AirSpace Transcript - Season 10, Episode 4: Crater Dating

Emily: Not like dating Hinge profile, like dating as in getting the age date.

Matt: Yeah *laughs*

AirSpace theme in then under

Emily: Welcome to AirSpace from the Smithsonian's National Air and Space Museum. I'm Emily.

Matt: And I'm Matt. The oldest rocks we've ever found on Earth are 4.3 billion years old. We've found even older rocks on the Moon, but how do we know how old something is if we don't have a rock to test?

Emily: Rocks preserve history. History of their formation and what they've gone through over geologic time. For the Earth and the Moon, we can measure the age of these rocks. That knowledge helps us model when geologic events may have happened in other places in the solar system.

Matt: But how do those models work, and why are rock samples from the Moon such a key part of this process? We find out today on AirSpace, sponsored by Lockheed-Martin.

AirSpace theme up and out

Matt: So I know we're going to be focusing a lot on what we've found out from the Moon rocks and studying craters on the Moon today, but I wanted to sort of start this story with something that's not even in the outline, which is that even before we got to the Moon and got rocks back from the Moon, rocks from space were very important in determining the age of the Earth.

It was in the 1950s, like a decade before we landed humans on the Moon and brought rocks back that Clair Patterson[1] used a meteorite and used the zircon crystals and uranium lead ratios to determine that the Earth was 4.55 billion years old, sort of blowing away the older estimate of 3.3 billion years. And it was all possible because of new radiometric techniques and because of, you know, samples, rock samples from space that had just happened to fall on the Earth and had been found.

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[1] https://www.iowapbs.org/iowapathways/mypath/2549/clair-patterson-20th-century-geologist

Emily: And I think that's really good context, Matt, because what we're talking today is not the age of the Earth or the age of the Moon. It's the age of the rocks on these places. And I think if you're not the, I'm going to call you a geology nerd, Matt. If you're not a geology nerd like us, if you're not a space geology nerd, it's sometimes kind of hard to think about how different rocks on Earth have different ages, right?

We still have volcanoes going off all the time. And the rocks that come out of those volcanoes are going to be zero years old, right? Um, so there's different rocks associated with geologic events or rocks that experience geologic events, and those events reset those geochemical clocks inside those rocks, and that tells you when a something happened here on Earth or when a something happened on the Moon in the case of having lunar samples.

But what you're talking about, which I think is really important because it's really the beginning of this story, is using space rocks, to get an idea of how old our solar system is as kind of the, what's the limit in which we have to work with, right? We can't say that this rock is 8 billion years old because the solar system's not that old.

So today our main theme is to talk about the age of rocks, on the Earth and the Moon specifically, and how that helps us understand the age of different geologic events in other places in our solar system.

So we reached out to Dr. Beau Bierhaus[2] to tell us more about how this process works.

Beau: My name is Beau Bierhaus, and I'm a Senior Research Scientist at Lockheed-Martin in Denver, Colorado. I've been fascinated by space ever since a kid, and I'm just really grateful that I get to do it as my job.

Emily: So in geology and planetary geology, we talk a lot about time, but when we talk about time, we're talking about two different flavors. We're talking about absolute time and relative time.

Beau: Absolute time is thinking about, uh, setting a, a, time zero in the solar system, which really is, you know, the time at which things formed and then establishing dates since that time. Relative time is just knowing that something happened before or after something else.

If you see, for example, a crater on top of a volcano you know that impact crater happened after that volcano formed, but you don't have a good sense in absolute time

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[2] https://www.europlanet.org/blending-science-and-engineering-to-make-space-missions-possible/

necessarily of when that volcano formed or when that crater formed. You just know that the crater happened after the volcano.

Emily: And I think there's a really important distinction here that I wanted to talk to Beau about because we have hundreds, thousands, millions, dare I say, meteorites that have fallen to Earth. These are space rocks from all over the solar system that have fallen through Earth's atmosphere and landed here on Earth.

And so we have access to all of these rocks, and we've had access to these rocks for a lot longer than we've had access to those Apollo samples. And they're valuable and they're incredibly useful, but they're not going to help us do what we need to do in terms of dating things on other planetary surfaces.

Beau: You know, when we pick up a meteorite[3] and we examine it and we can take very exquisite geochemical compositions, we can understand that it's not from Earth. But we don't know where it's from.

And maybe now we're even at the point where we have enough data from the Moon, we can say, okay, this is originally from the Moon, but we still don't know where on the Moon that came from. And one of the reasons why the Apollo samples are so important is because we know exactly where they are from on the Moon and, um, in, you know, the spirit of, of geology, an important aspect of geologic work and geologic investigation is context.

Matt: One of the things that's kind of fascinating about this story of looking at the surfaces of other worlds and looking even at the surface of our own world and talking about, you know, time, whether it's relative or absolute is that it's such a recent story, right?

Like, we didn't actually have detailed geologic maps[4] and geologic explanations or stories to tell about the Moon until the 1960s and into the 70s when those first geologic maps were made.

Beau: There weren't actually very good methods to identify how old planetary surfaces were. There were, I think some analyses that were done by analogy to Earth in the

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[3] https://naturalhistory.si.edu/education/teaching-resources/earth-science/meteorites-messengers-outer-space#:~:text=The%20Smithsonian%20National%20Museum%20of,Collections%20Manager%20at%20the%20Museum.

[4] https://www.usgs.gov/news/national-news-release/usgs-releases-first-ever-comprehensive-geologic-map-moon

absence of direct information at other planets. But it really was the Apollo program and the, um, very intensive, uh, scientific and engineering effort that we put into getting to the Moon that really opened up this field to be something completely new and revolutionary that hadn't been possible literally in, in any time, you know, prior in science.

Matt: Yeah. So this is an exciting time in the 1960s as all of this stuff is coming together. And we're now getting, you know, more access to lunar rocks and better views of the lunar surface. But also, you know, this is the time when we kind of take this for granted, but we were also seeing for the first time in detail the surfaces of Mars and Mercury, the other rocky bodies, seeing that they had kind of similar features sometimes to the Earth, sometimes to the Moon but you know, some kind of geologic history was preserved in those places.

Beau: The rocks from Apollo, um, well, one of the interesting surprises is that the composition of things that we found on the Moon are actually relatively similar to things that we find on Earth in terms of different sorts of magmas and so that was a fascinating discovery in and of itself.

But then that also, uh, helped us understand, um, that, you know, we can take these minerals and apply the same sorts of radiometric age analysis that we do on the lunar samples as we do on terrestrial samples.

Matt: Cast your mind back to the years just after the end of World War II, atomic science is booming in the United States, right? And university science departments are looking for new ways to use the atom and radioactivity in their work.

So now focus in on the University of Chicago, where a group of nuclear physicists and chemists who have all worked on the Manhattan project or something adjacent to it, have now come to try and apply, you know, nuclear, atomic, radioactive methods to the study of nature.

And it's here that you find a few labs like that of Willard Libby[5] and Harold Urey[6], where folks are trying to learn how to read nature with the naturally occurring isotopes that they find there. So it's in Libby's lab in particular, where we find the emergence of radiocarbon dating.

Emily: Radiocarbon dating[7], or you probably have heard it called carbon-14, is how we date things like an archaeological discovery, whether it's dating food scraps that you find

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[5] https://www.nobelprize.org/prizes/chemistry/1960/libby/biographical/

[6] https://www.nobelprize.org/prizes/chemistry/1934/urey/biographical/

[7] https://news.uchicago.edu/explainer/what-is-carbon-14-dating

in an ancient trash bin or some kind of human remains that you want to know how old they were when they died, you would use carbon-14.

And you hear about this all the time when you hear some new cool discovery. And they say, oh, we used carbon-14 to figure out how old this thing was. And without trying to get too into it, because I'm not a nuclear physicist and I don't do this. Essentially, once an organism dies, they're no longer absorbing carbon, and organisms are carbon based, so there's lots of carbon there. Carbon-14 decays really slowly, and when I mean decay, I mean it changes from carbon-14 into another atom called nitrogen-14. How does this happen? I don't know, but it happens at a really predictable rate. And so if you can measure how much carbon-14 you have and how much nitrogen-14 you have, you take that ratio, knowing how long it takes to do that, you can estimate how long something has been dead. Essentially how old it is, when it died.

And when we do this with geological samples, we are not using carbon-14. Carbon-14 is only good for about, you know, backwards in time for about 50,000 years. When you're talking geologic time, you're talking millions of years, billions of years. So you need something that has that rate of decay is really different, much longer time spans in order to be able to measure these ratios that far back in time.

It's this principle, though, of one atom decaying into another atom and that happening at a very predictable rate that allows you to use all kinds of different elements with their very specific rates to date things like rocks. Rocks on the Moon, rocks on Earth, because the physics, that's the beauty of physics, happens the same way here on Earth as it does on the Moon and everywhere else in the Solar System.

Beau: It's not a particularly well known element necessarily outside science or geology, but you have rubidium[8] and rubidium can decay into another element called strontium and that, uh, decay process has a, a half life that I'm, uh, forgetting off the top of my head, but it's a, it's a relatively long period of time, and so if you look at the relative abundance of, uh, rubidium versus strontium, and you know the rate at which rubidium decays into strontium, you can actually assign an age to that rock.

Emily: So we need to make the leap now about, you know, we now kind of have an understanding of how we've used Moon rocks from very specific locations where we know what those rocks have been through and how old those rocks are, to using that information to help us get the age of other rocks and other geologic events on other planets where we don't have samples.

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[8] https://cires1.colorado.edu/people/jones.craig/WUStectonics/CRFB/strontium.html

Beau: What allows us to then take that measurement on the Moon, and apply it to other bodies is by a, a different investigation, which is looking at the accumulation of craters on a surface[9]. And at first glance, they may seem like totally unrelated processes, and in some ways they are totally unrelated, but importantly, the way in which they are aligned in the way that they are similar is that they are events that evolve over time in some statistically somewhat predictable fashion.

And so just as, um, uh, elements, uh, decay according to a half life, uh, a very regular half life, there are asteroids and comets that hit the surface of the Moon at some sort of regular cadence. And so the rate at which those things hit the Moon, and so therefore the rate at which you form craters on the surface of the Moon, is in some ways another kind of clock.

Matt: So you're a lunar scientist in your laboratory. You have a rock and you know exactly how old it is. You know where it came from on the Moon and you know essentially how many craters were there, what that surface looked like, how heavily cratered was it? And so you can kind of make the connection, right, that that rock is the same age as that area and therefore an area that is that cratered is that age, right?

That's kind of essentially what we're talking about here. There's a lot more nuance to it, but then you can apply that, that idea that an area with this number of craters or craters of this type is of this age and therefore apply it to things on other worlds like Mars.

Emily: Being able to get an absolute age date for a rock on the Moon and translating that through craters seems like it doesn't make any sense because you're like, 'Oh, I already have the rock and I already have the age of the rock. So why do I care about craters?' And really what it comes down to is the importance that Apollo samples has had on the development of tools for planetary scientists to use, not just for the Moon, but for everywhere else in the solar system.

And so this kind of middle ground of like talking about craters on the Moon and how that has anything to do with craters anywhere else in the solar system is a really important thing that was developed to take this information we had about Moon rocks and extrapolate it across the solar system to better understand the timing of different geologic events everywhere else.

Matt: But there's at least two degrees of separation between where you started; measuring the age of that rock, to then applying that to the age of a cratered surface on the Moon, to then applying what that looks like to a similar feature on another rocky

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[9] https://www.planetary.org/articles/0401-the-lunar-chronology#:~:text=That's%20the%20lunar%20crater%20chronology,rest%20of%20the%20solar%20system.

body. So there's still some room for error there, even though it's getting you much closer than you ever were before to understanding the age of features on that other world.

Beau: That is kind of just the tip of the iceberg in terms of the uncertainties in the process because, um, you have uncertainties related to, um, the impact population. So the abundance of the impactors that are hitting the surface and the speed at which they're hitting. And then you also have uncertainties in the surface properties itself.

And so, if you have a very strong surface and you hit it with a certain sized impactor, you're gonna make a small crater. Whereas if you have a very weak surface and you hit it with that same size impactor, you're gonna make a much larger crater. And so, um, if you try to calculate an age based on, let's just say, the number of one kilometer craters, making a one kilometer crater requires you to have some understanding of, um, the strength of that surface, and therefore, you know, what impactor could make that, that one kilometer crater.

And so this relationship between impactors and craters and a derived crater chronology depends on relatively detailed information about the impacting, about both the impacting population as well as the surface properties of the things that the impactors are hitting

Matt: By bringing those rocks back from the Moon and then using those to put dates onto the relative timescales that had been developed for the Moon. We kind of created with the Moon, a Rosetta Stone that helped us read the history of the other planets in the solar system. But if we were to bring rocks back from the surface of Mars, if we were to bring rocks back from Mercury to any of those other rocky bodies, just the same way we're bringing samples back now from asteroids, um, we would be able to tell such a more complete story about the solar system than we can right now, even though the Moon has been just a remarkable resource in terms of being able to tell that story.

Any samples that are brought back can expand and improve modeling for the ages of things. There are several recent and ongoing missions that have brought back samples or that will in the new, near future.

Beau: So the the first is OSIRIS-REx[10], which was an asteroid sample return. I, I happened to be involved in that. So those samples are now, um, back on Earth. They returned in September of 2023. And so scientists have been busy analyzing them in labs for over a year now.

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[10] https://science.nasa.gov/mission/osiris-rex/

Emily: Matt, have you been to Natural History to see the Bennu sample[11]? So Bennu was the asteroid visited by OSIRIS-REx and Natural History has a teeny tiny piece of it

Matt: It's incredible. Um, I mean it is tiny, but the types of information that they're getting from the samples about the chemistry of life being out there present[12] in the solar system is just remarkable stuff. I do love sample return missions. We have the Stardust return mission, which was very similar in design to OSIRIS-REx.

We have that return capsule on display at the museum downtown. So, you know. Folks can come and see the types of technologies that are allowing us to tell these stories by bringing back these samples.

Emily: And asteroid sample return missions I think have been incredibly successful and I think one of the hallmarks of that success has been the international collaboration that's been going on because there's additional asteroid sample return missions that JAXA[13], the Japanese Space Agency, has completed.

So we're building up a collection of samples here on Earth and there's ongoing missions that are working to bring samples back from the Moon, there's a Moon lander planned that will be able to provide samples that will be used for new absolute dates from a new part of the Moon.

Beau: Another mission which is upcoming, this is actually a payload is the DIMPLE[14] payload. And DIMPLE is going to do the first in-situ radiometric age dating ever on a planetary body. They're going to land on a feature called Ina, it's an irregular mare patch, they're very unusual, uh, lunar features and what makes them unusual is their superimposed crater population has a very low density. And so it suggests that they're very young if you just go by their crater population, but they're considered to be volcanic features. And if you have a very young volcanic feature on the Moon, then that implies there was volcanism on the Moon very recently, which would be yet another, you know, major upending of our understanding of the Moon.

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[11] https://www.si.edu/newsdesk/releases/smithsonian-open-first-public-display-asteroid-bennu-sample-collected-nasas-osiris

[12] https://www.nasa.gov/news-release/nasas-asteroid-bennu-sample-reveals-mix-of-lifes-ingredients/

[13] https://global.jaxa.jp/projects/sas/hayabusa2/#:~:text=Hayabusa2%20itself%20is%20continuing%20its,asteroid%201998%20KY26%20in%202031.

[14] https://www.nasa.gov/news-release/new-nasa-artemis-instruments-to-study-volcanic-terrain-on-the-moon/

On the other hand, there could be aspects of the mechanical properties of the material or something else that would cause their superimposed crater population to be different from the rest of the Moon, in which case they might still be old.

So the the impact terrains are very interesting and DIMPLE's going to land on one of those and address, uh, a fundamental question about either the evolution of the thermal interior of the Moon, or a totally new and different geologic feature. And it's, it's kind of, you win either way. If Ina is young, it's awesome. If Ina is old, it's awesome. So, um, anyway, so DIMPLE is really, uh, really an amazing payload and looking forward to to that happening.

Matt: And, you know, robotic missions have played a very large role in helping us to understand the surfaces of other worlds, especially Mars, where we've had this incredibly successful history of robotic exploration. Um, and we have absolute ages for a lot of the cratered surfaces of Mars because we’ve extrapolated from the Moon. And the Perseverance[15] rover is up there right now gathering samples and putting those aside so that scientists can one day study those in the laboratory and get even more precise ages for the Martian surface and the features that we’ve found there. And those samples right now are just waiting to be retrieved and brought back to Earth.

And between those lunar samples that we have and the ones that we might have soon, the asteroid samples, and then hopefully soon Mars samples, scientists like Beau will be able to develop even better models for estimating the ages of surface features.

AirSpace theme up then under

Matt: We do want to point out here that Beau works for our sponsor, Lockheed-Martin, but AirSpace is editorially independent from its sponsors.

Matt: AirSpace is from the National Air and Space Museum. AirSpace is produced by Jennifer Weingart and mixed by Tarek Fouda. Hosted by Dr. Emily Martin and me, Dr. Matt Shindell. Our managing producer is Erika Novak, our production coordinator is Sofia Soto Sugar, and our social media manager is Amy Stamm.

It's a wonderful group.

A big thank you to our guest in this episode, Dr. Beau Bierhaus from Lockheed- Martin.

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[15] https://science.nasa.gov/mission/mars-sample-return/

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