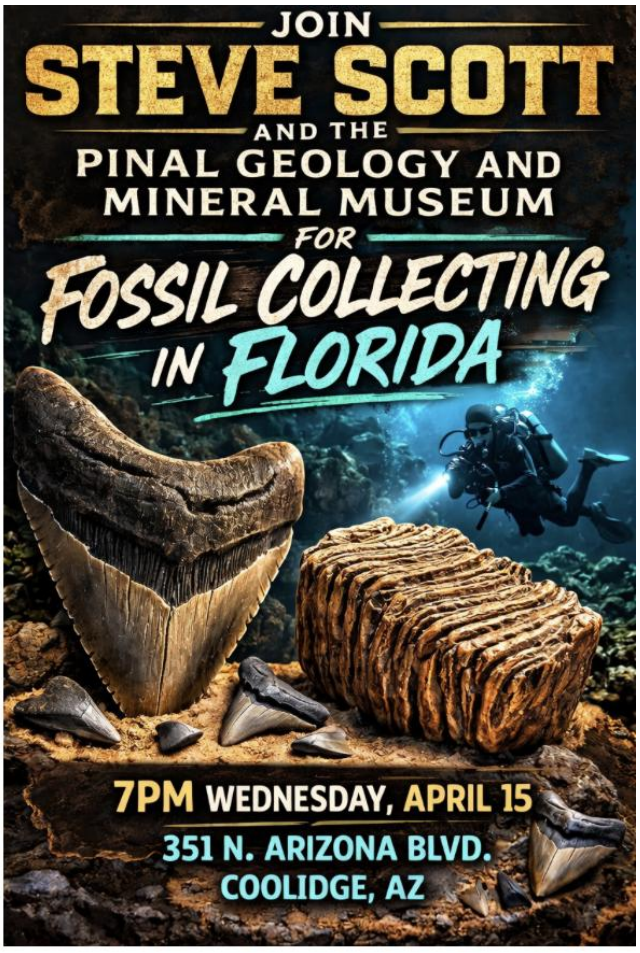
April 15, 2026

Meetings are the third Wednesday at 7pm, doors open at 6:00 so stop in early to have a look around and see what is new--we have added new displays and will have new loaned specimens on display!

www.pinalgeologymuseum.org

Ray Grant ray@pinalgeologymuseum.org

Pinal Geology and Mineral Museum
museum open Fridays & Saturdays from 10 - 4
admission is free.
Groups can arrange special visits please call 520-723-3009.



AZ Mining, Mineral & Natural Resources Education Museum Update March 2026

https://ammnre.arizona.edu/

Catie Carter Sandoval
cscarter@email.arizona.edu
703.577.6449

Help support the museum at:
http://tinyurl.com/SupportMM-NREMuseum

March has been a busy month for outreach. Marta and Catie started by attending 'Mining Day at the Capitol' on March 4th, hosted by the Arizona Mining Association. Mining Day is a yearly opportunity for us to connect with legislators and mining industry partners and celebrate the profound importance of mining in our copper state. Shortly after, we participated in the Tucson Festival of Books on the University of Arizona campus, where we joined other campus museums in the Science City tent. We brought our industrial mineral activity, which showcases mined materials in their raw and processed forms, and chatted with visitors about how we use rocks and minerals in our daily lives. Catie was also invited to be the guest speaker at the Sun City Rockhound Club's March Lunch and Learn event, and gave a presentation about the history of gold and silver mining in Arizona. It was a fun opportunity and the Rockhounds continue to be great friends to our museum. Finally, we gave an update about the museum at the Flagg Mineral Foundation's 33rd Annual Minerals of Arizona Symposium, where attendees expressed continued support for our project.

Outreach scheduled for April includes a school visit and exhibiting at the Galaxy STEM Fest at Heritage Square. We continue to work with our Governor-Appointed Advisory Council and design-build team to move towards construction on the building and will have some very exciting updates this fall.

Marta with Stantec colleagues at Mining Day at the Capitol.

Marta greeting visitors at the Tucson Festival of Books on the University of Arizona campus.

Group photo with the Sun City Rockhound Club at the Lunch and Learn event.

Sun City Rockhound Mineral Museum
Sundial Recreation Center
14801 N. 103rd Ave.
Sun City, AZ 85351

The museum offers private party tours for schools, clubs and individuals. We'd love to show off our museum to your club or private group. If you are interested, please contact the museum at scrockmuseum@gmail.com.

Please take a minute to check out our new website at scrockmuseum.com.

Oldest and Newest Specimens in the Museum

By Carol Bankert-George
Museum Director Emeritus

As you walk into our museum, you will see a sign that reads: "from a 2.3-billion-year-old rock to current man-made minerals". Let us start with the ancient end of the spectrum.
In cabinet # 5 you will find on display a 2.3-billion-year-old rock. It is **Kona Dolomite** from Michigan's upper Peninsula area. The intriguing patterns and inclusions you see in the rock are **Stromatolites** - layered structures formed by ancient cyanobacteria (blue-green algae). These are among the earliest known fossils of life on Earth, evidence of microbial mats that built up in shallow ancient seas over billions of years.
It is a humbling reminder of how far back our 'rockhound' passion goes!

On the other end of the spectrum is human-created specimens produced in laboratories and industrial settings. These synthetic materials have been engineered for use in industry, jewelry, and scientific research.

Within display cabinet #10, the second shelf features an array of metals and Tri-State minerals, accompanied by several specimens of mineral-like materials engineered by humans.
Bismuth – although bismuth occurs naturally, the colorful geometric crystals in the collection are lab grown or produced by smelting and slowly cooled to promote crystal growth.
Zincite – Zincite is zinc oxide typically bright orange - red color due to manganese and iron. Natural zincite is extremely rare and primarily found as small crystals from the Franklin, New Jersey mines. This specimen is a byproduct of zinc smelting from Poland.
Refined Zirconium- Zirconium is a corrosion-resistant metal extracted from mineral sands and alluvial deposits as a byproduct of titanium or tin mining. It is an essential material in nuclear reactor construction.
Fun fact – Cubic Zirconia (CZ), a synthetic form of zirconium dioxide, is a laboratory-created diamond simulant.
Silicon Carbide – A crystalline compound of silicon and carbon that was originally developed as an abrasive for grinding wheels and sandpaper. Today, it is also used in applications such as bullet-resistant armor and brake pads.

Come explore the journey from oldest to newest, the story comes full circle in display cabinet #10 as these four specimens represent the youngest in the museum collection. – be sure to visit and learn more.
Special thanks to Dana Slaughter of Pinal Geology and Mineral Museum for helping us identify these spectacular specimens!

Arizona Rock and Gem Shows

Arizona Rock and Gem Shows

ANNUAL SHOW
White Mountain Gem and Mineral Club
July 10-12, 2026
Fri. 9-5, Sat. 9-5, Sun. 10-4
Adults $5, Kids 17 and under free
Elks Lodge
805 E. Whipple
Show Low, AZ
whitemountain-azrockclub.org

22nd Annual Prescott Gem & Mineral Show
Prescott Gem & Mineral Club
July 31,2026 - August 2,2026
Fri. 9-5, Sat. 9-5, Sun. 9-4
$5 Admission,
$4 Seniors, Vets and Students
Children Under 12 Free
Findlay Toyota Center
3201 N Main St
Prescott, AZ
https://www.prescottgemmineral.org/

Arizona Rock and Gem Clubs

Apache Junction Rock & Gem Club
Meetings are on the 2nd Thursday
Next Meeting: April 9, 2026, 6:30 pm
www.ajrockclub.com
@ Club Lapidary Shop
2151 W. Superstition Blvd., Apache Jct.

Daisy Mountain Rock & Mineral Club
Meetings are on the 1st Tuesday
(unless a Holiday then 2nd Tuesday)
Next Meeting: April 7, 2026, 6:30 p.m.
www.dmrmc.com
@ Anthem Civic Building
3701 W. Anthem Way, Anthem, AZ

Maricopa Lapidary Society, Inc
Meetings are on the 3rd Tuesday
Next Meeting: April 21, 2026, 7:00 pm
www.maricopalapidarysociety.com
@ North Mountain Visitor Center
12950 N. 7th St., Phoenix, AZ

Mineralogical Society of Arizona
Meetings are usually on the 3rd Thursday
(Except June & December)
April 16, 2026, 6:30 pm
@ Franciscan Renewal Center, (Piper Hall),
5802 E. Lincoln Drive, Scottsdale, AZ
www.msaaz.org

Pinal Geology & Mineral Society
Meetings are on the 3rd Wednesday
Next Meeting: April 15, 2026, 7:00 pm
www.pinalgeologymuseum.org
351 N. Arizona Blvd., Coolidge

West Valley Rock & Mineral Club
Meetings are on the 2nd Tuesday
Next Meeting: April 14, 2026, 6:30 pm
www.westvalleyrockandmineralclub.com
Buckeye Community Veterans Service Center
402 E. Narramore Avenue, Buckeye, AZ

Gila County Gem & Mineral Society
Meetings are on the 1st Thursday
(unless a Holiday then the next Thursday)
Next Meeting: April 2 2026, 6:30 pm
www.gilagem.org
Club Building
413 Live Oak St, Miami, AZ

Wickenburg Gem & Mineral Society
Meetings are on the 2nd Friday
(February & December on the 1st Friday)
Next Meeting: April 10, 2026, 7:00 pm
www.wickenburggms.org
@ Coffinger Park Banquet Room
175 E. Swilling St., Wickenburg, AZ

ESM's Meeting Notice

ESM's next meeting will be at North Mountain Visitor Center, 12950 N. 7th St., Phoenix, on Tuesday, TBA 2026, at 6:30 p.m.

BECOME A MEMBER!
Join the Earth Science Museum's

IS IT TIME TO RENEW YOUR MEMBERSHIP?
Please renew today! ☺☺☺

_ _ _ _ _ _ _ _ cut here _ _ _ _ _ _ _ _ _ _

ESM Earth Science Investigation Team Membership Form

_____ New Member _____ Renewal

Membership levels:

_____ ESI Family $20

_____ ESI Individual $10

Membership benefits:

- Monthly e-newsletter *Earthquake*
- Official team membership card
- Knowledge that your contribution is making a difference in earth science education.

MANY THANKS TO OUR MAJOR DONORS!

AZ Leaverite Rock & Gem Society

Flagg Mineral Foundation
www.flaggmineralfoundation.org

Friends of the AZ Mining & Mineral Museum

Maricopa Lapidary Society
http://maricopalapidarysociety.com/

Mineralogical Society of AZ
www.msaaz.org

Payson Rimstones Rock Club
https://www.rimstonesrockclub.org/

Sossaman Middle School

White Mountain Gem & Mineral Club
www.whitemountain-azrockclub.org

Sun City Rockhound Club & Mineral Museum
https://suncityaz.org/recreation/clubs/rockhound-club-mineral-museums/

Wickenburg Gem & Mineral Society
http://www.wickenburggms.org
www.facebook.com/pages/Wickenburg-Gem-and-Mineral-Society/111216602326438

West Valley Rock and Mineral Club
http://www.westvalleyrockandmineralclub.com/

Staples Foundation
www.staplesfoundation.org

Anita Aiston	Will & Carol McDonald
Peter & Judy Ambelang	Debbie Michalowski
Stan & Susan Celestian	Janet Stoeppelmann
Russ Hart	Dennis & Georgia Zeutenhorst

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We're on the Web!

Visit us at:

www.earthsciencemuseum.org

Mission
Our Mission is to excite and inspire all generations about earth sciences through educational outreach.

Vision
We envision a community where students and the general public have curiosity about, passion for, and understanding of the underlying principles of earth sciences.

For more information about the ESM, how to become a member or how to arrange for a school visit or Community function, go to: www.earthsciencemuseum.org.

NOTICE:
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THANK YOU FOR YOUR CONTINUING INTEREST & SUPPORT!!!

Earth Science Museum
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