LATE DEVONIAN EXTINCTION
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In Our Time is hosted by Melvyn Bragg. Melvyn's guests on this podcast are:

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And

Mike Benton
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[Melvyn Bragg] Hello. Some mass extinctions happen instantly, as when an asteroid hits the earth, and some can take millions of years. The late Devonian extinction was one of the slower kind, but still devastating. The Devonian had seen the first trees and soils and such a diversity of sea life that it's known as the age of fishes, some of them massive and armored. But roughly 370,000,000 years ago, around 70% of species disappeared and we're still trying to establish exactly what happened, when and why. With me to discuss the late Devonian extinction are Jessica Whiteside, Associate Professor of Geochemistry in the Department of Ocean and Earth Science at the University of Southampton, David Bond, Professor of Geology at the University of Hull, and Mike Benton, Professor of Vertebrate Paleontology at the School of Life Sciences, University of Bristol.

Mike Benton, just how different did Earth look in the Devonian period pre extinction?

[Mike Benton] I think if you'd gone back to the Devonian world and looked at it from space, it would have looked very different immediately because the layout of the continents was most unusual. Most of the continents, in fact, were in the southern hemisphere forming a supercontinent called Gondwana, and Britain or Europe as a whole and North America were joined together. There was no Atlantic Ocean and we were hovering around the equator. In fact, for some of the time we were south of the equator. And then if you had landed on that strange landmass, which is sometimes called "the old red sandstone continent", you wouldn't have seen very much on land. So one of the key points, as you mentioned, of course, is this was the time when the land seriously began to green. And we think of that perhaps as life crawling out of the ocean, plants and animals, and once they're on land, they're everywhere. But the key point is they're not, because, of course, moving out of the water was quite a dangerous thing to do, really. And the initial plants, in a sense, kept their toes in the water. And then that supercontinent of Europe and North America was pretty warm because it lay across the equator. So in many ways it would have seemed alien. And yet we look back to it importantly as a really big switch in the history of the Earth and the history of life.

[Melvyn Bragg] It's called the age of fishes. It's been called the age of fishes, Mike. What was swimming in the water?

[Mike Benton] Again, you're right, the fishes were there and they're related to modern fishes, of course, related to us, because these are all vertebrates with backbones, and yet most of them would have looked very, very strange. They were swimming in the seas which contained reefs, coral reefs. There were various other shellfish on the seabed and swimming creatures, and some of the most remarkable ones were trilobites. They're familiar to many, I suppose, they're legged creatures that looked like wood lice, but much bigger. And there were various kinds of shellfish. And the reefs were built of corals and sponges, but types that are very different from what we see today. And in fact, the name Devonian comes from Devon, based around the area of Torquay and Tinmouth where these great reefs occur, and some [of our listeners] may have visited. But it seems very unusual for us to think of those kinds of tropical phenomena in this country. And then the fishes, many of them are heavily armored. And so at first sight, they would have looked very alien to us.

[Melvyn Bragg] David,... David Bond. Before we get any further, how do we really know that there was an extinction?

[3:53]
[David Bond] Well, yes, we know that there was an extinction here and that other major boundaries in geological time by looking at the rock record, by looking at rocks and looking at the fossils that are in those rocks. And quite simply, fossils of many, many species that are found in rocks before any any extinction event, whether that's the Davonian or some of the other big mass extinctions, ...are just not found in younger layers of rock after that extinction event and they never come back. And we can go back a long time. In the late 17th and early 18th century, the the canal surveyor William Smith, wildly known as Strata Smith, the founder of modern stratigraphy, he noticed

that certain layers had characteristic fossils in them when he was surveying canals. And then he noticed that some of the younger layers had different fossils. So it was clear that something had happened to life on Earth between time A and time B. And, of course, over the last 200 years or so since Smith's time, many paleontologists and geologists have done lots and lots of geological field work. It's a wonderful job, we get to go all over the world and we collect new data. And this gives us better and better understanding of the timing and the magnitude and, of course, the causes of extinction. And then it was in the 1970s and 80s, as computers improved, that paleontologists started to put together fossil databases and this allowed paleontologists such as Jack Sepkoski and David M. Raup to tease out the timing and the magnitude of various mass extinctions. They actually coined a phrase the Big Five extinctions of the Phanerozoic, and the late Devonian was actually the second of those to occur in time. And if we looked at a rock before this mass extinction, we would have seen globally widespread, very spectacular reef ecosystems and these are bigger than anything on the planet before or since.

[Melvyn Bragg] Let's just take the phrase "mass extinction". All sorts of things were bubbling and kicking off, and volcanoes exploding, and goodness knows what, what was the distinction about an extinction?

[David Bond] Yeah. So there is no formal definition, it's something that's I tell my students. Sepkoski's definition of a mass extinction is the one I like, but there isn't actually a formal definition. You would think it would be defined as something more than 50% of species disappearing or 75%, but it isn't. But in Sepkoski's definition, some of the key things are that it has to be geographically widespread, so it couldn't just be localized to a particular region - it has to happen all over the world. It has to affect multiple higher taxons. So if we look at Linean classification, we're not just wiping out some species, but we need to wipe out families and whole orders of life. And it has to be geologically abrupt or in a short geological time. Now, that's very subjective, and we don't know whether that means 10,000 years or 10 million years. So it's a good question, there's no real formal definition, but as we tease through the databases, we see that there are these Big Five. But there are also lots of lesser "calamities", as they've been called.

[Melvyn Bragg] There are some place names that figure in this discussion. Devon, for instance?

[David Bond] As Mike mentioned, rocks of Devonian age were first described in detail around Torquay in Devon. There are also several black shale events which are associated with these extinctions. And these are widespread throughout, particularly in Central Europe. And these have lots of Central European names, such as the Kelwasser Event.

[Melvyn Bragg] Thank you. So, Jessica, that's what you've got to play with. And then what's thought to have happened at what's now called Kelwasser event, which, let's start, can we use that as a starting place for this mass extinction?

[7:25]
[Jessica Whiteside] It's a complicated, ultimate "Who'd done it?" here. We can start with the observations, now, as David just shared, there are a number of black shale

events. They punctuate the geological record of the late Devonian. They represent extinction, but there are two in particular that stand out. David described the Kelwasser. There's also the Hangenberg event that happens 13 million years later. That Kelwasser event, that David was sharing, has two black bands in the rock. So there are two black shales everywhere. That's the motif of the Kelwasser event. They're "petroliferous", that means that when you crack them open with your rock hammer, they give a stinky gasoline scent. And in fact, they're the material that's being fracked in the United States. If you see one of these black shale layers, there's a stagnating ocean. That's the symbol that is conjured in your mind, it's lacking oxygen, that means it's widespread death for the organisms that live there, they were essentially asphyxiated. Now, in terms of the geological upheaval, the upper Kelwasser is the bigger ... event....That's one of the Big Five mass extinctions that represents the changing life since the dawn of animal life on our planet. Mike and David both alluded to the big Devonian reefs. So, they go extinct at this event and they also ... vast stores of oil in Australia and Canada. But a lot of those reefs die out, they go extinct. They leave behind an edifice of carbonate. So a relic. And that relic becomes covered with cyanobacterial mass. Just like you might envision a shipwreck, a sunken shipwreck that then is covered over by microbial community. And that structure lasts and that actually carries on for millions of years. Mike also talked about some very strange fish, trilobites and conodonts - these eelike, jawless vertebrates, fish-like with razor-sharp teeth. They almost completely dissapear. Lampreys go off, most of them anyway, they stagger onwards, but they have a massive die off. So we have 70% to 80% of extinction at this Kelwasser event. But those black shales themselves imply death by anoxica, by low oxygen conditions and asphyxiation. And then 13 million years later, the extinction and the black shales happen again, but they happen differently.

[Melvyn Bragg] Must bring in Mike here. Do you think it could be called the best of times and the worst of times? Why was it so good for plants?

[Mike Benton] It was partially opportunity because various plants had crept onto land in a very minor way long before. And in fact, there's quite a debate among paleobottanists and others to determine absolutely when plants first began to green the landscape. And we know about these very early ones, and I think it's probably because the main continent, the old red sandstone continent of Europe and North America, was athwart, the equator conditions were warm, but there wasn't a great deal of food on land because it was just bare rock and without much soil. And so it's hard to say. It's probably more to do with plants in some way had reached this point in their evolution, because in coming onto land, they had to conquer a couple of things. One, of course, was if you creep away from the edge of the water a bit too much, you've got no water. And if there's no soil or not much soil, how on earth do you develop roots and how is water stored and how do you obtain it? And the other one is support, because in the water, as we know, plants can be quite large if we.. well, seaweeds are not exactly plants, but they can be huge and they float. But once you go on land, you've got to kind of stand up, because the key thing the plants need is sunlight in order to be enabled to photosynthesize. But the early plants that we know at the beginning of the Devonian, they're fantastically well known from a locality called Rhiny in the northeast of Scotland, the Rhynie chert. And chert is a silica rich material. And so these plants, which were tiny, none of them are bigger than your little fingers. So you can imagine these little things sprouting out around the edges of the water like little fingers or smaller. And they didn't really have roots. They were just connected by stems that crept into the water. So even though they were living maybe a meter away from the edge of the water, they just kept their toes in the water just to be safe. And so this is at the beginning of the Devonian. There, there were plants that were not creeping out very far, as David and Jessica mentioned, most of the landscape is rocky, but what they found was good. They were getting sunlight, they could photosynthesize. And so they presumably gradually got bigger and crept away from the water side. And as the lignin and the vessels improved, they were able to obtain carbon dioxide and water. And the story about that I can only mention briefly, but they were first discovered long ago. But a couple of paleobottanists, Kidston and Lang, studied them about 100 years ago and when they put thin sections of these very early land plants under the microscope, they were absolutely amazed because the quality of the detail, the cells ... they reported, it was just like looking at a modern plant. And in some cases, they even found little creepy crawlies, little spiders and things that had somehow crept in and eaten their way into the plant.

[Melvyn Bragg] Sorry, one of the problems about this program is that every stage it stops, you want to know more and more and more because it's so extraordinary. But I'm moving on now. David Bond, what happens to the rock when it's covered with soil? And why does that matter in this extinction story?

[David Bond] Yes, as Mike has just explained, the plants appear and they spread firstly not far from water. But by the end of the Devonian ... they're pretty much everywhere. And this is a fundamental change in the earth system. The first soils appear at this time and the plants develop roots through the Devonian. And they do this by two processes. The first is what geologists would call chemical weathering. And this is where the organic matter of those plants interacts with the rock. It will cause chemical changes and slowly break down that rock bit by bit and turn it into soil. But there's also physical weathering, which is the physical action of roots growing into that. And that itself will break up that rock and form these soils. So these are the first soils that the planet has ever seen. And so we've got a fundamental change from a barren, rocky planet with a few tiny, finger-sized plants around the edges of water bodies to this green planet with the world's first soils. Now, this features in several extinction scenarios for the late Devonian. It was the American geologists Tom Algeo and Stephen Scheckler who recognized that this was a potential driver of extinction with a couple of very important papers in the 1990s. And they came up with what seemed, and still seems, a very neat theory that explains how the evolution of plants on land could have driven the extinctions in the ocean. We tend to think of plants as really good, and they are really good for the planet of course. But at this point in time, they may not have been as good as we might have thought. So soil is full of nutrients, including things like nitrogen and phosphorus, and these are some of life's macronutrients. So these are needed in fairly substantial quantities for life to exist. And suddenly you have a planet which hadn't had any soil previously, that's now got loads of soil, and the rivers wash this soil from ... the mountains, ultimately into the oceans, and they're picking up whatever they pass on the way. So they're picking up lots of this soil, fertilizing the oceans with those nutrients. And then what this does is if we suddenly have an excess of nutrients, we create blooms of things like algae that then consume that oxygen, and then ultimately they can starve the seawater of that oxygen, which is the term for this, is anoxia, which seems to be the main driver of the extinction here.

[Melvyn Bragg] Jessica, can you tell us what happens to all the carbon that's been in the air in which the plants have used? Why does that matter?

[Jessica Whiteside] Sure. So in addition to stripping out the oxygen from shallow seas, as David described, these killer trees, these archaeopteris that form the first forest, over a 50 million year interval, they're spreading and they're contributing to that accelerated soil formation, which is resulting in accelerated silicate weathering, as David is sharing. And what that does is that this process removes carbon dioxide from the atmosphere and it creates calcium and magnesium carbonates. The point of that is that that actually stores two moles of carbon dioxide for every 1 mol of carbon dioxide that's released back in the carbon cycle through other processes. So what happens is that as the plants are photosynthesizing, it's not just the above ground, it's that below ground soil conspiracy that is breaking down rock, making it a soil, and then releasing for the first time those critical nutrients and material back into the ocean, which is actually storing it. Now, when that material goes into the ocean and seeds fertilize the top of the ocean for life, where you have these massive algal blooms. Those algal blooms themselves are storing carbon dioxide as well through photosynthesis. Just like in the modern world, it's thought that phytoplankton buffers the oceans by about 30% by storing carbon in the top of the water column for some time before it goes through its degradation, the breaking up decomposition process by bacteria. And so it's thought that that loss of the greenhouse gas contributes to global cooling. So you then have a short but intense episode of glaciation occurring at the variant of the Devonian in parts of Gondwanaland, the southern hemisphere, and it's possibly associated with the Hangenberg extinctions at the end of the Devonian.

[Melvyn Bragg] Right, right, right... Mike, Mike Benton, can we look at some of the life forms navigating this climate over millions of years? Of fish that come onto land, for example, how do they manage that?

[17:36]
[Mike Benton] There were big stages in the evolution of various groups during the Devonian. Fishes were becoming tetrapods. So we care about that because we are tetrapods. Four footed, well two footed, but all the four legged vertebrates. And the story there is known in quite a lot of detail. We now have many stages between fish and tetrapod. And of course, in making that transition, a fin has to become a leg. But lots of other things go on. But we do know excellent fossils from Greenland, which at that time, recall, was close to the equator - it was actually part of that old red sandstone continent. And there are fish like and tetrapod like things afterwards. And you can see that there was a group of fishes of which today the lungfish and the coelacanths are examples, which have lube fins. So unlike the fins of a fish, like a cod or a goldfish, where there's no muscles within the fin, lungfishes and coelacanths have got muscles within the fin. Their ancestors did too. These became the arms and legs of tetrapods. So they were staggering out of the water.

[Melvyn Bragg] Why were they doing that?

[Mike Benton] Well, of course, the land was covered with plants. They were gradually expanding. Towards the end of the Devonian, we got even big forests. We've mentioned briefly, and there's a fantastic example in New York, the Gilboa Forest, where there were trees that maybe were a meter in diameter and maybe 6-7 meters tall. And so these early tetrapods were just coming on to land. Not in great numbers, though. And again, it's a little bit like the the appearance of the plants on land. You would think this would have happened once they crept out. This would have been a very rapid spread, but it was kind of cautious. They just sort of put their toes on land. "Is this all right? Let's step back into the water."" But they were there. They were kind of ready for the next step after the extinction event.

[Melvyn Bragg] David, David Bond how quickly did this extinction start to set in?

[David Bond] There are these multiple anoxic black shale events through the period and each of them is quite discreet. And, as Jessica has mentioned, the two larger extinctions are those associated with the Kelwasser event and the Hangenberg event at the end of the Devonian period itself. And these are separated by about 30 million years. But I view these as two completely discrete and separate events that had different impacts on the fauna and the flora and they're separate extinctions. So I would argue that the big one, the Kelwasser Horizon or the Kelwasser Event, is actually quite a rapid and abrupt event. Others have different interpretations of that and it's actually very difficult, once you go ... this far back in time, to 372,000,000 years, to say how abrupt an extinction was because it's so hard to ...

[Melvyn Bragg] What does abrupt mean to people like you?

[David Bond] Well, yes, I would say anything less than half a million years or a few hundred thousand years is quite abrupt. But it's so hard to date rocks of this age that really we don't have a great understanding of whether this was tens of thousands of years or hundreds of thousands of years.

[Melvyn Bragg] And you're saying that's when it starts to set in - the Kelwasser.

[20:48]
[David Bond] Yes. And this is going back to the point I was making about the plants driving these extinctions. This is where a little chink in the armor of that scenario creeps in because I would argue that the Kelwasser Extinction, the late Devonian or the Famennian for many (it has multiple names, which makes it confusing) is quite abrupt, whereas the evolution and the spread of land plants is quite slow. It takes some time. So we have an issue here of timing. And could the sort of slow march of plants across the land actually drive what was really quite an abrupt extinction or several quite abrupt but discrete extinction events?

[Melvyn Bragg] Jessica, can we come to you about the other major blow that has a name, the Hangenberg? What caused that?

[21:30]
[Jessica Whiteside] The Hangenberg is very interesting. This is towards the end of the Devonian and the Hangenberg and the Devonian-Carboniferous boundary. Both are the final catastrophes - they emphatically end the period. And it's a story of ice and fire, so an icy and fiery climax for those two. There's been some very interesting recent evidence that indicates that this terrestrial extinction - so this is when you have the dead clade [waking] of the Archaeopteris forest going extinct and also the demise of the placoderms - ...armored fish the size of double-deckered buses. But let's just talk

about the terrestrial extinction because that's where we have the best data. For the terrestrial extinction, it's apparently potentially caused by a dramatic drop in stratospheric ozone, maybe due to increased global temperatures or even a cosmic intervention from a nearby supernova explosion or even explosions that delivered some accelerating cosmic rays with ionizing radiation for up to about 100,000 years. So the facts that we have here, there's a catastrophic thinning of the ozone potential, exposure to UV radiation, and it's based on the observation of mutations in the formation or ornamentation of spores. So the reproductive bits of plants from Hangenberg age lakes in Greenland - they look as if they got a sun tan. They look mutated, sometimes they have double features, like the rare instance when you have a double strawberry in your packet. And it's actually something that's been in the literature since the 1920s. There was a paper in the American Naturalist by Harry Marshall on ultraviolet and extinction. These spores show these changes and it's similar to what people have seen when they play around with UV light where they can actually see pollen and spores getting what looks like a sun tan. So they'll turn on the light. The forms aren't properly forming and it's because there's damage at the level of cells and DNA. So the reproductive material has defects. And when that DNA is trying to make its little wall, it's not making it properly. But all you really need is to get a hot summer. If you have a hot summer, then you have increased transport of water vapor and storms into the upper atmosphere. Water vapor carries with it naturally occurring compounds and that destroys the ozone layer. And there are various chemicals that are produced by plants and algae and fungi. These are things like methyl chloride and methyl bromide. When they get up in the upper atmosphere, they start to get energy from the sun and that dissociates and that gives free-radical chlorine and an oxygen. And that oxygen then zips around, knocking the third oxygen off an ozone molecule and turning it back into normal oxygen. And since that ozone layer is the shield that protects the Earth's surface from the Sun's UV damage to that layer, it leads to an increase in the UV that's reaching the ground. And the evidence for that increase is in the temperature records. And then another group independently has done some work to look for a supernova. So there are multiple ways that one could get the malformations in these spores, and one of them is from the heat and the high temperatures themselves, and another is from having a supernova or an exploding star. And that would give a cosmic ray burst that would strip the ozone layer and lead to ultraviolet radiation coming in, which is lethal to life.

[Melvyn Bragg] Thank you. Mike Benton, can you give us a bit of a scan over this? What life forms were being lost from our planet in this extinction and whereabouts?

[Mike Benton] Yes. So the events were worldwide. And I think we can look briefly, I guess, at reefs and fishes and land. And we've already mentioned a few of these aspects. So the loss of the reefs, I think, must have been astonishing because, as David mentioned, they were truly huge and they were important sources of biodiversity. So just as today, tropical reefs are where we find many, many species, many more than in other kinds of habitats. So to remove the reefs, that must have been pretty devastating because there are all sorts of other creatures that depended upon them. So many of the trilobites and brachiopods and various other creatures disappeared and it does appear to have been worldwide. So from the equator to the poles, the fishes massively changed. We've mentioned a few, but I haven't entirely painted a complete picture of what was there. But the key ones that were lost were the armored fishes. And it was such a pity because there are such weird otherworldly looking creatures. The ostrachoderms were jawless fishes that were heavily armored and they would have crept around like sort of little self-moving hoovers on the seabed, slurping up the mud. They were jawless, but they were massively covered in armor because they were preyed upon by some, possibly some other armored fishes, the placoderms. And Jessica mentioned, one of them as big as a bus. And that's hard to imagine. This enormous creature that was maybe six or 7 meters in length, jaws would gap a meter and a bite force of 6000 Newtons. So just the same as the great white shark. ... And yet it was covered. It had a very bony head shield that protected the entire front half of the fish. This is a creature called Dunkleosteus, and if you've never heard of it, it's worth thinking about and imagining what on earth that could do. But it could clearly crunch through all the other fish of its day. Sadly, they all went, and that's it. And the modern types of fish groups appeared and then on land, finally, Jessica mentioned that all those forest trees and various other Devonian plant types seem to have disappeared. And again, [we don't know] exactly why, but it may be connected with some of these atmospheric changes, temperature changes that were going on.

[Melvyn Bragg] Thank you. David, David Bond, where do you look in the rock formations for evidence of what happened and how easy is it to find evidence?

[27:34]
[David Bond] Yes. Just before I come to, I just like to follow on from Mike's point about Dunkleosteus. If you're ever lucky enough to find yourself in Vienna, there's a fantastic skull in the Natural History Museum in Vienna and you really get an amazing feel for the size of those beasts. It's wonderful. When looking for evidence of extinctions, particularly for the Devonian and the early extinctions, one of the key challenges when trying to understand what was going on is simply to find rocks of that age. And the further you go back in geological time, the less rock remains from that time because the Earth has tectonic plates that are always moving around and this means that one plate will subduct. That means it just gets driven down into the interior of the Earth. So one plate will subduct beneath another over time and then it gets pushed down into the earth, it melts and eventually becomes igneous rock and eventually will form new crust. So this is the rock cycle which is fundamental to life on Earth but it also means it can be quite hard to find rocks of great age. Once we do find rocks of late Devonian age, we apply a number of techniques because we're trying to not only work out what the extinction meant for life, so to do that, as I mentioned earlier, we look at the fossils and build up a story of what became extinct. But we also apply a range of largely geochemical proxies. So this is where we might grind up a piece of rock and shove it into a machine - a mass spectrometer will be a key tool where we actually extract chemical information from that rock to piece together what past environments were like. So oxygen isotopes, for instance, Jessica mentioned evidence for glaciation at the end of the Devonian, and we have oxygen isotope studies from rocks through the Devonian that tell us that there was much warming and much cooling, which may well have stressed life out throughout the Devonian. And one of the really novel techniques that we're using now to try and get to the bottom of this extinction event is looking at the mercury content of ancient sediments or rocks. And this is a proxy now for volcanic activity and we see now that there are spikes in the mercury record from the late Devonian as far afield as Morocco and Siberia and China. So we think this is real evidence now that this extinction, like the other big mass extinctions, may well have been driven by huge volcanic eruptions.

[Melvyn Bragg] Thank you very much. Jessica, is there any other evidence that hasn't been brought to the argument?

[Jessica Whiteside] Yes, well, just to follow up from David about the volcanism, there are these mercury signatures, and they are linked to the Kelwesser event. So the large example of late Devonian volcanism is the village traps, and they were humungous. And it's kind of like the Russian doll concept of dolls within dolls within dolls. There are massive eruptions, too. And within each of those, there are multiple pulses within that that would spew out enough cooled lava material that actually equates to something like 1700 Mount Everests. So that's a perennial favorite in terms of mass extinction events. It's linking them to these massive volcanism, these large igneous provinces, but there are other cosmas causes as well. One in particular is sometimes people look to the skies, so for cosmic intervention, celestial causes and with that, there are things to look for in terms of trying to decipher if asteroids or commentary impacts are important. And it turns out, so the famous mass extinction associated with an asteroid impact is the one that kills the non-flying dinosaurs at the Cretaceous-Paleogene [boundary]. But the first time that it was actually brought up as evidence for an extinction was for the Devonian. Unfortunately, it was ten years too early and there wasn't much evidence. But there are tantalizing pieces related to this. One is that scientists are interested in finding iridium. That's a platinum group element. It's relatively common in asteroids and comets, but exceedingly rare in the Earth's crust. And it falls out all over the globe, so you can imagine dust falling out from the atmosphere, so it should be in every single site if an asteroid were to hit. Another thing that people look for is looking for shocked quartz. So there's a type of quartz where all the fractures have been activated by short-lived intense pressure, shocking it. And it's only known from sites like known asteroid impacts like Meteor Crater in Arizona, or high pressure experiments in the lab, or even nuclear test sites. It's never been seen in any volcanic eruption anywhere on the planet. There have been some reports of the shocked quartz, but it turns out there's always been a little bit "win some, lose some" with those. And it's ended up - one was from the Alamo Brettcha - that's an exposed site along Nevada State Route 375, which is actually Nevada's Extraterrestrial Highway because of UFO sightings. And it's just north of the Forbidden Area 51, where the US Department of Defense conducts secret tests, but that's a little bit too young to actually be associated with the Kelwasser event and extinctions. There's also been reports of little glass sphereals raining down, and it turns out that was another piece of evidence that couldn't be accurately verified and actually ended up being little artificial glass sphereals. They looked like globs of glass, but they were actually coming from cars that were eroding white stripes on roads, so that fluorescent white line in the middle of the road, and they can all get into the tiny cracks and rocks. So what superficially looked alike melted glass sphereals known from the Cretaceous paleogene mass extinction weren't actually that.

[Melvyn Bragg] Mike, Mike Benton, with all the shifting of tectonic plates, what part did tectonic plates play in this? And have we said enough about volcanic activity?

[Mike Benton] I think that's hard to say. I don't think people look at tectonic movements directly as a cause of this. It was once a way that geologists would try to explain important moves in the history of life. They would look at the breaking apart and amalgamation of continents and the opening of seaways and so on. But I think those sort of processes are rather slow moving and the events we're looking at here are quite sudden, and there wasn't so much going on between the Devonian and the Carboniferous, which was the period that followed. And so I think what carried on after the events were the glaciation at the South Pole, which Jessica mentioned, that carried on into the Carboniferous and some of the volcanic activity continued. There were some further eruptions in different parts of the world, but whether they got to the scale that they could have global effects... we know that volcanic eruptions always kill life, but the scaling of those is very important because it's often just local. The level of volcanism has to be absolutely vast before it can have these kind of earthwide processes.

[Jessica Whiteside] I think to some extent there's a universality of vulcanism and extinction, but I think the closer we look at these patterns, I think we'll see that the system usually is already primed for something to happen, a tipping point to happen. So I think that there is mounting evidence for vulcanism for the Kelwasser event, but I don't think that it explains the pattern or the empirical evidence that exists for the Hangenberg event, which seems much more to be something that's a culmination of waxing and waning of ice sheets. Ice hadn't gotten so close to the equator since snowball Earth time - so a massive cooling - and then a huge extreme just within a 300,000 year interval, you have massive cooling and massive warming. And I think there's something about that particular extreme in the climate system that primes it for it going over the top with, say, something like maybe a supernova or some other event. There's very little evidence to point to for a volcanic event at that extinction. There's some mercury, but that's a developing proxy and there's not mercury from everywhere. One of the beauties of the mercury proxy was that it was something that you would see from far afield of a volcanic province, and from some of the margin areas there's very low rates there. It's also normalized to their organic matters. You have to have a few other things present. And so I think the jury is still out on that Hangenberg event.

[Mike Benton] Yeah, that's interesting because, of course, where we've seen volcanism in the Permian and Triassic perhaps, there was no ice cap because there were no continents at the poles. But nonetheless, something was carrying on into the very beginning of the Carboniferous period that followed the Devonian, because life didn't bounce back immediately. And therefore there's some debate about how long it took for life to recover but certainly some of the rather grim conditions that Jessica described at the very end of the Devonian, they probably carried on into the Carboniferous for a certain amount of time.

[Melvyn Bragg] ...There's some people who say that there wasn't really a proper extinction at all. What do you think about that?

[Mike Benton] Yes, that's right. I've sort-of lived through this, but up to a point, many people denied an extinction, particularly amongst plants and vertebrates. I think it's always been crystal clear in the marine sediment. But I think that was based largely on poor collecting, poor fossil record and perhaps poor dating. So now that it's possible to date the rocks a lot better, we definitely see this major extinction of the fishes that I mentioned with the armored forms disappearing. We then definitely see a subsequent diversification of the ancestors of sharks and the ancestors of bony fishes. There is a gap, though, on land, so there's sort-of gap in the fossil records of plants and tetrapods on land for the first ten or 20 million years of the Carboniferous. And you're absolutely right, could that be that we just need to collect more? I think people have been looking at that quite intensively. It probably is that there is a deficit, there's a sort of low point of many of these groups, and they did take a while to bounce back.

[Melvyn Bragg] David Bond, one of the things that I've read from all of you is that an extinction can lead to evolution. Extinction does lead to evolution. Perhaps there's no evolution with that extinction? Anyway, what new forms came from this late Devonian extinction?

[David Bond] Yes, so evolution does depend on extinction. I think if the non flying dinosaurs hadn't died out at the end of Cretaceous, then there wouldn't have been the space for mammals to rise and we may not be here today. And like all mass extinctions, the late Devonian extinction is quite selective in what gets wiped out. And as we've discussed, it's clearly devastating for reef ecosystems and the organisms that depend on reefs for life. But even within certain groups there are winners and losers from this event. So Mike mentioned the brachiopods being a major casualty and some members of the brachiopods were completely wiped out, for instance, like the atrypid brachiopods, whereas other brachiopods got off quite lightly and actually occur in great profusion in post extinction ... strata. So we have the rhynchonellids, which you can't fail to find in post extinction rocks. The jawed vertebrates in the ocean, so the gnathostomes, were relatively ... unaffected by the loss of reefs at the Frasnian and Famennian boundary. And these did fairly well in the Famennian until the Hangenberg where they suffer really badly. And we can see that there are other success stories such as the [placoderms??], the sarcopterygiian fish - these are lobe-finned bony fish - that did okay in the Frasnian-Famennian events, but then really got their comeuppance at the end of the Devonian, which is one of the reasons why I treat these as two discrete events that have different selectivity. But what we see through time is each of the big five extinctions really paves the way for the fauna and flora that comes after these events.

[Melvyn Bragg] And finally, Jessica, what has the study of this extinction told you about the way major events move through the history of the planet?

[Jessica Whiteside] Well, the jury is out on some of the details still of this event, but we do know that all the major mass extinctions seem to be associated with some form of abrupt climate change, whether that's massive warming or massive cooling, a confluence of various cascading features. And so it's really a warning, a lesson from deep past that's in terms of the climate and biotic evolution. But very much this story is one that's rooted in the tetrapods and their rebound or their coming through. So they go in as aquatic animals with front and back seven fingers. They live in freshwater and swam in the seas and they come out in the Carboniferous as terrestrial five-digit animals. In fact, people are listening to this on their phone or computers with one of their ten fingers instead of 16 fingers. And that might actually be an artifact of the evolutionary bottleneck at the late Devonian.

[Melvyn Bragg] Thank you very much. Thank you very much, Jessica Whiteside, Mike Benton and David Bond and to our studio engineer, Jackie Marjoram. That was fascinating.

And the In Our Time podcast gets some extra time now with a few minutes of bonus material from Melvyn and his guests.

[41:12]
So, who wants to kick off? What did we leave out? What did you leave out that you like to talk to about?

[Mike Benton] I think one of the things that's been quite interesting, and David as well, of course, he's highlighted, is the fact that although there are many extinction events of different sizes, often we seem to be coming up with a kind of shared model. The volcanic model seems to be shared amongst a whole bunch of these events, definitely in the Permian and Triassic. So whether these Devonian ones fall in line with that as well... And the model is that the volcanic eruption happens. We don't bother about the lava terribly much, but we do focus on the gases that come out, and those include carbon dioxide, water vapour or methane, which are all greenhouse gases. They drive global warming, quite sharp warming. They can also lead to acidification of the ocean, acid rain on land, we get anoxia, lack of oxygen, in the deep sediment. So there seems to be a kind of common pattern that's emerged for a whole bunch of mass extinctions, and smaller events. I don't know whether we're moving in that direction for the same model in the late Devonian, whether this becomes more general.

[42:26]
[David Bond] Yeah, I mean, I think so. It all comes down to timing. So we've known about the Viluy Traps in Russia for many years and one of the issues to this extinction event was the dating of them. But in the last few years, our dating techniques have got better and better and better and the technology has improved. And now the latest ages for the Viluy traps do seem to overlap quite neatly with the late Devonian extinction. There's other volcanism going on at the same time. So there's the Pripyat-Dnieper-Donets rift system which has a similar age. So again, it just comes down to more and more field work collection, as we talked about earlier, and improved techniques to actually find out if if there is that temporal link between volcanism and the extinction.

[Mike Benton] Yeah, and of course, the the late Devonian events, they were recognized 100 years ago by the anoxic layers, the black layers. So that was the key. And then we look for this volcanic cause. Interesting.

[David Bond] And I don't think we really covered the kind of scale of temperature changes through the Devonian. I think each of these black shale events was related to probably initially a warming. But the burial of carbon and the removal of carbon dioxide has been linked to cooling. And as you say, Jessica, this kind of waxing and waning cooling and warming throughout the period must have stressed life out to leave it quite susceptible to whatever came next.

What sort of ups and downs are you talking about, David?

[Mike Benton] Yeah, so the oxygen isotope studies, for instance, the Frasnian-Famennian boundary boundary, we're looking at temperature shifts in the region of between seven and ten centigrade. So major, nowhere near as big as the 15 degree C that we associate with the Permian-Triassic boundary, but these are big shifts. I think it's very interesting to compare that sort of shift in temperature globally to what we're looking at as being IPCC predictions for the next hundred years or so. In the worst case scenario, for the next 100 years is something like six and a half degrees C of warming. So today we're experiencing the same sort of warming that may have occurred or may be associated with the Frasnian-Famennian extinction. And clearly, the development of glaciation during the Famennian saw a huge amount of cooling, as Jessica says, up to the end of the period.

[Jessica Whiteside] The data that we do have does suggest that the tropics are decimated, that there's ice encroaching up into the latitudes of what Tennessee would be, so getting into tropical regions. And that right up against that Devonian Carboniferous boundary, there's a marked increase in seasonality. So the wets get really, really wet and the dry intervals get really, really dry. All predictions of an increased CO2 extreme temperature and intensification of the water cycle.

[Mike Benton] Yeah, that difference in temperature is quite important, I think. Sometimes people think about the current day with one or two degrees temperature rise and think, oh, that's fine. We can grow vines further north. We can make wine in parts of Europe and North America that we couldn't do so before. Of course, we need to notice the enormous increase in the size of the Sahara Desert and the impact on life of only two or three degrees. And I guess here we are in the Devonian, six or seven degrees, killing off reefs. And it's the tropics that get or the equatorial belt that tends to get hit first. But I'm not sure whether in the Devonian we can actually... do we have that information yet that we can pick out those kind of geographic differentiations? Can we actually show that something is happening worse at the equator than elsewhere?

[Jessica Whiteside] Also, the pattern, even though it could be better resolved, does show that the high latitudes seem to eke by the tropics being more severely affected, and that the shallow water organisms seem to go out where the deeper organisms seem to have a little bit of a better position to get through.

[David Bond] I mean, yes, there is much less data from the Devonian simply because of the great age of the rocks. If we compare that to a modern or relatively recent climate-change events such as the Paleocene–Eocene thermal maximum, 55 million years ago, there's tons and tons of data on that because there's plenty of rock and fossil ...from that from that time.

[Mike Benton] I guess in deeper water they're a bit more buffered from severe temperature change. Or maybe they're less dependent on exact temperature ranges, I'm not sure.

[Melvyn Bragg] But you see temperature intensifying and becoming a very big factor again.

[Mike Benton] Yeah. It's very interesting that all these events which depend on, or which are driven by volcanic eruption, I think they give a very good variety of data sets for informing our current discussions where all kinds of interdisciplinary work is happening. People are attempting to model climates in the future with different scenarios of temperature change. Of course, we have these wonderful past events where we can treat them as experiments that actually happened. The frustrating thing is you're looking at them through a very dim glass that is covered with grime and mess, so you can't really get to the level of detail, as Jessica and David were saying, trying to date the rocks accurately enough. When we say abrupt, we may mean less than half a million years. It's not good enough measuring the chemistry of what's going on. Again, you have to be very careful that the rocks have not been subsequently altered in any way, that the measurements you're making are informative.

[Melvyn Bragg] Well, thank you very much indeed.

In our time with Melvyn Bragg is produced by Simon Tillotson.