Planetary Geochronology: How Old is That?
Dr. Kip Hodges, Arizona State University,
Andrea Jones, LRO Education and Public Outreach Lead
Moderator: Jeff Nee
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Coordinator: Thank you all for standing by. I'd like to inform parties that the call is now being recorded. If you have any objections, you may disconnect at this time. Throughout the call you will have open and interactive lines. You can press star 6 to mute and unmute. Thank you. You may begin.

Jeff Nee: All right. Hello everyone and welcome. I'm Jeff Nee from the Museum Alliance, the moderator for today's talk. Thank you all for joining us today. And to anyone listening to the recording in the future, welcome as well.

Today we'll be talking about planetary geochronology -- a nice big mouthful.

As a final reminder, do not put us on hold even if you have to step away because some phones play holding music which can disrupt the talk. And just be sure your phone is on mute so that no noises from your end disrupt the talk, either. If you want to test your mute, you can say your name real quick. No? Great. Don't hear a thing. Okay.

The slides for today's presentation can be found on the Museum Alliance and Solar System Ambassador sites.

If you have any problems, you can email me at JNEE@jpl.nasa.gov.

Our main speaker today is Dr. Kip Hodges, a foundation professor at the School of Earth and Space Exploration of Arizona State University. Dr.

Hodges has broad ranging interests in earth and space sciences, which has driven him to do research all over the world. You can read more about that on the sites.

In recent years though, he and his research group have developed techniques in isotope geochronology to explore the evolution of the moon and other rocky bodies in the solar system.

He has been active in the training of NASA, Canadian Space Agency, and Japanese Space Agency Astronauts in field geological techniques. And he's a former member of the Planetary Science Sub-Committee of the NASA Advisory Council. But he now serves as a member of the National Science Foundation Advisory Committee for Geosciences.

Andrea Jones is also going to talk about International Observe the Moon Night. She's the Director of that and she's also the EPO Lead for the Lunar Reconnaissance Orbiter.

Now one final time before I turn it over, does anybody want to check their mute settings? I hear a little bit of something, but it could be from Kip. Okay. Great. And without further ado, Dr. Hodges take it away.

Kip Hodges: Slide 1: Okay. Thanks Jeff and thanks everybody for sharing some of your time this afternoon. I'm going to do my best to try and enlighten you in a relatively short time on some sort of basic concepts behind planetary geochronology and then be happy to answer any questions in the time that we have left.

As was said, Andrea's got a few things she wants to talk about as well. So with that, we'll just go ahead and get to it.

The topic that I'm going to talk about today is actually of a tremendous amount of interest in NASA. And if you switch to the second slide, Slide 2, you'll see a sort of an introduction to that. I'm the guy there in the middle with the white hair and the gray jacket who's pontificating. And the guy right beside me with a cap on is Jose Hurtado. And the rest of the people on this image are actually of the class of 2013 astronaut candidates now who are awaiting assignment to mission.

And this was a project that was put together by Johnson Space Flight Center to actually do geological field training of these astronaut candidates. This is northern New Mexico in the Rio Grande riff in northern New Mexico and you'll see that the astronaut candidate directly in front of us is hammering on a rock. And you might ask the question, "Why are you hammering on a rock if you're going to be an astronaut? Is this something that's really going to be important?"

And it really is, because without the samples that are returned from those sorts of missions or without the samples that are returned robotically, it just makes it very difficult for us to understand the age of things in the solar system and also the pace, the tempo of planetary evolution.

So we're going to today talk about the way we sort of try to quantify that. And I'm going to have one theme that I'll come to several times during this talk, one of the most important things for you to remember, and that's on the next slide, Slide 3, and that's that some things stay the same but some things change, and planetary bodies are like this.

Everything you can image that could be an exploration target is actually constantly changing. And one of the things we want to figure out is what's the rate of that change.

Before we start talking about planets though, I want to talk just a minute about the earth because this is the planet we know best and it's one that we know a great deal about with regard to change.

So if you go to the next slide, Slide 4, it's this fantastic drawing by a guy named Ray Troll that's sort of the geological history of Earth as preserved in the rock record. And long before we knew how to do isotope geochronology, we knew about radioactivity.

For example, there was a sense of the antiquity of the Earth that was provided by relative ages of fossil assemblages that went back through time, sort of the left hand side of this diagram. And based on that kind of information, a geologist built a sequence of events that are coded in the rock record that are referred to in terms of things like periods and stages and eons and eras and that sort of thing that you can see on the right like the Holocene down through the Archean.

But on the very far right hand side of this image are actual numbers, so actual quantification of these things. And you'll note that these numbers range from things that are not terribly well-known like about 4.6 billion years ago down at the bottom to things that are known with very, very high precision. And something that should be of interest to all of us is why do some of these things that have relatively high precision -- things that are known to one decimal place or even better in some places -- how do we get those numbers? And why should we believe those numbers in particular?

Slide 5: And really, one of the things that we're trying to get at in these kinds of studies is when do things happen. But another thing is what's the tempo of planetary evolution? And actually a lot more research really has to do with the tempo of planetary evolution than it does with the absolute ages of things or the quantitative ages of things. And we'll talk about both of those in here for a second. Next slide.

Slide 6: There should be -- if I didn't forget one -- there should be a mountain on this slide. For those of you who might know the area of the world, this is Mount Everest and my own - from the north side, from the Chinese side. And my own interest in geochronology actually stems from a long, abiding interest in how mountain ranges evolve through time.

And in particular, I'm interested in how mountain ranges get to be as tall as they are? How long does it take them to do that? How long does it take them to erode away? What are the rates of erosion associated with various surface processes like wind and rain and snow glaciers? And so that's really how I got started in this business. But I've turned more and more, as Jeff said at the beginning, into studies of planetary evolutionary tempos over time.

And so I would go from this, this image of the highest mountain on Earth -- which is about just a little bit less than 9,000 meters high -- to this. And for those of you who don't know, this is an image from the Lunar Reconnaissance Orbiter in the next slide, Slide 7, of a portion of the moon that actually happens to be the highest point on the moon. The arrow points specifically to that. And you can see that the topography in this kind of an image is very different from the topography around Mount Everest, which is telling you something about the difference and the processes that are responsible for this. So the processes of surface evolution on the moon are dramatically different from the processes of surface evolution on Earth.

The evolution on Earth of mountains like Mount Everest is really associated with plate tectonics. And in that case, the collision between India and Eurasia that started about 50 million years ago and is still ongoing at about two centimeters a year.

As opposed to what's going on here on the moon. And the dominant landscape that you see on the moon in this particular instance is related to meteorite bombardment. It's through time. And so you end up with a very different kind of landscape, but in the same sense really very high mountains but high mountains for a very different reason.

In this case, this is about 2,000 meters higher than Mount Everest -- the highest point on the moon -- but it doesn't even have a name, it's so non-descript.

So let's talk about how these kinds of landscapes form. If you go to the next slide, Slide 8, and you look at this beautiful compository photograph from LRO of the moo in the foreground obviously and Earth in the background, and how do we try to quantify the pace, tempo of these particular processes?

So again -- next slide, Slide 9 -- we're going to take advantage of this saying that some things stay the same and some things change. And if you go to the next slide, Slide 10, we can ask these sort of fundamental questions about our universe. What are things made of? And where does that come from?

So we're used to thinking of the Earth as made of chemical components. And this is a table of the elements. In this particular case, it's color coded in a little bit of an unusual way. And it tells you where these elements are forged in our universe. So some of them are very old, like traced back to the big bang. Some

of them are formed as a consequence of cosmic rays. Many are formed in stars and supernovae. A few are man-made, especially since the 20th Century or so.

But even though these are all of the elements that we have that we're all made of, everything is made up of, in general not all of those elements are the same. And the reason for that is that most of these elements, essentially all of these elements, consist of multiple isotopes.

Slide 11: And so isotopes, if you remember back to chemistry, are the atoms of an element that have equal numbers of protons but different numbers of neutrons. And different isotopes have different masses. We usually refer to those different isotopes in terms of their mass. So here are two isotopes of oxygen, oxygen-16 and oxygen-18. And the 16 and the 18 have to do with the specific masses of those specific isotopes of oxygen.

But what's really interesting from our perspective is that some isotopes undergo spontaneous radioactive decay, which is defined as a spontaneous breakdown of an atomic nucleus resulting in the release of both energy and matter. And it really reflects the natural tendency of matter to try and seek stability.

Slide 12: So we can talk about three different isotopes of carbon -- carbon-12, carbon-13, carbon-14. And the reason carbon-14 is in a different color on this is it's one of the radioactive isotopes that you probably are familiar with for the purposes of dating.

And if you go to the next slide, Slide 13, a radioisotope like carbon-14 decays spontaneously to a stable isotope -- in this case to nitrogen-14. And we write that reaction in iso-geochemistry using the formula shown at the bottom of the slide here. Carbon-14 goes to nitrogen-14 in this case.

And the reason that that's important, that sort of reaction is important to us when we're thinking about geochronology is that it results in what we can think of as isotopic clocks. So next slide.

Slide 14: The rate of radioactive decay is constant over time. This is one of those things that does not change over time. It stays the same. And that means that we can use these isotopic clocks, these isotopic transitions through radioactive decay as a clock.

So we tend to talk about that rate of decay when we're generally speaking about these things in terms of half-lives. And you may recall that the half-life is the time that's required for half of the amount of radioisotope to transform through radioactive decay.

And so for example, the half-life of carbon-14 is 5,730 years. And we'll come back to the significance of that in a minute.

I want to break for a second to talk a little bit about in the next slide, Slide 15, sort of some of the fantastic experiments given the audience of this particular talk that can easily be done in classrooms with very low-tech on the radioactive decay. And it turns out to be one of the best ways to try and educate K-12 students -- not so much K, but students in our schools -- about things like exponential change in materials. So because this is an exponential change, it's an easy thing to illustrate.

So this is a photograph of an example of an experiment that has been run for quite a number of years. It's from the Exploratorium Group. You can see the details down below. But there's many different ways to run this kind of

experiment and I'll let you follow some of these links to get a sense of how they work.

But basically it comes down to simply taking a large number of coins -- in this case pennies -- putting them in a jar, shaking them up, throw them out on the table. And if you do that and your number of pennies is large enough, there's a very high probability that about half of those pennies are going to be head and half of those pennies are going to be tails.

And so in isotope geochemistry, we can use those as proxies for the radioactive element, which is often - the radioactive isotope, which is referred to as the parent isotope. Don't ask me why. Myths of history. And the tails we can refer to that show up after we've thrown these pennies, the tails we can refer to as daughter isotopes. So why daughter and not son, I'm not sure. But it's an interesting sort of question as we go back and look at where this technology comes from.

But if we do that and then take all of the tails that came up the first time, put them off to the side for a second, and we take all of the heads, put them back in the jar, shake them up, throw them out on the table again, we'll probably end up with something like about half of those coins being heads and half of them being proxies for daughter isotopes, being tails.

And so if you go look at the next slide, Slide 16, if you were to plot something up like this, this is sort of what the result would look like. So we plot percentages of the total number of coins on the Y axis and the number of tosses, which we'll let be a proxy for half-lives of radioactive decay. And we can just plot the number of coins remaining, those parent isotopes and the number of coins that we've removed as the daughter isotopes.

And one of the things that I think you can see sort of instantaneously from this kind of a relationship is that if any given time after you've done a number of tosses -- doesn't matter how many you've done -- you add up all of the removed coins and all of the remaining coins and you figure out the ratio between removed coins and remaining coins. And that is actually a direct indication of the number of half-lives that have transpired. In this case, the number of tosses that you've made.

And so it's a pretty obvious and easy thing to understand that knowing the concentration of daughter, knowing the concentration of parent, we can actually calculate the date from that kind of information.

So if you look at the next slide, Slide 17, there's sort of three basic tenets to isotope geochronology that I'm going to talk about. One is that the parent isotope has to have an appropriately long half-life. And by appropriately, I mean appropriate to the problem that I'm trying to study scientifically.

So for example, you remember that the half-life of carbon-14 is a little over 5,000 years. Which means that carbon-14 is a really good isotopic system to use for chronology on sort of human civilization times scales on things that have happened during the plastecine. But it's completely useless to work on ricks with great antiquity because all of the carbon-14 that might have been in one of those rocks is now essentially decayed away to nitrogen-14 and no longer remains.

So the system that you use, the isotopic decay system that you use, has to have an appropriately long half-life.

The second is that minerals and rocks have to have been closed systems with respect to gain or loss of parent and daughter isotopes. So just like in the little

experiment that I showed you, if somebody is surreptitiously taking coins off of the table during that experiment, I can no longer calculate how many half-lives or how many tosses have transpired.

And then the third thing is that the target rocks -- rocks I'm interested in studying -- must include minerals that contain the parent element in sufficient abundance. And that turns out to be important from the perspective of which decay schemes we can realistically use.

The next slide, Slide 18, here is a list, a table of key decay schemes that we use in planetary geochronology. So the first one is a parent isotope with a layer of element Samarium -- Samarium-147. The decay is MA 143. And you see that it has a half-life of 106,000 million years. We use this term MA a lot in the talk today. MA stands for millions of years.

So the half-life of Samarium-147 is much, much longer than the age of the solar system. So it means that it's an appropriate kind of system to use for a wide variety of things that are really old. It's not so great to use for things that are really young -- for example, Plasticine or Holocene, something like that.

Then we have Thorium-232 which naturally decays to Lead-208. So a little bit shorter half-life. Uranium-238 which naturally decays to Lead-206. Potassium-40, the only major element in this group that decays to the noble gas Argon-40 And Uranium-235 decays to Lead-207.

One thing that you should notice about this table that is particularly interesting is that of these decay schemes that are often used for this sort of thing, three of them produce isotopes of lead --Lead-208, Lead-206, and Lead-207. And that has some special advantages in terms of doing high precision geochronology -- when we're worried a little bit about the closed system behavior material. So

you'll hear about that one a lot, particularly the combination of Uranium-238 to 208 Lead and Uranium-235 to 207 Lead.

And as a consequence of combining those two analyses, it can be done on the same rocks at the same time. We can think of things - we can talk about things like what are called lead-lead ages. In other words, the age of something that's entirely dependent on the ratio of two isotopes of lead. Okay. So next slide.

Slide 19: So let's go back to Ray Troll's image in this case. And most of the numbers -- all of the numbers really -- that you see on this diagram are produced by some combination of those radio isotopic systems. So all the way from about 10,000 years at the base of the Holocene down to our Earth forming 4.6 billion years ago.

And a question that I really like to ask my own graduate students and undergraduate students when I get the opportunity to do it -- and I've done it with high school students as well -- is I ask them how old they think Earth is. And a great many of them will come up with the number of 4.6 billion years. They'll say the Earth is 4.6 billion years old or 4.5 billion years -- something like that. And that begs the question immediately, how do we know that? Right? Why do we say Earth is four and a half, four point six billion years ago years old?

And often when we make that comment, the presumption is that we've actually dated things on Earth that are 4.6 billion years old. But that's not true.

So if you flip to the next slide, Slide 20, I'm going to go through a series of sort of record holders in terms of the oldest things we know using isotopic systems going back through times.

So in the next slide, Slide 21, is the oldest known rock on Earth. It's a meta sedimentary gneiss. And so for those of you who know a little bit about geology, that's interesting in and of itself because it's a metamorphic rock, it's a gneiss, and it's a metamorphic rock that is metamorphose sediment, which means that there must have been something older than this rock. Otherwise, it would not be eroded and redeposited as a sediment and it would not have been metamorphosed as a gneiss, in this case.

But this sample is from the Acasta Gneiss complex in the northwest territories in Canada. This is a picture of some of the actual outcrops. Actual oldest rock didn't come from this outcrop. It was nearby. I've been there. And the date for that particular rock -- it's a lead-lead date using the system I told you about before -- and it's a little bit more than four billion years old. It's not 4.6 -- 4.031 plus or minus about 4. And that's approximately the 95% confidence level in that number. So you can see how precisely this sort of thing can be done.

And then if we ask what's the oldest known rock from the moon, it's sample 60025. It came from the Apollo 16 collection. It's an anorthosite, a very rich igneous rock from the Moon in this case. And the lead-lead date of that is 4.36 billion years old or 4,316 million years with an uncertainly of about 3 or so. So older than the oldest rock on Earth but still not 4.5 4.6 billion years.

So how about the oldest minerals? If you look at the next slide, Slide 22, the oldest known earth minerals are zircon, the zirconium silicate mineral of zircon. These are some photomicrograph of some samples from Jack Hills in Australia. These are the oldest zircons on Earth as far as we know. And the ages of these zircons is about 4.374 billion years old -- so 4730 - 4,374 millions of years old. But they're still not 4.6 billion years old.

Slide 23: So it turns out that the oldest thing we know from the solar system are calcium aluminum rich inclusions in chondrites, in chondritic meteorites. And that oldest material right now is from a meteorite that's referred to as NWA2364. The NWA stands for the fact that it was found in northwest Africa, in this case. And this particular meteorite has yielded a date of 4.568 billion years, which you can round up to 4.6 billion years. And that's the number that is generally assumed to be the age of the solar system, with the notion that Earth is about the same age as the solar system.

So when we say the Earth is 4.6 billion years, really you have to rely on data that's available from carbonaceous chondrites to be able to come up with something, a number that's really that old. It forms a foundation for it.

So the last thing that I wanted to talk a little about is to bring this all back to some of the work that we have been doing as part of the SERVI project for NASA in particular. And it's actually a part of it that is a relatively minor part of this SERVI project FINESSE that's being run out of NASA Ames that Andrea and I are part of. The part of that work that's actually taking place in craters of the moon in Idaho and it's focused on field analog studies of volcanic landscapes.

Slide 24: But one of the things I'm really most interested in because it provides a tremendous amount of information with respect to the temporal evolution of the moon because a meteorite impact has been such a pervasive part of the evolution of the moon, is actual analog sites we can go look at meteorite impacts on Earth. And there are actually not that many. There are just about 200 that have been identified on the surface of the Earth. Most of them are in very, very old rocks like the areas where the Acasta Gneiss is found in the Northwest Territories.

And the reason for that is that plate tectonics destroys a lot of the evidence through Earth time of impact events, in particular. So for the really old ones, we really have to go to places like the Canadian Shield to be able to look at those things when we go on Earth.

And if you go to the next slide, Slide 25, if we've kept face, the next one says something like Clearwater East and West impact sites on top. And this is one of the study areas that we've been interested in working on in the northern part of Quebec as part of this particular project.

One of the things that led us here is really the interesting observation from space that there are two impact craters that are right next to each other. They're referred to as Clearwater East, Clearwater West. East is to the right-hand side of the picture that you're looking at here. And for many, many, many years, those two impact craters have been thought to be the same age.

And it turns out that just over the last few years, as we've been applying these techniques of iso geochemistry to understanding the age of these impact sites, they're actually very different ages. And so the emerging dataset that we have right now is that the one to the west -- the one to the left-hand side of this diagram -- is about 286 million years. And the one to the right that forms the lake that you see on the right is actually about 200 million years older than the one on the west side.

The uncertainty on this one is not that great. There's much more work that needs to be done. We need better analytical work on these, and that's part of what we're working on right now. But it just goes to show that without this kind of high precision -- or increasingly high precision -- geo-chronologic work, it's very difficult to tell just by the way things look how old they actually are.

Slide 26: So I want to finish up before I open it up to questions, I want to finish it up talking a little bit about educational resources. For those of you who are - if you go to the next slide. So for those of you who are interested in incorporating these sorts of ideas into classroom exercises or museum exhibits and things like that, there are a lot of resources on the web. And you should feel free to get in touch with me if you want sort of introductions to different ones that are specific to the kind of things you want to work on.

But I just want to talk about three different sources that are great. There's a program, a project that was run that still continues to be run by the National Science Foundation called Earth Time. And it's the idea of trying to sort of sequence geologic time through the rock record and the fossil record on Earth.

This particular project is fantastic. It involves hundreds of people all over the world trying to approach this. And sort of their portal to this website is www.earth-time.org. And there are a lot of educational resources that have been put onto that. Some of them are a little bit dated now. So if you're interested in getting them and you haven't seen - somehow you have funds working, I can try and put you in touch with people who can probably give you more up to date components of it. But that's a great place to start, in my opinion.

Another thing was the National Association of Geoscience Teachers has workshops that are online. One that I'll refer to specifically here is one called Lakes, Dates, and Geologic Time. The URL is down below that. That's another good place to get access to the sort of information I've been talking about today.

And then with regard to a very popular book about this, both of planetary geochronology and also earth geochronology in particular, I'd like to recommend a book by a guy named Brent Dalrymple who's been a great practicing geochronologist for many, many years. He's retired now. But he has a great way with writing things in a very accessible way.

And so his book Ancient Earth, Ancient Skies -- you can find it on Amazon.com -- is a fantastic introduction. Lots of ideas about ways to get these concepts across to students.

So that I think I'll wind it up. I don't know Andrea, Jeff. Do you want to jump right in, Andrea? Or maybe answer questions first. How do you want to do it?

Jeff Nee: Yes, I think we can take a few questions now while ideas are fresh in our head. I know I certainly have some, but I always like to let people go first. So if there's any other questions our there from other people, feel free to jump in now.

Otherwise, I have a really basic one. And this shows my ignorance of geochronology. But when you were talking about radioisotope decay and actually dating things, when you're measuring, you're measuring the ratio of the parent isotope to the daughter isotope to date things. Is that correct? Is that - am I saying it right?

Kip Hodges: It's a little bit - yes, that's sort of the fundamentals of it. It's a little bit more complicated than that because of the sort of interferences that we see when we measure these numbers using mass spectrometers. So we actually have to measure more than just those two isotopes.

And in some schemes, it's a lot easier to measure them than others. Sometimes we use tricks with our isotopes. So for example, one of the methods that I talked about was this decay of Potassium-40 to Argon-40. And analytically, that is a bit of a challenge because obviously Potassium is a metal and Argon is a noble gas. So those of you who know a little bit about analytical chemistry, that's not tough and easy thing to measure a ratio with, to measure a ration of a gas to a metal.

And so the way we handle that is that we actually take the sample and put it in a nuclear reactor and create a synthetic isotope of Argon-39, which we know about the efficiency of that production in a nuclear reactor when you bombard it with fast neutrons. And so we can actually relate the size of the 39 peak, the number 39 as a measure in a particular sample, carrying the analyses to the amount of Potassium-40 that was in the sample.

So just by measuring the ratio of Argon-39 and Argon-40, we can get a date. But it's because we're making synthetic Argon-39 in that case.

And many of the other techniques that I talk about require some chemical preparation so that you can separate the parent isotope and the daughter isotope in particular. But ultimately we use the ratio of those two things to determine the age. Does that help?

Jeff Nee: Yes, it does. And I guess then my follow up question to that would be when you're measuring the decay rates, you're measuring it from the creation of that substance. So let's say you're measuring carbon-14. You're measuring the decay rate from the creation of carbon-14.

How can you be certain that the creation of the carbon-14 is - I mean, I guess I'm having trouble putting this into words.

Kip Hodges: Well…

Jeff Nee: How do you…

Kip Hodges: That's okay. I sort of see where you're going, but remember that the rate of radioactive decay as far as we can tell is constant over time, right?

Jeff Nee: Yes.

Kip Hodges: So I don't need to know the rate of radioactive decay from the creation of the element. I only need, starting at any given time, like today I can do an experiment. I can put a bunch of uranium-238 in a box and then I can come back after a very long time and I can measure the amount of lead daughter isotope that's produced by that 238 and from that information get the decay rate.

Jeff Nee: So if you have like the oldest rock, for example.

Kip Hodges: Yes.

Jeff Nee: How do you know that that rock sat there and started with all carbon-14 for example, just as an example? Or U-238? As opposed to coming in with a mixture of the daughter?

Kip Hodges: So you might recall early in the set of slides, one of the ones I said is the system has to be closed…

Jeff Nee: Right.

Kip Hodges: …with respect to gain or loss of the parent and daughter. So if it's open -- so you're talking about an open system, right? And so if it's open with respect to the gain or loss of daughter or it there's a daughter that's in the sample to begin with before we start, then we have to make some kind of correction associated with that.

And there are actually ways that we can do that. For quite a lot of these systems, there is a little bit of that daughter product that's already in there to begin with. So by looking at the ratios of the other isotopes of that daughter product, we can actually back calculate and correct for that.

Jeff Nee: Okay.

Kip Hodges: It's actually very easy when we're doing noble gas work because for example, with a terrestrial sample, if we're doing noble gas work we sort of know what the initial ratio is between Argon-40 and Argon-36, which is a stable isotope of Argon in particular because we can actually measure it today in the atmosphere. And that ratio that we measure today in the atmosphere we can compare that to what we get from the sample and actually do a correction associated with that.

A little more complicated than other isotopic systems, but not too much.

Jeff Nee: Sure. Okay. And I have…

Man: Question.

Jeff Nee: If other people have questions, go ahead.

Man: I have two actually. One, how is the half-lives of these isotopes determined? I mean, no one's around to measure U-235 to 207 at 710 million years. Is that measured directly or is that inferred or is that calculated? How is it determined?

Kip Hodges: So these are actually measured directly. And…

Man: Really?

Kip Hodges: …the precision with which we can measure them, it's variable depending on the isotope. And as you correctly surmised, it depends on the half-life. But remember when we talk about a half-life of say 710 million years, that is the amount of time it takes for half of however much the parent element was there to decay to the daughter.

So you don't necessarily have to have that much material to count it, right? To determine how much it is. So we can run an experiment for a relatively long time -- usually on the order of years -- but we can run it for a long time and it literally is as simple as putting the material in a box, waiting several years, coming back and see how much of the daughter is there.

And that's been done with all of the systems that I have given you information about today.

Man: Okay. All right, the other question is…

Kip Hodges: You don't have to wait until you get half I guess is the simple answer to your question.

Man: Okay. And the other question I have is the dating of the solar system with the calcium aluminum inclusions. I collect meteorites so I have a nice specimen of Allende. And I thought Allende because this is a CD3 carbonaceous chondrite too NWA2364, but this was a find that highly terrestrialized was Allende was a nice fall. And I'm looking up the date on the internet and it's 4.56718 plus another 0002 billion years by lead-lead iso-chrome age. So you're splitting hairs.

Kip Hodges: Yes. You're getting - almost all of the chondrites that have been dated. And there's another thing that's important to remember in isotope geochronology. It's like any other analytical technique -- some analyses are better than others, right? Some are higher precision than others. Some are more carefully done than others.

And so there are a lot of dates that one can find for different meteorites and different geologic samples on Earth, for example. And not all of them are going to be at these very high precisions. So I wouldn't, I don't specifically know the result that you're finding when you just look this up on the internet.

So clearly comment on that -- might be a really good date, might not be. But the ones I've tried to give you today are what I consider to be the most precise and the most reliable numbers. But there could be, and people are working on these problems all the time. Everybody's trying to push back as far as they can and determine as precisely as possible the age of the solar system.

Man: Okay. Thank you.

Kip Hodges: You're quite welcome. Other questions?

Man: Yes, I had a question.

Kip Hodges: Sure.

Man: It's my understanding that the date gives the time, since the rock kind of solidified into a solid. Is that correct or am I misunderstanding that?

Kip Hodges: It's a little trickier than that. In the ideal case, you are correct. If I'm working on an igneous rock that crystallized from a melt.

Man: Right.

Kip Hodges: That's in the ideal case. One of the things that we have to think about with some of these isotopes are the kinetics of that daughter product. Because a lot of times, that daughter product that's produced during this decay has the ability to diffuse out of the system. It goes back to this open and closed system behavior.

Man: Yes.

Kip Hodges: And that ability to diffuse out of the system is very strongly temperature dependent. So very high temperatures you can end up having some of the daughter product diffuse away. And of course obviously if some of the daughter product diffuses away, the sample looks older than it really is, if what we're after is that crystallization age that you were originally talking about.

So we have to take that into consideration with all of these different systems as we interpret what we actually calculate using the equations as a date, but as we interpret it as the age of something. Like the age of crystallization or something else.

Man: Yes.

Kip Hodges: And that's the reason why people tend to use uranium lead dates as sort of the gold standard in all of this. And the reason for that is that of all of the elements that we've been talking about here, the one that is lease susceptible to diffusive loss under most geologic circumstances are the isotopes of lead. And when they are lost as a consequence of that, they tend to change in their relative abundances. The lead isotopes tend to change in their relative abundances.

There's a term in geochemistry we refer to as a fractionation. And that kind of fractionation tends to be in such a way that there's like a fingerprint of it having happened in the isotopic systematics of what we're trying to date. So we can actually tell if the sample has been compromised in terms of its lead isotopic systematics and we can know not to necessarily believe that date has a specific geologic significance like the crystallization age.

Man: Okay. Thank you.

Kip Hodges: Does that make sense? Was that where you were going with that or were you going in a different direction?

Man: Yes, that's partly where I was going. The other thing was as far as that Acasta Gneiss complex, it was a…

Kip Hodges: Yes.

Man: …sedimentary gneiss. Are we looking at maybe individual minerals within there to date? Or are we looking at the rock as a whole? If that's a little confusing.

Kip Hodges: Yes. The best date for that particular material actually uses zircon date from that sample.

Man: Okay.

Kip Hodges: So yes, we tend to do that. And the reason for that is if you remember the slide, when we try to get minerals, get things to date that tend to concentrate the elements of the interest. And zircon is a mineral that concentrates uranium. So it's a particularly good mineral to work on if you're trying to do uranium-lead or lead-lead geochronology.

Man: Okay. Thank you.

Kip Hodges: You're welcome. Anyone else?

Jeff Nee: I had some questions about the drawing by Ray Troll.

Kip Hodges: Yes.

Jeff Nee: Is that free to use? Can we use that for classrooms and…?

Kip Hodges: It's interesting, you can download that directly off the Earth Time website that I gave you the information to. And Ray is a really good guy. I've met him at several of these meetings and he does a lot of work with Kirk Johnson who some of you might know. He's at the Smithsonian now, was at the Denver Museum of Natural History.

And so I think that - and they're written books together, actually -- beautiful picture books that Kirk and Ray have written together, illustrated by Ray. And I'm sure that they would be happy for people to use that. I think it would be a good idea, you know, to make sure that you show that it's Ray's work because he does such a wonderful job. But I'm sure he would have no problem with that. But if you have concerns, the thing to do would be to contact Kirk and I would describe that it's part of this network. But Kirk's at the Smithsonian. I can send you his email address if you'd like.

Jeff Nee: Great. But you said it's on the Earthtime.org.

Kip Hodges: It's on the Earth Time website. It's part of the teaching materials that are available for free download.

Jeff Nee: Great. And I was looking at this because it's not to scale. Is that correct? Or is it to scale?

Kip Hodges: No. It's not that carefully drawn.

Jeff Nee: Okay.

Kip Hodges: It's pretty close, but it's not that carefully drawn. And you particularly lose the scale at the very top of the section, in the Holocene. And now we're going to have to redraw it with the Anthropocene on top. But it loses scale up there and really loses scale down at the bottom, as you can easily see.

Jeff Nee: All right. And I hate hogging this, so if people have questions, don't let me just go on. But I did have a question about the elements. Someone once asked me is there a point when we can actually say in the universe that a certain

element emerged in the universe? Or is it all mushed together in the early universe and we can't really tell?

Kip Hodges: Well, if you go back to the information that I showed you on sort of periodic table right where you had a bunch of different sources of the evolution of elements, a lot of those things are not primordial. In other words, a lot of the elements are not produced at or near the big bang or the ionization period, for example.

A lot of them are constantly being forged in stars. And so if something is not radioactive and does not have a very long half-life so that there's still some of that material there from when it was formed, it would really be impossible to determine the age of it, of a particular atom of that material.

So I don't think there's an answer to your question. There are some clever ways to try and estimate things like the average amount of time verses a variety of different things like that or in the solar system of a variety of the elements. But I don't think really precisely determining the exact age is something that's in the cards.

Jeff Nee: Sure. Okay, thank you. Let's see. I want to make one more call before we turn it over to Andrea. Any last second questions? Okay, great. Well, thank you very much, Dr. Hodges. This is really, really cool. I'm really fascinated. I'm really looking forward to using some of this myself.

Kip Hodges: Great. Quite welcome. And if anybody wants to get in touch, please feel free. I think my email is on that very first slide. I planned to put it there, anyway.

Jeff Nee: If anyone has questions, I have your contact info so they can email me.

Kip Hodges: Okay.

Jeff Nee: Again, my email is JNEE@jpl.nasa.gov and people can just email me if they need to.

Kip Hodges: Okay. Sounds good. Yes, I forgot to put it on the first slide. Sorry about that. But, yes.

Jeff Nee: No worries. Okay. Andrea, did you want to take it away for a few minutes?

Andrea Jones: Sure. So Kip, thank you so much. That was wonderful. And clearly a lot of interest, based on everyone's questions, so that's terrific.

I just wanted to jump in here with a few comments on slide 27 to let you know a little bit more about the education program that we have associated with FINESSE. The Solar System Exploration Research Virtual Institute, which we're a part of, has different education projects along with it. And FINESSE's is called Spaceward Bound. This is built on the NASA Spaceward Bound Program.

And it's really concentrated on bringing students and teachers out into the field to have them participate in planetary science research. So sometimes we have people observe. Sometimes we teach teachers in a classroom or educators in a classroom. But this way we're trying to really immerse teachers in the process of science, get them involved, get them learning how to use the instruments, collecting data, and then actually even all the way participating in publications and getting their name on scientific publications. So they're really actually contributing to NASA research.

We're doing this in partnership with the Idaho Space Grant Consortium. And we have brought teachers out every year since when this started three years ago. And we're building our numbers a little bit over the time. But really, small numbers. So we had five teachers this summer, I think. Actually no. It was seven teachers this summer that we accepted, and not everyone was able to make it at the last minute. But we're building it.

But we want to keep small numbers so that we have a really high scientist to teacher ratio. So if you are a teacher or if you know teachers, particularly in Idaho, this is a way for them to really get involved in NASA science, learn about a lot of really interesting volcanism here on Earth and how we're using that information to learn about volcanism on other planets and getting ready to explore other planets with robots and with human explorers in the near future.

So that is slide 27. And then our next slide, Slide 28, is just about International Observe the Moon Night. Have to remind everyone that of course it is coming up again. I hope you are all familiar with this program. This is a global celebration of lunar and planetary science. And it is of course an opportunity to let everyone you know - give them an update on some of NASA's lunar science results and discoveries, which are happening all the time. We have new data coming in from our Spacecraft LRO and other spacecraft at the moon right now.

But then the connections of the moon to other moons in the solar system, other planets in the solar system, XO planets, maybe XO moons -- all of this is tied together. And it's an opportunity to talk about that kind of research and that kind of discovery. And then also celebrate that this is our nearest neighbor in space and it has inspired songs and poetry and books and paintings and all kinds of art and our language, our month, and all of those things. And to just think about hey, do you have a favorite memory of the moon? You probably

do. And everyone around you probably does, too. So a chance to talk about that, unite in a peaceful way, and to learn about some really exciting finds.

So I encourage everyone to participate in that. It's coming up on October 8th, 2016. Anyone anywhere can host an event. Anyone anywhere can get involved. And there is no set agenda for how you need to have an event. Really, we just want you to look at the moon. And if you have poor weather, we have resources to help you do that even in the rain on our website. So I encourage you to go there, check out the resources that we have, join in the lunar conversation with people around the world through social media through hashtags such as observe the moon. And we're also on Facebook and Flickr.

So join in with lunar enthusiasts everywhere and look at the moon on October 8th, 2016.

On the last slide, Slide 29, I wanted to also mention that in addition to having International Observe the Moon Night coming up in October, we are already preparing for the 2017 (IOMN) event. And that will be a little bit - a little over a month, about five weeks before the total solar eclipse that will be coming on August 21st. So getting everyone excited. We will focus on lunar science related to the eclipse such as knowing the topography of the moon better than any other object in the solar system -- including the Earth -- and how that affects things like where we see Baily's beads, how that affects the ruggedness of the edge of the eclipse path, and things like that.

So we'll have lots of public webinars. We'll have an observation journal that will go from the date of International Observe the Moon Night all the way up through the total solar eclipse so that you can finish your journal with an eclipse, which is very exciting.

So I encourage you to get ready for that as well. It's going to be very exciting. Even if you're not along the path of totality, anyone in North America will be able to see a partial eclipse. So everyone can get involved and there's lots of ways to do that.

So thank you for your attention. I hope that you all join us on October 8th and on July 15th. And there are lots of resources. And if you have any questions, please let me know.

Jeff Nee: Andrea, for the Spaceward Bound, when is the application process for that?

Andrea Jones: Yes, so at the current time if you are an Idaho teacher, you can find it through the Idaho Space Grant Consortium website in the spring. So they haven't even released it yet. This is something to be thinking about around April or so for that summer.

If you are not from Idaho, if you would like to be considered, we are trying to get other space grant offices involved. This year we had someone from Massachusetts participate for the first time.

But this is a new thing. So if you're interested, if you are an educator -- mostly we target classroom teachers, but we had someone from a science center come this summer as well. So just send me an email. Maybe contact Jeff and he can put you in touch with me and we can try to see if there's something that we can work out. Again, the numbers are pretty small, but it's a really intense experience, really exciting. So I would encourage all of you to at least consider it.

Or there are other NASA Spaceward Bound programs that bring teachers to really rugged, tough environments around the world where you can

experience planetary science research in different place. So beyond craters of the moon, there are other opportunities as well.

Kay Ferrari: Andrea, this is Kay. Are you the person that I should put down as the leader of Spaceward Bound?

Andrea Jones: I am the leader of FINESSE Spaceward Bound.

Kay Ferrari: Okay.

Andrea Jones: NASA Spaceward Bound is a larger program. We just modeled…

Kay Ferrari: Right.

Andrea Jones: …our program off of that.

Kay Ferrari: Okay. Because Spaceward Bound Educators had been part of our NASA Nationwide network until I lost contact with the person who was coordinating it. So I'd like to know who that it.

Andrea Jones: Okay. Well, that had been someone who retired.

Kay Ferrari: Liza.

Andrea Jones: And the scientist is still involved. So Kay, send me an email…

Kay Ferrari: Okay.

Andrea Jones: …and I'll see if I can track down the person who you should get in touch with.

Kay Ferrari: Great. Thank you.

Jeff Nee: Awesome. Any other questions for Dr. Hodges or Andrea? I don't mind ending three minutes early. We all have things to do. All right.

Well in that case, thank you so much to Dr. Hodges and thank you so much to Andrea for taking the time to teach us a little bit about this really cool stuff. And I would like to - yes, of course.

Kip Hodges: Just saying thank you, Jeff and thanks to Andrea for helping to set this thing up. And thanks to everybody for listening.

Jeff Nee: Yes.

Andrea Jones: Yes, this has been great. Thanks so much to everyone.

Jeff Nee: All right. Well thank you everyone for joining us today. Remember that this talk will be recorded and archived on the Alliance site and the Solar System Ambassador sites if anyone wants to hear it again.

And if you have any further questions about this topic either now or in the future, always feel free to email us. Again, my name is Jeffrey Nee and my email is JNEE@jpl.nasa.gov.

And we hope you'll join us for our next telecon on Thursday, September 15th all about the new Globe Observer app. It's really cool and I hope you guys join us.

Thank you again everybody and have a wonderful day.

Woman: Thank you.

Man: Thanks.

Woman: Thank you.

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