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

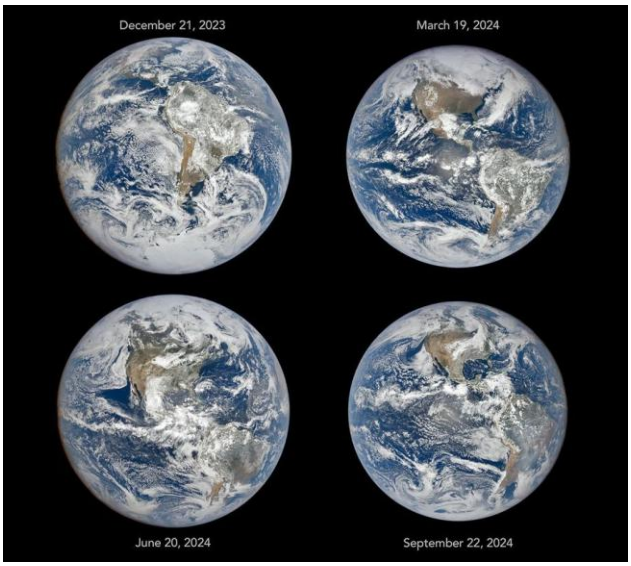
Earth Science Museum, 3215 W. Bethany Home Rd., Phoenix, AZ 85017
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October, 2026
Volume 15, Issue 10

Journey to the Earth's Center of Mass

By Harvey Jong

The Earth's center of mass (CM), or geocenter, represents a key reference point that is crucial for satellite navigation, elevation measurements, and geophysical studies. It moves relative to the Earth's ideal geometric center, or center of figure (CF), due to seasonal redistribution of water, ice, and air.



An EPIC View of the Seasons
Michala Garrison/NASA Earth Observatory image, -PD, via science.nasa.gov

These images were captured by NASA's Earth Polychromatic Imaging Camera (EPIC) during the December and June solstices and March and September equinoxes. They show the tilt of the Earth, shifts of the continents' apparent positions, and variations in atmospheric conditions throughout the year. Note that the image sizes differ due to the spacecraft's changing orbital path which varied from 1,447,327 kilometers (899,327 miles) from Earth on December 21, 2023 to 1,561,901 kilometers (970,520 miles) on September 22, 2024.

The geocenter is monitored using a combination of different space-based techniques, and a recent article published in the *Geophysical Journal International* described a more accurate way of estimating CM movements. This new approach suggests that variations are only half of what was previously thought (Argus et al., 2026).

Origins of the Center of Mass

When the concept of the center of mass originated is unknown, but the idea was known in the ancient Greek world with the writings of Archimedes of Syracuse (c. 287 BC-c. 212 BC), an ancient Greek mathematician, physicist, and engineer.



Archimedes of Syracuse (c. 287 BC- c. 212 BC)
Carlo Biondi (1811-1841) engraving, -PD, via Wikimedia Commons

Archimedes described the concept of the center of mass in his two volume treatise *On the Equilibrium of Planes*. He noted that the force exerted on a lever by weights resting at various points along the lever is the same as what it would be if all of the weights were moved to a single point—their center of mass. He also developed ways of determining the center of mass for various shapes, such as a triangle and hemisphere.

Determining the Earth's CM is complicated and involves monitoring our planet's ever-changing geometry using a number of ultraprecise techniques.

Satellite Laser Ranging (SLR)

Satellite Laser Ranging (SLR) uses short laser pulses to measure the round-trip time of flight from a ground station to a satellite equipped with corner cube mirrors or retroreflectors. Currently, over forty stations track these satellites for the International Laser Ranging Service (ILRS).

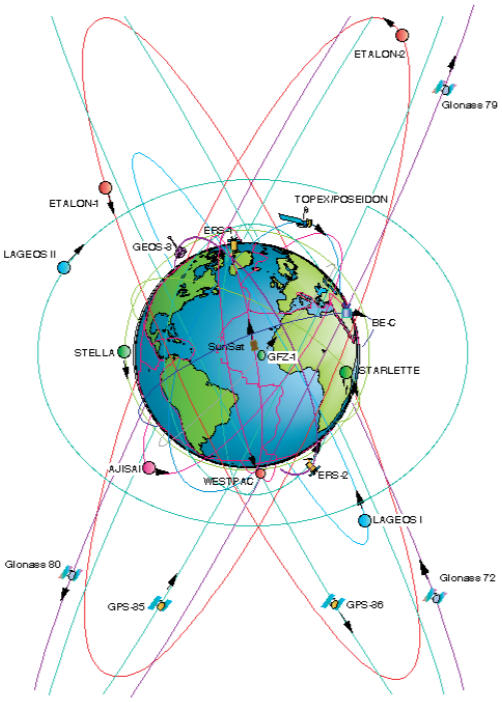


Next Generation Satellite Laser Ranging (NGSLR) System

Goddard Space Flight Center/NASA photo, -PD, via earth.gsfc.nasa.gov

The NGSLR system fires low energy (~1 mJ) pulses of a green laser (wavelength 532 nm) at a rate of 2 KHz. A sensitive single photon detector measures the arrival time of the reflected light with an accuracy of 1 ns. The overall range measurement precision is at the millimeter level.

The range data is used to establish the International Terrestrial Reference Frame (ITRF). To ensure that the reference frame origin is aligned with the center of mass, a model is constructed to estimate the motion of the geocenter.



Orbits of Some Satellites Tracked by the ILRS

Goddard Space Flight Center/NASA illustration, -PD, via ilrs.gsfc.nasa.gov

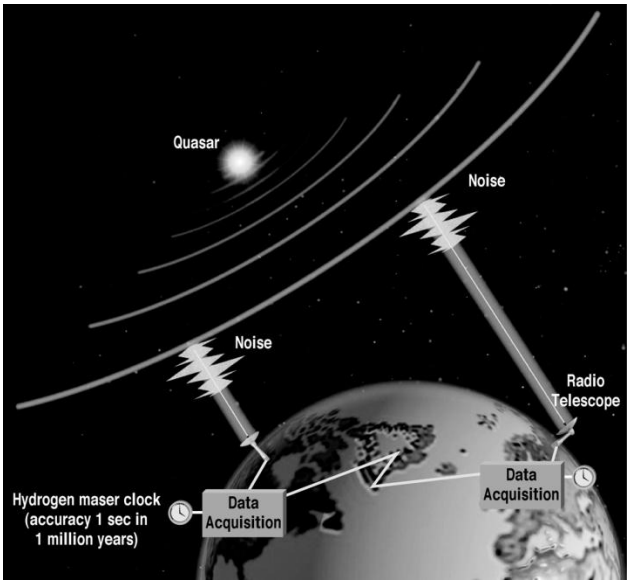
A number of space agencies, including NASA, ESA, JAXA, CNES, and DLR, have contributed to a global network of satellites equipped with retroreflectors. Over 120 satellites at altitudes ranging from 250 km (155 mi) to 35,000 km (21,748 mi) are routinely tracked.



NASA's LAGEOS 1 Satellite
Nasa photo, -PD , via Wikimedia Commons
The Laser Geodynamics Satellite (LAGEOS 1) was developed and launched by the NASA Marshall Spaceflight Center on May 4, 1976. Resembling a big disco ball, the 0.6 m (2-ft) diameter, 411 kg (906 lb) satellite orbits pole to pole and is used to measure movements on the Earth's surface. A second identical satellite was deployed on October 22, 1992 by the STS-52 space shuttle mission.

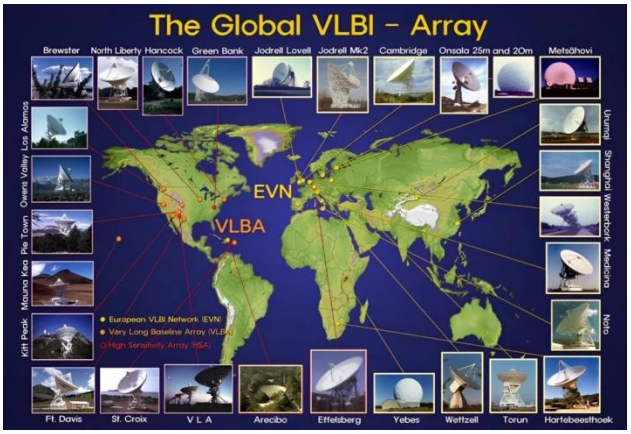
Very Long Baseline Interferometry (VLBI)

Very Long Baseline Interferometry (VLBI) uses a network of widely-spaced radio telescopes to observe distant quasars billions of light years away from Earth. It measures the difference in the arrival time of a quasar's radio signal between two telescopes.



Concept of VLBI
Goddard Space Flight Center/NASA diagram, -PD, via ivscc.gsfc.nasa.gov
The arrival of a radiowave front from a quasar is recorded by two radio telescopes. The data are time stamped with precise atomic clocks and cross-correlated to eliminate potential sources of error.

Since the time difference measurements are precise to a few picoseconds, VLBI can determine the relative positions of telescope antennas to a few millimeters. Instantaneous tracking of the Earth's orientation in space is possible since the telescopes are at fixed known locations. The technique has been used in monitoring plate tectonic motion, regional deformation, ocean tides and currents, and local uplift and subsidence which affect the geocenter.



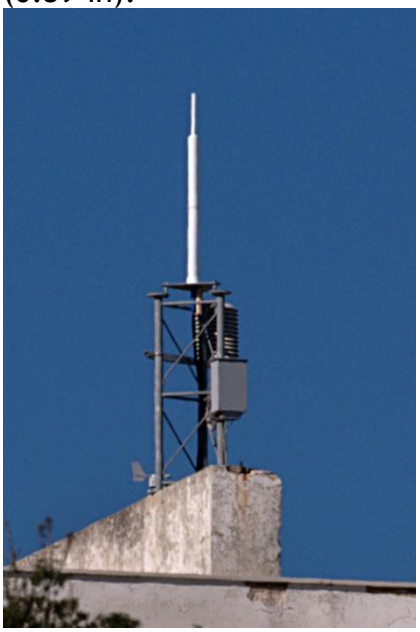
Global VLBI Network of Radio Telescopes
T. Krichbaum, MPIfR illustration, - CC_BY_SA-4.0, via
Over 50 radio telescopes are utilized in VLBI measurements.

Doppler Orbitography and Radiopositioning Integrated on Satellite (DORIS)

The Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) system was developed in the 1980s by the French space agency Centre National d'Etudes Spatiales (CNES) with the cooperation of Groupe de Recherche en Géodésie Spatiale (GRGS) and the Institut Géographique National (IGN). The system provides precise orbit determination and high accuracy location data of ground-based beacons. As indicated by its name, DORIS relies on satellites receiving signals transmitted from radio beacons on the ground. The frequency of these signals experience a Doppler shift due to the movement of a satellite.



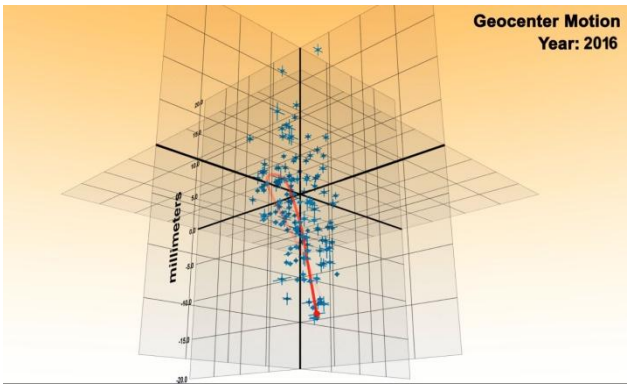
Artist Rendering of the Jason-3 Spacecraft
NOAA Satellites drawing, -PD, via Wikimedia Commons
The Jason-3 satellite, which was launched on January 17, 2016, measures sea surface height using a radar altimeter. Its instrument payload includes an improved DORIS receiver. Using two separate frequencies (401.25 MHz and 2036.25 MHz) to correct for ionospheric effects, this receiver allows the satellite's position to be determined with an accuracy below 1 cm (0.39 in).



UHF Transmitting Antenna of a DORIS Ground Station
SV1XV photo, - CC0-1.0 UPD, via Wikimedia Commons
Currently, the DORIS radio beacon network includes 60 sites which are distributed across the globe. This beacon is located at Dionysos, Greece.

New Method of Estimating Geocenter Motion

Satellite tracking data point out that the geocenter oscillates around the planet's geometric center. The total amount of annual oscillation is around several millimeters (Ralls, 2026).



Screen Capture of an Animation of Geocenter Motion from 1993-2017

NASA Scientific Visualization Studio animation, - PD, via nasa.gov
This animation traces the millimeter-scale geocenter movements from 1993-2017. Click on the above image to download the animation and view it using a video player."

Seasonal redistribution of air, ice, and water is responsible for these shifts, and for many years scientists have tried to estimate the size of the movements.

The accuracy of the geocenter motion estimates may be affected by the deformation of the Earth's surface, such as earthquakes, or by sample bias. Sample bias, which is known as the network effect, involves the clustering of tracking ground stations in North America and Europe while only a limited number of sites are located in the southern hemisphere. A variety of methods have been developed to compensate for these errors; however, big discrepancies in the estimated motion have occurred. For example, the last two ITRF estimates, made in 2017 and 2023, varied by 7 mm (0.28 in). This difference is almost as large as the total oscillation (Younger, 2026).

To reduce the uncertainty, a research team led by NASA's Jet Propulsion Laboratory proposed a new technique which includes:

- Integrating data from GPS and low Earth orbiting satellites to fill in gaps from the uneven distribution of ground stations
- Considering the deformation of the Earth's surface due to the weight of water and ice
- Identifying three drivers of seasonal geocenter shifts - atmosphere, oceans, and continental water. Continental water includes land ice, snow, lake water, river water, soil moisture, and groundwater.

In analyzing each of these causes, the researchers found that snow accumulation in North America and Eurasia peaks around March which shifts the geocenter about 3 mm toward the North Pole. In April, the Amazon's rainfall reaches a maximum (around 2,400 gigatons), and this moves the CM 2.2 mm southward. Between August and October, the oceans swell with meltwater and rain, and due to the size of the Pacific Ocean the geocenter is pushed toward the South Pacific Ocean. Around December 21 dense winter air tips the geocenter balance toward Arabia, Asia, and North Africa. The geocenter has a similar atmospheric shift toward South America and southern Africa around June 21.

Overall, the resulting estimate of the annual geocenter motion is about half of the value that was calculated eight years ago. This finding suggests that the mass of water and air moving between the Earth's hemispheres is smaller than previously thought (Argus et al., 2026).

References

Argus, D.F, K.M. Gaastra, B.J. Haines, M.B. Heflin, F.W. Landerer, A. Peidou, D.N. Wiese,1 G. Blewitt, C. Kreemer, H. Dobslaw, and M.J. Swarr (2026) Estimation and cause of the seasonal oscillation between Earth's centre of mass and centre of figure. *Geophysical Journal International* 247: 1-20, https://doi.org/10.1093/gji/ggag314

Ralls, E. (2026) "Earth's center of mass is moving, and scientists just found something surprising." Earth.com News, September 21, 2026, https://www.earth.com/earth-science/earths-center-of-mass-is-moving-and-scientists-just-found-something-surprising.

Younger, S. (2026) "NASA Watches Earth's Weight, Finds Center of Mass". NASA - Jet Propulsion Laboratory, September 16, 2026, https://www.nasa.gov/science-research/earth-science/nasa-watches-earth-weight-finds-center-of-mass.

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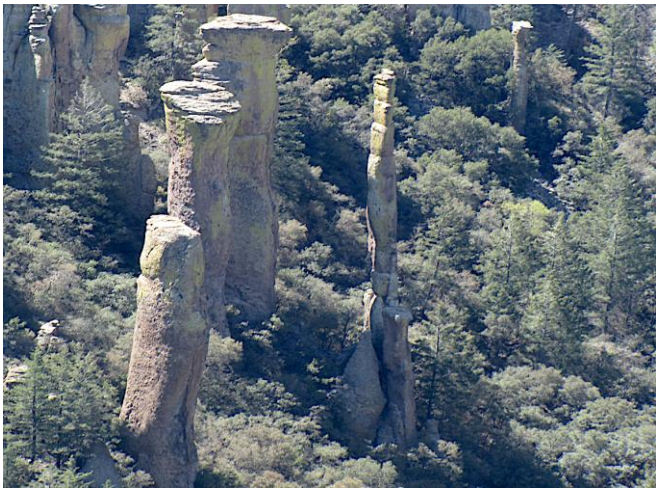
Arizona Rocks 161

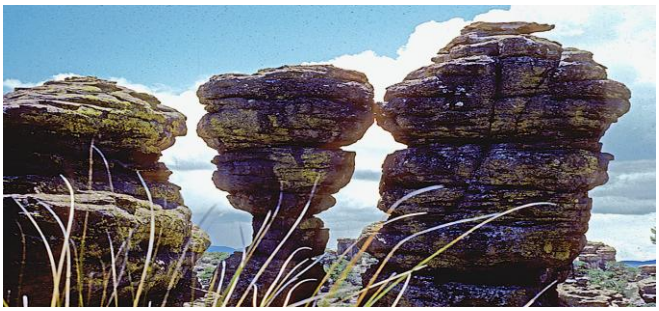
by Ray Grant
Text and photos by Ray Grant

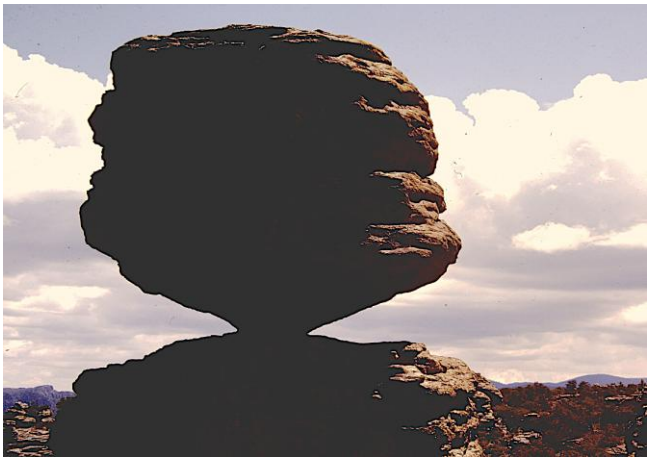
Here is a headline from the USA Today on October 21, 2026 about Arizona's new National Park, the fourth one in Arizona.

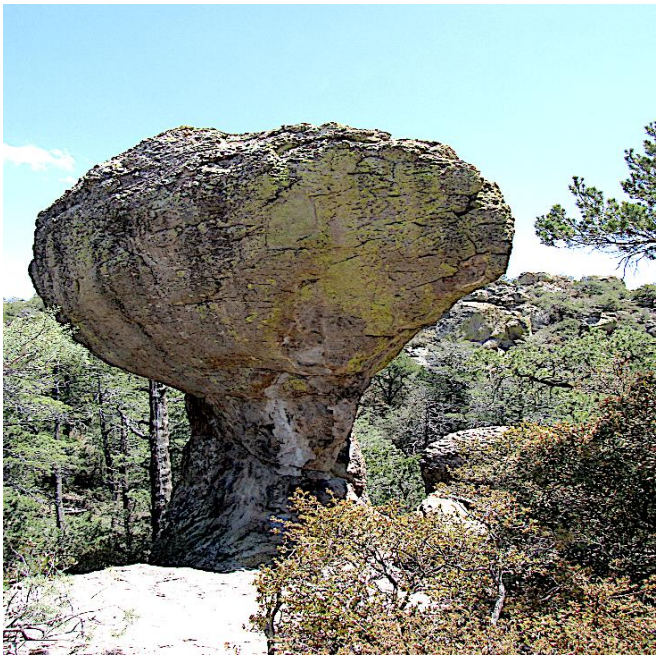
This "Wonderland of Rocks" just became America's newest national park

It is the Chiricahua National Park known for its unique rhyolite rocks. The rocks there are the same as the rocks in the Superstitions. The Chiricahuas formed from an explosive volcanic eruption 27 million years ago, and erosion has formed the columns, pinnacles, and balanced rocks. Arizona Rocks 104, January 2022, has a description of the geology of the park. You can see it by going to the ESM website and going to newsletters.











Pinal Museum and Society News

351 N. Arizona Blvd., Coolidge, AZ

Pinal Geology and Mineral Society next meeting

November 18, 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 Winter Hours

The museum is open Wednesday through Saturday from 10 - 4 admission is free.

Groups can arrange special visits, please call 520-723-3009.



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.



Winter Hours
October – April
10 am to 1 pm
Closed Thurs., & Sunday
Summer Hours
May-September
10am-1pm
Saturdays only

Tektites- Glass from the sky
Carol Bankert-George
Museum Director Emeritus

Here's a stone with a wild origin story: it was earth rock, thrown into the sky, and turned into glass before it ever landed.
Our museum's three tektites began with a catastrophe. When a meteorite slammed into the Earth, the impact melted the surface rock at the crash site and blasted it high into the atmosphere. The molten material cooled rapidly as it flew, and hardened into small glassy objects before falling back to the ground.
That flight left its mark. Tektites are often shaped like rounded drops, spheres, teardrops, or dumbbells, sculpted by spinning through the air while still molten. Most are black, dark brown or olive green. They also contain very little water, a clue that they formed at extreme temperatures.
They are not meteorite material, which they're often confused as. They are melted earth, not space rock. The meteorite supplied the energy and our planet supply the ingredients.

As for the three specimens the museum has on display, their exact locality is a mystery. That's not unusual for older collections, but it adds a little intrigue. Next time you're in the museum, take a look at these specimens that are located in the Arizona Treasures room located within the display cabinet housing our small collection of meteorites.



One of three tektites on display in museum

Fall Arts and Crafts Festival 2026

In November our annual fall festival at the Sundial recreation center will be held on Friday November 27th from 8 AM to 4 PM and Saturday, November 28 from 8 AM to 3 PM. Many Sun City clubs (including three lapidary clubs) will be selling handcrafted items. The Rockhound club will have eight tables of rocks and minerals for sale at 'rock bottom' prices. The museum will be open, extended hours on both days.

Arizona Rock and Gem Shows

Gila County Gem & Mineral Society
Show and sale
November 7, 2026
Bullion Plaza Cultural Center &
Museum Yard
150 Plaza Circle
Sat. 9-2
Free Admission
Miami, AZ




54TH ANNUAL
FLAGG GEM & MINERAL SHOW
A TRIBUTE TO PAUL HARTER
MALACHITE PS. AZURITE, QUARTZ
FLAGG MINERAL FOUNDATION
MALACHITE PS. AZURITE
BISBEE, COCHISE, ARIZONA
PAUL HARTER COLLECTION
PHOTO BY JEFF SCOVIL
JAN 8 TO 10 2027
ROSASITE, MALACHITE PS. AZURITE
VANADINITE PS. WULFENITE
MALACHITE PS. AZURITE, QUARTZ
MESA COMMUNITY COLLEGE NE CORNER
OF US 60 AND DOBSON ROAD
FRI-SAT 9AM - 5PM | SUN 9AM - 4PM
www.Flaggshow.info
FREE ADMISSION | FREE PARKING | FREE SAMPLES FOR KIDS

Arizona Rock and Gem Clubs



Apache Junction Rock & Gem Club
Meetings are on the 2nd Thursday
Next Meeting: November 12, 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: November 3, 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: November 17, 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)
Next Meeting: November 19, 2026
Meeting Location: Franciscan Renewal Center, Piper Hall
5802 E. Lincoln Drive, Scottsdale,
Go to our website for more info.
www.msaaz.org



Pinal Geology & Mineral Society
Meetings are on the 3rd Wednesday
Next Meeting: November 18, 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: November 10, 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: November 5, 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: November 13, 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! ☺☺☺

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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:
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.

THANK YOU FOR YOUR CONTINUING INTEREST & SUPPORT!!!

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