Peter Brannen (00:00:00):

And it might be that civilization is more brittle than the biosphere. You might not need a proper mass extinction to bring down global industrial civilization. You just need one of these run-of-the-mill climate events that happens once every few tens of millions of years rather than one of these apocalyptic things that happens once every 100 million years or so.

Nate Hagens (00:00:25):

Greetings. I am very pleased to welcome Peter Brannen to the show. Peter is an award-winning science journalist and contributing writer at The Atlantic. He's particularly interested in geology, ocean science, deep time and earth's carbon cycle. So in this show we nerd out about the importance of carbon to earth's prior mass extinctions. Peter previously wrote a popular book about earth's prior five mass extinctions called the Ends of the World. He is currently a visiting scholar at the Kluge Center at the Library of Congress, as well as an affiliate at the Institute of Arctic and Alpine Research at the University of Colorado in Boulder. This is a topic that I find fascinating and is relevant to all of our futures. Please welcome Peter Brannen. Peter Brannen, welcome to the program. Great to see you.

Peter Brannen (00:01:34):

Thanks. It's great to be here.

Nate Hagens (00:01:35):

In your case, I think you may be in Colorado, but given your expertise of the world, I put where I thought Pangea might've been in the past on my globe in the past in your honor.

Peter Brannen (00:01:49):

I appreciate it. I'm actually in DC right now for the fall.

Nate Hagens (00:01:52):

Oh, in DC.

Peter Brannen (00:01:52):

For a fellowship. But I just moved out of Boulder, Colorado, which is a dream for someone like me who's interested in geology and all things earth science.

Nate Hagens (00:02:02):

And bike riding and hiking and everything else. I love Boulder.

Peter Brannen (00:02:08):

Yep.

Nate Hagens (00:02:09):

We have a lot to cover. Let me just first ask you right off the bat, you're an expert on earth's mass extinctions. Why should viewers pay attention to this podcast?

Peter Brannen (00:02:23):

Well, I wrote a book about the so-called big five mass extinctions in earth history. And the reason why I wrote that book is because I had noticed that in the geology community over the last few decades that the conversation had changed from how it existed in the public imagination, where with the success of the asteroid impacts hypothesis in 1980 when it was first introduced in a pair of papers written by Luis Walter Alvarez and another one by Jan Smith, and then a decade later when they discovered the crater, geologists thought that they had this general explanation for why mass extinctions happen, which is they're what happen when big rocks fall out of the sky.

(00:03:08):

And in the last 30 years as geologists fanned out across the world and looked into the earlier mass extinctions to try to tease apart the causes of those, they thought maybe they'll find a similar layer of asteroid dust or a big crater somewhere. And for the most part, in these other really extreme chaotic episodes in earth history, some of which were much worse than the extinction that wiped out the big dinosaurs, there wasn't evidence for an asteroid impact really at all, at any of them, that's very convincing. And instead people have been investigating these other kill mechanisms intrinsic to the earth system itself, that in some ways, each mass extinction is different, but the focus has turned more towards things intrinsic to the earth system itself and things changing.

(00:04:03):

And in some of the same ways that the levers we're pulling today, we're not quite at the level of devastation as these ancient mass extinctions, but it's concerning that we're starting to see the first check engine light signals that we know from earth history. If you go as far as you can in this direction, you can literally do the worst things that have ever happened in earth history. So we'll get into the specifics of those, but I thought that was newsworthy and worth bringing to the public attention that the conversation had changed in the earth science community.

Nate Hagens (00:04:37):

So if the check engine light on earth is on, who are the expert mechanics?

Peter Brannen (00:04:42):

I would say it's geoscientists. I mean, especially people with a deep time perspective. I think in my book I refer to it as if you're having chest pains and you have a history of heart attacks, that's what we're experiencing now, the first warning sign. So in a lot of the ancient mass extinctions, you see things like, in some cases, huge eruptions of CO2 out of these mind bending volcanoes. You see evidence of warming and ocean acidification and the ocean losing its oxygen. And a lot of the same things we're seeing today in an extreme level in these ancient events. But what's alarming is that it is in our capacity to reproduce them if we really don't get our act together. That we're even in the same conversation as these psychedelic horrors and the deep past is amazing.

Nate Hagens (00:05:37):

Except most people have no idea about these mass extinctions. So you mentioned the word deep time. I have a chapter in my book for students, Reality Blind on deep time. Your book is all about deep time, which for you and I, we can geek out on that. Can you define deep time and why is it important that we educate young people and maybe all people about deep time?

Peter Brannen (00:06:13):

I mean, I think it really just evokes this idea that in the same way that distances in space are... When we evolved on the savannah as primates, we did not evolve to intuit these quantum distances or distances between stars. It's just these are scales that we have no way of reckoning with. So in the same way that astronomers come up with mnemonics or aides to help them think about these expanses, so have geologists because the time behind us, in the rear view, is similarly expansive and mind blowing. And I think most people don't really appreciate this. Sorry.

Nate Hagens (00:07:02):

No, no, no. I mean, the way that I talk to my students about it is our ancestors evolved to define and have words for one, two, three, and many. And even today, I think a million, a billion, a trillion are just fancy words to represent a lot. But a million seconds is 12 days, a billion seconds sounds a little bit bigger, is 31 years. So when we look backward, it's very difficult for the human brain to comprehend these time periods on earth. So what I do with my students is I hand out little pieces of amber with insects in them that were alive 90 million years ago, or I think you've watched my podcasts in the past, I show this, this is 2 billion year old column of cyanobacteria, stromatolites, and when you hold it in your hand and this thing was alive 2 billion years ago, it gives you a little emotional mnemonic to think like, "Holy crap, this existed 2 billion years ago."

Peter Brannen (00:08:18):

I mean, that's one of the things that's so strange about the geologic record is you can have intervals in it. So there's this thing called the great unconformity. It's primarily known from North America, but a similar pattern exists over a lot of the world where something like a billion years has gone missing and there's a lot of debates and fights about why that is. But you see that it's just huge erasure of earth history in the fossil record. There are outcrops here and there, but it's way more rare to find things from that interval and then you can find an imprint of a raindrop that fell on a specific day 2 billion years ago. And it's just these changing scales are just mind blowing.

Nate Hagens (00:08:57):

How could we possibly find evidence of a raindrop that fell 2 billion years ago?

Peter Brannen (00:09:04):

There are fossil raindrops. They're on a muddy surface that got hit by a raindrop and then was covered in sediment and it just gets preserved as this little impression on the rock.

Nate Hagens (00:09:21):

Wow.

Peter Brannen (00:09:21):

Yeah, but it's a tool that I use in my first book, and I often use to demonstrate these expanses that we're talking about, I borrowed from the geologist Robert Hazen at the Carnegie Institute because I just think it's really evocative and mind blowing is that if you imagine every footstep you take is a century and you go for a walk and you guess how long does it take to get to the beginning of Earth history? So you take one footstep back and it's 1923 and the Ottoman Empire has just disbanded and World War I ended and the night side of the planet is still pretty dark because electrification hasn't really happened in most of the world. That's one footstep and a lot has changed. You take 20 more, and the Roman Empire is there. 60-80 more, and there's wooly mammoths and you haven't walked that far and sea level's 400 feet lower and there's Antarctica's worth of ice on North America and there's camels and lions in North America.

(00:10:22):

So the world's totally transformed. You've barely walked down the hallway. So you must think, "Oh, it's probably, I don't know, a mile to the dinosaurs and then a few miles to the beginning of earth history." But in fact, you would have to walk for 20 miles a day for almost four years to cover the rest of earth history. So those are the expanses of time that we're talking about. And once you start thinking in those scales and you start to realize that we are doing things on this planet that are almost unprecedented over a lot of that span, then it brings home just how radical the experiment we're running on the planet really is. That's why I think it's important to think about tiers on that scale

Nate Hagens (00:11:04):

I happen to agree, which is why I invited you to share your research and your outlook on this. With some of my scientific experts that, we have a wide array of listeners, some may know your work a lot and some may not know it at all. Could we do a speed round of the five mass extinctions? Name them, when they were, what was the general impact and what was the cause? Try to do it in under two minutes per, which as a science writer and someone who's studied these things deeply, is probably difficult, but go for it.

Peter Brannen (00:11:49):

Well, I think a helpful milepost for people is the dinosaurs because everyone knows the dinosaurs and the dinosaurs evolved on Pangea, but Pangea started breaking up about 200 million years ago and dinosaurs evolved about 245 million years ago. So with the first few mass extinctions, we are way before Pangea, we're way before the dinosaurs. So the first mass extinction, so the Cambrian explosion has happened in about a half a billion years ago and there's this progression of life and it really flourishes in this age known as the Ordovician period where there's this thing called the Great Ordovician Biodiversification Event where species on Earth triple over, I think it's about 10 million years, and all the life is basically in the water. You might have a few little sprigs of archaic plants on lake margins and things, but for the most part, the interior of the continent looks like the Mars Curiosity Rover feed.

(00:12:49):

But the action is really under the waves. And you have this whole world of invertebrates and squid-like things with cone shells and things that look like horseshoe crabs. So that's the world we're in. And the Ordovician ends in this devastating Ice Age where sea level dramatically falls and the ocean circulations upended. And that one's actually thought to be caused by declining CO2, possibly from weathering of the early Appalachians. So some of your listeners might be familiar with the idea of enhanced rock weathering to sequester CO2 and the planet does that all on its own, and it was very effective at doing that maybe in the lead up to this extinction, CO2 passed the threshold-

Nate Hagens (00:13:32):

But it takes a really long time for that to pull CO2 down.

Peter Brannen (00:13:36):

Yeah, so these are on the order of a hundred thousand year processes and then later mass extinctions, when lots of CO2 goes into the air and it gets really hot, eventually the earth is rescued by these weathering processes that happen over hundreds of thousands of years that sequester that CO_2 and cool it off again. And that's going to happen in our future too, if you wait long enough.

Nate Hagens (00:13:58):

So this was the first mass extinction and what was happening on land there? Not much.

Peter Brannen (00:14:07):

Not much. There might've been the first inkling of plant life trying to establish a beachhead, but for the most part, there's not much going on on land. And its-

Nate Hagens (00:14:16):

And it was covered in ice pretty much then, right?

Peter Brannen (00:14:20):

Well, when the Ice Age struck, this is so long ago that Africa and Saudi Arabia are over the South Pole. And so what's interesting is that, so I'm from New England originally where you can go hiking and see remnants of the last Ice Age because you'll see these scratch marks on the rocks from where the glaciers were. And that's from only 20,000 years ago. In the middle of the Sahara Desert and in Saudi Arabia, you see similar evidence for ice sheets, only they're from 445 million years ago from this extinction. Africa's not over the South Pole anymore.

Nate Hagens (00:14:57):

I hate to keep interrupting you, but sometimes I wonder, which is more amazing, that we evolved from the sea, from the last universal common ancestor and all the forms of life and navigated through all these mass extinctions and 99% of the species to ever live on earth are extinct. Is that more amazing or is it more amazing that we figured all that out and we can look backward in time and get clues and scientists like yourself can puzzle this together and tell a story about the history of this planet? I just find it amazing.

Peter Brannen (00:15:42):

No, I mean I'm similar. I feel very grateful to live at a particular time on earth where I have access to this story and can be reasonably sure that it somewhat adheres to what actually happened. Unlike previous creation myths that every culture comes up with, we have a pretty rigorously defined story of where we came from. There's still a lot to discover. That was one of the surprising things in reporting the book is how open-ended some of these questions still are. That we're looking at other planets for life, but we really don't understand the steps that made this place habitable. So it's a very exciting time if you want to get into the field to answer some of these big questions

Nate Hagens (00:16:34):

As is my prerogative. And frequently, what happens as the host of this podcast. I've interrupted your speed round several times.

Peter Brannen (00:16:42):

Oh no, that's okay.

Nate Hagens (00:16:43):

That was the first mass extinction and that was called what?

Peter Brannen (00:16:46):

The End-Ordovician mass extinction, about 445 million years ago.

Nate Hagens (00:16:50):

Okay, what's next?

Peter Brannen (00:16:51):

The next one around 375 million years ago is this thing called the Late-Devonian extinction. And the Devonian is a weird time because it's an age of 25 million years where you repeatedly have pulses of mass extinctions and one really big one and another pretty big one at the end. And by the Devonian, the planet has changed pretty dramatically. There's now trees and forests, first of all, in the middle and late Devonian period. Fish have started to waddle onto land. So our ancestors are showing up. Arthropods, things like insects are on land as well. So this whole land ecosystem is taking off in this period. But weirdly, it is racked with pulses of extinction and it's, in many ways, a mysterious age and especially the pulses of extinction. But I would say the weight of evidence is on actually the evolution of trees and forests as driving a lot of the chaos that's happening.

(00:17:56):

So I like to think of this one as trees embarked on this incredible geoengineering project of where the land previously had been uninhabited, spreading out all over the world, developing things like roots and breaking up rocks and seeds so they can push inland. And as they did that they're releasing all these nutrients from the land, things like phosphorus that are washing into rivers, then out into the ocean, and they're driving these pulses of anoxia. So the ocean's losing its oxygen repeatedly in this age of extinction and devastating sea life. And I guess ironically, in a way, a lot of that dead life that died in these extinctions is what we frack now. So in the Midwest, a lot of that stuff is Devonian. It's from these pulses of anoxic seas that buried all this carbon in them because you have all this life that's dying and falling to the bottom of these seas and there's no oxygen so they don't decay, so that carbon just stays there for 380 million years until a weird primate decided to come along and dig it up and start burning it.

(00:19:03):

But another consequence of this extinction is trees are also very good at sequestering carbon. And when they're fueling these big algae blooms that's burying a lot of carbon. So there's evidence as well for pulses of Ice Ages in this one as well. So the first two extinctions are pretty weird. It gets more cinematic, I would say, with the latter three, but they show that it's really environmental change on a pace that life can't keep up is the thing that's driving these things because you can pass these cold thresholds that can wipe life out. And then in later extinctions, you see incredible heating and life is adaptable and it can bend, but it can also break. And I think that's what's happening in these extinctions.

Nate Hagens (00:19:51):

Talking about theatrics and drama, I have Peter Brannen on the podcast talking about earth's mass extinctions sitting in Washington DC where the Eye of Sauron is directing its gaze around the world and there's a police car in the background during our conversation-

Peter Brannen (00:20:10):

Yeah, sorry about that.

Nate Hagens (00:20:11):

There's an allegory there. I don't know what it is. Okay, keep going.

Peter Brannen (00:20:16):

Okay, these next two I can sort of speed through because they're basically the same thing happens two times in a row. So 252 million years ago, you have the biggest mass extinction of all time. There's no real close second place. It's called the End-Permian mass extinction. It's also known as The Great Dying, and it lives up to its name. Life, at this point, it's starting to get a little more familiar, but we're still before dinosaurs. This is still an alien planet, but there are reptiles on land. There's things that look like reptiles that are actually closely related to us that are on land. There's trees and forests and life has recovered from these previous mass extinctions. And on on the ocean there are these big sponge reefs and things like Trilobites are still swimming around.

(00:21:02):

And a great place to actually see what life was like in the Permian is if you do what I did, and you go to the Permian Basin Petroleum Museum in Midland, Texas. They have this wonderful reef diorama. And the reason why there's a reef diorama in the Permian Basin Petroleum Museum is because all this life, again, left behind a trillion dollars of carbon in Texas. But at the end of the Permian, you just have this completely devastating mass extinction where you look for fossils in the millions of years afterwards, and sometimes the rocks are almost empty and it takes about 10 million years for the earth to fully recover. There's all sorts of weird signals right at the mass extinction boundary, like this thing called a fungal spike, which might be the signal of... And the most dramatic interpretation is it's just stuff rotting all over the world. It's the only extinction that really affects insects. And what caused it? People thought with the dinosaur asteroid, maybe there's a big evidence of an impact in the Permian and there really isn't.

(00:22:08):

But what there is in Siberia is this incredible expanse of volcanic rock known as the Siberian Traps, which they're one of these things called a large igneous province, or when they happen on land, a continental flood basalt. And it's really just the continent turning inside out. The amount of lava that erupts in Siberia at the end of the Permian is mind boggling. So the volcanic rock, the magma and the lava, is enough to cover the lower 48 United States a kilometer deep in this stuff. So when we talk about Yellowstone, it would cover a few states and a few inches of ash. It would be very devastating to global industrial civilization. But this thing is just on a totally different scale.

(00:22:57):

But as dramatic as lava coming out in Russia is, that doesn't explain why things at the bottom of the ocean on the other side of the planet are going extinct. And so it's not the proximity to the volcanoes that's killing things, it's the gases that are coming out of the volcanoes. And these things would've been emitting all sorts of horrible stuff. So mercury, maybe there was some mercury poisoning. They were on their way up through the Tunguska Basin in Russia. They were burning through a lot of gypsum and halite and putting all sorts of ozone destroying chemicals in the air.

(00:23:31):

But what's really been honed in on as the kill mechanism in this extinction is all the CO2 that came out of these volcanoes. And it truly is a mind boggling amount, but on their way up, they would've burned through vast coal deposits from previous ages and natural gas and limestone. So they were igniting fossil fuels and limestone to an insane degree. And you see evidence of something like a 10 degree Celsius rise in temperature, the oceans lose something like half their oxygen, I believe. There's evidence of ocean acidification. So all these things that we're seeing today, this is like the RCP8.5, just a few hundred years out. Maybe we're not going to reproduce it, but it's amazing that it's in our power to bring about another End-Permian mass extinction.

Nate Hagens (00:24:31):

Well, we're going to get into the details of that, but just to be clear and a couple of questions, I don't think even RCP8.5 comes close to the amount of carbon that was emitted in that time. Because what happened was that was over thousands or even 10 thousands of years. So we can't reproduce what happened, but what we could possibly do is reproduce the effects.

Peter Brannen (00:24:58):

Right, so it's interesting because we could never emit as much CO_2 as the Siberian traps did. The estimates are on the order of tens of thousands of gigatons to some exceed over a hundred thousand gigatons, so that's just completely out of the question. But as far as we can tell, we're doing it about 10 times faster. So the rate is faster. And for things like ocean acidification, it's the rate that matters. And the earth has ways of washing CO_2 out of the system on long time scales. If you have a huge one of these big volcanic events, but it takes tens of millions a years, you're probably not going to acidify the ocean. It's probably not going to get that much warmer because the planet is continually scrubbing it from the atmosphere through these things like weathering. It's when you really jackknife the system in a short amount of time. But it's definitely an open question. How relevant are these analogs to what we're doing today? And the fact that it's an open question is what worries me. I would say.

Nate Hagens (00:25:57):

So slight tangent here, interrupting you again, but I think it's relevant because...

Nate Hagens (00:26:03):

... For interrupting you again, but I think it's relevant because sometimes on social media, well quite often you hear, oh well a single volcano emits more CO_2 than all of human industrial activities so human CO_2 is not a big factor. So, what is the deal with volcanoes? And obviously there were the Siberian traps, which was 1000s of years of giant provinces of lava basalts and CO_2. But what about something like Mount Pinatubo, or Mauna Loa, or modern volcanoes? How does the CO_2 equivalent of volcanoes on land or in the sea compare to the scale of modern industrial fossil carbon burning?

Peter Brannen (00:26:57):

Yeah. So I mean, the best estimate I've seen is that humans emit 100 times more CO_2 every year than all the volcanoes on earth. CO_2 is the second most abundant gas that comes out of volcanoes, other than water vapor. This is a good thing that volcanoes put CO_2 up into the atmosphere. The Earth needs CO_2, so that it's not a snowball Earth situation and so the plants have food to eat. The behavior of CO_2 on this planet is fundamentally what makes Earth, Earth. It's this thing called the carbon cycle, and it's supposed to come out of volcanoes, sort of move between the oceans and atmosphere and through life, and then back into the rocks. Then, they get subducted and they come out of volcanoes again. But what we're doing is really not like the background rate of CO_2 emissions from volcanoes, and it more resembles these once every 50 to a 100 million year sort of crazy events that you see in the fossil record.

Nate Hagens (00:28:01):

Leave it to those clever fire apes. Okay, go to the fifth one then.

Peter Brannen (00:28:11):

Oh, yeah. Okay. No, the fourth one. So basically 50 million years after the end Permian, life picks up the pieces and starts to look modern, which is a weird way to describe a world that has dinosaurs evolving. But you get the first, you get dinosaurs evolving and there is twice as many species of dinosaurs today as there are mammals.

Nate Hagens (00:28:30):

That's right.

Peter Brannen (00:28:31):

So, we're still sort of an age of dinosaurs. The first-

Nate Hagens (00:28:33):

They're birds.

Peter Brannen (00:28:34):

... modern-

Nate Hagens (00:28:34):

They're birds.

Peter Brannen (00:28:34):

Yeah, they're birds.

Nate Hagens (00:28:35):

10,000 species of birds.

Peter Brannen (00:28:36):

Right. Right, right. The first modern mammals evolve. The first modern conifers and stony corals, and the pieces that would eventually make our modern world are evolving in the wake of the worst thing that's ever happened. So if you're looking for a sort of silver lining to the worst thing that's ever happened, it's we wouldn't be here having this conversation probably if it hadn't happened and the world would look completely different.

Nate Hagens (00:29:03):

That's very meta, Peter.

Peter Brannen (00:29:05):

Yeah, yeah. And I've said before, I just as easily could have written a book about the mass radiations after the extinctions as the extinctions themselves because it's just as spectacular the rebirth that happens as the destruction is.

(00:29:20):

Okay. So it's worst thing ever, 252 million years ago, and then around 201 million years ago, you have this thing called the end Triassic mass extinction. And basically, the same thing happens. It's not quite as bad, but as Pangea is drifting apart, you have this thing called the Central Atlantic magmatic province that starts erupting in another one of these big huge continental flood basalts in the seams where Pangea is ripping apart.

(00:29:48):

So you find rocks that are these flood basalts that are dated exactly to the extinction in New Jersey across from New York City and the New Jersey Palisades, Brazil, France, Morocco, Nova Scotia. So, it's another one of these continent-scaled eruptions. It gets really hot. The ocean acidifies, it loses its oxygen. 75% of life on Earth goes extinct.

(00:30:16):

And so that one, I've described the kill mechanism already, so we can jump to the Cretaceous, which is the one everyone knows about. This is 66 million years ago when the most charismatic creatures in the fossil record, the big dinosaurs get wiped out in possibly the most spectacular way imaginable when this rock the size of Mount Everest hits the planet going 20 times faster than a bullet.

(00:30:44):

But, what's strange about that extinction is at the same time, there is another one of these big volcanic provinces in India at this time. I would say researchers are still trying to tease out the relative effects of the two things that are going on at the same time, essentially. And given the importance of these volcanic events in previous mass extinctions, it just seems like a bizarre coincidence that it's also happening at the end of the Cretaceous. To put it in some perspective, these are called the Deccan Traps and if enough lava erupted out of them, they could cover the lower 48 United States in 600 feet of lava. So nothing to sneeze at, but not quite as big as the Siberian Traps. I would say the smart money is still on the asteroid, but this is still very much a intensely researched area.

Nate Hagens (00:31:29):

Yeah. Peter Ward has been on the show before. Do you know Peter?

Peter Brannen (00:31:34):

I've interviewed him before, yeah. I interview him in the book actually.

Nate Hagens (00:31:38):

Yeah. So, he thinks it's a combination that we were starting to see the effects of a carbon pulse and the asteroid was the Coup de grâce. Yeah.

Peter Brannen (00:31:50):

Yeah. It's weird as people have gone back to date both the asteroid and the volcanoes, if you can get something within a few 10s of 1000s of years, the date down, that is incredibly precise. And so, I've seen papers where there's a warming pulse before and there's a warming pulse after, and we're still-

Nate Hagens (00:32:09):

Right, yeah. So, let me ask you that. As a scientist, I just got this bizarre self-perception in my mind as I'm speaking. Did you ever see the movie Best In Show?

Peter Brannen (00:32:25):

I did, a long time ago.

Nate Hagens (00:32:27):

Where Fred Willard is just asking these knucklehead questions of commenting, oh it's Shih Tzu, did you-

Peter Brannen (00:32:34):

Right.

Nate Hagens (00:32:34):

I kind of envisioned myself in Fred Willard's role interviewing you as a scientist about this. I care about this, but I know a tiny fraction of what you do. So, a lot of my questions might be naive-

Peter Brannen (00:32:48):

No, no, no.

Nate Hagens (00:32:48):

… but I'm playing the role of my viewer who might not have heard this stuff before. So how do we know as scientists to date something within 10 or 20,000 years even of something that was 60 or 200 million years ago? How confident are we of that, and what is the process?

Peter Brannen (00:33:08):

Right. Well, first I should correct you, I'm a science writer and I like to think that I do translation from the science world to the general public.

Nate Hagens (00:33:14):

Yeah, perfect.

Peter Brannen (00:33:14):

I don't want to claim the mantle necessarily of scientists, but at this point I feel like I've sort of earned an honorary membership in the geo science community.

Nate Hagens (00:33:22):

Well, how many 100s and 100s of papers have you read to get to where you could write these books?

Peter Brannen (00:33:32):

Many, many 100s. I would say that people have asked me or have said, I want to write a book, but I'm not sure about what. And I've said, then you don't want to write a book because it needs to be Saturday morning and all you can think about is going to read more papers on a topic, and-

Nate Hagens (00:33:50):

Seriously, when you were writing End of the Worlds were you like, oh god, I got to do this chapter and I have to learn about that, oh my God, I can't wait until this is over? Or were you like, I want to find out the answer to this puzzle?

Peter Brannen (00:34:06):

Yeah. No, I was completely obsessed the whole time. I mean, that's almost become a hazard of the job is that now I'm very in the weeds, and I think stuff is interesting that my editor would never find interesting.

Nate Hagens (00:34:19):

Right, right. Well, I feel the same about this podcast, but go on. How do we know with-

Peter Brannen (00:34:24):

Yeah. No. Yeah. I mean, a lot of it is you need to get lucky finding a strata that is easily dateable, and so volcanic ash layers are really are sort of like the prize. You're looking for those because those you can use radioisotopes. You find these things called zircons, which trap a certain amount of uranium that you know decays to lead over... You know the half-life of it. So if you know this thing hasn't been messed with it all, you can tell when it came out of a volcano within... I'm not sure what their bars on those are, but within 10s of 1000s of years I think. And, there's other systems. There's argon argon, and there's a bunch of these. You're looking for an ash layer for sure. There's other ways you can do it too. You can correlate. There's big dramatic dinosaur fossils, bones and things, but most of the fossil record is these tiny little shelly creatures that you'll find in lime stones and things.

Nate Hagens (00:35:27):

One of the examples I give my students is Lake Suigetsu in Japan. Every Spring, they have the cherry blossoms that bloom, and then they fall to the bottom, and then the leaves fall to the bottom.

Peter Brannen (00:35:39):

Oh, right.

Nate Hagens (00:35:40):

So there's these alternate white and green layers, and they drill down and they got a 100,000 years of these layers. And then they did carbon dating to see, and they were really, really close to 100 or 110,000 years ago with carbon dating. But what you're talking about goes way beyond what carbon dating could do, correct?

Peter Brannen (00:36:01):

Yeah. I think carbon dating sort of beyond 50,000 years, I think it's kind of useless just because the half-life of it. But, you can find much longer-lived radio isotopes. Yeah, but you can also-

Nate Hagens (00:36:17):

That's how we know all of the history of the one century per step going back for 20 miles a day for as long as you said. We know that from isotope dating of different elements.

Peter Brannen (00:36:34):

Yeah. I think the age of the solar system we know because you get these meteorites that have just been pickled out in space since the formation of the solar system, and they preserve signals that go all the way back to the beginning, the birth of the solar system.

Nate Hagens (00:36:51):

Wow.

Peter Brannen (00:36:52):

But yeah, I mean another way you can do it is if you know have a good extinction exposure, you can correlate the sort of weird, little life forms. Do they look like the one on the other side of the planet where you have dated it well? So it's this huge, distributed, global, correlation game of what strata is when and where are the fossils, where in the strata, and how does this one look like that one over there on the other side of the planet. So, it's amazing that we've pieced together this story of the history of the planet through this.

Nate Hagens (00:37:26):

Thank you for all that. A follow-up question, you have listed five mass extinctions. I would argue there was more than that because for instance, I showed you this Stromatolite before. That was probably the first one, 2 billion years ago, where their waste product was oxygen and we had a CO2 nitrogen atmosphere then, and that killed off themselves. Other things would evolve to eat them, and they couldn't photosynthesize the same way that they used to. But, were there lots? I assume that there were many, many extinctions that were not quite to the level of a mass extinction that we would refer to as minor extinctions. So what is the threshold to be called a mass extinction, and how many minor extinctions are scientists aware of?

Peter Brannen (00:38:29):

Yeah. Depending on how you count, there's dozens of minor mass extinctions, and some of them are pretty dramatic. The big five are notable because they pass this arbitrary threshold of it seems like over 75% of life on Earth goes extinct species wise. But-

Nate Hagens (00:38:49):

All right, let me clarify that. 75% of species, which is not necessarily 75% of life?

Peter Brannen (00:38:57):

Right. Although to wipe out a species, you can have something that loses 99.5% of its individual members and it doesn't go extinct. And, you're doing this without hunting or any human interven... You're making the chemistry of the planet so unpleasant that you are driving the majority of life on Earth extinct. So we're doing all sorts of bad stuff today, overfishing and hunting, and habitat fragmentation, and this has to be all climatic and chemical. And, to do that is pretty dramatic.

Nate Hagens (00:39:31):

So here's a question that will lead into your second book, which you're writing now, and it'll be part of our discussion. Of all the mass extinctions and all the dozens of minor mass extinctions, how many of those were related to CO2 pulses?

Peter Brannen (00:39:54):

Well, they're all related to dramatic changes in the carbon cycle. So, when I was describing the-

Nate Hagens (00:40:00):

All of them?

Peter Brannen (00:40:02):

Well, yeah, I mean just because life is made out of carbon. So when the asteroid hit, if it was the darkness that did it,, it shut down photosynthesis. So, there was less energy available to flow through food webs through this organic carbon. But specifically, the warm pulses from volcanic CO2, I would say the majority of them, there are a lot of large igneous provinces throughout Earth history, and a lot of them are timed really eerily to many of these minor mass extinctions. Or, at least it's like a reorganization of life on Earth. If they're not a mass extinction, sort of dramatic changes.

Nate Hagens (00:40:44):

So most of the minor and mass extinctions in Earth's history were eerily correlated with CO2 pulses, largely from volcanic provinces?

Peter Brannen (00:40:58):

Yeah, I think that's fair to say, but I would have to tell you that-

Nate Hagens (00:41:03):

Why don't most people know that?

Peter Brannen (00:41:05):

Well, I think a lot of this research is fairly new, or at least hasn't pierced the public consciousness because in the 90s all those asteroid movies got made. And there hasn't been a disaster movie about, or I guess there have been, but sort of slow gurgling things-

Nate Hagens (00:41:24):

Well, Don't Look Up is becoming eerily accurate the more I think about it.

Peter Brannen (00:41:28):

Yeah. Yeah, I actually haven't seen it. It's one of those things where I'm sure I'd be preaching to the choir, but I should probably check it out. But no, I think most people don't know-

Nate Hagens (00:41:38):

Yeah. It's a little bit of a comedy, and I thought you were going to say you haven't seen it because it's too painful for you. But, that one wasn't really painful. It was kind of funny, but I can't watch BBC Planet Earth anymore. I used to love those shows. I just get too sad.

Peter Brannen (00:41:56):

Yeah. No, I understand that.

Nate Hagens (00:41:59):

Although there is a new Netflix series, that one you have to watch. It's narrated by Morgan Freeman. Life on Earth, is it called?

Peter Brannen (00:42:07):

Oh yeah, yeah. No, I've heard good things.

Nate Hagens (00:42:09):

It's all about what you're talking about. It's about the evolution and they use computer AI to represent different dinosaurs. I've only watched part of it, but it's so good so far.

Peter Brannen (00:42:21):

Yeah. No, I have friends who are consultants on that show, and so they definitely do it right on the BBC bringing this stuff to life.

Nate Hagens (00:42:27):

Yeah, excellent. So minor mass extinctions, CO2 pulses. We are living through what I refer to as the carbon pulse, which also most people don't understand that we're drawing down ancient carbon millions of times faster than it was sequestered. Many, many more questions, Peter. I wrote down some things as you were speaking.

(00:42:56):

You mentioned that after, what did you say, 10,000 years or 100,000 years after a mass extinction, things start to recover because the Earth generates life? What are your thoughts on the Gaia hypothesis versus Peter Ward's Madea hypothesis, which is the contrast that Earth is trying to get to an equilibrium in the service of supporting life. The Medea hypothesis is the opposite, which is the Earth eventually finds ways to kill off life. What are your thoughts on that?

Peter Brannen (00:43:37):

I think there's truth in both of those. I don't think there's really a teleological endpoint.

Nate Hagens (00:43:43):

Yeah, I know.

Peter Brannen (00:43:43):

There's nothing that Earth is straining towards. So in the book I'm writing now, my eyes have been open to this idea that life, ever since its origin, has sort of been this channel of energy dissipation through carbon chemistry that was opened at hydrothermal vents 3.54 or 4 billion years ago that was unavailable to the planet before. When you have systems that are out of equilibrium, they'll find these channels of energy dissipation. Life is really this planetary process that does that.

(00:44:19):

So if there's any end goal, I think it's this second law of thermodynamics straining towards equilibrium along with the rest of the universe, and life is just a channel that a planet explores to relieve the frustration of systems that are out of equilibrium.

(00:44:38):

That was all very abstract. But if I was going to think about the planet and these broader, what's the point kind of terms, I think that is a unifying concept for me increasingly is that hurricanes relieve the upper ocean of the heat in them. They're these complex, dissipative structures that no one is there to organize, but they somehow make these beautiful structures to dissipate this heat. People have made the analogy that is what life is doing as well, just in a different domain, in carbon chemistry. So I don't know if that was too left field, but-

Nate Hagens (00:45:21):

I caught the fly ball to left field, and now I'm going to throw it back to you.

Peter Brannen (00:45:26):

Okay.

Nate Hagens (00:45:27):

Are humans just energy dissipating structures as aggregate civilization?

Peter Brannen (00:45:34):

I've thought about that. I think there's a yes because like all life we find sources of free energy and we dissipate it, and that's how we've stayed alive. But there's a risk of sort of naturalizing the last two centuries, which there is human agency and there's historical contingency, and humans are sort of different than just a blind thermodynamic process. But then sometimes I think, well maybe we're not. I think if you have this hugely out of equilibrium system where you have tons of flammable stuff underground and you have tons of flammable air above and you have this fire creature in between them, it better not figure out how to reunite these two reservoirs to interact with each other. And, that's what's happened in the last few centuries.

Nate Hagens (00:46:28):

Yeah, that is exactly what's happening.

Peter Brannen (00:46:28):

Yeah.

Nate Hagens (00:46:29):

But even if we are as a species, as a modern culture, an energy dissipating structure that is uniting the two don't unite these two areas, there is the possibility that there's a Heisenberg principle phenomenon at risk that knowing that we are uniting those two spheres maybe gives us the possibility to restrain ourselves, maybe.

Peter Brannen (00:47:04):

Yeah.

Nate Hagens (00:47:04):

Which is the purpose of this podcast.

Peter Brannen (00:47:06):

Right. No, I think that is the reason why I don't just become totally nihilistic is that, yeah, in some ways we're like the asteroid or we're like one of these big volcanoes. But, maybe there's a steering wheel on this agent of chaos and destruction. I think that's the open question for the next few centuries is whether we can control this, or whether we're just going to wait around for the planet to correct us and then figure it out.

Nate Hagens (00:47:40):

Why would you say next few centuries and not next few decades?

Peter Brannen (00:47:46):

Well, it'll definitely be focused in the next few decades. The window in which we can really change the trajectory and not get too far down this sort of scary, dark path that we've seen before in Earth history really does depend on what happens in the next few decades. But I mean, I'm only now dipping my toe in human history in this next book, and for me, even thinking on centuries is ridiculously short. So I'm trying to think in shorter timescales, but the planetary processes, if we have any ambition to live into geological time into the future, we need to start thinking on how can we live in accordance with these cycles that take place over 1000s and if not 100s of 1000s of years.

Nate Hagens (00:48:40):

So dinosaurs if you include birds, have lived over 200 million years. Humans have been 300,000 years in our modern form anyways. So yeah, we have a long ways to go in theory, in possibility we do. So, we are 45 minutes in and I have a long list of questions for you, Peter Brennan. You are originally a science journalist with a focus on ocean trends. What was it like working on that subject oceans, and do you feel like I do that a lot of the ocean related topics are under-reported and under-acknowledged by mainstream media?

Peter Brannen (00:49:25):

Yeah, I think there's this tendency to see it as happening out there, and it's like learning about something happening in space basically. It's this vast unknowable thing, and it's hard to get people to feel much sympathy for the plight of a bait fish like Menhaden or even cod and things like that. But, there is no division between life on land and life in the ocean. We depend on the ocean for a habitable planet, just as much as the ocean relies on mineral nutrients from land. There's no real disentangling these two systems, but reporting on the ocean, I think anyone who does so learns pretty quickly that a lot is going wrong in the oceans in some pretty worrying ways.

(00:50:17):

So you have coastal pollution and nutrient pollution and warming, which is driving this loss of oxygen in the ocean. So, the oceans have lost 2% of their oxygen since 1960. And that might not sound like much, but when you're talking about percents of oxygen change in the ocean, again, these are sort of geologically rare to see a change that big in such a short period of time.

Nate Hagens (00:50:40):

And, the 2% I assume is accelerating.

Peter Brannen (00:50:44):

Yeah. Yeah.

Nate Hagens (00:50:48):

What would happen if the oxygen on land dropped by 2%? I probably wouldn't be able to go for a bike ride the way that I do.

Peter Brannen (00:50:59):

Yeah, I think you'd definitely feel it. I'm not sure what the respiratory effects would be, but there would definitely be effects. I mean, we've changed CO2 by 100s of million-

Nate Hagens (00:51:12):

A 100%.

Peter Brannen (00:51:13):

Yeah, but we're talking on the range of 100 parts per million, and already plants have 30% fewer pores on their leaves since the start of the Industrial Revolution, these things that they fundamentally use to mediate their relationship with the outside world. When CO2 is high, they want to minimize their water loss, so they reduce the number of pores on their leaves. You see this in geological history. During high CO2 periods, plants get fewer pores. We've already done that in the last 150 years, this huge physiological change in plants on Earth that has untold effects on the water cycle. And so, very small changes in these things can have dramatic effects on the planet and life.

Nate Hagens (00:51:54):

Wait a minute, I didn't know that. So since the Industrial Revolution, all plants, many plants, a sampling of plants have fewer pores?

Peter Brannen (00:52:03):

The ones they've studied.

Nate Hagens (00:52:03):

... plants. A sampling of plants have fewer pores.

Peter Brannen (00:52:03):

The ones they've studied. So, there's this global warming event 56 million years ago where it gets about five degrees warmer, and CO2 briefly goes up from these volcanoes in the North Atlantic. And you see in ginkgo leaves in the fossil record that the density of pores on their leaves shrinks. People have used this to try to reconstruct CO2 over time just looking at the number of pores, usually on ginkgo leaves.

Nate Hagens (00:52:32):

So, that would be the plant equivalent of me moving from Canada to Florida, I would be shedding my clothes and wearing less clothes because the temperature was different? So, that would be a...

Peter Brannen (00:52:46):

Yeah, it's evolution on such a rapid timescale that's driven by this injection of CO2 into the atmosphere. I forget how we got on this topic, but...

Nate Hagens (00:52:58):

Well, you brought up this.... I'm going to get back to your original question. But this is something relevant to, again, the memes that we hear in the news. Because people correctly claim that CO2 helps plants grow and is a natural fertilizer. But then the implications of that, making it out to be an expansion from where we are today at 420-some parts per million, that a further expansion to 500 or 600 or 700 parts per million would be good for plants. It would be good for crop yields with higher concentrations. How true is that, and what are the trade-offs to that phenomenon?

Peter Brannen (00:53:41):

Yeah. As with a lot of these sort of cherry-picked things, there is truth to that. Plants do like CO2. They photosynthesize by taking CO2 in through these pores I was talking about on the leaves. In fact, actually I looked this up before we talked. There was at least one study that came out in 2021 that said that the global annual levels of photosynthesis have increased by about 12% between 1981 and 2020. So, you can just look at that in isolation and say, "Well, what's the big deal? This seems like a good thing."

(00:54:19):

But to anyone who's looked into this, the big problem is the world's going to get a lot more erratic. So, there's going to be worse droughts than there have been, and when it does rain, it's going to be a worse storm than it's ever been, and the grain belts will shift around. We're just making the planet more unpredictable, and I feel like our global system sort of relies on predictability and tomorrow looking something like it does today. But there are some crops, like corn I think is expected to dramatically decline under future warming scenarios.

Nate Hagens (00:54:57):

So, this is the same way of looking at stock market returns. There's an average, and then there's a standard deviation, and what you're saying is higher CO2 because of the impact on weather is going to increase the bands of the standard deviation. Which means we might have really good yields or no yields.

(00:55:17):

On average they might be higher, but here's another thing that I've looked into. I don't know if you are aware of this, but plants, when there's more CO2, it affects the distribution of where they put the energy within the plant, and sometimes we don't get the same nutrients that we would. Can you speak to that?

Peter Brannen (00:55:38):

Well, no, I've seen the same study you have, that there's this prediction that plants will become less nutritious. But I also think there was a study that came out recently saying that even yields in total will actually decline. So, it's not my air of expertise, but I think if anyone confidently tells you what the world's going to look like in a relatively geologically unprecedented level of CO2, they don't. So...

Nate Hagens (00:56:12):

I don't know that you've watched it. Yesterday I had a podcast released with Sir David King, a former Chief Science Advisor to the UK, and one of the things we talked about is that... And also I have a podcast that will come out in two weeks from this date, which is October 26th with Jeremy Grantham, and we also talked about people's attitudes towards global heating.

(00:56:44):

I said, "Well, half the people still don't believe in climate change and some of the things that you're talking about, Peter," and he interrupted me and he corrected me. He's like, "Half of the people in the United States, not half of the people." So, I think there really is a misinformation, a lack of education, or some failing in our science communication, (perhaps offset by different incentives), to really understand what's going on here.

(00:57:19):

Now, granted, once we agree what the problem is, the auto mechanics are diagnosing, "What's the problem?" then there's a totally different discussion on what to be done. That I understand, that people might respond differently, and it might affect their identity or their situation. I get that. We still need to have that conversation. But I don't think we're even there. Half of the people in our country do not recognize that we're alive during a carbon pulse, prior carbon pulses led to minor and mass extinctions. This is a big deal, capital B and D. Do you have any thoughts on that?

Peter Brannen (00:58:00):

Well, yeah. I might've touched on this when I was talking about the importance of deep time. But I think most people don't really understand how rare and extreme the planetary experiment we're doing, (on, as far as we know, the only habitable planet that we know of), is in Earth history. For me, that was the biggest eyeopening thing.

(00:58:26):

I was actually reading Peter Ward's books in the early 2000s that kind of alerted me to this. And then actually when I was writing about the oceans, I did this fellowship with the Woods Hole Oceanographic Institution, and there people were looking at these sediment cores from tens of millions of years ago, and showing this line in this chalky sediment that just turns to clay for 200,000 years during this ocean acidification event.

(00:58:50):

It's thinking on, some people will talk about, "There was the Little Ice Age, and The Medieval Warm Period, and there's Locke and Tambora," and these things are not even remotely on the same scale of the change that we're imposing on the planet now, and some of them are kind of spurious. Like the Medieval Warm Period, yeah, in Europe there's evidence that the climate was a little different. But it was sort of a reorganization of the climate rather than a complete phase shift, which is what we're sort of pushing it towards.

(00:59:23):

So, yeah, I've also found that talking about climate change and from a deep time perspective has been sort of a Trojan horse for some people who have their minds made up about it, where they've only heard about it as these things that happen on computer models, and it's all in the future, and it's theoretical. And if you start talking about these science fiction worlds from hundreds of millions of years ago, and you explain how the carbon cycle and CO2 actually works on the planet, people I've found are more receptive to this message.

Nate Hagens (00:59:57):

Well, that's why looking at human history and human behavior is so central, because the way that our brains are as short-lived biological creatures is we have to see evidence of something before we change our minds and our behaviors. But in this particular case, if the carbon pulse fully manifests, by the time we see the evidence of a mass extinction, we will have been part of a mass extinction.

Peter Brannen (01:00:27):

Right, yeah. So, that's a scary possible thing at play in some of these mass extinctions, is you'll see these volcanic eruptions happening over the course of sometimes hundreds of thousands of years, but the extinction pulse is usually pretty quick that everything sort of goes to hell. And some people like Doug Erwin at the Smithsonian Institution is trying to figure out whether it's: You have this background stressor, and then once you switch into a mass extinction mode, it's more of a network collapse dynamic.

(01:01:03):

He compares it to this blackout that happened on the East Coast in the early 2000s, I think, where it goes back to a software glitch in a control room in Ohio and suddenly the Eastern Seaboard all the way up to Canada went dark. It's not that it was caused by that one thing, but it was because this system, you chip away at the different components, and you're going to find that one that makes the whole thing collapse non-linearly. So, if that is how mass extinctions unfold, then we don't know where the event horizon really is.

(01:01:42):

Part of my book was excerpted where I said, "We're not in the sixth mass extinction yet, because if we were, it might be completely game over." And people sort of took that as like, oh, I'm saying it's not a big deal what we're doing, and I wasn't saying that. I was actually saying conservation is doubly important because we don't know where this threshold is, if that's how these things actually unfold. Because by the time you're in mass extinction mode, it might be too late to do anything, and you're in this sort of network collapse dynamic.

Nate Hagens (01:02:09):

What is your new book about, and do you have a title for that, and when's it going to be done and out?

Peter Brannen (01:02:14):

So, over the course of writing this book about the bad things that can happen in Earth history when lots of CO2 comes out of the ground, I realized that there was this much broader story to tell about carbon dioxide and the way the carbon cycle works for a general audience, to reintroduced them to this thing they've heard about in the news as this random industrial byproduct that comes out of smokestacks as sort of fundamental to how the planet works. Which is one of the reasons why you don't want to mess with it too much. So, hopefully the book is coming out next year. I'm finishing it up now, and the title is quite grandiosely, The Story of CO2 is the Story of Everything. So, we'll see if I can live up to that.

Nate Hagens (01:02:58):

Good luck with that. When it comes out, please come back on the show and we can talk about that.

Peter Brannen (01:03:04):

Yeah, I'd love to.

Nate Hagens (01:03:05):

Lots more questions here, Peter. On the topic of CO2, I asked this question of Sir David King, and I will ask you. I'm sorry to use you as a sounding board for common memes that are minimizing this, but I think some of them take hold and I want to get your scientific answer. So, pre-industrial CO2 parts per million were near the lowest of the last... Ever, really.

Peter Brannen (01:03:35):

It's about as low as it's ever been.

Nate Hagens (01:03:37):

About as low as it's ever been. 280 million parts per million. Now we're 425, 430. So, if you think about that, we've gone effectively from three parts per 10,000 to four parts per 10,000. Big deal. And there are graphics showing little grains of sand, and the white one is the CO2 and we added one per 10,000. How do you explain that that actually is a big deal?

Peter Brannen (01:04:15):

Well, this was starting to mature as a science in the 19th century when we discovered that CO2 is a powerful greenhouse gas. And you even have people like Svante Arrhenius, this Swedish chemist or physicist who made this calculation in 1896 that if you double CO2, it'll get about four degrees warmer. Which is still roughly in line with our best supercomputers. So, the physics of the spectroscopic-

Nate Hagens (01:04:44):

But the...

Peter Brannen (01:04:44):

Yeah, sorry.

Nate Hagens (01:04:48):

But why? A doubling of a tiny, tiny thing, is it that potent in how it absorbs infrared radiation and keeps the thermal blanket on Earth?

Peter Brannen (01:05:03):

Yeah, it is that important. An irony is, (and it makes sense once you know Earth history), that this is about as low as CO2 has ever been. It got down to about 180 during the peak of the last ice ages, and then about 280 as we came out of the ice ages, and now we're up to 420. But we have pretty good proxies for what CO2 was in the geological past, and the last time it was at the level it is today was the Pliocene when the North Shore of Arctic Canada looked like Michigan, basically. And last time it was a thousand parts per million, there were alligators at the North Pole, and sand tiger sharks in Alaska, and palm trees in Alaska.

(01:05:52):

And we know that water vapor is the most powerful greenhouse gas in the atmosphere, but water vapor isn't the primary knob. It responds to the level of CO2, and the reason is because CO2 takes so long to come out of the atmosphere. It warms the planet up, and then the feedback is you get all this water vapor, which is a really potent greenhouse gas. But until you get that CO2 out of the air again, the temperature of the planet isn't going to come down, whereas water vapor cycles through the system very quickly. So, it's sort of unusual in that respect, and one of the reasons why people describe it as the principle knob governing the Earth's temperature. I don't know if I answered your question, but...

Nate Hagens (01:06:35):

To answer my question would take the full interview, but people who minimize these risks of human-caused global heating frequently point out that CO2 levels and temperatures were higher to much higher in our geological past without threatening life. So, how do you explain that?

Peter Brannen (01:06:56):

Well, I've never really understood this objection. Because they'll say things like what I just said, which is, "Well, 50 million years ago, CO_2 was high, and life was perfectly happy with alligators at the North Pole." I'm like, "How is that relevant?" Imagine if we jumped from our world partitioned by borders and national creeds and language and global trade, and within a few centuries you're in an alligator at the North Pole world. It's true that that was the case 50 million years ago, but that would be unfathomably destructive for us.

(01:07:33):

And again, it's this thing about the rate of change. The early Eocene, when that was true, you're coming out of the greenhouse, the dinosaurs, and the planet had been pretty warm for a pretty long period of time. And then there's this slow descent over the last 60 million years or so where CO_2 has been declining, and we're suddenly past this threshold where we're in these glacial-interglacial cycles. Which is the world that we evolved on. We did not evolve on the Cretaceous hot-house of the dinosaurs. We're an ice age animal, so we're really not evolved for that older world, when it's true that life was very happy, but that's just not our planet.

Nate Hagens (01:08:12):

Well, putting on my Fred Willard Best in Show questioning hat, would humans even be able to live at the CO_2 levels of the late Triassic or the early Jurassic? Not 8 billion humans, but would humans have been able to live and thrive?

Peter Brannen (01:08:28):

The early Triassic is probably about as hot as it's ever been. I think things cooled down over the course of the Triassic, but then they get super hot again in the next mass extinction. But no, I think in the warm periods in Earth history, it would've been intensely unpleasant. Because also, we have a sort of climate niche, and with each degree (℃) of temperature rise, the atmosphere can hold 7% more water vapor. So, just imagine the most brutal New Orleans summer day, and then make that even worse, and that's sort of the regular state of affairs.

Nate Hagens (01:09:10):

So, every one degree (℃), the humidity on average is going to go up 7%? The water content in the air?

Peter Brannen (01:09:19):

The atmosphere can hold 7% more water just because it's expanded. So, that's why you can have such more powerful storms when it warms up. You just have more energy and more water in the system moving through it faster.

Nate Hagens (01:09:33):

I've asked a few people on the show about the Wet Bulb temperatures, so you don't really need to define that. But how worried are you about the combination of more humidity and higher temps on human health, especially in places that don't have access to air conditioning?

Peter Brannen (01:09:52):

I think it's hugely worrying, and we're starting to realize that the thresholds are actually much lower. Because a lot of these things are theoretical, and when you read about how the Wet Bulb temperature is actually defined, you're imagining someone sitting in the dark, naked, doused in water with gale force winds on them, and that's not the situation. That is where the thermal tolerance comes in. It's what level where even that doesn't cool you off. That's the Wet Bulb threshold. But in the real world, these effects will kick in much sooner because people are working, people are outside.

(01:10:28):

I think a paper came out recently saying that even with two degrees of warming, we're going to start passing these thresholds in pretty significant parts of the world. From a geologic perspective, you also see physiological adaptations to warming. So, you have these transient warming events like this one I've sort of offhandedly mentioned a few times, 56 million years ago where in the interval of the warming, (which, it takes about 200,000 years for this thing to play out), horses get smaller briefly, and then they get back to their normal size, because it's easier to dissipate heat if you're a smaller animal.

(01:11:07):

So, if we make the planet really warm for 200,000 years, there probably will be a fossil record of animals adapting to that. In fact, I think fish are getting smaller as well.

Nate Hagens (01:11:19):

So, it's possible we will re-evolve back into Homo floresiensis, the hobbit man?

Peter Brannen (01:11:27):

Yeah.

Nate Hagens (01:11:28):

We can't imagine. We're doing a planetary experiment here in deep time, in real time. It's great you and I can be in a climate-controlled environment with effectively Zoom cameras and lights and do this, but it's really fricking profound the time that we are alive.

Peter Brannen (01:11:54):

Yeah. I think I'm sort of motivated in part in my work to show people that climate change is almost like this cosmically important issue. It's not just the acid rain, it's not methylmercury. It really is this thing that's geologically pretty profound, and we don't know what's going to happen. But we do know that when you go down these roads that things can go pretty wrong.

Nate Hagens (01:12:25):

Some people talk about conceptually the Venus- ification of Earth. Can you briefly say what the CO2 situation is on Venus, and how we know that, and is that relevant at all to Earth's future?

Peter Brannen (01:12:43):

I don't think it's relevant. I think we're actually too far away from the sun to cause a runaway greenhouse effect. I'm pretty sure that's true. But the atmosphere of Venus is... So, we're 0.04% CO2, I think, and the atmosphere of Venus I think is like 99.5% CO2, and it's also way more of just a crushing atmosphere, and it's hot enough to melt lead, and... So, we don't have to worry about that.

Nate Hagens (01:13:12):

Excellent.

Peter Brannen (01:13:13):

But there's a long way between now and Venus where it can get pretty unpleasant.

Nate Hagens (01:13:17):

Well, on the way, this is another Peter Ward thing, on the Earth clock of life we have around what, 500 million years left before the sun expands and the oceans boil and all that? Right? But 500 million years is a lot.

Peter Brannen (01:13:38):

Potentially. I think that's still kind of an open-ended question, exactly how long of a lifespan we have that the Earth is habitable to complex multicellular animals. There was a study last week about how in the next supercontinent, which is 250 million years from now, it's mostly going to be an uninhabitable wasteland. So, it's very far in the future, but...

Nate Hagens (01:14:04):

Wait, why is that going to happen, the next supercontinent? Just because of all the tectonic shifts that happen on very small timescales are going to aggregate into some new Pangaea called "Brannen"?

Peter Brannen (01:14:17):

Yeah, yeah. I think it's called Pangaea Ultima, is the name they've given it.

Nate Hagens (01:14:21):

Oh, really? Oh, okay.

Peter Brannen (01:14:21):

Yeah. There's this thing called the Wilson Supercontinent cycle, which we've had a few of these things. You had Pangaea, and then before then the continents are sort of disparate. But before then you have this thing called Rodinia, which is another supercontinent, and we've been breaking apart for around 180, 200 million years ever since. New Jersey and Morocco used to be contiguous and they've been pulling apart since then.

(01:14:48):

But it's projected that in another 250 million years we're going to be in another one of these situations. And what we know about from Earth history is supercontinents are not very pleasant places to be. Things usually go wrong for all sorts of interesting reasons.

Nate Hagens (01:15:04):

Well, 250-

Peter Brannen (01:15:05):

The sun will also be brighter.

Nate Hagens (01:15:06):

Sorry?

Peter Brannen (01:15:07):

I said the sun will also be significantly brighter than it is today. It'll be a pretty unpleasant place. So, I think we need to get through the next few decades and centuries before we have to worry about that.

Nate Hagens (01:15:18):

Yes, let's focus on that. Let's focus on that. Speaking of that, there are other cycles in addition to CO2 pulses. The sun also affects our climate, obviously. As another debunking or another point that's commonly out there, that it's the sun that is responsible for our climate and not cattle or Volvos, could you describe the interplay between solar forcing and CO2 forcing over the last several hundred million years?

Peter Brannen (01:15:58):

Well, you have these very regular solar cycles every I think 11 years or so. But over a cosmological timescale, the sun in the course of being a main sequence star is fusing hydrogen and helium and increasingly getting brighter over time. So, about over the past 250 million years or so I think it's gotten something like 10% brighter. Some people have said that this actually has over time sped up the hydrologic cycle, and increased rock weathering, and actually is responsible for this sort of secular decline of CO2. Where from hundreds of millions of years ago to today, actually the sun's getting bright, and to offset it, CO2 has been going down, which is an interesting idea. But there was a wild paper a few years ago saying that because the sun has slowly brightened over the past few hundred million years, that if we actually did push CO2 up to an end-Permian level, it would be worse because we're also dealing with a brighter sun. So, we actually could do something totally unprecedented, which is a little frightening.

(01:17:13):

I think the ice ages are complicated to talk about, because they are sort of paced by these astronomical things like the tilt of the Earth, and the eccentricity of its orbit, and the obliquity. So, there are all these things the planet is doing around the sun that changes the distribution of sunlight on its surface that when certain latitudes are favorable to the development of ice sheets, (which can account for sort of the rhythm of the ice ages), but to go in and out of the ice ages the last two and a half million years, it's also these CO2 feedbacks that happen that you can't explain why the planet warmed and cooled without these CO2 feedbacks included. But there have always been these-

Peter Brannen (01:18:03):

These CO_2 feedbacks included, but there have always been these orbital mechanics going on. It's just that CO_2 and Earth's past has been high enough that it isn't really relevant to ice sheets. So, if you go to the Triassic, Newark Basin outside of New York City, you can see these Rift Valley lakes from where Pangaea was pulling apart. And you will see the lake level rhythmically change sort of over the same timescale that we have had ice ages. And it's because these, what are known as Milankovitch cycles, which is the way the Earth's orbit interacts with the sun to sort of rhythmically change, but you see the lakes get deeper and then you see sort of mud and then you see this deep layers and mud. And so, these things have always been there and you can't explain the broader changes without CO_2. The Earth is complicated.

Nate Hagens (01:19:00):

Yeah. Well, its complexity is one of the reasons that we're not doing anything about it. The other reason is we're addicted to our current consumption and comfort and convenience and status. But complexity is a huge challenge on all these things. The whole human ecosystem and the meta crisis. Every topic is complex and then when you integrate them, there's an even a bigger level of complexity. I will say this though, while you're speaking, I do think we need more of the following integration. We need the science and then we need a science journalist like you to amass everything and then there needs to be a podcast or a communication vector. You need all three of those things because any one of those areas is not sufficient to get the complexity out to people to integrate in their understanding of our world.

Peter Brannen (01:19:56):

Yeah. No, and I'm struggling to explain some of these concepts just because I know them and they come naturally to me, but I forget what it took to build up to that point. And you can pull out little cherry-pick things here and there in Earth history, but unless you understand the broader context like the role of the sun or yeah.

Nate Hagens (01:20:20):

Well, I will say this, that you are a brilliant and captivating and poetic author. The Ends of the World is an excellent book. Could you briefly opine on what the difference is between the end of the world and the end of civilization or even the end of civilization as we come to understand it now?

Peter Brannen (01:20:44):

Yeah, so I think when I tell people I wrote a book about mass extinctions, and that is sort of a defined term in paleontology, but sort of more colloquially people just think I'm talking about the collapse of civilization. And it might be that civilization is more brittle than the biosphere. You might not need a proper mass extinction to bring down global industrial civilization. You just need one of these run-of-the-mill sort of climate events that happens once every few tens of millions of years rather than one of these apocalyptic things that happens once every a hundred million years or so.

(01:21:24):

So, I don't know whether two or three degrees of warming is dramatically devastating to the current global network society we have. It is a complex non-linear system that we don't fully understand, in the same way, we don't really understand the food webs that collapsed in some of these mass extinctions, or it could be that you really need to destroy the world to bring humans down. I do think humans are probably not going extinct anytime soon. We're incredibly adaptable and we made it through crazy swings in the ice ages. But what we have come to know as modern industrial civilization, maybe that disappears much sooner than humans do, so.

Nate Hagens (01:22:18):

Well, and it could disappear much sooner even without any of the CO_2 impacts that you're discussing.

Peter Brannen (01:22:25):

Right, right.

Nate Hagens (01:22:27):

If you follow my podcast, so from a perspective of another carbon pulse on planet Earth, this one caused by Volvos and Volkswagens and vacations as opposed to volcanoes. You as a science journalist that understands Earth's past, what do we need to do and how?

Peter Brannen (01:22:59):

Up until now I've mostly been sort of writing descriptively and avoiding the prescriptive stuff, but I'm increasingly-

Nate Hagens (01:23:07):

I understand that. I understand that completely.

Peter Brannen (01:23:10):

But I'm increasingly realizing, and I think this is sort of one of the thrusts of my next book, is that human society is now a component of the carbon cycle and it really is impossible to extricate politics and economics from planetary science. So, we need to negotiate a way of living on this planet that is in within the proper context of our role in the carbon cycle and not one that sort of drives it as far out of equilibrium as possible, as fast as possible, because we know where that leads. So, I don't know specifically, I mean, I have trouble making heads or tails out of policy. I just know that we live in a very exciting time because something has to change. A real eye-opening paper for me was actually one of your former guests, Tom Murphy, where he just does this back of the napkin calculation that if you even have the most conservative relationship between energy and economic growth, and of course there is one, because we can't just hand things back and forth to each other forever and see the economy go up forever.

(01:24:29):

If you have this very conservative relationship between energy and the growth of the economy within 400 years, the oceans are boiling away just from the waste heat of the economy. And within a thousand years it's more energy than the sun puts off in all directions. So, 400 years, obviously that's never going to become a problem because we're not going to make that much waste heat, but something is going to change and 400 years, not even geologically, but in human history is not that long. So, whatever comes next is going to look dramatically different. And I don't know what it is, but it's exciting to be alive at a time where we get to sort of chart out that future, however scary and terrifying that prospect is. So, I'm not answering your question intentionally because I am not smart enough to work on the policy stuff.

Nate Hagens (01:25:21):

Well, or you're too smart and wise that you know your role is to paint the picture and as soon as you go into prescriptions, your audience is much smaller. So, I get it. Let me ask you this though, this you can give me your personal opinion. You've listened to this podcast, you've done a ton of research on the current unfolding CO_2 pulse. You're aware of some of the complexities and the fact that probably RCP 8.5 and the other RCPs are maybe energy blind and they assume that all this stuff will be extracted because the molecules exist. But if you had to describe the distribution in your mind of the carbon pulse, what's the midpoint of your distribution of eventual temperature increase on Earth? You mentioned two to three degrees a Celsius from pre-industrial times earlier. Do you have an opinion or are you just unsure?

Peter Brannen (01:26:34):

I am totally unsure and it's because I'm also completely skeptical of, you'll see these a lot online passed around of these charts to 2100 about our CO_2 emissions or our energy use, and I've seen very reputable versions of those graphs that are literally outside the range of uncertainty within their first year, and these go to 2100. So, I think the future is way more open-ended and the range of possibility is way kind of scarier and broader than most people think. I mean, maybe I don't don't know what I'm talking about, but I do think there also as you do, the link between energy and the economy is I think an under theorized sort of area.

(01:27:25):

And I think the coming out of the pandemic was sort of a helpful exercise for humanity because it reminded us that the economy isn't just charts on a graph and price discovery and things. It's a physical material world. It's flows of energy and it's a material. And if a supply chain can't get a thing from this part of the world to that part of the world, or you can't ramp up energy production fast enough, then you see this shock in the global economy. And there are people working on that that are making our understanding of the economy a much more physical thing. But I think that's sort of the cutting edge and something that we're really going to have to figure out if we're going to figure anything out.

Nate Hagens (01:28:10):

One of my deepest hopes is that your very distant descendant, the Peter Jr. to the eighth power a hundred thousand years from now, if he or she exists, seeing a layer of nuclear residue in the geological record of the future because I think that is the most direct path to the next mass extinction. And I'm really hopeful that we can avoid that.

Peter Brannen (01:28:48):

Yeah, I mean the thing that really keeps me up at night is the unknown response of the carbon cycle itself. So, there's this tendency to think that it's only going to get us hot as we let it basically. And I think that is generally the output that you get from a lot of models. But I know people who study geoscientists, who study events deep in Earth's past who actually attribute a lot of the chaos to pushing the carbon cycle out of bounds enough that then it kind of goes on a bizarre trajectory. And I think the more we push on the system, the more chance that there is of something sort of unpredictable like that happening.

Nate Hagens (01:29:28):

I'm sure you've seen the data the last few months, Peter, this is being recorded on October. Are we in a phase shift right now with the reduction in ice, the global temperature, the storms, the floods, or is this just El Nino linked and we're going to mean revert?

Peter Brannen (01:29:47):

I've tried to navigate the conversation among atmospheric physicists, and it seems like there's some debate about that exact question, and I'm not equipped to come down with the judgment, but it could be either. The fact that it's a possibility that we could be entering a new regime is certainly frightening, but I think it's possible that this is just El Nino and the natural climate variability in the same way that the so-called warming pause was natural variability that people sort of pointed to as indication that warming had slowed down.

(01:30:28):

There's a lot of noise in the system and it's extracting the signal out of it that's difficult. But yeah, I mean there was an op in the New York Times by a atmospheric scientists the other week asking whether global warming was accelerating. I saw people debating that online, but it's definitely frightening that I've heard people say, "Oh, it's all happening much faster than we thought," and that's not true at all. James Hansen's testimony was 35 years ago, or 25 years ago, so 35 years ago. So, it's right on schedule. What I worry about is that that sort of linear trajectory gets a little steeper, so hopefully that doesn't happen.

Nate Hagens (01:31:10):

So, given that I know a lot and care a lot about this topic, I could keep you for three or four hours, but I want to be respectful of your time. If you have a few more minutes, I'd like to ask you some personal questions that I like to ask all my guests. So, you're a science journalist, used to live in Boulder, now in DC writing another book. You obviously think about living through the CO_2 pulse and you're aware of energy, the economy, geopolitics as an observer of these systems. Do you have any personal advice to the viewers of this show at this time of what some call the meta crisis?

Peter Brannen (01:31:54):

I think it's figuring out what you lever. You can push what your contribution is. There's a risk in just sort of being saturated by the news or refreshing your social media feed and just feeling overwhelmed, but figuring out what the pressure point is that you can contribute to, whether it's answering these fundamental science questions or organizing if that's more of your skill. And if you give yourself a concrete goal, you can feel a little less helpless in the face of this stuff for, I mean, I think especially with social media and of this just terribly addictive, constant feed of dreadful news from all over the world, disengaging not in a sort of apathetic way, but trying to step back from the news. I mean, that's one of the great gifts of Earth science and geology is I'm able to think on longer time scales than just who's the next speaker of the house going to be? Because if you're constantly reacting and you're not doing any strategizing or organizing or difficult work, then you're not going to have the most adaptive response to... This is all very vague, but-

Nate Hagens (01:33:23):

No, it's good advice to your podcast host as well because we are, I mean, everything is unfolding. It's not just climate, it's geopolitics, its interest rates are going up, it's affordability, it's inequality. I mean, it's just a tragic and beautiful and amazing time to be alive. And I think you're right that knowing that this deep time perspective, it makes it a little bit more of a story. And I don't know, it feels calming to me that we're part of this planetary evolving.

Peter Brannen (01:34:05):

I mean, there's something consoling to know that the earth will be fine in the long run. Not that matters on human time scales. It's more just what an utter shame and embarrassment it would be to get this incredible sort of cosmic gift here where the planet's been handed to us on a silver platter. We live in this miraculously habitable place and within a geological eye blank, we could completely screw it up in 10 million years. Even if we do that, there's going to be cool animals and the Earth won't even have any signs that we were ever here unless you're really combing the Earth looking for extinction boundaries where we disappeared. But yeah, we live on human time scales and we care about relationships in our lives and people we love, and unless we figure out how to live in concert with the planet's sort of cycles, then there's the chance for a lot of short-term misery in the next few centuries for human beings.

Nate Hagens (01:35:07):

Are you married? Do you have kids?

Peter Brannen (01:35:12):

I'm not. I think that would also change my perspective.

Nate Hagens (01:35:14):

Yeah. Well, I mean I don't have kids either, but I used to teach kids or 19-year-olds. What recommendations do you have for a young person listening to this program?

Peter Brannen (01:35:26):

The world that I know best, which is the research community and the academic community, it is increasingly the problems are going to be interdisciplinary and there's a lot of resistance to that in academia. People who sort of try to make grand sweeping statements about that unite several different fields are often attacked for doing so, sometimes with good reason. But that's where all the big questions are, I think. And so, if you're going into academia, and I think it's good to explore not the well-trod territory, but sort of try to unite these different fields like global geochemical cycles and human history or the global economy. It seems like that's where a lot of the exciting work is.

Nate Hagens (01:36:20):

So, this is a question that I think I'm going to start asking my guests, which is I believe that one of the largest underutilized human resources in the world is grad students and postdocs that are following the academic superorganism and the linear reductionist worldview that could be asking really relevant questions in their research to the meta crisis and kind of the things that you were just mentioning. So, in your field climate, oceans, extinctions, can you offer a few big questions that postdocs should or could be working on that need research and answers? Or is that field relatively covered in that space?

Peter Brannen (01:37:13):

You'll have these rock boundaries where the extinctions happen. You know what happens in a layer, what happened within 20,000 years, but the dynamics of how those things actually play out, we don't have a century by century sort of accounting, which is what's sort of scary about them. They're kind of black boxes where we know everything goes wrong. So, that's still very much an area that's open. How this planet became habitable, if you're interested in that, that is still very much a open question. The rise of animal life and the oxygenation of the planet, all these things that from my perspective, the more I learn about Earth, I used to be a total space nerd and dream about going to other planets. And the more I learn about this place, the more I realized just kind of how special it is and what a bizarre series of accidents there is in our geologic past to get us to this point, to have this conversation. So if your imagination is fired by these sorts of big cosmic questions, that's definitely an area to go into.

(01:38:12):

And yeah, I mean it's these interdisciplinary topics. So, I've seen conferences recently that are about how to energy and information structure society throughout human history, what is the relationship of how humans are organized and their interaction with the sort of physical and energy world around them. And if you're getting a history PhD and you propose that you could be laughed out of the room because such an abstract and bizarre topic. But I think if we really want to understand what the phenomenon of humanity on the planet really is, it's trying to bridge these worlds. If we're going to persist into geological future, we need to understand how things like society and institutions are now structuring the nature around us.

Nate Hagens (01:39:11):

Well, here's a specific one. I'm sure you're familiar with Jeff Bezos and Elon Musk's attempts to get to outer space to eventually colonize outer space, which given what you just said, we don't even know our own planet quite well enough. But you just mentioned you used to be a space nerd, but you've also studied the history of life on Earth. Do you think there's life on other planets and what's the math and the logic of your opinion?

Peter Brannen (01:39:46):

I think mean depending on how out there you want to get, if the universe is extraordinarily big and possibly infinite, which there's some reason to think it's somewhere in that ballpark, then it's a mathematical certainty that me and you are having this conversation. It's just repeating at a certain distance over and over again because there's only so many arrangement of atoms that you can have in a certain space that you're eventually going to do all the combinations and start repeating them again. So, physicists have actually, I've seen a paper where it has the exact how many meters you have to go away. It's like 10 to the 10 to the 26 meters away. There's an exact replica of you.

(01:40:24):

So, that's the super out there question or the super out there answer. But yeah, I think there's probably intelligent life out there. I would imagine given how unusual this planet is and its history, is there probably so far away that we're not really going to talk to them because I do think intelligent life is very rare, just given the number of contingent steps that took us to get here. I think life is probably a pretty general phenomenon, especially if it is this sort of channel of energy dissipation that planets is available to planets that yeah, if you have alkaline hydrothermal vents somewhere else in the universe and the chemistry is pretty similar to our early solar system, you'll get life. But getting energetic, aerobic, intelligent life is probably pretty difficult.

Nate Hagens (01:41:11):

And so, for the indeterminate future, we are left with this pale blue dot, which is where we'll make our stand to quote Carl Sagan. Thank you for your research and your time today, and I really look forward to reading your upcoming book next year. And maybe we'll have you back for a CO_2 or Extinction Round Table.

Peter Brannen (01:41:38):

Yeah, that'd be great. Thanks so much for having me. I'm a big fan of the show, and so it's an honor and pleasure to be able to talk to you today. So, thank you.

Nate Hagens (01:41:48):

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