

Speaker 1: Welcome to Office Hours, a production of the University of Pennsylvania's Office of University Communications. Through this series we bring you candid discussions with some of campus's great minds, dialogue a little more unbuttoned than you might find in the lecture hall. Today, we knock on the door of Doug Jerolmack, professor of Earth and environmental science with a secondary appointment in mechanical engineering and applied mathematics. He works on experimental geophysics or the science of scenery.

Speaker 1: He poses questions ranging from why pebbles found along river sides are round to why sand dunes take shape and move the way they do. Here, Jerolmack discusses his research related to these subjects, what a rounded-pebble found on Mars might actually mean, his twin brother who also studies the environment, and what he'd name his first memoir.

Speaker 1: Welcome to Office Hours.

Doug Jerolmack: Thanks a lot.

Speaker 1: How's your summer going?

Doug Jerolmack: It's going well. There's been a lot of projects I've been working on. Summer is a time that I try to get a lot of writing done, but I run a lab and so summer is also a time when I get pulled into the lab a lot more to work on a lot of problems that people in my group like the PhD students and postdocs are getting into. So bouncing around a lot between the lab and trying to set aside blocks and hours of time to write manuscripts and proposals.

Speaker 1: Do you have to get back in the swing of things whenever you go back to the lab?

Doug Jerolmack: Yes. I mean, there's this inexorable trajectory it seems that you become more and more of a manager and less and less of an active scientist as you go along. And there are things you can do to fight that, but you have to be active in fighting it because the more sort of history and reputation and experience you have, the more you get asked to take part in structural organizational things that are not the doing of science. And so, yeah, it's a lot to shake off and try to switch my mind in the gear of doing science. I don't have the big blocks that I had in graduate school.

Speaker 1: Right. So I guess explained for the interwebs the shorthand of what you do because it involves sediment and pebbles and all sorts of natural phenomena at the science of scenery as your bio put it, but it's pretty complicated.

Doug Jerolmack: Yeah. It gets pretty complicated, but ultimately I say water moves downhill, wind blows, and they drag things with them. And everybody can understand that. It just turns out that that problem is a problem of turbulent fluids, air and water, picking up and moving granular material, soils and particles, and it turns out the two grand unsolved problems in physics. One is turbulence. We just

don't understand it. And the second is granular materials that can behave as a solid, a liquid, or a gas for example when you have a sand pile and then you shake the ground and suddenly it liquefies and becomes a flow.

Doug Jerolmack: The discipline is ostensibly called geomorphology which is what you were talking about with the science of scenery, and that's what we're trying to do is really figure out the physics of particles and the fluids that move them, and how the movement of those particles by fluids over long timescales creates patterns that you see on the surface of the Earth. And so the last point I'll make there is I study landscapes, and landscape is a word like... So I love landscapes and I love surfing.

Doug Jerolmack: Now, the reason I bring those up is there's two words that are used for many, many things, but without a modifier mean only one thing. So if you say surfing with no modifier it means getting on a surfboard and riding a wave. And only if you add things to it does it mean something else. And if you say a landscape without any modifier, it means the land outside, and the scenery, the scape that you see, right?

Speaker 1: Right.

Doug Jerolmack: I especially say that when I talk to physicists because they have, and biologists they have so many metaphorical landscapes, energy in landscapes and fitness landscapes. And I say, "No, no, no. Landscapes like when you look in your camera and it says do you want landscape mode and it has a little mountain." That's what we study.

Speaker 1: Okay. I think where that gets especially interesting I was kind of looking into this it's if you, I guess kind of work backwards. So if you're looking at something like Mars or something like that I'm trying to understand how water got there which I think I'm right. That it's a thing, right?

Doug Jerolmack: Yes. That's a thing. There's frozen water there now. Water did a lot of action in the past, so, yes, yes, that's a thing.

Speaker 1: Right. Are there any examples you can think of that are kind of like that that you've maybe looked into in your work that people can relate to? I know you've done some work related to the roundness of stones that...

Doug Jerolmack: Yeah. So I would say, you're right to bring up the idea that there's what you could call the forward problem and the inverse problem. So the forward problem is the approach that you usually have in physics, which is okay. Theoretically I want to... I can have a theory and my theory I don't mean a layperson version of theory, I mean the physics version of theory which is that you have based on fundamental principles and physics, you can describe the behavior with a series of equations that is well vetted and experimentally tested, and that's a theory.

Doug Jerolmack: And then the forward ways say, if I understand this, the theoretical framework makes predictions about patterns and behaviors like how soil will suddenly liquefy and make a landslide and how fast that landslide will flow. And if you could do that in the forward way I could say I can solve all the equations and utilize the theory and I can say something about how, and when, and where that kind of pattern will happen or that process will occur.

Doug Jerolmack: The inverse way is saying I've got the result of some process and I want to work backwards from the result be it a river deposit locked up on Mars or a rounded pebble that I pick up in a stream that I know somehow it wasn't born rounded and somehow it got rounded. And the inverse process is trying to take the result of some behavior and work backwards to figure out what caused it. So in our lab we do both. So ultimately we would like our understanding of the creation of patterns and flows on the surface of the Earth to all be forward problems, which we could understand and lay out all of the theory that undergirds these things with sets of equations and we could solve those equations under different conditions and predict for you all the patterns and behaviors that we see.

Speaker 1: Right.

Doug Jerolmack: And of course you if you see me smiling it's because, well, in certain well contained isolated cases we can do that, but in most of them we cannot because these are complicated systems with a lot of interacting parts. And those interactions, any uncertainty or things we don't know about those interactions can get propagated and spun up to create huge differences in behavior from what we expect. And so the inverse problem is challenging because of what we call non-uniqueness which is that well very many different processes could produce the same result. And so the classic problem on Mars is that... You brought up the idea is water on Mars a thing, and it definitely is, so I don't want people to get the wrong idea.

Doug Jerolmack: But for decades we've been gathering circumstantial evidence that channels, canyons, deposits that we see were formed by rivers of water that we're picking up particles and moving them and doing the same things that we see on Earth. And it is circumstantial evidence, but it has grown to the point where it is... Certainly the most plausible explanation is that water did it, and you have to reach ever further and ever harder to gin up some other explanation.

Doug Jerolmack: However, part of being doing science is being skeptical right even if the most likely explanation is the simplest that doesn't mean that is the right one for sure and there may be another simpler explanation that you don't know about because your information is incomplete. And so the example with river channels on Mars is as long as we can't solve the forward problem and say there is literally only one way to make that exact pattern right there and it's these ingredients, water and particles moving under gravity in this way, a skeptical scientist which is part of their job could say, "Well, I could imagine some other set of processes that could do it also."

Doug Jerolmack: And so then one of the things that we do then in terms of connecting the forward and the backward problem is are there some signatures, patterns, or behaviors that are more indicative of process, or if you will more special than others. And so that then is that you're using physics not necessarily to predict an exact result, but to ask which patterns are so common that they'd be very hard to attribute to one particular cause and which aspects of patterns only arise under very particular combinations.

Speaker 1: Have you had any instances where the most likely explanation was not in fact the explanation?

Doug Jerolmack: That's a good question. I've had instances where I had a guess about the most likely explanation, and I would say that half the time that my first guess of what I think is the most likely based on what I think is simplest is wrong. So I would say there are many instances of that situation. But to give you an example maybe of a problem we've worked on where someone else's first guess of a result we demonstrated was not correct is related to that problem that you talked about with rounded pebbles. So just a bit of a backstory because the rounded pebbles is kind of a fun problem but it connects to a lot of different things of how much you can and can't take simplified idealized theories and extend them to the natural world.

Doug Jerolmack: So we know that when we go to a river that we see pebbles that are rounded and the more downstream you go in the river the more rounded the pebbles are. And indeed the egg-shaped pebbles that we take out of rivers, people like them, you make foundations and houses out of them and things like that. But the other thing that we know is that often when you go to the beach you find that pebbles are flat. They're more like disks than they are like eggs. So you have this observation that a lot of river stones are egg-like and a lot of beach pebbles are disk-like, and some river pebbles if you get to the lower stretches of the gravel rivers and the lowest energy part of the rivers are also disc-shaped.

Doug Jerolmack: And so there was this idea then that it's been around for a long time. Well, we know that these particles get rounded because they chip off. The pebbles are not born round, you have rock that fragments and breaks apart into angular shapes and those angular shapes get carried along by the current of the river and they get banged together, and little chips break off and that will make it move toward a rounded shape. The thing I always say to my students is if you imagine a chalkboard eraser and if I just throw it at the wall the probability that a very flat face of that eraser will exactly make contact with the flat face of the wall is essentially zero. What's going to happen is a corner or an edge is going to strike the wall. So you can actually write an equation that describes the probability if that eraser is flying around and flipping randomly. The probability for it to strike an edge at a face in a corner.

Speaker 1: Do we have some rounded erasers somewhere at Penn?

Doug Jerolmack: Well, erasers are soft so it doesn't work.

Speaker 1: You're just throwing sort of.

Doug Jerolmack: So we don't have rounded erasers but we did make... So the erasers of course don't chip, but in order to prove this we do experiments where we make cubic particles out of cement which is weaker than rock, and we can tune the strength or weakness of cement. And we put it in a drum, and we tumble it, and we actually observe precisely how it evolves toward a sphere. So we can show that an idealized geometric theory when we run an experiment actually precisely describes that experiment. The question is does it describe real life? Well, that idealized geometric theory that says that the probability of chipping is related to the sharpness or curvature of the edge that predicts that everything evolves toward a sphere.

Doug Jerolmack: Well, there's no spheres in nature. So then is the theory wrong or the theory incomplete, and how general is it? And so it turns out that if you look at what pebbles do going downstream, in the first part of their trajectory when their very angular fragments in the mountains and they tumble down and they get rounder, they are evolving toward a sphere precisely as the idealized geometric theory shows. They're getting more and more spherical, but what you find as you go downstream is they start to fall off of the curve, the predicted trajectory toward a sphere.

Doug Jerolmack: And so then you have a theory that works for part of the space, but then the particles start to fall off of that space. And why are they falling off of that space? And so the geological simplest explanation of flat pebbles versus round pebbles is that flat pebbles are what happens when you have... The rocks are actually geologically layered, so they're thin layers of rocks. And therefore the reason why you make flat pebbles is because you start out with flat pebbles. The rock is in layers and those layers fracture, and you get angular disks that break out of the rock, and then they just get rounded off.

Doug Jerolmack: That might happen. That seems like the simplest explanation because that then would explain why you get flat pebbles some places and more spherical pebbles in other places.

Speaker 1: Right.

Doug Jerolmack: What we found actually is that as the particles are bouncing, and bouncing, and bouncing they evolve more toward a sphere. But once the energy gets so low that the particles can only slide and not bounce, then sliding is like imagine you had a pebble with a slightly flat face on a table and you just pushed on it. It wouldn't tumble and bounce, it would slide along that face right which is actually gonna plane it down like planing a board. And so what we found is that only when the energy is so low that the particle can only slide does it start to make a flat-like pebble.

Doug Jerolmack: That's actually a hard explanation to come up with. You need to know something about its mode of transport and it turns out that it's only under very, very specific conditions do the pebbles turn flat. It would seem a simple explanation that layered rocks make flat particles. Just layered rocks are everywhere. But it turns out that that's not the dominant explanation.

Speaker 1: Does the river really produce that much turbulence to do all that?

Doug Jerolmack: As much turbulence as what?

Speaker 1: To do all that?

Doug Jerolmack: Oh, yes. I mean, just to give you an idea. In the steep headwaters of streams, water alone can pick up and move one meter, two meter diameter pebbles. So pebbles that are as... Their diameters as tall as you are. Water alone can do that. You make the slope steep enough. So if you think about it, if I want to move a boulder under gravity alone I need a slope that is at the angle of repose like when you dump a pile of sand it achieves a critical angle. If the slope is that high, if you add a grain it will tumble down. Just gravity alone can take it. So if you consider that limit that a mountain at 30 degrees every pebble that you placed on it would tumble down then you can consider that as the slopes get lower, you need more and more energy from something besides gravity alone in order to move the particles.

Doug Jerolmack: But if I've got a river with a 10-degree slope which is pretty steep it takes an energetic river but not an unusually energetic river in order to pick up pebbles. So it's kind of like the turbulence or boulders. So turbulence plus gravity can move those boulders downstream. Just the last point about the rounded things since you brought it up in relation to Mars, and if people are listening and they're curious about that, I want to close the loop on that. We did a lot of this, the forward part of the physics problem was determining that particles in idealized conditions should evolve towards spheres.

Doug Jerolmack: And then we did the hard work that showed that in the field that they do evolve towards spheres until they don't. So we have conditions where they have all towards sphere and then parts of their trajectories where they do not. The inverse question is if I go into some random environment and I pick up a pebble, and I look at its shape how much can I say about what made this pebble and how far it's come since it was born by breaking off of a chunk of rock? And if you're wondering why you might care about that problem, well I'm going to... I'll admit, it is not the most important problem in the world, okay? I mean, understanding round pebbles is not like curing cancer or something.

Doug Jerolmack: However, often figuring out where sediments came from helps us connect landscapes. So one thing is if we want to figure out... If you're trying to figure out how connected sedimentary deposits are, this is a classic problem if you're trying to look at reservoirs of sediment that contain oil or gas in them. So you

find oil or gas in one place and you want to know how connected is this body of sand? Is it worth drilling here and pumping this out if it's a little tiny sand body that's isolated from other sand body, impermeable mud, then even if there's oil in it, it's not worth trying to pull it out.

Doug Jerolmack: But if it's connected to a big reservoir of interconnected sands then it's worth doing. And so one thing that people are interested in is when they find sediments and figuring out how far did these particles come from and how much of a connected river deposit might there be. But another thing that you might be interested in this is that if you're trying to figure out the energy of a river system that existed in the past. So a lot of times you go to a desert, but you look in deserts today and you see that there are ancient river deposits in them, and immediately it tells you that the climate some time ago was very different from today. In a desert with sand dunes migrating across and yet if they're river deposits it says at some point in the past this was a wet enough place that we had rivers moving sediment.

Doug Jerolmack: And so then if you wanted to figure out what is the history of climate been in this region and how has climate changed in this region, one answer to that is how much water has been in this place and how is the amount of water changed. So a lot of times people use ancient river deposits on Earth to figure out how much water there may have been in the past and how the amount of water has changed. And so when you look at these deposits, the shape and size of the particles is one or two factors among many that you use to put the pieces together to try to speculate or even calculate how much water there was in this area. So how rounded the pebbles are might be indicative of how energetic the flow was to make this.

Speaker 1: Got you.

Doug Jerolmack: But people got really interested when we find these things on another planet like Mars because when you spend billions of dollars to land a rover on another planet, and it unfurls its gates and it drives down, and it takes a picture and you see rounded pebbles that look just like a river deposit on Earth. All of a sudden everybody wants to know I paid \$3 billion for that picture. What does it mean? What does it mean? And so some of the work after we did this forward problem of figuring out the relationship between roundness of a pebble and its transport, we realized that we could constrain very well the inverse problem of picking up a pebble and measuring its shape and saying how far that pebble had traveled with a few other physics based formulations and assumptions that I won't get into.

Doug Jerolmack: And so the images on Mars from the Curiosity rover, the first images that it beamed back in the first scientific paper published from the Curiosity mission on Mars was we found rounded pebbles, and it confirms that this is a river deposit. And so we were then able to use our theoretical framework to say based on the roundness of these pebbles they had to have traveled at least 30 or 40 miles

and that's actually consistent with the geological evidence that says these particles were deposited here the closest Canyon that we think was eroded to make them is 50 miles away.

Doug Jerolmack: So we were actually able to demonstrate on another planet that this shape is related to transporting. The last little bit I want to get about that just because I find it it's so incredible. In 2004, which was a long time ago now but there was the Cassini mission and the Cassini mission was a spectacular mission to Saturn, but one of the things that happened was they sent the Huygens probe to land on the moon Titan. And so there's this moon Titan that we didn't know almost anything about, but it looked like based on SATA, based on telescope observations that it had oceans of methane. And then it had mountains where the rock was water ice, was frozen water.

Doug Jerolmack: And they wanted to send a probe to move through the atmosphere and then land on the surface and they didn't even know whether they were going to land on solid or liquid. And they didn't know what they were going to find. So there was this one in a million chance that this whole thing would work and that we'd find something interesting. And so they shot this Huygens probe off from the Cassini satellite, and it went through this opaque atmosphere and when it came out it snapped two pictures on its descent that showed an erosional river drainage network. So it showed a series of canyons converging together just like we see on Earth to make a channel that then came to a shoreline that looked like a lake that was now dry.

Speaker 1: Wow.

Doug Jerolmack: And then it landed right there on that seeming lake bed opened up and it had two cameras. One of them failed, but one of them took one in exactly one picture, and what did it see all the way off into the horizon was rounded pebbles. So these were rounded pebbles made of water, frozen that were moved by liquid methane and so despite the fact that these are very exotic materials, it shows that the same physics play out even with very exotic materials to make the same patterns.

Speaker 1: Wow.

Doug Jerolmack: And so I just find that profoundly beautiful.

Speaker 1: Yeah. What are you working on right now then?

Doug Jerolmack: Yeah. So the reason I'm laughing is the thing I'm most excited about is an experiment that I say is like watching paint dry except slower and much more exciting. And so one of my graduate students, Nakul, he is working on an experiment and the reason I'm describing this particular experiment is I think it's representative of the surprise that can happen when you decide to look at something very common and familiar in a new way.

Speaker 1: Okay.

Doug Jerolmack: So the basic experiment is this, take a bunch of sand, pour it. So just pour it out of a cup into a pile on a table and let's just say that... Let's just make this extra controlled. The table will be vibration isolating so it eliminates most of the vibrations in the ground and this is what we're doing. We control the temperature in the humidity in the room so there's very minimal variations, not zero, but very minimal, and you just let it sit there. So what do you think would happen?

Speaker 1: Oh, god. I have no idea.

Doug Jerolmack: Well, you pour it. What's your everyday experience? You pour a pile of sand on the table, and then you let it sit there.

Speaker 1: As one does.

Doug Jerolmack: And you let it sit there. You take your rice home, take your rice home from the store and you dump it into a vessel and what happens? Nothing, right?

Speaker 1: Nothing, right.

Doug Jerolmack: You feel like absolutely nothing happens. If I pour... If I'm at the beach and I take a bucket of sand-

Speaker 1: Maybe my cat gets to it, and that's a problem.

Doug Jerolmack: Exactly. If you disturb it, something could happen. So the whole idea here is that we've demonstrated that no, it's not that nothing happens, it actually slowly moves. So it's moving slowly enough that if you stare at it with the naked eye, you don't see it. So you might then say okay.

Speaker 1: And there are no vibrations?

Doug Jerolmack: Well, okay, here's the thing. You can never say there's no vibration, right?

Speaker 1: Right.

Doug Jerolmack: And so the amount of the amount of money and resources it would take to reduce the noise that we have in our experiment by a factor of 10 would be inordinately expensive. It's very, very, very hard to eliminate vibrations. We've done everything we can reasonably under a constrained budget. So of course there's always some disturbance, but your everyday experience of staring at the sand pile says that it's not going to do anything and we've done better than what you might do in your home because we tried to eliminate a bunch of disturbances that might be there.

Doug Jerolmack: What you find is that if you look at it carefully that it's actually moving so then you might say, "Okay, it's moving. But it's moving slowly so do I care?" It turns out that if you measure it very carefully you find that it's moving a speed of about 10 nano meters per second. So if a human hair is a hundred microns then it's moving at one ten thousandth of the width of a human hair per second. So that's not very fast.

Speaker 1: No.

Doug Jerolmack: However, if you play that out over longer time scales that corresponds to meters per year or many feet per year. It turns out that if you look at the dirt on hillsides which is inexorably creeping down hillsides and causing fence posts to bend and trees to bend the kinds of things that is moving the landscape, cracking the foundations of houses and eventually making sediment move into the rivers, that soil is moving at meters per year. And so it turns out that an undisturbed pile of sand sitting isolated on your countertop is moving at the same speed that dirt moves downhill out in nature. And the reason that this is startling to us is that the way that we typically think of a granular material is that it behaves as a solid, meaning that it doesn't do anything.

Doug Jerolmack: If I pour it then it sits there without moving until I push on it beyond some critical force. So if I push on it nothing happens until I push on it hard enough, and then it turns into a liquid and it flows. This is the way that all of the theory that we have that is built on granular materials and that is used to predict how landslides happen is all built on the idea that granular material is a solid until some critical force, and only when you push harder than that does it turn into a liquid.

Doug Jerolmack: But we all know that soil is actually slowly creeping even though it's in angle on the hillside too low to flow and be a liquid because a landslide is a granular material behaving as a liquid. So then the geologists and the engineers have to think about how do we explain that this stuff is a solid and yet it's moving? And so you invoke all kinds of explanations. So if you look at dirt out on a hillside when it rains and you get some water into the dirt, it moves a little faster, and then when it dries out it slows.

Doug Jerolmack: We also know that trees fall and gophers and wombats, and worms burrow and soil freezes and thaws. So we know that soil is getting disturbed and churned all the time. And so those factors have long been the explanation for how and why soil can creep or move at an angle that is less than the angle at which it flows. Now, we're not saying that those factors don't matter. However, everybody that is informed I mean everybody in the geology and engineering and physics world that knows about granular materials or has experience out in the world of soil, they're completely shocked and it is entirely counterintuitive to them that an undisturbed pile of sand-

Speaker 1: Right. There's no burrowing happening.

Doug Jerolmack: Right. And so there's minor, minor perturbation shore of some kind, but at that point it becomes entirely academic. In other words if disturbances that are so small that we can't eliminate them and we can't measure them are making the movement, well, it basically still says though that you don't need to invoke any additional disturbance of animals and moisture fluctuations and all of that. And so what we're trying to understand now is that clearly these... If I agitate sand, if I shake it I can get it to move and flow even if it's angle is lower than that critical angle.

Doug Jerolmack: So clearly we know that disturbances matter, but we also now have discovered that we can creep at significant rates without disturbance. So now what we're trying to figure out is since I have creeping without disturbance, how does disturbance and the inherent creep of a granular material, how do they play with each other? If I shake it do it does it creep the same way just faster, or is it a different kind of behavior from what I have when I'm just not creeping at all? And so the surprising thing with us is that what we're finding is that the more and more that we look at granular materials and how they just behave when you put them in a pile and they sit there and then when you jiggle them and shake them is that they actually behave more like glass does.

Doug Jerolmack: The way that most people understand that like glass in your window is a solid, but you maybe have heard things that over very long timescales that it kind of flows. And with a glass, the thing about a glass is that the materials that we call glass are different from other materials because they don't make crystals. The thing is the molecular arrangement of a glass is highly disordered. So the molecules don't all line up in a nice arrayed pattern. So the way to think about it on art scale is that a crystal with oranges is if I stack all the oranges carefully in some kind of arrangement that can make a cube or a pyramid, right?

Speaker 1: Got you.

Doug Jerolmack: But if I take a bucket of oranges and I just dump them, they will not be in that ordered pattern, right?

Speaker 1: Mm-hmm (affirmative).

Doug Jerolmack: So you can think that molecules can make crystals or make disorder materials and granular materials can be disordered or can be crystalline. But it turns out that nature doesn't really typically have a way of taking grains and arranging them in a highly ordered way. But nature does have a way of arranging molecules in very ordered ways or in not ordered ways. The basic thing with a glass is that it's solid on human timescales, but it does flow and deform on very long timescales. And so whether you consider it a solid or liquid is really a matter of convenience or the time scale of the measurement. The deal with that, the thing that's important about disordered versus crystalline is that if I take the glass that's in your window and I melt it, and then I slowly cool it, what

happens is that it doesn't cool, cool, cool but stay at liquid, and then at some critical temperature all the sudden become a solid.

Doug Jerolmack: What it does is it becomes gradually more solid like. An opposite example is water. So if I take water as I cool it, start it from a hundred degrees and cool it down, and cool it down, and it's a liquid, it's a liquid, it's a liquid until I get to 32 fahrenheit, and then all the molecules suddenly arrange into this ordered array. And so there's this very abrupt phase transition where I go from being a solid to being liquid. And the liquid is the thing that has viscosity and flows, and a solid has infinite viscosity and it doesn't flow. Well, a glass can't do that. Basically, because it can't make a crystal is that I can have an arrangement of molecules or particles that is kind of stable, but there's an infinite number of configurations that are all equally stable or unstable.

Doug Jerolmack: So if I go in and I just jiggle one molecule or one particle I can cause a rippling effect in those motions to ripple through the material. So the thing is that in class we understand this reasonably well, not perfectly. But that we understand it because molecules jiggle. Molecules are small enough that they're just... Thermal energy is they're just jiggling all the time. A grain of sand is not jiggling. The air molecules that are colliding with it it's too massive to jiggle from the collisions of those air molecules.

Doug Jerolmack: So in a glass we understand that the molecules are jiggling and so occasionally they jiggle enough to break a bond and that causes a rearrangement. But in a granular material they're not jiggling right so it actually leads to a very deep question which is that this pile of sand or dirt is behaving like a glass, but there's no molecular fluctuations that allow it to break bonds spontaneously. And so what is going on? And so this question which was a geological question about how to soil creep has actually led us to a fundamental question in physics which is how the granular materials behave like glasses even though they're not made of molecules that vibrate. And so-

Speaker 1: So your sand research is still ongoing?

Doug Jerolmack: Oh, yes. So you asked me what we're working on right now and this is one of the most surprising. And fundamental, and interesting things that we're working on right now. We're also working on problems like you know large-scale atmospheric flows and how they move sand and make dunes. And so we've discovered for example very recently that... And the work is ongoing, but we've discovered with my graduate student Andrew that dune fields make their own wind. And the basic idea is that when I heat the ground if I've got a sand surface that if the sun rises and heats the sand surface, and they only have a sandy dune covered surface in arid environments where you don't have water around. And so we know that in arid environments the day/night temperature swings are huge because you don't have moisture to sort of hold on to that temperature.

Doug Jerolmack: And so what we've actually demonstrated though is that in arid environments once you've got a pile of sand that the reradiation of heat from that sand heats the lower atmosphere, it heats the whole atmosphere enough to make it unstable because now the lower atmosphere gets heated enough compared to the air above that it actually is buoyant. It weighs less and so it overturns. And that convection like when you heat a pot, the convection that happens in these desert environments actually mixes the atmosphere and it takes the winds from high up and mixes that momentum down to the ground. So we've actually shown that dune fields create their own wind and that actually then creates a possible positive feedback for creating deserts or desertification.

Doug Jerolmack: So if sand is expanding and spreading out through deserts but that creates more temperature change which creates more winds, which spreads the sand out even more, that can be something that allows... If I start with some initial sand deposit in an arid environment then it can kind of bootstrap itself to grow into a desert.

Speaker 1: Wow.

Doug Jerolmack: And so nobody's ever identified that mechanism before.

Speaker 1: So you have explained why we have deserts.

Doug Jerolmack: Well, partially. So there's a necessary condition. You have to have an arid environment in the first place, but we're saying there's probably that... The climate system alone, systems outside of the desert so create an arid enough environment where water is now not a key player, but then if you start blowing sand around that there's a positive feedback that can expand deserts. So I won't say that we've discovered what creates deserts, but we've identified a new mechanism for how they might grow.

Speaker 1: Got it.

Speaker 1: So I have to start with you have a twin.

Doug Jerolmack: Yes, I have an identical twin brother.

Speaker 1: Right. Who is also...

Doug Jerolmack: A professor.

Speaker 1: Yes, in the same relatively same subject area. So how does this happen?

Doug Jerolmack: Here's the funny thing is that... So I am... I consider myself... It doesn't really matter, but in broad terms I consider myself a geophysicist because I work on the physics of the Earth. But to people that are not familiar with such terms

what I do is also related to environmental science. I mean, I do science out in the environment. My twin brother is a sociologist. And the particular kind of sociology that he does is ethnography which is kind of what you might call participant observation kind of stuff. So you embed yourself with a group of people and you try to understand through that embedding the way in which they essentially create identity.

Doug Jerolmack: But my brother's primary interest within that field of ethnography is environmental sociology. So he's really interested in humans and both their relationship with the environment and the consequences of the environment on them, but also the ways in which they conceive of the environment in their relationship to it. So Colin, I'm giving you free props by the way and hopefully I didn't butcher your science. So the funny thing is that on the one hand and the broadest sense we're professors and working in the environment. But on the other hand we are as far on opposite ends of what you could call environmentally related work, right?

Speaker 1: Right.

Doug Jerolmack: So my brother is not only a sociologist, he is a qualitative sociologist. So he will tell you that he's not a numbers person at all. He's interested in how humans create stories about themselves and what those stories say about how we create identity and community. And I am very much on the numbers physics quantitative end. So on terms of technical areas, we have no ability to talk to each other at all. And so I don't know how it happened.

Speaker 1: You want to know how the pebble got there, he wants to know how we feel about the pebble?

Doug Jerolmack: Yeah. He might get upset about that, but I would say sure, yeah. So the thing is, is that clearly... So we don't have any academics in our family. I mean, we had a family that cared about education and supported us being interested in getting educated, but we don't have any academics in our family.

Speaker 1: Do you have some sort of nature background in your family?

Doug Jerolmack: Some kind of nature background?

Speaker 1: Yeah, like did you spend a lot of time in nature where you grew up in a small community.

Doug Jerolmack: Well, we grew up in a suburb of Philadelphia called Downingtown. I will say that our activity typically growing up was we would just go to the creek as we called it, and we would just go to the creek and make dams and set things on fire. So we wouldn't hang out in nature in the way that kids might do get into a little trouble. But, yes, we did spend a lot of time out in nature. Yeah, I think that clearly there's some aspect of us that is wired the same way. I mean, we have

literally the same DNA. And also the fact that both of us felt that being a professor was really the only job that could work for us despite the fact that we don't have any professors in our family.

Doug Jerolmack: On the other hand, I realized that you know some twins, if you had any experience with identical twins growing up, there are some twins that are almost quite literally the same person. They're best friends with each other, they dress the same, they talk the same. It is their identity that they are twins. And then there are other twins, which is my brother and I growing up we were so sick and tired of people confusing one of us with the other that we reacted to what the other was doing and tried to intentionally do something different. And so I think that one way of looking at this is it's a consequence of us having the same wiring, but intentionally trying to differentiate ourselves. It's just a guess.

Speaker 1: Yeah, but I'm sure your Thanksgiving conversations are just...

Doug Jerolmack: They're good.

Speaker 1: Yeah. And then another interesting thing about you or maybe your wife is that you have like a taco shop.

Doug Jerolmack: Yeah. So sadly to the residents of West Philadelphia my wife hasn't reopened the taco shop. So she threw in the towel mostly because it was too much work. My wife did open a taco shop. She's from LA and it was a darling of the West Philadelphia community. It was an outdoor business. So it was only open seasonally. So it's challenging to run a seasonal business and keep hold of and then retrain workers every year. And it was very beloved and pretty successful, but ultimately too much work for her. But we are thinking about building a building on that lot because we own it.

Speaker 1: Okay.

Doug Jerolmack: So stay tuned.

Speaker 1: Who or what makes you smile the most?

Doug Jerolmack: Well, I mean this is cheesy but my kids because I have twin five year olds.

Speaker 1: Also twins, right.

Doug Jerolmack: Yeah, they're fraternal twins. I mean, obviously they make me smile in a normal way that kids do. Being a scientist I'm particularly attuned to the process of discovery. And the thing is that if you really value discovery and curiosity driven people. You don't need to do much work with any kids. And so for me I share the fascination and love that everybody else does with having kids, but also I'm particularly interested in how they develop an ever-growing sophistication of

their understanding of nature and cause-and-effect and drawing inference. And so I love just exposing them to new things and watching them react to it. In terms of in terms of science though, I know we're doing a freewheeling thing.

Speaker 1: It's like its own little experiment.

Doug Jerolmack: It is.

Speaker 1: Probably more exciting than watching sand.

Doug Jerolmack: Well, it is and yet sand is still pretty exciting. But in terms of science, I mean I know we're in the freewheeling part, but it's related. The part in science that actually makes me smile the most is it sounds cheesy, but seeing that same process happen with PhD students. So in other words, obviously they're not children but they come in, they're self-selected by people who are now in their 20s and yet they still have that burning curiosity and their love of being surprised, has it been shut off or hasn't been ground down. So when they choose to do a PhD they're self-selecting in that way, but they're naive. And I don't mean that naive in a pejorative way but they just don't know what makes science different from other things that we humans do.

Doug Jerolmack: And so the thing that brings a smile to me is I can't tell them this is what science is about in a statement, learn it. It's like in year three or in year four when they've got some fundamental realization, a deep realization that is related to what I consider that it's a dawning realization of what makes science different from all the other things that people do, and that is the thing that makes me the happiest is seeing somebody become a scientist and the landmark examples of that where you're like, "Yeah, that's what I wanted to happen and there's no way for me to just teach you." You can only provide somebody the space to discover that on their own.

Speaker 1: Cool. What is a weird-

Doug Jerolmack: And then surfing.

Speaker 1: And surfing.

Doug Jerolmack: I mean it's riding a wave, moving on the face of a wave under the power of nature brings a ridiculous smile to my face.

Speaker 1: Okay.

Doug Jerolmack: Even though I know the physics of how it works it is completely mysterious to me that it can happen.

Speaker 1: Where do you surf around here?

Doug Jerolmack: We go to Jersey. We surf up and down Jersey. Wherever. We are not specific-

Speaker 1: People do it. I see a guy coming back from like an early-morning surf session pretty frequently.

Doug Jerolmack: Yeah. To be honest that's my boundary on this meeting is I got to bail because there's some decent swell this afternoon.

Speaker 1: Oh man.

Doug Jerolmack: I am allowing myself to take off a little early and go surfing.

Speaker 1: What is a weird hobby that you have or is surfing maybe your weird hobby?

Doug Jerolmack: I think surfing is probably the weirdest hobby. I don't have time for too many hobbies. And I will say that I let my kids... I allow room for my kids to have hobbies. It's not very weird, but I mean one of my girls has gotten really into rock climbing which is not anything I had any experience with. But she's five yet she's really good because it turns out little kids can climb almost anything. And so I've actually had inspired-

Speaker 1: And they're willing to.

Doug Jerolmack: Yeah, and they're willing to. So I've had to start learning a little bit of rock climbing in order to be able to keep up with my daughter. So I would say that surfing and rock climbing, but this is not a hobby. It's not fair because it's related to science, but it's one thing that I think we build weird stuff in the lab, weird stuff. I mean, almost by definition every experiment that we do is unique. You ask a question no one's asked. So I mean it's part of... I always say to my students if you want to be a successful scientist make science also your hobby. And what I mean by that is that science is about answering questions, but the way in which you answer, if you think that... If you're impatient with tinkering, and toying, and building, and trial and error, and if you think spending a year on making some really weird contraption is a waste of time because you just want to get to the answer then you're not going to be a good scientist.

Doug Jerolmack: So this is why I tell them make science your hobby also is I mean we do a lot of like what you could consider hobbying. Like you know all these people that do hobbying electronics where you buy modular electronics parts and you go... People write code for you to make weird devices that do things for you and Rube Goldberg contraptions to like turn on that machine when you trick...

Speaker 1: Right.

Doug Jerolmack: We build those things all the time in order to do experiments. So I think that we do a lot of tinkering making really weird stuff and so I keep that tinkering alive

because you need to keep those skills honed. And so that's something that's kind of a hobby, and that most people might not think is central to science, but at least to the experimental part of science it is.

Speaker 1: What is an overrated virtue?

Doug Jerolmack: An overrated virtue?

Speaker 1: Mm-hmm (affirmative).

Doug Jerolmack: While genius is rare and when you see it allows people to do things with great ease, what I find is that most people think that when they see some scientists talking in very technical jargon about very complicated things there's a presumption that this person was born a genius. I think the idea of genius and brilliance is important, but is actually far overrated. And in my experience it's certainly true that not everyone could become a scientist, however, most people and most undergraduates that I find stumble upon their scientific interest in a rather haphazard way.

Speaker 1: Serendipity.

Doug Jerolmack: Yes, serendipity. So brilliance and genius is overrated, serendipity is underrated. And essentially the main thing is that you need to be passionate enough to just hammer, hammer hammer, and the one thing you'll find with most scientists than most academics is that they just worked too hard, but they were committed enough and were interested enough. So there are sprinklings of true geniuses that figure things out immediately and with ease, and just see things that no one else can see. But there's a thousand just hard-working you know generally intelligent but not significantly above average intelligent people that are just persevering. I mean, that persevering pushing part can seem kind of depressing, but I find it encouraging in the sense of like I've had students take my class that were fine arts majors that are now... Literally, that are professors now in Earth science because they took a class that changed their life. And so I think the genius is overrated and hard work and perseverance are underrated.

Speaker 1: What are you reading or watching at the moment?

Doug Jerolmack: So I did watch that Chernobyl series on HBO. It blew my mind. It was so extraordinarily well done.

Speaker 1: It was kind of jarring with the accents.

Doug Jerolmack: Yes.

Speaker 1: It took me a while to pick up that that was...

Doug Jerolmack: Yeah. You mean like why are they all British people?

Speaker 1: Right.

Doug Jerolmack: Yeah, that's right.

Speaker 1: [crosstalk 00:50:11]

Doug Jerolmack: I will admit that like shows that I watch are often so things like that or like the Ken Burns Vietnam series or something like that. But I mean I'm into like Game of Thrones like anybody else. My wife and I currently are really into the show Los Espookys, if you've seen that on HBO.

Speaker 1: That's on HBO. Yeah, I haven't watched it, but [crosstalk 00:50:34]

Doug Jerolmack: It's really good. In terms of reading, I'm going to admit that all I read is journal articles. I haven't read a book... This is humiliating, but I haven't read a book in five years. I'm always so down about how behind I am on keeping up with the scientific literature which is just growing exponentially all the time. So in any spare moment I read journal articles for pleasure. I read highly technical articles for pleasure. And I read the New York Times every day.

Speaker 1: I think it's a pretty common answer for academics.

Doug Jerolmack: Yes, it is.

Speaker 1: I'm noticing a trend here.

Doug Jerolmack: Yeah. So academics that write books, so there are fields in academia like my brothers where they write a lot of books. So then they read a lot of books but nonetheless their academic books. If you're in academia like in science and engineering where it's journal articles, it's like all we're reading is short articles, yeah. Sorry.

Speaker 1: If you had to write a memoir what would you call it?

Doug Jerolmack: Oh, no. This is going to sound terrible, okay, but this is not very interesting. I have a mantra that I say to my students all the time, since we work at the interface of geology and physics, which is that geologists are wrong and physicists are boring. And that's not true, okay? It is an exaggerated caricature though, and what I mean by that though is that geologists are in some sense it's the area of science where people are still inherently adventurous and connected to the outdoors, and are actually really creative and are really interested in working on messy problems. If you're interested in geology you're not working on idealized little problems that you can eliminate all this variability.

Doug Jerolmack: The reason I say geologists are wrong though, I don't really mean it they're wrong but I would like to see more... It's not that none of it exists, but I would like to see more rigorous systematic physics based research in geological problems. It's just culturally that the discipline of geology didn't emerge that way and so it's changing, but it's slow. And so when I say geologists are wrong what I really mean is I'd like to see more of the approach that I like. When I say physicists are boring I don't really mean that they're boring people as individuals, but my training is in engineering Earth science and when I started working more in physics I had a feeling that these people they work on everything.

Doug Jerolmack: Physicists work on so many different problems, but what I realize is that while they might work on problems that seem different, they usually, because they're very, very rigorous people, will have an approach, a particular approach that is very, very refined because they want to be very, very rigorous and precise. And I became surprised about an unwillingness on average. Not with everyone but an unwillingness on average to use a new approach because you're like, "Well, I'm not a dilettante. I don't just want to try a new approach that I can't do really, really well and then I can't be really rigorous in." And so it's my reminder because when I say it gets geologists mad and physicists mad, and that's the point.

Doug Jerolmack: I want people in geology to reconsider, "What do you mean geologists are wrong?" And physicists say, "What do you mean physics is boring?" So physicists, it can be hard to look at a messy problem in geology and say, "Yeah, I think I can ask and answer a question rigorously that's relevant to the messy world. So maybe in a memoir would be geologists are wrong and physicists are boring.

Speaker 1: I like it.

Doug Jerolmack: Because it reflects my journey from Earth science into physics and my changing in how I conceive of problems and what I think the value of science is.

Speaker 1: Well, when you eventually need a memoir title you can come back to this podcast.

Doug Jerolmack: There you go, there you go.

Speaker 1: Problem solved. So where do you like to spend time on campus? What is your favorite spot?

Doug Jerolmack: Let's see. Well, I mean I go to Joe for coffee.

Speaker 1: Okay.

Doug Jerolmack: And my days are too busy and I like to be home at 5:00 to spend time with my family, and therefore I don't spend too much time on other places on campus. And so I like the coffee at Joe and I have to walk a couple blocks so it makes me feel like I'm getting out. But occasionally I go down to Pennovation because I collaborate with people in engineering. And I like those weird little gritty pockets like you know next to the Schuylkill River. So like where this forgotten little corner underneath of that bridge where there's a skate park. So I don't get to spend much time there, but when I go down I usually stop and hang out in one of those weird little corners.

Speaker 1: Maybe campus can get a wave pool.

Doug Jerolmack: Oh my god, I love it.

Speaker 1: Dream come true. And then finally what gives you hope? And you can interpret that however you would like.

Doug Jerolmack: What gives me hope? Well, I'm only going to interpret it because my first reaction is always to think about my profession and not to think about other things. I think the thing that gives me hope is so in my profession of science and academia as much as the broader country, despite the challenges that we face what I actually see is a change in dialogue and a change in attitude and concerted efforts that are making science and academia more accessible and more diverse. So for example the fact that Penn like a few other universities decided to do need-blind admissions and need-based aid. That's the kind of thing that gives me hope.

Doug Jerolmack: I want to work in a scientific place that is a powerhouse, and I'm stimulated but that everybody can come to. And the thing that gives me hope is look, man, stuff is changing slow, it's not changing fast, but the conversations that we're having, the organizations and committees, and training that is going on there's no magic formula and there's a lot of implicit bias and things that are hard to overcome, but I showed up here 12 years ago at Penn and we weren't having these conversations. And the thing that happened at the undergraduate level with the need-blind admissions and need-based aid, the thing that has happened on hiring committees with conversations, and training, and efforts to overcome implicit bias, I'm actually seeing slow but consistent change in a diversification and an enthusiasm in the people that are coming in. And that gives me hope that at least within this area of science and academia that I don't know if we can change the dialogue at the political level and the national level, but science should be representative.

Speaker 1: This podcast is a production of the Office of University Communications at the University of Pennsylvania. We hope you'll join us again soon for another session of Office Hours.