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

On February 12th, Shirley Coté conducted another mineral identification class at North Mountain Visitor Center. In attendance were nine members from local rock and mineral clubs and an interested local hiker.

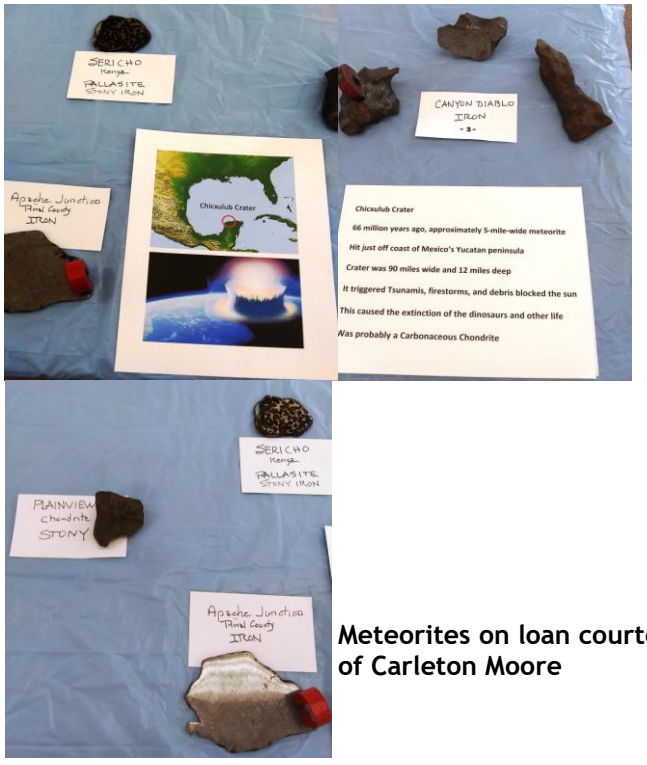
Shirley and participants during Mineral ID class

On March 10th, Lynne and Terry Dyer with the help of Tom Osborn attended a science fair at Chandler Traditional Academy. Lynne reported that they were constantly interacting with students and parents for two hours and were told there were around 500 in attendance. "*It was amazing! Tom was a tremendous help*".

After a well deserved day of rest, Lynne and Terry set up their "mini museum" at the Pinal Geology and Mineral Museum for the Pinal Gem and Mineral Show.

ESM members Doug Duffy, Shirley Coté, Mardy and Dick Zimmermann helped with selling egg cartons, lapidary material and mineral specimens taking in over $200 for the museum's operations.

Ray Grant oversaw the hands-on meteorite display where attendees at the show could hold some of the different types of meteorites.



Meteorites on loan courtesy of Carleton Moore

Iron meteorites from Canyon Diablo and Apache Junction, a stony chondrite from Plainview and a rare stony iron pallasite from Kenya containing olivine crystals.

On March 14th, Lynne and Terry Dyer once again set up their "mini museum" of rocks, minerals, and fossils to teach 34 sixth grade students and 129 third, fourth and fifth grade students, and eight teachers at Challenger Basic School in Gilbert.

Challenger Basic School

Also on March 14th, Doug and Shirley gave a presentation to 35 members of the Rockhounds West Club in Sun City West on "Rockhounding in Arizona" in which they included some photos of displays from the old AZ Mining and Mineral Museum on the subject and the ever popular "Banquet of Rocks".

Lapidary material found in Navajo and Coconino Counties

Yavapai County

Mohave County

"Banquet of Rocks"

Highlights of the 2022 Tucson Gem and Mineral Show® Exhibits – Part 2 Daylight Displays

By Harvey Jong

In the last edition of the newsletter, we presented a few highlights of the fluorescent mineral displays at the 67th Annual Tucson Gem and Mineral Show®. This month we will focus on the daylight displays which involve the secondary show theme of the apatite supergroup and a tribute to Richard "Dick" Graeme III.

Apatite Supergroup

The apatite supergroup represents another attempt by the International Mineralogical Association (IMA) to standardize mineral nomenclature. In 2008, the IMA proposed "tidying up" mineral names by adding suffixes, hyphens, and diacritical marks. The changes included renaming fluorapatite to apatite-(CaF), hydroxylapatite to apatite-(CaOH), and chlorapatite to apatite-(CaCl). The new scheme was not well-received given the widespread, historical usage of the original mineral names. So, the IMA nomenclature subcommittee revisited the changes and restored fluorapatite, hydroxylapatite, and chlorapatite as valid species names. The subcommittee, however, went on to define the apatite supergroup that includes any mineral with the generic chemical formula of:

$$^{IX}M1_2{}^{VII}M2_3(^{IV}TO_4)_3X\ (Z = 2)$$

where

M may be Ca^{2+}, Pb^{2+}, Ba^{2+}, Sr^{2+}, Mn^{2+}, Na^{+}, Ce^{3+}, La^{3+}, Y^{3+}, or Bi^{3+}

T may be P^{5+}, As^{5+}, V^{5+}, Si^{4+}, S^{6+}, or B^{3+}

X may be F^{-}, $(OH)^{-}$, or Cl^{-}

(See Pasero et al., 2010) The new supergroup encompasses phosphates, arsenates, vanadates, silicates, and sulphates resulting in an unwieldy number of member species. So, using crystal chemistry and symmetry attributes, the supergroup was divided into five groups:

1. Apatite group
2. Hedyphane group
3. Belovite group
4. Britholite group
5. Ellestadite group

It's not clear if the new hierarchical taxonomy has really helped clean up the naming of minerals, but it certainly has introduced more confusion.

Several museums and private collectors assembled displays featuring the apatite supergroup. Some cases presented the wide, colorful variety of minerals belonging to the supergroup.

American Museum of Natural History (AMNH) Exhibit

The AMNH display pointed out the importance of the apatite supergroup in hosting most of the phosphorus in the Earth's crust. In addition to the vibrant specimens from various groups, the case included fossil shark teeth to highlight how phosphorus (via hydroxylapatite) is present in bones, teeth, and even horns of vertebrates.

Carnegie Museum of Natural History Display

The Carnegie Museum case involved a rock 'n roll theme where minerals were treated as "rock stars" and "groupies" of the apatite supergroup. Specimens included several fluorapatites, mimetites, pyromorphites, and vanadinites.

Other displays focused on just the apatite group or a specific species, such as fluorapatite.

Apatite Group Specimens from the John Rakovan Collection

This display presented apatite group specimens from worldwide locations along with background on the discovery and naming of the mineral. It pointed out that apatite was recognized as a distinct mineral in the late 18th century and because it is easily confused with other minerals its name is derived from the Greek word "apatáō" which means "to deceive".

Apatite Type Locality, Specimen, and Commemorative Medals

The Rakovan case featured the apatite type locality, Sauberg Mine, Ehrenfriedersdorf, Germany, and a specimen from this mine. It also included a pair of medals commemorating the locality and apatite discoverer, Abraham G. Werner.

Apatite Group Display from the Collection of Don Dallaire

This case described the different occurrences of the apatite group and presented specimens found in pegmatites, alpine-type clefts, carbonate vein-dikes, and magnetite-apatite deposits.

Harvard University Mineralogical & Geological Museum Display

The Harvard Museum case featured fluorapatite specimens from various worldwide localitites including Brazil, Canada, Mexico, Pakistan, Portugal, Sweden, and the United States (California, Maine, Massachusetts). A few faceted gemstones from Madagascar, Maine, and Mexico were also on display.

Fluorapatite Gemstones
Left: Madagascar; Middle: Pulsifer Quarry, Auburn, Maine; Right: Cerro De Mercado, Durango, Mexico

Maine Mineral & Gem Museum's Fluorapatite Display

Maine has many granite pegmatite quarries that have produced excellent, well-formed fluorapatite crystals. The Maine Mineral & Gem Museum presented a suite of purple and blue fluorapatite specimens from 13 different localities which included the Bennett, Mt. Marie, Mt. Mica, and Pulsifer Quarries.

Tribute to Richard "Dick" W. Graeme III (1941-2021)

Richard "Dick" Graeme III was a well-known and respected collector of Bisbee minerals. He started collecting minerals at the age of six and compiled an exceptional and very comprehensive assortment of specimens along with an extensive research library and photo archive on the mines of Bisbee. He worked in the copper industry for 55 years in a variety of roles ranging from a "mucker" in the Campbell Mine; resident geologist at the Copper Queen Branch; to Senior Vice President/General Manager of Lumina Copper SAC. He retired in Lima, Peru and passed away on June 2, 2021.

In 1959, Dick Graeme collected some unusual specimens from an ore car at the 1200 level of the Cole Mine. A sample was later analyzed in 1975 by Sid Williams. A new copper tellurite mineral was identified and named graemite (Williams and Mater, 1975). The rare mineral was on display as part of a special exhibition of Bisbee minerals and mining artifacts assembled as a tribute to Dick Graeme.

Graemite

This well-known specimen was featured on the back cover of the third edition of the *Mineralogy of Arizona*. It is from the Shattuck Mine and is part of the Arizona-Sonora Desert Museum collection.

Arizona-Sonora Desert Museum Display

In addition to graemite, the Desert Museum case included fine specimens of aurichalcite, azurite, brochantite, chalcotrichite, malachite, rosasite, turquoise, variscite, and even a wulfenite.

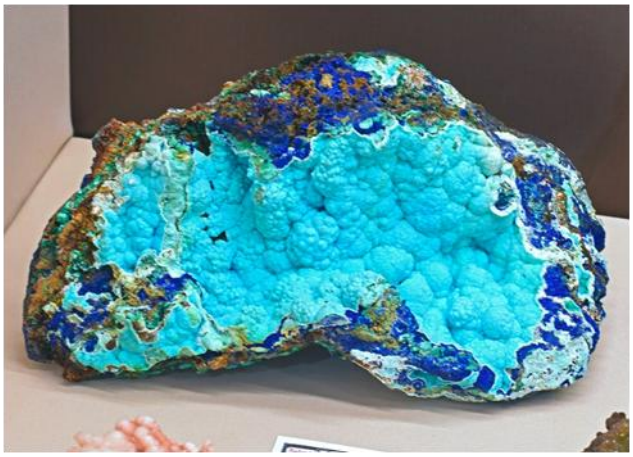
Wulfenite

Wulfenite is a somewhat uncommon, minor occurrence at Bisbee and has been found in the Campbell orebody (Rasmussen, 2008). This specimen is from the Holbrook Mine.

Some other museum displays included:

Arizona Mining, Mineral, and Natural Resources Education (AMMNRE) Museum Display

Large specimens of azurite, calcite, chalcoalumite, copper, malachite, and siderite along with a candle holder and crucible were featured in the AMMNRE Museum exhibit.



Chalcoalumite with Azurite

The AMMNRE Museum case included this bright turquoise-blue botryoidal chalcoalumite from the Holbrook Mine. Chalcoalumite was discovered in Bisbee in 1925 and is named for its composition which includes copper (chalco) and aluminum (alum).

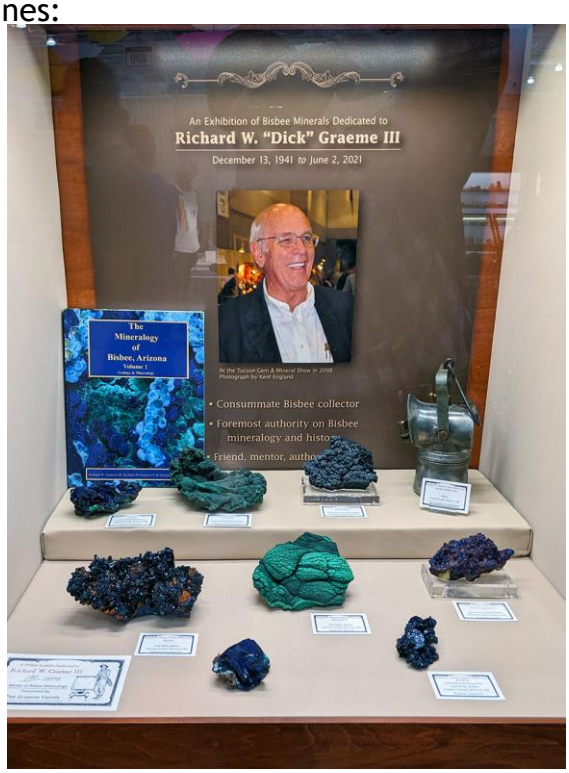
Bisbee Mining and Historical Museum Display

The Bisbee Mining and Historical Museum's case included a miner's hard hat and carbide flask and a colorful assortment of azurite, copper, and malachite specimens. The copper after hammer in the middle of the display provided an interesting example of a post-mine mineral.

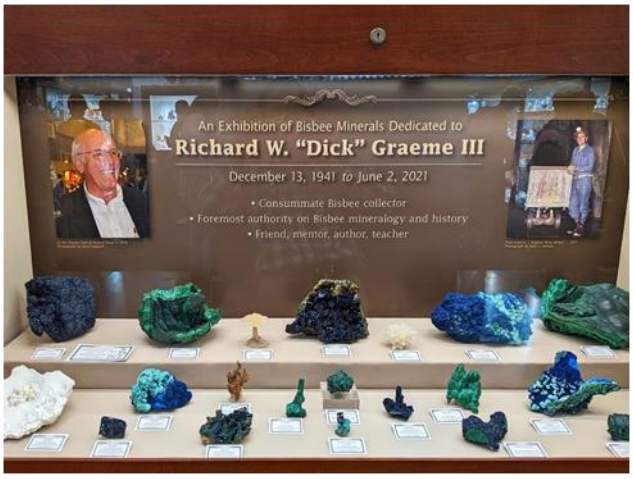
UA Alfie Norville Gem and Mineral Museum Display

The UA Alfie Norville Gem and Mineral Museum highlighted malachite "stalactites" in its display of Bisbee minerals. The exhibit also mentioned that Dick Graeme and his sons helped design the museum's stope diorama and similar underground mining exhibits at the Smithsonian Institution and the Bisbee Mining and Historical Museum.

Several private collectors presented exceptional specimens from various Bisbee mines:



Bisbee display from the Graeme Family



Display by the Graeme Family

Dick Graeme and his sons, Richard Graeme IV and Douglass Graeme, assembled the one of most comprehensive collection of Bisbee minerals with some 7000 specimens. This display presented just a few examples of the large azurite and malachite specimens and unusual forms of aragonite and calcite in the collection.

Pete Gustafson and Heidi Riedle Display

This case featured a large calcite from the Southwest Mine accompanied by azurite, copper, malachite, and malachite after azurite specimens from the Campbell, Czar, Holbrook, Junction, and Sacramento Mines.

Evan and Melissa Jones Display

Evan Jones, a longtime mineral collector and dealer, displayed a wide range of outstanding Bisbee minerals. This case featured many familiar aesthetic specimens, such as large azurite "roses", electric-blue botryoidal azurites, calcites with cuprite or malachite inclusions, lustrous cuprite crystals, velvet malachites, and malachite after azurite pseudomorphs. It also included several rare species, such as graemite, paramelaconite, and spangolite.

Paramelaconite

The Evan and Melissa Jones display included this very rare specimen of paramelaconite, a copper oxide mineral. Paramelaconite was discovered in 1891, and only a few crystals have been found over the 120+ years of mining at Bisbee.

Steve and Rita Maslansky & Irv Brown, Phil Scalizi, Rice Museum

This display highlighted the different forms of azurite and malachite with lustrous crystals, botryoidal clusters, pseudomorphs, and stalactites.

Paula and Les Presmyk Display

Examples of classic Bisbee minerals from classic mines were featured in this display. Specimens included azurites from the Czar and Holbrook Mines; calcites from the Czar, Holbrook, and Southwest Mines; native copper from the Czar, Dallas, and Shattuck Mines; cuprites from the Irish Mag Mine; and malachites from the Czar Mine and Lavender Pit.

Will and Pam Wilkinson & Central Arizona Collectors Display

This display presented the remarkable variety of colors and forms of Bisbee minerals. It also included a commemorative spoon and miner's brass tag.

Dave Witwer Display

An interesting assortment of calcite habits was featured in this case along with colorful azurite, copper, cuprite, malachite, and siderite specimens.

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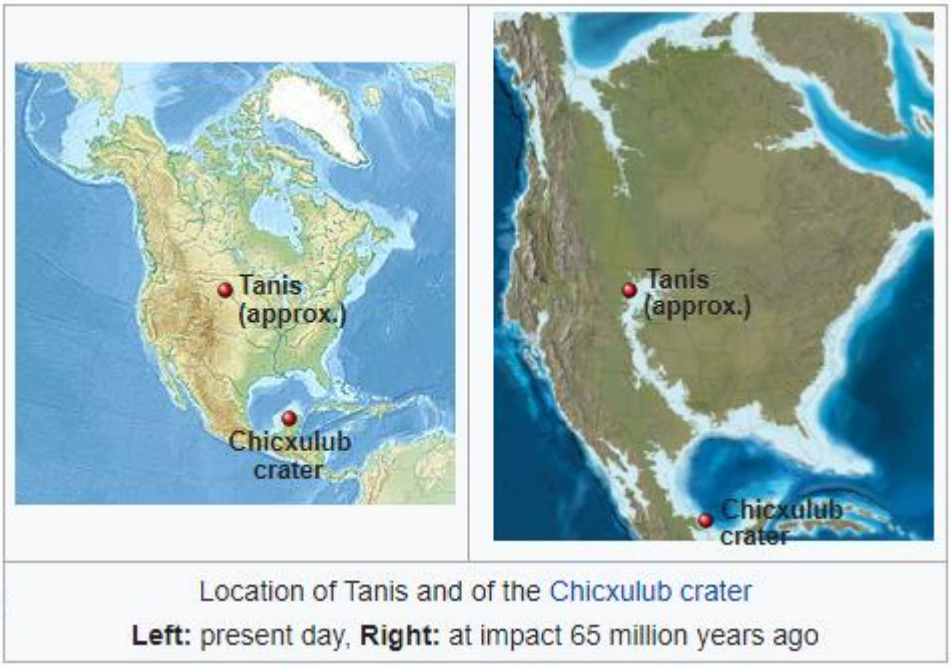
Tanis Fossil Site Connected to the Chicxulub Impact

https://en.wikipedia.org/wiki/Tanis_(fossil_site)



Location of Tanis and of the Chicxulub crater
Left: present day, **Right:** at impact 65 million years ago

Tanis is the name given to a site of paleontological interest in southwestern North Dakota, United States. Tanis is part of the heavily studied Hell Creek Formation, a group of rocks spanning four states Montana, North Dakota, South Dakota and Wyoming in North America renowned for many significant fossil discoveries from the Upper Cretaceous and lower Paleocene. Tanis is an extraordinary and unique site because it appears to record the events from the first minutes until a few hours after the impact of the giant Chicxulub asteroid in extreme detail. This impact, which struck the Gulf of Mexico 66 million years ago, wiped out all non-avian dinosaurs and many other species (the so-called "K-Pg" or "K-T" extinction). The extinction event caused by this impact paved the way for the domination of the Earth by mammals, including human beings.

The site was originally discovered in 2008 by University of North Georgia Professor Steve Nicklas and field paleontologist Rob Sula. Their team successfully removed fossil field jackets that contained articulated sturgeons, paddlefish, and bowfins. These fossils were delivered for research to the Field Museum of Natural History in Chicago. Recognizing the unique nature of the site, Nicklas and Sula brought in Robert DePalma, a University of Kansas graduate student, to perform additional excavations. The site was systematically excavated by Robert DePalma over several years beginning in 2012, working in near-total secrecy. Key findings were presented in two conference papers in October 2017. The full paper introducing Tanis was widely covered in worldwide media on 29 March 2019, in advance of its official publication three days later. The co-authors included Walter Alvarez and Jan Smit, both renowned experts on the K-Pg impact and extinction. Other papers describing the site and its fossils are in progress.

This handout photo obtained March 30, 2019 courtesy the University of Kansas shows a partially exposed, perfectly preserved 66-million-year-old fish fossil uncovered by Robert DePalma and his colleagues. (Credit: ROBERT DEPALMA/AFP/Getty Images)

At Tanis, unlike any other known Lagerstätte site, it appears freak circumstances allowed for the preservation of exquisite, moment-by-moment details caused by the impact event. These include many rare and unique finds, which allow unprecedented examination of the direct effects of the impact on plants and animals alive at the time of the large bolide impact some 3,000 kilometers (1,900 mi) distant. The events at Tanis occurred far too soon after impact to be caused by the mega tsunamis expected from any large impact near large bodies of water. Instead, much faster seismic waves from the massive magnitude 10 – 11.5 earthquakes probably reached the Hell Creek area as soon as ten minutes after the impact, creating seiche waves (A seiche is a standing wave in an enclosed or partially enclosed body of water) (between 10–100 meters (33–328 ft) high in the Western Interior Seaway and perhaps in other waters nearer Tanis, which was near an ancient river. These waves carried sea, land, freshwater animals and plants, and other debris several miles inland. The seiche waves exposed and covered the site twice, as millions of tiny droplets and debris from the impact were arriving on ballistic trajectories from their source in what is now the Yucatan Peninsula.

As of April 2019, reported findings include:

- animals and plant material preserved in three-dimensional detail and at times upright, rather than pressed flat as usual, their remains thrown together by the massive wave movements
- articulated and cartilaginous salt and freshwater fish and marine reptiles found together miles inland, with many micro tektites (molten debris particles from the impact) embedded in their gills as they tried to breathe
- millions of "near perfect" primary micro tektites "almost indistinguishable" in chemical composition from previously-reported Chicxulub tektites found buried contemporaneous to the fossils in their own impact holes in the soft riverbed mud, and also preserved in amber on tree-trunks
- large primitive feathers 30–40 cm long with 3.5 mm quills believed to come from large dinosaurs
- broken remains from almost all known Hell Creek dinosaur groups and some incredibly rare finds, such as:

- fossils of hatchlings and intact eggs with embryo fossils
- fossil pterosaurs for which no other fossils exist at that time
- drowned and nests with ants inside and chambers filled with asteroid debris, and
- tiny inhabited burrows from some of the first mammals in the area after the impact

The hundreds of fish remains are distributed by size, and generally show evidence of tetany (a body posture related to suffocation in fish), suggesting strongly that they were all killed indiscriminately by a common suffocating cause that affected the entire population. Fragile remains spanning the layers of debris show that the site was laid down in a single event over a short time span. A Triceratops or other ceratopsian ilium (hip bone) was found at the high water mark, in circumstances hinting that the dinosaur might speculatively have been a floating carcass and possibly alive at or just before impact, but the paper describing such remains is still in progress as of 2019 – the initial papers only include a photograph and its location within Tanis.

The exceptional nature of the findings and conclusions have led some scientists to await further scrutiny by the scientific community before agreeing that the discoveries at Tanis have been correctly understood. The site continues to be explored.

The K-Pg extinction event

The Cretaceous-Paleogene ("K-Pg" or "K-T") extinction event around 66 million years ago wiped out all non-avian dinosaurs and many other species. Proposed by Luis and Walter Alvarez, it is now widely accepted that the extinction was caused by a huge asteroid or bolide that impacted Earth in the shallow seas of the Gulf of Mexico, leaving behind the Chicxulub crater. The impactor tore through the earth's crust, creating huge earthquakes, giant waves, and a crater 180 kilometers (112 mi) wide, and blasted aloft trillions of tons of dust, debris, and climate-changing sulfates from the gypsum seabed and it may have created firestorms worldwide. With the exception of some ectothermic species such as the leatherback sea turtle and crocodiles, no tetrapods weighing more than 25 kilograms (55 lb) survived. It marked the end of the Cretaceous period and the Mesozoic Era, opening the Cenozoic Era that continues today.

However, because it is rare in any case for animals and plants to be fossilized, the fossil record leaves some major questions unanswered. One of these is whether dinosaurs were already declining at the time of the event due to ongoing volcanic climate change. Also, there is little evidence on the detailed effects of the event on Earth and its biosphere. No fossil beds were yet known that could clearly show the details that might resolve these questions. There is considerable detail for times greater than hundreds of thousands of years either side of the event, and for certain kinds of change on either side of the K-Pg boundary layer. But relatively little fossil evidence is available from times nearer the crucial event, a difficulty known as the "Three meter problem".

Hell Creek Formation

The Hell Creek Formation is a well-known and much-studied fossil-bearing formation (geological region) of mostly Upper Cretaceous and some lower Paleocene rock that stretches across portions of Montana, North Dakota, South Dakota, and Wyoming in North America. The formation is named for early studies at Hell Creek, located near Jordan, Montana, and it was designated as a National Natural Landmark in 1966.

The formation contains a series of fresh and brackish-water clays, mudstones, and sandstones deposited during the Maastrichtian and Danian (respectively, the end of the Cretaceous and the beginning of the Paleogene periods) by fluvial activity in fluctuating river channels and deltas and very occasional peaty swamp deposits along the low-lying eastern continental margin fronting the late Cretaceous Western Interior Seaway. The iridium-enriched Cretaceous–Paleogene boundary, which separates the Cretaceous from the Cenozoic, is distinctly visible as a discontinuous thin marker above and occasionally within the formation. Numerous famous fossils of plants and animals, including many types of dinosaur fossils, have been discovered there.

At the time of the Chicxulub impact, the present-day North American continent was still forming. Most of central North America had recently been a large shallow seaway, called the Western Interior Seaway (also known as the North American Sea or the Western Interior Sea), and parts were still submerged. This had initially been a seaway between separate continents, but it had narrowed in the late Cretaceous to become, in effect, a large inland extension to the Gulf of Mexico. The Hell Creek Formation was at this time very low-lying or partly submerged land at the northern end of the seaway, and the Chicxulub impact occurred in the shallow seas at the southern end, approximately 3,050 km (1,900 mi) from the site.

Although Tanis and Chicxulub were connected by the remaining Interior Seaway, the massive water waves from the impact area were probably *not* responsible for the deposits at Tanis. Any water-borne waves would have arrived between 18 and 26 hours later, long after the microtektites had already fallen back to earth, and far too late to leave the geological record found at the site. It is not even clear whether the massive waves were able to traverse the entire Interior Seaway. Instead, the initial papers on Tanis conclude that much faster earthquake waves, the primary waves travelling through rock at about 5 km/s (11,000 mph), probably reached Hell Creek within six minutes, and quickly caused massive water surges known as seiches in the shallow waters close to Tanis. Seiche waves often occur shortly after significant earthquakes, even thousands of miles away, and can be sudden and violent. Some recent examples include the 1964 Alaskan earthquake (seiches in Puerto Rico), the 1950 Assam-Tibet earthquake (India/China) (seiches in England and Norway), and the 2010 Chile earthquake (seiches in Louisiana). Notably, the powerful magnitude 9.0 – 9.1 Tohoku earthquake in 2011, slower secondary waves traveled over 8,000 km (5,000 mi) in less than 30 minutes to cause seiches around 1.5–1.8 m (4.9–5.9 ft) high in Norway.

The Chicxulub impact is believed to have triggered earthquakes estimated at magnitude 10 – 11.5a, releasing up to 4000 times the energy of the Tohoku quake. Co-author Mark Richards, a professor of earth sciences focusing on dynamic earth crust processes suggests that the resulting seiche waves would have been approximately 10–100 meters (33–328 ft) high in the Western Interior Seaway near Tanis and credibly, could have created the 10 – 11 m (33 – 36 feet) high water movements evidenced inland at the site; the time taken by the seismic waves to reach the region and cause earthquakes almost exactly matched the flight time of the microtektites found at the site. This would resolve conflicting evidence that huge water movements had occurred in the Hell Creek region near Tanis much less than an hour after impact, although the first mega tsunamis from the impact zone could not have arrived at the site for almost a full day.

ROBERT DEPALMA

Robert DePalma is a lifelong paleontologist with an M.A. in geology, the curator of vertebrate paleontology at the Palm Beach Museum of Natural History, and a doctoral student in paleontology at the University of Kansas. He has published several discoveries, including a 2010

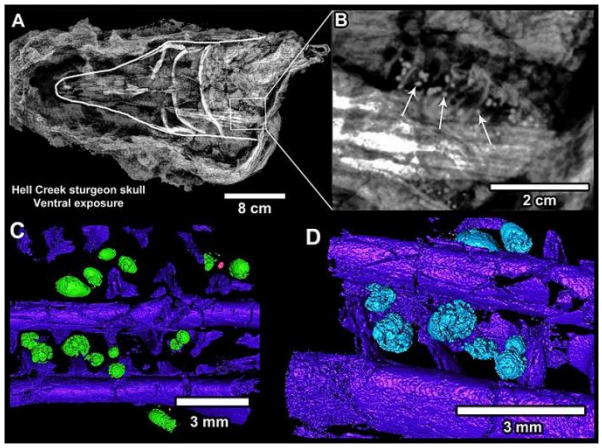
paper presenting the first known amber-trapped insect fossils from Hell Creek, and a 2013 paper presenting a tyrannosaur tooth embedded in a hadrosaur tail, showing that tyrannosaurs were indeed hunters rather than pure scavengers – a controversy at the time. Co-author Professor Phillip Manning, a specialist in fossil soft tissues, described DePalma's working techniques at Tanis as "meticulous" and "borderline archaeological in his excavation approach". His work with the 2013 tyrannosaur-hadrosaur specimen was similarly characterized as "meticulous" and "archeological" by the vertebrate paleontology department of the University of Kansas on its website.

In 2004, DePalma was studying a small site in the well-known Hell Creek Formation, containing numerous layers of thin sediment, creating a geological record of great detail. His advisor suggested seeking a similar site, closer to the K-Pg boundary layer. The original discoverers of the site (Rob Sula and Steve Nicklas), who worked the site for several years, recognized its scientific importance and offered it to DePalma as he had some previous experience with working on fish sites. The site lacked the fine sediment layers he was initially looking for. Instead, the layers had never fully solidified, the fossils at the site were fragile, and everything appeared to have been laid down in a single large flood.

The intermediate clay stone layer contains 1000 times more iridium than the upper and lower layers. It is the boundary between Cretaceous and Tertiary Periods. The rock is from Wyoming, USA. Picture taken by Eurico Zimbres at San Diego Natural History Museum

Discovery and exploration of 'Tanis'

DePalma began excavating systematically in 2012 and quickly found the site to contain very unusual and promising features. Everything he found had been covered so quickly that details were exceptionally well preserved, and the fossils as a whole formed a very unusual collection – fish fins and complete fish, tree trunks with amber, fossils in upright rather than squashed flat positions, hundreds or thousands of cartilaginous fully articulated freshwater paddlefish, sturgeon and even saltwater mosasaurs which had ended up on the same mud bank miles inland (only about four fossilized fish were previously known from the entire Hell Creek formation), fragile body parts such as complete and intact tails, ripped from the sea fish's bodies and preserved inland in a manner that suggested they were covered almost immediately after death, and – everywhere – millions of tiny spheres of glassy material known as microtektites, the result of tiny splatters of molten material reaching the ground. The microtektites were present and concentrated in the gills of about 50% of the fossilized fish, in amber, and buried in the small pits in the mud which



This fossil fish from *Tanis* shows microtektites (molten splattered glass droplets) that are a chemical match for ejecta from the Chicxulub asteroid crater. The microtektites are concentrated in large numbers in the gill rakers of approximately 50% of the sturgeon and paddlefish fossils, and show that the fish were alive when the impact occurred.

they had made when they contemporaneously impacted. The fish were not bottom feeders. They had breathed in early debris that fell into water, in the seconds or minutes before death. The sediment appeared to have liquefied and covered the deposited biota, then quickly solidified, preserving much of the contents in three dimensions.

Later discoveries included large primitive feathers 30–40 cm long with 3.5 mm quills believed to come from large dinosaurs; broken remains from almost all known Hell Creek dinosaur groups, including some incredibly rare hatchling and intact egg with embryo fossils; fossil pterosaurs for which no other fossils exist at that time; drowned ant nests with ants inside and chambers filled with asteroid debris; and burrows of small mammals living at the site immediately after the impact. Analysis of early samples showed that the microtektites at Tanis were almost identical to those found at the Mexican impact site, and were likely to be primary deposits (directly from the impact) and not reworked (moved from their original location by later geological processes).

DePalma quickly began to suspect that he had stumbled upon a monumentally important and unique site – not just "near" the K-Pg boundary, but a unique killing field that precisely captured the first minutes and hours after impact, when the K-Pg boundary was created, along with an unprecedented fossil record of creatures and plants that died on that day, as well as material directly from the impact itself, in circumstances that allowed exceptional preservation.

When I saw *[microtektites in their own impact craters]*, I knew this wasn't just any flood deposit. We weren't just near the KT boundary. This whole site *is* the KT boundary ... We have the whole KT event preserved in these sediments. With this deposit, we can chart what happened the day the Cretaceous died. — *Robert DePalma*

It is truly a magnificent site ... surely one of the best sites ever found for telling just what happened on the day of the impact. — *Walter Alvarez*

By 2013, he was still studying the site, which he named "Tanis" after the ancient Egyptian city of the same name, and had told only three close colleagues about it. Secrecy about Tanis was maintained until disclosed by DePalma and co-author Jan Smit in two short summary papers presented in October 2017, which remained the only public information before widespread media coverage of the full prepublication paper on 29 March 2019.

Initial papers at GSA Conference, 2017

Eighteen months before publication of the peer-reviewed PNAS paper in 2019 DePalma and his colleagues presented two conference papers on fossil finds at Tanis on 23 October 2017 at the annual meeting of the Geological Society of America. Jan Smit first presented a paper describing the Tanis site, its association with the K-Pg boundary event and associated fossil discoveries, including the presence of glass spherules from the Chicxulub impact clustered in the gill rakers of acipenciform fishes and also found in amber. DePalma then presented a paper describing excavation of a burrow created by a small mammal that had been made "immediately following the K-Pg impact" at Tanis.

Prepublication and authorship

A paper documenting Tanis was released as a prepublication on 1 April 2019. Simultaneous media disclosure had been intended via the *New Yorker*, but the magazine learned that a rival newspaper had heard about the story, and asked permission to publish early to avoid being

scooped by waiting until the paper was published. The discovery received widespread media coverage from 29 March 2019.

DePalma's co-authors include Jan Smit (retired paleontologist and world authority on the K-Pg impact and its tektites) and Walter Alvarez (professor, recipient of numerous prestigious awards, and co-developer with his Nobel Laureate father of the K-Pg impact theory, sometimes called the Alvarez hypothesis). Other authors are his advisor David Burnham, Klaudia Kuiper (professor of geochronology focusing on chronology of the late Cretaceous), Phillip Manning (professor of natural sciences, specialist in soft tissue scanning), Anton Oleinik (associate professor geosciences, specializing in Cenozoic periods of change and stratigraphy), Peter Larson (paleontologist and fossil collector), Florentin Maurrasse (professor specializing in stratigraphy and biostratigraphy, and the K-Pg boundary in the Caribbean), Johan Vellekoop (postdoctoral researcher, published on microfossil record of the Chicxulub impactor), Mark Richards (professor earth and planetary sciences, focus on earth crust tectonic and dynamic processes), and Loren Gurche (a colleague at the Palm Beach Museum of Natural History). Wide ranges of other people are credited with analysis, specific studies, and other contributions.

As of April 2019, several other papers are in preparation, with further papers anticipated by DePalma and co-authors, and some by visiting researchers.

2021 AND 2022 PAPERS

Three papers were published in 2021. The first two were originally presented in January of that year. The last was published in December in Nature.

The first documents a turtle fossil found at Tanis, killed by impalement by a tree branch, and found in the upper of two units of surge deposit, bracketed by ejecta. This further evidences the violent nature of the event. The second draws on *"patterns of growth history, including periodicity of $\delta^{18}O$ and $\delta^{13}C$ and growth band morphology, plus corroborating data from fish ontogeny and seasonal insect behavior"* to show that *"the impact occurred during boreal Spring/Summer, shortly after the spawning season for fish and most continental taxa"*.

The Nature "Scientific Reports" paper, published December 2021, builds on the two previous 2021 papers. It suggests that the Chicxulub impact occurred in late Spring or early Summer, based on analysis of fish bone growth rings and insect development in specimens recovered at the Tanis site.

A further paper was also published in *Nature* February 2022, by a separate team. It studied the fish skeletons found at Tanis, and identified annual cyclical changes, which corroborated the conclusion in the 2021 paper, that the impact had occurred in Spring, a timing which affected the surviving species.

Other media

A BBC documentary on Tanis, titled *Dinosaurs: The Final Day*, with Sir David Attenborough, is to be broadcast in Spring 2022.

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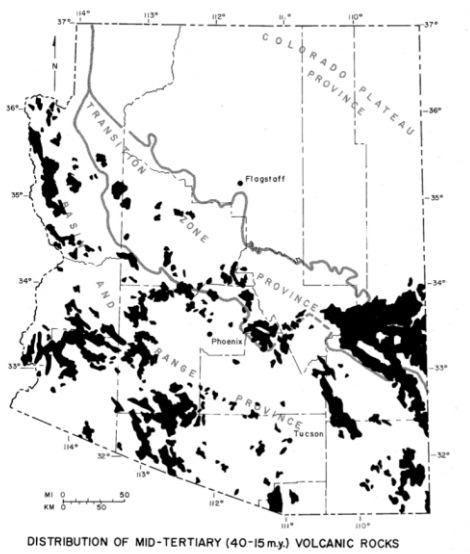
Arizona Rocks 106

Text and photos by Ray Grant

The last two Arizona Rocks (104 and 105) were about the 40- to 15-million-year-old volcanic rocks in the Chiricahua and Superstition Mountains. Volcanic rocks of this age are very widespread across southern Arizona, see map. Chalcedony and agate, the common names used for fibrous fine-grained quartz, are scattered where you find these volcanic rocks. Usually, the chalcedony is colorless or white and forms as flat sheets, but occasionally it will have a flower shape, and these are called desert roses. Also, a lot of this chalcedony fluoresces a bright green under short wave ultraviolet light.

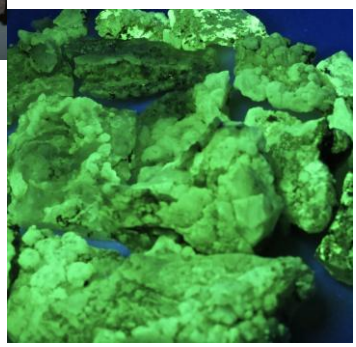
Sometimes the chalcedony has layered inclusions of an iron oxide mineral, which allows light to be diffracted into the colors of the rainbow. Arizona has several well-known fire agate localities. One is near Ed's Camp east of Oatman, in Mohave County. This is a pay-to-dig location, in the Black Mountains, and it is possible to look at other places along this range for fire agate. There are several collecting areas for fire agate in eastern Arizona near Safford, in Graham County, and near Clifton, in Greenlee County. The Bureau of Land Management has designated two rock hound collecting areas for collecting fire agate. The Black Hills rock-hound area is about eighteen miles north of Safford, and the Round Mountain area is southeast of Duncan.

So, the next time you are in one of these volcanic areas keep your eyes open for desert roses and fire agate. There might also be quartz crystals and geodes as both are found occasionally in these volcanic rocks.



Map of Mid-Tertiary volcanic rocks from AGS Fieldnotes Summer 1986

Chalcedony I picked up at a small hill with Superstition volcanic rocks near my house in Florence



Chalcedony from the small hill in Florence under short wave ultraviolet light

Fire agate from Black Mountains, Mohave County

Chalcedony (desert) roses Saddle Mountain, Maricopa County

Pinal Museum and Society News

351 N. Arizona Blvd., Coolidge, AZ

Pinal Geology and Mineral Society meeting

April 20, 2022

www.pinalgeologymuseum.org

Ray Grant raycyn@cox.net.

The Museum will be open four days a week from Wednesday - Saturdays from 10 am to 3 pm. So more opportunities for people to visit! This will be the plan until we close for the summer.

Masks are now optional at the Museum. Please bring your own mask if you wish to wear one. We will have some masks on hand at the Museum, but cannot guarantee to provide them.

Dinosaur Egg Hunt

Special event for kids, the week before Easter (April 13-16) (Museum open Wednesday to Saturday 10 to 3) we will have a dinosaur egg hunt. Kids can search the Museum for a dinosaur egg, fill out a questionnaire about it and get an egg with surprises inside.

Parent/Teacher Resource Pages

HTTPS://WWW.EARTHSCIWEEK.ORG/NEWSLETTER

EARTH SCIENCE WEEK UPDATE
March 2022

EARTH SCIENCE WEEK ADDS GEOSCIENCE TO EARTH DAY

Educators and young people worldwide will celebrate Earth Day 2022 on April 22 with activities, experiments, and investigations exploring how our world works — and those in the know will tap the wealth of education resources available through Earth Science Week.

Although Earth Science Week won't take place until October, the program offers education materials, information, and tools throughout the year. This year, for example, Earth Science Week provides education tools highlighting the theme of "Earth Science for a Sustainable World," including learning activities focusing on sustainability topics.

The Earth Science Week website offers hundreds of free classroom activities, Spanish-language resources, videos, visualizations, webcasts, local events and organizations, competitions and awards, and careers information. Learn more about Earth Science Week.

And help us spread the word that there is no better way to honor Earth Day than by celebrating the geosciences. Share the crucial message of our #EarthScienceForEarthDay hashtag campaign on social media platforms such as Twitter, Facebook, Instagram, and LinkedIn!

NGSS EARTH SCIENCE WEBINAR: CAN'T BE GROWN? MUST BE MINED

Join in an upcoming webinar titled "Why Is 'If It Can't Be Grown, It Must Be Mined' Important in Your ESS Classroom?" Organized by the a Next Generation Science Standards-Earth and Space Science (NGSS-ESS) Working Group and presented by Scott Brande of the University of Alabama Birmingham, the webinar takes place Thursday, March 17.

The website "Mineral ID: A Practical Online Study Guide" is filled with digital resources and classroom-ready activities for teaching mineral identification and more. Website access is free without registration and deployable to a variety of devices, from cellphones to Chromebooks and laptops.

During the webinar you will be introduced to resources and activities available on the website, view examples of online digital media available for teaching and learning mineral identification, receive instructions for accessing the website and an answer key to unknown samples, and share needs and concerns about teaching mineral identification remotely or face-to-face. Learn more and register for free at the NGSS-ESS Working Group website.

UA SCIENCE
ARIZONA GEOLOGICAL SURVEY
Geosciences serving Arizona since 1887

Arizona Geology Blog

The UA Lowell Institute for Mineral Resources' is launching a trilogy about how mineral resources influenced World War II. Part 1, narrated by Isabel Barton, covers mineral resources during the interwar buildup from 1919 to 1939: how mineral resources figured in national (and transnational) politics in the 1930s. For more details and a link to the video see today's Arizona Geology invited blog post by Dr. Isabel Barton. https://blog.azgs.arizona.edu/blog/2022-03/critical-minerals-world-war-2

The direct link to the video: https://youtu.be/Ww6Z_au3S2Y

Note: *Arizona Geology Blog (2007-2022) is a product of the Arizona Geological Survey.*

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AZGS Websites

AZGS Portal
AZGS Mining Data
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Gila County Gem & Mineral Society

4th ANNUAL GEM & MINERAL

"SPRING SHOW & SELL"

Saturday April 9th 2022

10am – 4pm

We invite you to come spend the day in Miami AZ on Saturday April 9th 2022. The Gila County Gem & Mineral Society is having our 4th annual Gem & Mineral "Show & Sell Spring Event" from 10am – 4pm along with the "2nd Saturday main event" which will be held in downtown Miami on Sullivan Street, with vendors, music, food and more from 1:00pm – 4:00pm.

Our event will again be held in the parking lot of Oasis Insurance at 411 W Live Oak (Highway 60), Miami, AZ. Come and see what we have to offer for sale, make your own rock covered copper tree, grab some popcorn and a drink and visit with other rock hounds and jewelry makers.

White Mountain Gem
and Mineral Annual Show
July 9-10, 2022
Sat. 9-5, Sun. 10-
Adults $2.00
Juniors 18 and under with Student ID
Free when accompanied by an adult
Elks Lodge
805 E. Whipple Street
Show Low, Arizona
www.whitemountain-azrockclub.com

Mohave County Gemstoners
Annual Gem and Mineral Show
May 7-8, 2022
Sat. 9-5, Sun. 9-4
Kingman Academy of Learning
3420 N. Burbank St. 86409
Kingman, AZ
Free Admission
Plenty of Parking

ALL ARIZONA CLUB MEETINGS MAY BE CANCELED DUE TO HEALTH CONCERNS!

Apache Junction Rock & Gem Club
Meetings are on the 2nd Thursday
Next Meeting: April 14, 2022, 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 5, 2022, 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: April 4, 2022, 7:00 pm
www.maricopalapidarysociety.com
@ North Mountain Visitor Center
12950 N. 7th St., Phoenix

Mineralogical Society of Arizona
Meetings are on the 3rd Thursday
Next Meeting: April 21, 2022, 7:30 pm
Please go to their website for more info
www.msaaz.org
@ Franciscan Renewal Center
Room: Padre Serra
5802 E. Lincoln Dr., Scottsdale

Pinal Geology & Mineral Society
Meetings are on the 3rd Wednesday
Next Meeting: April 20, 2022, 7:00 pm
On YouTube until further notice
www.pinalgeologymuseum.org
@ Artisan Village
351 N. Arizona Blvd., Coolidge

West Valley Rock & Mineral Club
Meetings are on the 2nd Tuesday
Next Meeting: April 12, 2022, 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 7, 2022, 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 8, 2022, 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 2022, 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

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

Staples Foundation
www.staplesfoundation.org

Anita Aiston
Peter & Judy Ambelang
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Phone:
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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 2022, at 6:30 p.m.

THANK YOU FOR YOUR CONTINUING INTEREST & SUPPORT!!!

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