Tracey Peake: [00:04](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=4.95) [inaudible]. Hello and welcome to NC state's audio abstract. I'm your host, Tracey Peake. How and why do planets look the way they do. What can earth tell us about other planets and vice versa. Paul Byrne is an assistant professor of Planetary Geology here at NC state who studies how tectonic, volcanic and impact processes shape planetary surfaces and what they can teach us about both distant worlds and our own. In part one of this two part podcast, we talked with Paul about what planetary geology is in part two we'll talk more about Venus and our other solar system neighbors.

Tracey Peake: [00:41](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=41.49) What do we know about Venus? What's going on there? I mean, I know it's hard to see anything because it's a giant gas cloud atmosphere covering it. But what have we found out about Venus?

Paul Byrne: [00:51](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=51.02) So it turns out we've, we've found out a lot of the low hanging stuff we know a lot about Venus, but unfortunately that's raised questions that we really should answer cause they're probably really, really important. And we don't have the data to answer those questions definitively. But what we do know is we know it's about the same size and mass as Earth, but 80% the size of earth, 90% depending on if you count volume or mass, but it's an earth sized world. It's got a surface that's covered in volcanoes. We recognize them because they have the same shape as land forms on earth. There's a lot of tectonic activity. We know what the surface is probably largely made of basalt, which is what most of the surface of earth is made of. That's what the ocean plates are made of.

Paul Byrne: [01:26](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=86.55) In fact, we see that same rock type on mercury the moon and Mars. This rock type is probably everywhere throughout the cosmos. Uh, we know that the atmosphere is CO2 rich. It's got 96 and a half percent pure CO2. A little bit of other stuff in there, but it would kill you extremely quickly. We know the surface temperature is that of a self cleaning oven. The surface pressure is about more than half a mile under the water equivalent on earth, so it's a hellish place. We know that the atmosphere as a whole has a quite different structure than earth's atmosphere. We know that there are parts about 55 or 60 kilometers, maybe 40 miles above the surface, where in fact the temperature and pressure are the same as this room right now, so you could safely operate a spacecraft there or you could even put astronauts in the future once they were able to breathe. You know, have rebreathers. We know a lot about the basics of Venus, but one of the things that was really surprising when we explore Venus in the sixties seventies eighties in particular was that Venus does not have that many impact craters. And I mentioned earlier that one of the most characteristic things we see on planetary surfaces are impact craters and we see them everywhere and we even the outer satellites that over Jupiter and Saturn, Uranus, Neptune, they're covered in impact craters. So impact craters they're not a surprise the only reason we don't have very many in earth is because they tend to get eroded, filled in, buried, but earth surely had many, many huge ones early in its days. But what we see when we look at impact craters in the solar system is that generally speaking, and we have good reason to think this, the more craters on a piece of this, of a planetary surface, the older it is simply because it's had longer to accrue a record of impact cratering.

Paul Byrne: [02:54](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=174.52) There are hundreds of thousands, millions, depending on how small you count - on Mercury, Mars, moon, even some of the icy satellites in the outer solar system, there are fewer than a thousand craters on Venus and that's really weird. And there are certainly are none of the really gigantic basins we call them impact basins that you see on mercury or the moon or Mars. And the reason for that is surely not because Venus didn't have them, but because some process or combination of processes has acted to remove them, to bury them. And one of the most effective ways you can bury something as you can have lava. And we know in Earth's geological record there were periods of time in Earth's history who are unbelievable volumes of lava poured out of the ground really, really quickly over huge areas and they would be quite effective at filling in some of these impact craters and basins. So the discovery on Venus in the sixties and seventies in particular that there are only about a thousand creators was genuinely surprising because it means that relatively recently, and there's me using that word as a geologist again perhaps within the last billion years, but that's still very recent. Something acted to bury most of the really big craters and basins on Venus and, and we don't know why and we don't know when and we don't quite know how. But that was a genuinely surprising discovery because we don't see that anywhere else in the inner solar system. We see some other weird textures and and combinations of tectonic structures that we don't really see any where else except on earth.

Paul Byrne: [04:10](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=250.18) Now we know that Venus does not have an earth plate tectonics like thing. It doesn't have the areas where it spreads apart in the ocean floors and where it subducts, some big giant mountain belts. It doesn't quite have that pattern, but there's definitely some kind of some sort of movement and motion of the surface of Venus and a much greater scale than we see from Mars, mercury, the moon and because some of these flows we think there are lava flows that have built in, are buried in and filled in. Some of these large basins have to be relatively young, a few hundred million years. That raises the tantalizing question of whether or not Venus might be active today. It's my guess that it is, but we do not have the data to hand with what we currently have available to be able to definitively answer it. And there's one more thing that's really interesting with Venus is worth talking about. A few probes, not many, not enough, but a few probes were sent into the atmosphere from the Soviet Union and and one probe from the US pioneer Venus in the seventies and eighties and some of these probes detected an interesting chemical property in the atmosphere and they found an isotope ratio of water that really was quite surprising. We call it the deuterium hydrogen isotope ratio. But what did we make means basically is the, the amount of this heavy type of water in the atmosphere of Venus is more than a hundred times greater than what we see in Earth's atmosphere today. And one of the ways we can explain this, and this really is tantalizing, is that it's possible at some point in Venus' distant past. It could have had as much water if not more on its surface in some kind of form than Earth does today.

Tracey Peake: [05:35](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=335.98) That somehow it ended up in the atmosphere?

Paul Byrne: [05:37](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=337.81) Well, because of this particular ratio suggests that in fact, not only is there some left in the atmosphere, but the lighter stuff is now lost to space. And it raises this idea, and this was originally proposed in the sixties before we really began to explore Venus. There were these great ideas that if you purely take Venus' distance to, the sun, to its star, that it would be not very much warmer than earth, but a bit warmer, maybe a few tens of degrees.

Paul Byrne: [06:02](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=362.21) And so in the 50s as recently as the 50s and these science fiction stories, people would paint, covers these books as these luscious forests and jungles and, and, and we wonder maybe this is like a weird jungle planet, some sort of humid earth. And it was really only in the early sixties when we began to send spacecraft to visit past, a fly pattern then ultimately to orbit, we realized, no, the surface of the temperature is a hundreds of degrees and that put pay to the idea of the forests. But what was interesting was we suddenly realized you can't just imagine or predict the conditions of the surface of a planet simply by its proximity to the sun. And so folks began to think, well, how would you get there? How would you, how would you take a world that really ought to be quite like earth in terms of what it's made of and which part of the solar system it's in? It's around the same kind of star. Why is it so different? And then when we found out this rate, this isotope ratio difference in the atmosphere and the possibility that originally was much, much more liquid water on the surface of Venus, it raised this sort of almost kind of tragic idea that at some point in its past there might even have been oceans on the surface of Venus, liquid water oceans, that may have looked just like earth today they might've been blue, there'd be white clouds, water rich vapor clouds and under an increasingly hot sun. There's an interesting angle here that that again, this is where astronomy and geology, work perfectly together. The Sun has been getting brighter and hotter as it gets older. This is a thing all stars do. It's a normal thing. It's been known for a very long time.

Paul Byrne: [07:19](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=439.91) If you go back far enough, the sun was originally pretty much dimmer and certainly much cooler, and you go back to maybe 3 billion years and you imagine a scenario where Venus is a lot like earth is today. Now we don't know if it's got green on it. We don't know if it's got plants or a life of any kind. We don't want to make that jump.

Tracey Peake: [07:35](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=455.63) Right. There was not a jungle Venus.

Paul Byrne: [07:37](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=457.52) We don't know, but there certainly would have been a lot of water hitting the surface and in the song gets brighter and hotter and it's for us to raise the surface temperatures slowly. Naturally. This is not like human driven climate change, which happens over a couple of centuries. This is probably a much, much longer process, but a more frightening process because whatever about else fixing our climate problems on earth today from anthropogenic climate change, this is a thing with the sun and this is not something you can fix. The sun is behaving pretty well, and will continue to do so. But over a billion, year timeframe, the sun gets hotter and brighter. And so we have this idea, this concept that as a sun gets hotter and brighter, surface temperature readings go higher and higher, and if you begin to sort of evaporate the oceans a bit faster than you would otherwise, and you slowly start to put more and more water vapor into the atmosphere. And as you do this, you actually end up into what's called a moist greenhouse effect. And suddenly it becomes that, bit easier to hang onto that moisture in the atmosphere and you actually drive more and more evaporation until eventually on this brightening sign and this evermore human atmosphere, you trigger what's called a runaway greenhouse effect. And this frightening phenomenon basically means that you reach a threshold beyond which you cannot stop this runaway train and you get ever hotter every more evaporation. Your water eventually it gets completely, completely moved up to the atmosphere and you boil off your oceans. And if this happens, then a lot of the water will reach the very highest parts of the atmosphere where the sun will chemically react with it and drive off a lot of that water. Leaving that evermore heavy isotope behind. Which is what's driving the ratio we know in Venus's atmosphere today. There's another interesting angle of this. Plate tectonics we discussed earlier cause a really important thing for keeping a planet's temperature fairly regulated. Well, one of the things Plate tectonics we think needs we think is water because the sediments that contain all this carbon that's in the ocean from these little tiny shells, that sediment is full of water and as the plate dives down under the continent, that water helps lubricate that process.

Paul Byrne: [09:33](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=573.24) It makes it a bit easier for that plate to get down and once that plate's down, you can fairly reliably sure that it's going to continue going down and you can keep the plate tectonic process alive. If you start to boil off your oceans under this runaway greenhouse effect and you suddenly lose the water that's lubricating this process. Even if Venus had plate tectonics, which is a massive and unanswered question, but if it did and it was somehow able to regulate its temperature through this process and trap the carbon that the volcanoes are putting into the atmosphere, once you lose the water, this plate tectonic processes, will stop and once that stops, now you lose the ability to control your temperature the way you might've had some chance of offsetting this ever more evaporation of your oceans. The inside of Venus, which is generating all this heat energy, it has no idea what's going on. It doesn't care, which means your volcanoes will continue to erupt, which means you're going to continue to put huge volumes of lava onto the surface, but now you won't be able to kind of keep things nice and cool because you won't be putting these cold plates into the inside and producing new ones at the, at the spreading center in the ocean. The whole thing jams up, but you can produce a lot of materials still from the inside and eventually it's thought somehow that this material will reach the surface and cover huge areas of the surface in very, very short periods of time, which might be the way that you bury all those original craters that might've been there and make the surface look relatively geologically young. So this idea of the brighter, hotter sun evaporating the oceans explains why Venus might look the way it does today with relatively few craters. Why it might have more tectonic and volcanic activity, than the other planets in the solar system except earth but not quite like earth. And it explains that odd chemical property in the atmosphere and we don't know this that we could test all of this with a variety of missions and landers, orbiters, fly bys. But what's important is we at least have a framework to help answer a really critical question. Was there originally a period of time in the solar system when there were two earth like worlds side by side and that has all kinds of implications for if you have a habitable world, are you sure you're going to hang on to it? Are you going to be able to keep those conditions in place long enough for complex life to evolve and this has implications not just for our understanding of Venus, it has implications for the geological history and the future of earth.

Paul Byrne: [11:45](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=705) The Sun is going to continue to brighten. It's going to continue to to warm up. There's a possibility that within the next one or 2 billion years what happened to Venus is definitively going to happen to Earth. The world we think of today that it's been like this for a few hundred million years, for a few thousand million years, it's going to look like Venus in about 2 billion years time we think, or at least as a possibility. Understanding whether this applies to Venus helps us understand the fate of our own world to say nothing of the fact that we are discovering more and more rocky worlds in other solar systems. And if we can understand the rules governing how planets about the size of earth behave, which path you take earth or Venus, that's going to be really, really important for us to understand what we're looking at, to make sense of what we see as we discover more and more earth like worlds in other solar systems.

Tracey Peake: [12:29](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=749.2) Well that has been terrifying and fascinating. So, um, that brings me to some other questions. The Venus stuff is amazing. Um, and certainly super cool. But what is something that like the most interesting thing that you've discovered in your research?

Paul Byrne: [12:47](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=767.27) What's really interesting, I think is that somewhere between Mars and Jupiter is what we call the frost line. Sometimes it's call the snow line or the ice line, but the concept is the same. You get sufficiently far from the sun that water can exist in ice form. And so this is presumably this concept applies to any solar only star system anywhere. Beyond the frostline so beyond the frostline, you get the, what we call the giant planets, the gas giant in the ice giants, Jupiter, Saturn, Uranus and Neptune. And these worlds all have moons of their own as some of them are rocky, but most of them are covered in icy shell. And this icy shell is simply because at those distances from the sun, at the temperatures at that part of the solar system, ice can form the solid and it's so cold. This solid is essentially a strong as rock, which means we see a lot of the same kinds of land forms like tectonic structures or even impact craters on these icy shells look very similar to what they look like on rocky worlds in the inner solar system because the ice really is that cold and that hard. What's interesting, what's fascinating about some of these worlds is that we have indirect evidence in most cases that there might be a liquid water ocean underneath those ice shelves. So you can imagine, you might have a rocky world it's still made a rock in the way that we understand the inner solar system worlds are made of. But on top of this rock, there's a liquid water ocean. And on top of that, the upper part of that ocean has frozen into this ice shell. And that's a bit we can see. So we only really know the outer bit is made of ice. And we know that because we have uh, devices, instruments that can measure what stuff is made of composition spectrometers and they tell us that it's a water ice and various stuff mixed in. But we have a bunch of indirect evidence from, for most of these worlds. So there's a liquid water ocean. In fact one direct evidence is a world called Enceladus, which orbits Saturn. Enceladus is tiny. I come from Ireland. So if you imagine basically Britain and Ireland together, Enceladus is about that big, that's not big for a moon now. And Enceladus, has craters and that has fractures and stuff and uh, you know, things we recognize in the inner solar system.

Paul Byrne: [14:40](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=880.15) But Enceladus has these huge four or five giant fractures or cracks in the south pole from which water is blasting out in jets right now. And it's been doing this, we don't know for how long, probably for a very long period of time, but we discovered these with NASA's Cassini mission, which visited and operated in the Saturn System from 2004 until 2017 and in 2005 we imaged these plumes, these jets erupting from the South Pole of Enceladus. In fact, Cassini flew through these plumes to sample what was in there. And not only did we determine that the plumes are made predominantly of particles of ice, so it's water and therefore it's probably liquid water at depth. There were organic compounds inside these as well. Now remember earlier we said there's three things we would look for for life or least for habitability. We want organic compounds, we want water, we want an energy source. So before this discovery, people have been thinking about what might happen on the ocean floors of these worlds where you have the ice, you have a thick water ocean, and then you have this rocky, the seafloor, where the ocean is situated. And when we discovered these organic particles coming out of these jets on Enceldaus it raised the possibility that maybe there were places in the solar system, many places in the solar system where water and rock are touching and where there are organic compounds. So you got your first tick water organic compounds if they're in Enceladus. And it turns out there are organic compounds that does not mean life, but carbon long chain organic molecules, we just, we find those in asteroids, we find them on the surface of comets. We know that they exist in the north pole of mercury. They exist in the poles of the moon, organic compounds form huge molecular clouds in deep space organic compounds seem to be really common. That again, not proteins, amino acids, something like that. We're seeing organic compounds throughout the cosmos. So that's our second thing. Tick. The third thing, energy. Well, what is really interesting is when rock and water interact, they drive chemical reactions that form new minerals and in the processes of forming new minerals, they produce things like hydrogen, which can be an energy source. It can be something that something can use and ingest bacteria could fix it for example. So you can have energy at rock/water interactions. If you have rock/water interactions, you have water. If you have them interacting, you have energy and if you have organic compounds as told to us by Enceladus, then you have your third of the Trifecta.

Paul Byrne: [16:53](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=1013.24) You've got the organic compounds. So for the last 15-20 years longer, but certainly the last 15 years has been a huge interest in understanding these icy satellites as potential habitable places. Does not mean life, but it might mean where those three compounds or those three things or factors are existing together. So work that I've been doing with some colleagues has been to understand what the ocean floors of these worlds look like and we talked earlier on that we look at other planetary surfaces that we can photograph to understand what they look like. We cannot look at the ocean floors of these worlds because in, in, in all cases they're there, they're hidden to us at least right now there are some audacious ideas as to how we could melt through the ice Shell and then deploy submarine. But we're hundreds of years probably from that technology. So we're not in my lifetime going to image or photograph the surface. So we figured out with what the little bit of data we have, what might they look like. If you were able to sail over in a submarine, what would the ocean floor look like? Would they be full of tectonic processes? Would they have chains of sea mats and volcanoes? Would they teem with life or would they be quiet and dark and featureless like the abyssal plains in our deepest parts of our oceans. So we've taken a bunch of data we have available, we have some geophysical data that suggests what the inside might look like we take data, we know of how rocks behave because remember that the ocean is sitting on regular rock. We don't quite know what it's made up, but we can make some educated guesses for what it's made of. And we have a fairly good idea as to how rock behaves at different pressures. And our question is this, you have rock and water touching for these worlds for rock and water to interact and to drive these chemical reactions that could provide an energy source for in life if it happened to be there. You need the rock and the water to touch and to continue to do so. And the way that happens on earth that these hydrothermal vents we talked about early on is that you have plate tectonics driving with a huge amount of energy pulling the crust apart. You create fractures, the water percolates through these fractures that it communicates the rock. You get these chemical reactions, but very quickly you fill those cracks up with minerals that you precipitate out. And, and we, we understand that on earth we see lots of examples in the rock record, but you've got a lot of energy from plate tectonics.

Paul Byrne: [18:53](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=1133.88) It's making new cracks, new fractures, so you're constantly forming a new way of making fractures in which the water, and rock are introduced for the first time, that particular local place, generating new energy. So you keep this process going. And our critical question for these oceans, these ocean worlds is for their sea floors. Sure, maybe the rock and water touch for a while. That may generate energy for awhile, but can you do this over the lifetime of the solar system? Is there some mechanism, some energy source or stress that will break the sea floor, create these new fractures, get the water and the rock interacting, they seal up? Is there a way you can make new fractures and therefore keep that environment habitable over hundreds to thousands of millions of years? And some of the work we've been doing so far suggest that sure, here might be a fairly long history of rock and water touching for maybe a few tens of millions of years, but so far we have not come up with a mechanism of keeping new fractures being made and keeping old fractures open over the lifetime of the solar system. So they might be habitable worlds for awhile, habitable environments, and where for a time that trifecta of water, organics, and energy exist together. But keeping that process going over geological time seems to be from our results so far, really difficult to do. And if that's true, then we do need to reconsider these worlds as potential places to look for evidence of current life.

Tracey Peake: [20:13](https://www.temi.com/editor/t/Mv_UR40sHViHo3hRL9lKKSNXMNostR9po2b8hADSHWcABZurNZLKXO_eX68veMX9EqGcsYjV99vXCG-5BakNdFyLFCE?loadFrom=DocumentDeeplink&ts=1213.88) I've been speaking today with Paul Byrne, an assistant professor of planetary geology here at NC State. I'm Tracey Peake and this has been Audio Abstract. Thanks for listening.