EARTHQUAKE

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

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ESM OUTREACH UPDATE

Mardy Zimmermann, Outreach Coordinator

The American Geosciences Institute (AGI) organizes this annual educational event which helps the public gain a better understanding and appreciation for the Earth Sciences.

Poster courtesy of the American Geosciences Institute

There are no ESM outreach activities to report this month, but please join ESM board members and members of the Maricopa Lapidary Society in Save Our Mountains Foundation's **"Geology Day at North Mountain Visitor Center"** in celebration of Earth Science Week Oct. 8-14.

Saturday, October 14, 2023

12950 N. 7th Street, Phoenix

9 a.m. to 3 p.m.

Please join the Maricopa Lapidary Society (MLS) members as they celebrate their 75th Anniversary and will offer:

- ✓ Silent auctions throughout the day
- ✓ Demonstrations of wire wrapping, cabochon cutting and gemstone faceting by Society members

MLS 75th Anniversary Cake and Beverages to be served - *While they last!*

At 9:30 a.m. please join Harvey Jong, ESM president, for his presentation on:

Volcanoes in the News, in History, and in Arizona

Volcanoes on Earth are openings in the crust where lava, ash, and gases escape. Volcanic activity has and continues to play a major role in shaping our planet and human history. This presentation provides an overview of how and where volcanoes form, the different types of volcanoes, and classification of eruptions. Numerous examples are described including recent eruptions, such as the Hunga Tonga and Mauna Loa volcanoes; historic eruptions, such as Vesuvius, Krakatoa, and Mount St. Helens; and volcanic fields in Arizona, such as the San Francisco field near Flagstaff. It concludes with an introduction and invitation to explore the Earth Science Museum's *Volcanic Rocks & Minerals* display which features samples from several famous volcanoes.

- ➢ Inspect a display of meteorites and get answers to your questions about them. Is your specimen a meteorite or a "meteor wrong"? Bring your specimen and find out!
- ➢ Examine specimens of metamorphic, sedimentary and igneous rocks.

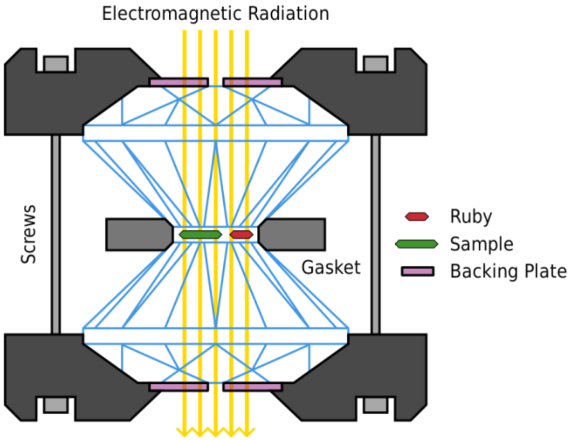
At 1:00 p.m. please join Alex Richardson, Grand Canyon Geology professor and Save Our Mountains Foundation at NMVC volunteer, for a talk on the "Geology of North Mountain."

The Mineralogy of the Earth's Core

By Harvey Jong

A recent paper (Ikuta et al., 2023) on a more accurate multimegabar pressure scale for evaluating the Earth's composition provided the inspiration for this article. The new scale, which is based on precise measurements of X-ray scattering and diffraction by a rhenium sample in a diamond anvil cell, suggested that earlier pressure standards may have overestimated values by at least 20%.

This error may imply that the light element content of the Earth's inner core could be double what was previously estimated; or that the Earth's inner core temperature is much higher than expected; or some combination of composition and temperature.



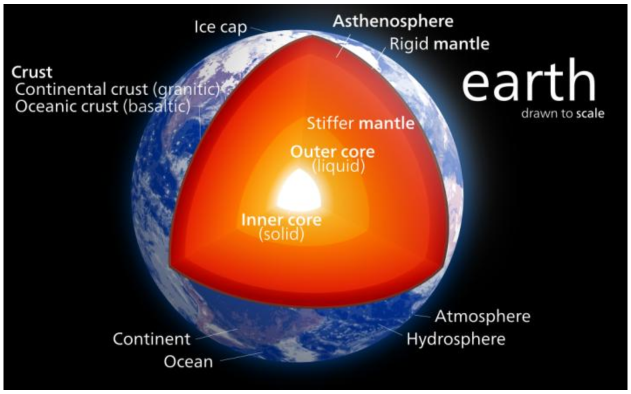
Cross Section of a Diamond Anvil Cell
Tobias1984 diagram, - CC_BY_SA-3.0, via Wikimedia Commons

Ultrahigh pressures (up to 770 gigapascals or 7.7 million times the atmospheric pressure at sea level) can be created when a sample is compressed between two opposing diamond tips. The pressure is monitored using a standard material, such as ruby as shown in the diagram, whose characteristics under pressure are known. Electromagnetic radiation, such as X-rays, passes through the sample chamber where interactions with the sample are measured.

I had assumed that the Earth's core consists mainly of a mixture of iron and an iron-nickel alloy, so a dramatic increase in light elements represents an interesting topic to explore. It raises several questions, such as which elements are involved, their concentrations, and how they might combine to form minerals that are stable at the core's ultrahigh pressures and temperatures.

Structure of the Earth

To start exploring these questions, we will first review the Earth's structure. Based on composition, our planet is divided into four main layers: the crust, the mantle, the outer core, and the inner core.



Internal Structure of the Earth
Kelvinsong graphic, - CC_BY_SA-3.0, via Wikimedia Commons

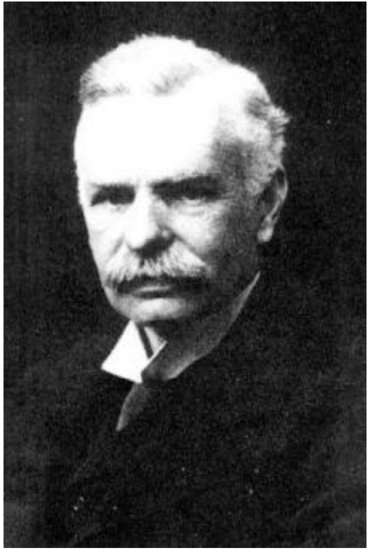
The depth, volume, and density of these layers are listed below:

Layer	Depth	Volume	Density
Crust	0-100 km	0.6%	2.7-3.3 g/cm^3
Mantle	100-2900 km	83.4%	3.2-5.7 g/cm^3
Outer Core	2900-5100 km	15.6%	9-9-12.9 g/cm^3
Inner Core	5100-6378 km	0.7%	12.9 g/cm^3

Discovery of the Core

The core is inaccessible due to its extreme depth, pressure, and temperature. The only direct observations involve the seismic waves from earthquakes which travel at different velocities through the Earth. Seismic monitoring stations record separate arrival times for different groups of these waves. The first to arrive are known as primary or P-waves and are related to compression. The next set of waves, called secondary or S-waves, are associated with lateral displacement or shear.

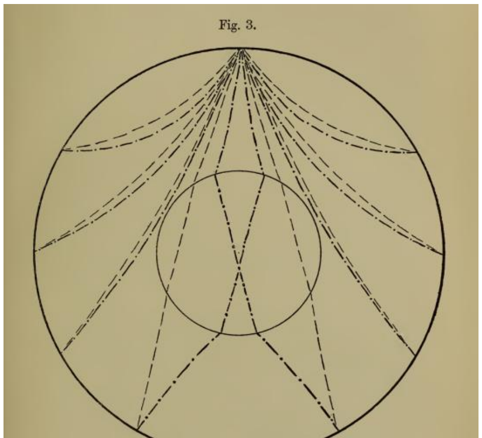
British geologist Richard Dixon Oldham (1858-1936) compared seismic data collected at different distances from the epicenters of numerous earthquakes.



Richard Dixon Oldham (1858-1936)
Unknown photographer, - U.S. PD, via Wikimedia Commons

He noted a discontinuity in the travel times for S-waves at about 120° from an earthquake and suggested that a dense core with a diameter of about 0.4 that of the Earth was refracting the waves. He published his findings in 1906 which presented the first direct evidence of the existence and size of the Earth's core.

Fig. 3.



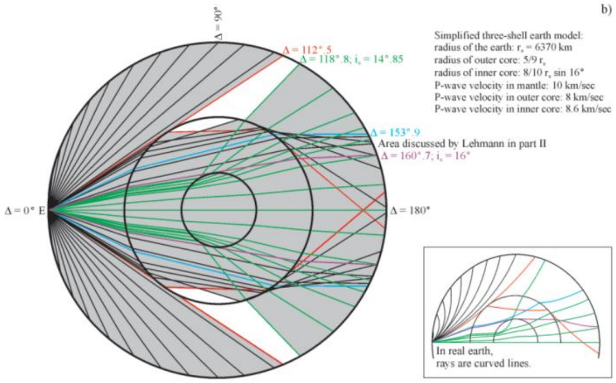
[The broken lines represent the first phase, the broken-and-dotted lines the second phase, and the continuous curve the third phase.]

Transmission of Earthquake Waves
Richard Dixon Oldham (1858-1936) diagram Figure 3 from (Oldham, 1906) which show different types of waves and how their propagation is affected by the Earth's core.

For many years, the core was believed to be a single molten sphere. This model, however, was unable to account for discrepancies in detailed seismic measurements. Danish seismologist and geophysicist Inge Lehmann (1888-1993) carefully analyzed the data and concluded that a solid inner core surrounded by a molten outer core could produce the seismic observations. In 1936, she published her interpretation in a classic geology paper (Lehmann, 1936) titled simply as P'.

Inge Lehmann (1888-1993)
Even Neuhaus (1863-1946) photo, taken in 1932, - U.S. PD/CC_BY_SA-4.0 International, via Wikimedia Commons

P’ refers to P-waves that pass through the mantle into the core and then pass through the mantle again. It is interesting to note that Lehmann conducted her research before computers were available and deduced a solid inner core by sorting earthquake locations and wave arrival times written on cardboard cards and placed in oatmeal boxes. Computer calculations would later confirm her conclusions 35 years after the publication of the article (Dahlman, 2005).



Propagation of P-waves Through Lehmann’s Simplified Three-shell Earth Model
Screen capture from Kölbl-Ebert (2001), -CC_BY_SA-4.0, via episodes.org
This drawing was created using data from Lehmann’s 1936 paper. The red rays correspond to P-waves that meet the outer core at a grazing angle. The blue rays indicate the critical angle of incidence involving the far boundary of the core’s shadow zone. The green rays depict P-waves that pass through the inner core. The purple rays meet the inner core at a grazing angle. Note that the waves travel in curve lines, but the rays are shown as simplified straight lines.

Recent seismic studies have detected additional discontinuities in how P-waves travel in the inner core, suggesting an innermost inner core. A consensus, however, has not been reached as models either estimate a radius varying from 300-400 km or propose anisotropic hemispheres.

Models of Core Composition

Unlike the mantle, no samples of the core have been found on the Earth’s surface. So, the exact composition of the core remains unknown, and the modeling of core constituents has been vigorously debated since the 1950s. Given the limited direct evidence, these models must work within geochemical and cosmochemical constraints and must match results from high pressure-temperature experiments, theoretical calculations, and seismic observations. A starting point for estimating core composition involves chrondritic meteorites, the oldest known rocks dating back to the origin of the Solar System (ca. 4,567 Ma).

Chondrites represent one of the three main groups of meteorites and have not been modified from either melting or planetary differentiation. They formed by the accretion of dust particles and small grains in the early Solar System. Chondrites are further categorized into three major classes:

1. Carbonaceous – most oxidized of the chondrites, contain iron as an oxide in silicates, and may be in rich in organic carbon
2. Enstatite – most reduced of the chondrites and may include native metals, especially iron
3. Ordinary – most abundant type and have an intermediate oxidation state

Some Carbonaceous Chondrites

NASA photo, - PD, via Wikimedia Commons
From left to right: Allende, Tagish Lake, and Murchison meteorite falls

A subclass of carbonaceous chondrites, CI, is noteworthy since their compositions closely match that of the Sun's photosphere. Since the Sun contains >99.9% of the Solar System's mass, a core composition that matches these chondrites might be assumed. However, the Earth formed under very different conditions involving planetary differentiation and extensive oxidation, so meteorites can only serve as a guide to understanding the composition of the core.

Light Elements in the Core

The core's light elements refer to elements with low atomic number, such as hydrogen, carbon, oxygen, silicon, and sulfur. Their presence accounts for a density deficit relative to a core model based on just pure iron.

To use chondrites to estimate which elements are present in the core and their ratios, a cosmochemical context is created where elements are classified based on predicted volatility in a protosolar gas and on chemical behavior observed in meteorites and the Earth.

With regard to volatility, elements may be divided into the following groups (Larimer, 1988):

1. Refractory: elements with condensation temperatures >1250 K
2. Moderately volatile: elements with condensation temperatures <1250 K and >600 K
3. Highly volatile: elements with condensation temperatures <600 K

From a chemical behavior perspective, elements may be partitioned into these categories:

1. Lithophile: elements that readily bond with oxygen and are concentrated in the crust and mantle
2. Siderophile: elements that readily bond with iron and are concentrated in the core
3. Chalcophile: elements that readily bond with sulfur and are distributed between the core and mantle
4. Atmophile: elements that are gaseous and are concentrated in the atmosphere and hydrosphere

Combining the two different classification schemes leads to a cosmochemical periodic table of the elements:

Cosmochemical Periodic Table of the Elements in the Solar System

K. Lodders diagram based on (Lodders, 2003)
Chemical behavior groups are shown as color-coded boxes, while volatility is indicated by condensation temperature values at 10^{-4} bar

Developing a model for the composition of the Earth's core involves a four step process:

1. Estimating the composition of the silicate Earth (the crust plus mantle)
2. Determining a volatility curve for the planet based on the abundance of moderately and highly volatile lithophile elements in the silicate Earth
3. Calculating the bulk Earth composition using the volatility curve, chemical data for chondrites, and first-order features of the planets in the Solar System.
4. Subtracting the mantle composition from the bulk Earth composition.

The following table from (McDonough, 2014) shows a possible composition of the Earth's core based on such an analysis. Concentrations are given in $\mu g\ g^{-1}$ (ppm) unless denoted by "%" in which they are expressed in wt%.

A Possible Model of the Composition of the Earth's Core

Elem.	Conc.	Elem.	Conc.	Elem.	Conc.
H	600	Zn	0	Pr	0
Li	0	Ga	0	Nd	0
Be	0	Ge	20	Sm	0
B	0	As	5	Eu	0
C (%)	0.2	Se	8	Gd	0
N	75	Br	0.7	Tb	0
O (%)	0	Rb	0	Dy	0
F	0	Sr	0	Ho	0
Na (%)	0	Y	0	Er	0
Mg (%)	0	Zr	0	Tm	0
Al (%)	0	Nb	0	Yb	0
Si (%)	6	Mo	5	Lu	0
P (%)	0.2	Ru	4	Hf	0
S (%)	1.9	Rh	0.74	Ta	0
Cl	200	Pd	3.1	W	0.47
K	0	Ag	0.15	Re	0.23
Ca (%)	0	Cd	0.15	Os	2.8
Sc	0	In	0	Ir	2.6
Ti	0	Sn	0.5	Pt	5.7
V	150	Sb	0.13	Au	0.5
Cr (%)	0.9	Te	0.85	Hg	0.05
Mn	300	I	0.13	Tl	0.03
Fe (%)	85.5	Cs	0.065	Pb	0.4
Co	0.25	Ba	0	Bi	0.03
Ni (%)	5.2	La	0	Th	0
Cu	125	Ce	0	U	0

Note that this model assumes that no radioactive elements are present in the core due to inconsistencies with chemical and isotopic observations in the mantle. It also proposes a core rich in chromium and vanadium (50-60% of the Earth's budget for these elements), and this is based on volatility trends and the silicate Earth composition.

Inner and Outer Core Compositions

As the Earth slowly cools, the inner core is crystallizing from the outer core resulting in a partitioning of light elements between the solid and molten layers. Seismic data indicates the density changes around ~4.5% and 6.7% across the inner core boundary. This implies that the outer core may contain ~5-10% light elements, while the inner core has ~2-3% light elements (Vočadlo, 2015).

Using mineral physics data along with cosmochemical and geochemical estimates, Hirose et al. (2021) determined a likely range of compositions for the outer core to be:

Fe + 5% Ni + 1.7% S + 0–4.0% Si + 0.8–5.3% O + 0.2% C + 0–0.26% H by weight

Based on molecular dynamic simulations, the researchers showed the compositional range of the inner core to be:

Fe + 5% Ni + 0–1.1% S + 0–2.3% Si + 0–0.1% O + 0–1.3% C + 0–0.23% H by weight

Mineralogical Models of the Core

After building a set of component elements and their concentrations, the next challenging aspect of modeling core composition involves how these elements might combine and form mineral phases. The candidate mineral assemblages have to account for density deficits with respect to a core made of pure iron. Their presence also has to be consistent with extreme core conditions; reflect the core's anisotropic properties and layered structures; and exactly match seismic observations.

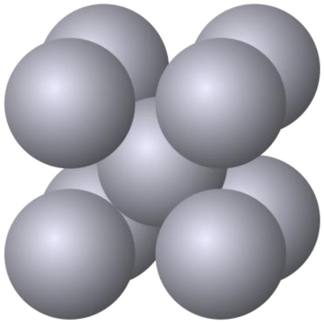
One early mineralogical model relied on the average composition of 318 iron meteorites and assumed the core contains a "considerable amount, up to ~5% or so, of phosphides (schreibersite, $(Fe,Ni)_3P$), carbides (cohenite, Fe_3C), sulfides (troilite, FeS) and carbon (diamond and graphite)" (Washington, 1925). This assumption seems reasonable for a rough approximation since phosphorus, carbon, and sulfur are among the 12 most common in the Earth, but it doesn't account for any of the key modeling constraints.

For a more detailed look, we will start our mineralogical journey into the core with the most dominant element, iron.

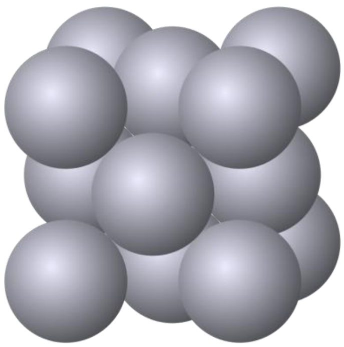
Iron Phases

Iron has four allotropic forms which can exhibit one of three different crystal structures. Three of these forms, alpha iron (α-Fe or ferrite), gamma iron (γ-Fe or austenite), and delta iron (δ-Fe), can exist at atmospheric pressure depending on the temperature. The fourth phase, epsilon iron (ε-Fe or hexaferrum), is stable at very high pressure (about 10-13 gigapascals [GPa]), but is controversial due to varying reports on the nature of its crystal structure.

Alpha iron (α-Fe), which occurs at temperatures below 912 ˚C (1,674 ˚F), has a body-centered cubic (bcc) crystal structure. A bcc structure includes 2 atoms per unit cell (the smallest repeating unit of a crystal), and α-Fe has a density of 7.87 g/cm^3.

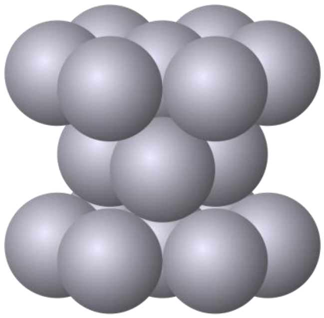

Body-centered Cubic Crystal Structure User:ARTE drawing, - PD, via Wikimedia Commons

When iron is heated about 912 ˚C but below 1394 ˚C, its crystal structure changes to a face-centered cubic (fcc) structure. Four atoms are present in an fcc unit cell which results in a greater density of 8.14 g/cm^3 for γ-Fe.


Face-centered Cubic Crystal Structure User:ARTE drawing, - PD, via Wikimedia Commons

If the temperature is raised above 1394 ˚C, iron reverts back to the bcc structure and remains stable up to its melting point of 1,538 ˚C (2,800 ˚F).

At pressures above 10-13 GPa and temperatures around 700 K, α-Fe transitions to the hexagonal close-packed (hcp) structure of ε-Fe. γ-Fe will also assume an hcp structure, but a higher pressure is needed due to the higher temperature. An hcp unit cell contains six atoms.


Hexagonal Close-packed Crystal Structure User:ARTE drawing, - PD, via Wikimedia Commons

Crystal structure represents an important consideration in estimating core composition since the space in a lattice unoccupied by iron atoms can be filled by other atoms.

Experimental results and computer simulations suggest that hcp-Fe, which has the lowest free energy, is likely the most stable iron phase at inner core pressures. These studies, however, also show that the free energy differences between the three phases are very small (within ~35 meV – atom^{-1}). So, with high temperatures and alloying with light elements, it is possible that fcc-Fe and bcc-Fe phases may also be found in the inner core (Vočadlo, 2015).

Iron Alloys

We will now focus on iron alloys with an overview of the general alloy characteristics. An alloy is a substance that is formed by metallic bonding of a metal with other elements. The other elements may replace some metal atoms producing a substitutional alloy. If, instead, these elements fill voids in the metal's crystal lattice, the alloy is known as an interstitial alloy. Alloys involving a metal and only one element are called binary alloys, while combinations of a metal; two elements are known as ternary alloys; and quaternary alloys involve three elements.

Alloys retain most of the key properties of metals, but certain attributes, such as density, elasticity, and melting point, may be modified. The effect of some elements will be discussed.

The Effect of Nickel

It is generally assumed that a small amount of nickel alloyed with iron will not have a significant effect on core properties since the two elements have similar densities while high core temperatures minimize the impact on seismic wave velocities. Nickel, however, has an fcc structure, so adding nickel in higher amounts, such as 10 wt%, can stabilize the fcc phase over the hcp phase. But geochemical models estimate nickel concentrations to be around ~5 wt%.

Light Elements

Unlike nickel, the presence of light elements in iron alloys can significantly modify core properties. Specifically, these elements can:

1. Depress iron melting points
2. Stabilize the bcc phase over the hcp phase
3. Reduce density
4. Decrease seismic wave velocities

Potential light element candidates include hydrogen, carbon, oxygen, silicon, and sulfur. Hydrogen and carbon, however, are highly volatile elements that are unlikely to be incorporated during core formation. These elements are also questionable since high amounts are needed to satisfy density deficit requirements.

Oxygen and silicon represent prime light element candidates given the outer core is surrounded by a silicate lower mantle. Oxygen, however, has two issues:

1. Geochemical models indicate the core formed with little or no oxygen
2. Oxygen and silicon seem to be mutually exclusive in liquid iron. In fact, silicon is used by the steel industry as a deoxygenating agent

Recent experimental and computational studies, though, show that it is possible for Fe_nO compounds to form under core pressures (Liu et al., 2023).

Silicon and sulfur seem promising given their relatively high estimated concentrations (~6 wt% and ~1.9 wt%, respectively) and the elements reduce core elasticity and shear-wave velocities.

Ternary and Quaternary Iron Alloys

Li et al. (2018) reported that despite extensive studies over many years no single binary iron alloy has been identified that simultaneously match all the constraints on core density and seismic wave velocities. Using computer simulations, the investigators found that a ternary alloy (hcp-$Fe_{30}Si_1C_1$) and solid solutions of a number of other ternary and quaternary alloys are able to satisfy the constraints. The stability of these phases under core conditions is not known.

Summary

Since the Earth's core is inaccessible, its chemical composition is unknown. Seismic observations provide the only direct evidence, so indirect sources, such as high pressure-temperature experiments; cosmo- and geochemical relationships; and theoretical calculations, help in inferring estimates of the nature and concentration of core constituents. Improvements in seismic monitoring and computational capabilities reveal new details about core evolution and revise assumptions about core conditions. This enhanced data, however, also serve as constraints that a composition model must satisfy. Other constraints include core density deficits, anisotropic seismic wave propagation, and layered structures. As a fully consistent, widely accepted model has not yet been constructed, the mineralogy of the Earth's core remains a work in progress.

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On Saturday, Oct. 14, an annular solar eclipse will be visible in parts of the U.S., Mexico, and Central and South America. Only a partial eclipse (~80%) can be seen from Phoenix. Below is a NASA pinhole projector, and instructions on using the viewer can be found at https://nasa3d.arc.nasa.gov/detail/usa-eclipse-2023

AZ Mining, Mineral & Natural Resources Education Museum Update September 2023

https://ammnre.arizona.edu/

Catie Carter Sandoval
cscarter@email.arizona.edu
703.577.6449

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

In September, we continued working with our design-build team to prepare for building renovations, and assembled the Governor-appointed Advisory Council for a meeting to discuss design plans, funding strategies and the Museum Director search. That search has progressed, and University of Arizona administration is currently conducting interviews with candidates. Expect to hear more soon!

In other news, we are finalizing plans for a guest exhibit at the Sun City Mineral Museum, run by the Sun City Rockhound Club. It is a fabulous museum located at the Sun Dial Recreation Center in Sun City, AZ. They have over a thousand rocks and minerals on display, with cases featuring historic Arizona minerals, gemstones, fluorescents, fossils, lapidary items and more. Our display will feature a selection of collector's pieces, mining ores, industrial minerals and lapidary art. Below are a few of the specimens we have selected for the exhibit. We will share more about the final product after installation in October.

Thank you all for your continued support!

Cases of minerals at the Sun City Rockhounds Mineral Museum - We highly recommend a visit!

Close up of barite from the Magma Mine, Superior, AZ showing tabular crystal form.

Malachite, quartz and chrysocolla from the Inspiration Mine, Miami, Gila Co., AZ.

Travertine from Mayer, Yavapai Co., AZ

Vanadinite (in a less common color) from the Puzzler Mine, Castle Dome Mts., Yuma Co., AZ

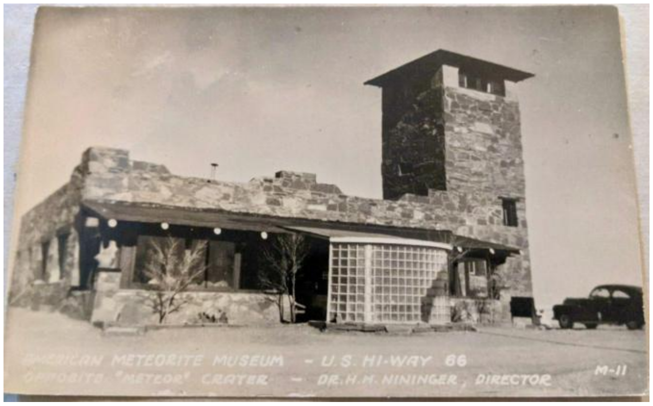
Arizona Rocks 124

Text by Ray Grant

Arizona is important in the study of meteorites in large part because of Meteor Crater and Harvey Nininger. He collected hundreds of meteorites from the Midwest and opened the American Meteorite Museum in 1946 on route 66 about 5 miles from Meteor Crater. Nininger wanted Meteor Crater to be part of the National Park system, but the Barringers, who owned the crater, fought him and after that they would not let him on the crater property. When the highway location was changed in 1950 he lost most of his customers and in 1953 moved his museum to Sedona.

Nininger, being in his 70s in the late 1950s decided to sell his meteorite collection. There was interest from many places including Harvard and the Smithsonian. Finally the British Museum bought about 20% of the collection and in 1960 the rest went to Arizona State University. It was Nininger's preference that the collection stay in the U.S. and that it end up in Arizona due to the importance of crater research. With the meteorite collection at ASU, they established the Center for Meteorite Studies. Carleton Moore was the first director. He led the research center for over 40 years and published many scientific advances and continued to build the meteorite collection. In Carleton's memory the ASU collection has been renamed the Carleton B. Moore Meteorite Collection.

ASU photo



Nininger's Museum by Meteor Crater from 1946 to 1953

Nininger's museum in Sedona from 1953 to 1960

Harry Nininger

Pinal Museum and Society News

351 N. Arizona Blvd., Coolidge, AZ

Pinal Geology and Mineral Society next meeting

October 18, 2023

The Pinal Club October meeting speaker will be:
Dana Slaughter talking about the Minerals of Bisbee

Meetings are the third Wednesday at 7pm, doors open at 6:30.

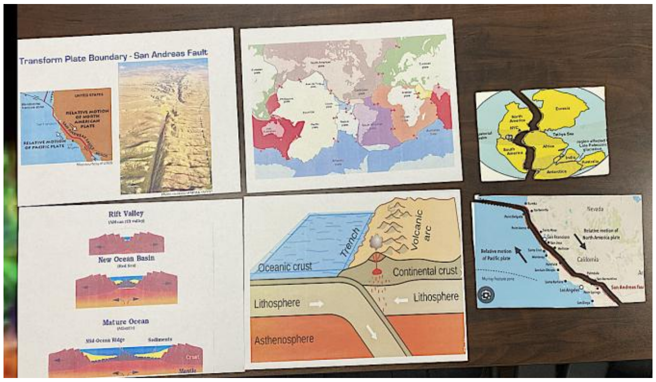
www.pinalgeologymuseum.org

Ray Grant ray@pinalgeologymuseum.org

Starting on Wednesday September 6 through next May, we will have our hours of 10 to 4 Wednesday through Saturday, admission is free.

On September 8, the Museum hosted another home school group visit. There were 41 students and 16 parents. Eleven students older than 12 had a lesson in plate tectonics and the whole group did the Museum tour and treasure hunt.

Each older student got a set of plate tectonic handouts; these are from Mardy Zimmerman's ESM school visits material.



Arizona Rock and Gem Shows

West Valley Rock & Mineral Club

Annual Show

October 13-15, 2023
Fri. & Sat. 9-5, Sun. 9-2
Adults $3, Children under 13 free
Buckeye Arena
802 N. 1st Street
Buckeye, AZ

Huachuca Mineral and Gem Club

49th Annual Show

October 14-15, 2023
Sat. 9-5, Sun. 10-4
Free Admission & Parking
Sierra Vista Mall
2200 El Mercado Loop
Sierra Vista, AZ

Sedona Gem and Mineral Club

Annual Show

October 21-22, 2023
Sat. 10-5, Sun. 10-4
Adults $5 Children 12 and under free
Sedona Red Rock High School
Hwy 89A at Upper Red Rock Loop Rd.
Sedona, AZ

October 21 & 22
Sat 10-5 / Sun 10-4
Sedona Red Rock High School – 89A at
Upper Red Rock Loop Rd, W. Sedona
Hourly Raffles
Grand Prize
Admission - $5
Children 12 & under Free
SEDONA Gem & Mineral Club

Lake Havasu Gem & Mineral Society

53nd Annual Lake Havasu Gem & Mineral Show

November 11-12, 2023
Sat. 9-5, Sun. 9-4
Adults $2
Children 12 and under free
Aquatic Center
100 Park Avenue
Lake Havasu, AZ

Wickenburg Gem & Mineral Society

Wickenburg Gem & Mineral Show
November 25 & 26, 2023
Sat. 9-5, Sun. 10-4
Free Admission
Hassayampa Elem. School
251 S. Tegner
Wickenburg, AZ

Wickenburg Gem and Mineral Show
Nov 25 & 26, 2023
Free Admission
gemclub.info
Jewelry
Fossils
Minerals
Over 40 Vendors Best Rock Contest Raffle
Door Prizes Kid's Area Silent Auction
Hassayampa Elementary School
251 South Tegner Street Wickenburg, AZ
9am - 5pm Saturday • 10am - 4pm Sunday

Apache Junction Rock & Gem Club

Meetings are on the 2nd Thursday
Next Meeting: October 12, 2023, 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: October 3, 2023, 6:30 p.m.
Please go to their website for more info
www.dmrmc.com
@ Anthem Civic Building
3701 W. Anthem Way, Anthem, AZ

Maricopa Lapidary Society, Inc

Meetings are on the 1st Monday
(unless a Holiday then 2nd Monday)
Next Meeting: October 2, 2023, 7:00 pm
www.maricopalapidarysociety.com
@ North Mountain Visitor Center
12950 N. 7th St., Phoenix, AZ

Mineralogical Society of Arizona

Meetings are on the 3rd Thursday
(Except December & June)
Next Meeting: October 19, 2023, 7:30 pm
Franciscan Renewal Center, (Piper Hall),
8502 E. Lincoln Drive, Scottsdale, AZ
Please go to their website for more information
www.msaaz.org

Pinal Geology & Mineral Society

Meetings are on the 3rd Wednesday
Next Meeting: October 18, 2023, 7:00 pm
In person meeting
www.pinalgeologymuseum.org
351 N. Arizona Blvd., Coolidge

West Valley Rock & Mineral Club

Meetings are on the 2nd Tuesday
Next Meeting: October 10, 2023, 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: October 5, 2023, 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: October 13, 2023, 7:00 pm
www.wickenburggms.org
@ Coffinger Park Banquet Room
175 E. Swilling St., Wickenburg

ESM's Meeting Notice

ESM's next meeting will be at North Mountain Visitor Center, 12950 N. 7th St., Phoenix, on Tuesday, TBA 2023, at 6:30 p.m.

BECOME A MEMBER!

Join the Earth Science Museum's

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

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

Sossaman Middle School

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

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

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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.

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

Name: ______________________________

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Phone:
602-973-4291

Editor E-Mail:
scote@earthsciencemuseum.org

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 2023, at 6:30 p.m.

THANK YOU FOR YOUR CONTINUING INTEREST & SUPPORT!!!

Earth Science Museum
3215 W. Bethany Home Rd.
Phoenix, AZ 85017