THE ORIGINS OF LIFE - Curated Transcript of BBC In Our Time podcast
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In Our Time is hosted by Melvyn Bragg. Melvyn's guests on this podcast are:

Richard Dawkins, Charles Simonyi Professor of the Public Understanding of Science at Oxford University;

Richard Corfield, Visiting Senior Lecturer at the Centre for Earth, Planetary, Space and Astronomical Research at the Open University;

and

Linda Partridge, Biology and Biotechnology Research Council Professor at University College London.

Curated transcript:

[Melvyn Bragg] Hello. Scientists have named 1.5 million species of living organism on the land, in the skies and in the ocean of planet Earth, and a new one is classified every day. Estimates of how many species remain to be discovered vary widely, but science accepts one categorical point - all living matter on our planet, from the nematode to the elephant, from the bacterium to the blue whale, is derived from a single common ancestor. What was that ancestor? Did it really emerge from primordial soup? And what did, in the explanation of evolutionary science, provide the catalyst to start turning the cycle of life? With me to explore the scientific explanation for the origin of life are Richard Dawkins, Charles Simonyi Professor of the Public Understanding of Science at Oxford University and author of "The Ancestor's Tale a Pilgrimage to the Dawn of Life", Richard Corfield, Visiting Senior Lecturer at the Centre for Earth, Planetary, Space and Astronomical Research at the Open University and author of

"The Silent Landscape", and Linda Partridge, Biology and Biotechnology Research Council Professor at University College London.

[Melvyn Bragg] Richard Corfield, can we start with the time the Earth was formed? What timescale was that and what were the conditions of Earth then?

[Richard Corfield] Well, the Earth accreted out of the primordial solar system disk about 4.5 billion years ago. The convention in geology is that we call a billion "GA", and so you might hear me refer to it as GA from time to time. A more helpful analogy though, when you think about the span of geological time, is to consider one single day, 24 hours, and midnight is taken as 4.5 GA, 4.5 billion years [ago]. That's when the Earth formed. From then on, the first eon of the history of the Earth is called the Hadean, so called because the Earth and the other planets which were forming at the same time [in our] solar system ...[were] being continuously pummeled by a rain of asteroids and meteorites. That's where the name Hadean [like "Hades"] comes from. That's called the heavy bombardment period of Earth history. And that ended at 3.9 billion years before present 3.9 GA, which if you're thinking about the 24 hours clock equates to twelve minutes past three in the morning.

[Melvyn Bragg] And then we move on to the time when life may or may not have emerged. Now, what were the conditions on the planet, this planet Earth then? What were the basic conditions, the necessary conditions?

[Richard Corfield] Okay, the first thing to say is that the early Earth was quite, quite different to the world we know today. The green [and blue] planet, which was famously shown ... from the Apollo 8 mission, is a result of oxygen photosynthesis and the greening of the world. There was no oxygen at the end of the Hadean. Indeed, ... oxygen at that time would [have been] toxic to ...the organisms... which were just beginning to evolve.

[Melvyn Bragg] But there was an atmosphere, wasn't there? There was a gravitational field which would hold an atmosphere.

[Richard Corfield] There was.

[Melvyn Bragg] Can you tell us how important that was?

[4:13]
[Richard Corfield] Okay, the atmosphere was the so-called "reducing atmosphere", to distinguish it from an "oxidizing" atmosphere. It had carbon dioxide, methane, hydrogen, ammonia, nitrogen, carbon monoxide. And this broth of basic chemicals was continuously cooked by lightning discharges, and the surface of the Earth was pocked with continuous volcanism. It was a very unpleasant place indeed.

[Melvyn Bragg] So the three things there (if I can pick up the word "reduce" and "reduce it to that"!) there's an atmosphere around [because of] the gravitational pull, ... there were volcanoes bringing stuff out including water, carbon dioxide, methane, and so on, and there were flashes of lightning coming in. This is what was there then.

[Richard Corfield] That is the condition of the Earth at 3.9 billion years before present, when the Late Heavy Bombardment period had just finished.

[Melvyn Bragg] Richard Dawkins, could you take up the point made by Richard Corfield, which will surprise a great number of listeners (it surprised me when I came across it) ... that there was no oxygen then, and oxygen was not necessary for this process, the origin of life, to begin? Can you just develop that?

[5:23]
[Richard Dawkins] It is a surprising fact that the oxygen that we breathe and which we utterly depend upon is itself a biological product, that it comes from green plants and green bacteria. I think many people are surprised by that, as you say, because they sort-of feel that there's something fresh and wonderful about the oxygen in our atmosphere. As Richard Corfield said, it was originally a pollutant, it was toxic, it was poisonous. When green plants and green bacteria released it into the atmosphere, it then became the condition that life had to adapt to. And we are ... are the product of that. We are now the product of natural selection in an oxygen rich atmosphere. And not only do we tolerate our oxygen, we depend upon oxygen. And we've taken biochemistry much further.

[Melvyn Bragg] And in the 1950s, a man called Stanley Miller performed an extraordinary experiment. Can you tell us about that experiment and why I use the word extraordinary?

[Richard Dawkins] He got together the ingredients that were thought to be present in the early Earth atmosphere..

[Melvyn Bragg] Around the 3.9 billion [years ago] mark, Richard?

[Richard Dawkins] Yeah.. And he set up an apparatus in which he had a flask that represented the sea and a flask that represented the atmosphere above it and put into the atmosphere the ingredients, the non oxygenated ingredients of the early Earth. There was a circulation tube going up, tube going down. There was electric spark which was simulating lightning strikes, and he just left it for a couple of weeks. And at the end of this time, there had accumulated in the sea the lower of the two flask, the one with water in a thin brown liquid, which, when he analyzed it, it turned out to be pretty much what JBS Haldane had speculated as the "hot brown soup". It contained numerous organic compounds, many of which were vital to the origin of life. amino acids of various kinds, including several amino acids from the 20 that life actually uses.

[Melvyn Bragg] But we're not talking yet about the origin of life as we are going to come to discuss it...that [hot brown soup] in itself would not have led to the development of life?

[Richard Dawkins] No, there was nothing living there.

[Melvyn Bragg] So what did it prove?

[Richard Dawkins] It proved that the conditions of the early Earth were ripe for the synthesis, under the ordinary laws of chemistry, of many of the basic building blocks of life. It was a precondition for life. It wasn't life itself.

[Melvyn Bragg] Linda Partridge can you tell us the place that carbon played in all this and why it's so fundamental?

[8:16]
[Linda Partridge] Carbon is an absolutely critical atom for this process to occur. The reason is its structure. Each element consists of a nucleus surrounded by electrons. And the interesting thing about carbon is that its electron space is half filled. So it's very eager to interact with other elements and make more complicated molecules. So it can form bonds with oxygen, with nitrogen, with sulfur - all of the elements that make the ingredients of living organisms. So it is its bond structure and the fact that it's so keen to interact with other molecules ... that allows it to make large, complex polymers and molecules with complicated shapes [and this makes it] such a vital building block in living creatures. And almost certainly, I think, if life has evolved somewhere else in the universe, it will be based on carbon for that reason. There is no other element that has this set of properties that make it such an ideal building block for living things.

[Melvyn Bragg] As a digression, but as we will be coming onto it, as this is the precursor to the great work of Darwin. Darwin wrote a famous letter to Hooker in 1871. Can you tell us about that, Linda, and why you think it's significant?

[Linda Partridge] It was quite extraordinarily prescient, this letter that Darwin wrote. He almost described the conditions that existed on the primitive Earth and almost seemed to foresee the experiments that Miller and Urey eventually did with the gases and the electric discharges and the organic synthesis. He described it in a rather cozy way compared with the picture that we've been given of what the conditions on the early Earth were like. They were almost certainly extremely hostile. Darwin described a nice, warm little pond, and that's almost certainly not the circumstances under which life evolved, but he did foresee the importance of this mixture of organic compounds and the possibility that they would form larger and more complicated molecules and eventually give rise to life.

[Melvyn Bragg] Okay, well, that's a sort of platform, I hope, really. Now, then, Richard Corfield, could you give us a working definition of life before we talk about its origin? What would life be? How would we say, well, this [object] is [alive]...?

[10:33]
[Richard Corfield] Well, that, of course, is a nontrivial question, and I was rather hoping you'd give it to Richard Dawkins, actually. But to be blunt, a definition of life is something that we have to strap on immediately so that we all know what we're talking about. I was looking at a paper recently, and I saw that there are 102 criteria to define life, but they can be boiled down into about four, really, and the question is whether even those four are all mutually applicable. Life replicates itself. It makes copies of itself, but that doesn't make life unique - crystals do the same thing. Life is about metabolism. It builds things up as opposed to letting things break down. And that leads me to my personal favorite definition of life. The single thing which I happen to think is most important, and I have done since I was a schoolboy, which goes back to Erwin

Schrodinger's 1944 definition of life, which is that it is "reverse entropy". And that is based on Boltzman's formulation of the Second Law of Thermodynamics, which, simply put, means that systems will tend to run down to the lowest energy level: I have a glass of water in front of me. Eventually, that will assume the same temperature as the rest of the room - that's entropy occurring. Life does the opposite thing, it forms complexity, so it runs uphill against the entropy gradient. If I can give you an example, an analogy: I have the builders in at the moment. I watched them knock down my study. That's entropy. Now they're building it up again, I hope, and that's negative entropy. And that is my personal favorite definition of life a reversal in the entropy gradient. [So far we have the three features of] replication, reverse entropy, and metabolism - which is a kind of part of the reverse entropy thing. And the [fourth] thing which perhaps Richard Dawkins should address, which is susceptibility to Darwinian evolution - visibility to natural selection.

[Melvyn Bragg] I think you should three should just take this program over--- - it would be perfectly okay by me! Richard, could you talk about that, especially with relevance to heredity, because that is a point you make very firmly in your new book.

[Richard Dawkins] Yes. I think that when you ask, "what is life?". One could treat that as "what would life be wherever one found it, anywhere in the universe?"" Or it could be, "what do we happen to observe about life here?" And I suspect that the four which Richard Corfield has mentioned are universal. I don't think they're just particular to life on this planet. And I think that the really fundamental one is "susceptibility to natural selection" or "a product of natural selection". Life is what you get when the ordinary laws of physics and chemistry which pervade the entire universe find themselves filtered through this remarkable process of natural selection. And natural selection will arise on any planet in the universe wherever you have "true heredity" and "true heredity" means that you have entities which are "self replicating with high accuracy but not perfect accuracy" such that you get a population of such replicating entities which are not all identical. Therefore some of them are better at replicating than others. Some of them die away, others increase in the population of replicators. And that is the starting point for natural selection because once that starts, then everything else follows which we call life.

[Melvyn Bragg] But the real question is how does that start? How does the first replicator replicate? And do we know that with any degree or certainty?

[14:22]
[Richard Dawkins] That's exactly what we don't know, and that's exactly what the whole field of origin of life research is about in my view. It is "how do you get from the ordinary laws of chemistry to ... an entity which is self replicating in this peculiar sense?" And that must have happened. It did happen because here we are. If it happened anywhere else in the universe, there will be another kind of life.

[Melvyn Bragg] Well, let's just stick to this planet. It's quite hard enough. But at ... what you postulate has to be that at some stage at one time (or several times, but let's say at one time) there was a spontaneous generation of something that then became susceptible to natural selection which then became divergent as soon as it became susceptible to natural selection, and then the whole game was afoot. But what is the scholarship now about what that first spontaneous generation was? We're thinking it's between 3.9 billion and 3.5 billion years. Putting that aside for a second, what happened?

[15:28]
[Richard Dawkins] Well, when you say "it's spontaneous" - ... "spontaneous" is right, but of course ... spontaneous things are happening all the time with the ordinary movements of atoms and molecules in chemistry. The particular spontaneous thing that had to happen was that a molecule arose which, whatever other properties it had, it had the property of making copies of itself. ...A chemist might call that "autocatalysis". A catalyst is a molecule or a chemical agent which facilitates a chemical reaction without participating or other without being used up. An autocatalyst is a catalyst which facilitates its own production.

[Melvyn Bragg] If I remember correctly,...in your book, you say you use even the word "luck". It could have been luck that caused this...I mean, people creationists and Christians and religious people listening to this would ... say this would be the "divine spark". Well, one has to say that because that is what a lot of people would believe would happen, but you also use the word "luck". I was interested by your use of the word luck.

[16:33]
[Richard Dawkins] It simply means an improbable event. We know it's an improbable event because if it wasn't, it would be all over the I mean, there'd be life on Mars, Venus, Jupiter.... It's certainly a very improbable event. We don't know quite how improbable. I've speculated that it could be absolutely vanishingly improbable because we don't know there's life on more than one of the billions and billions, of the trillions, of planets that exist. So it could have been very, very improbable indeed, in which case we're totally wasting our time trying to trying to speculate about it. But I don't actually believe that... I think it was improbable to be present here and probably dotted around on isolated islands as well. But it was very improbable, and that's another way of saying "luck".

[Melvyn Bragg] Linda and Richard want to come in. Linda, can we just keep ... rummaging around this particular small vital point?

[17:23]
[Linda Partridge] It may have been very improbable, but it happened extraordinarily quickly in geological terms... 3.9 billion years ago, we stopped being bombarded, and 3.6 [billion] years ago [is the date that we find] the first fossils. So life presumably evolved well before that. So, I mean, one could argue that if the conditions are propitious, it's actually extremely likely to happen.

[Richard Dawkins] I agree

[Melvyn Bragg] Richard [Corfield]?

[17:48]
[Richard Corfield] One of the interesting things is that the oldest sedimentary rocks we know on this planet are from the Isua Complex in western Greenland. And there is evidence to suggest, and these rocks are 3.8 billion years old, that's 100 million years

younger than 3.9 [GA] when the starting gate went up and life could have got started - and that's only half an hour on our 24 hour clock. Now, if there is evidence for photosynthesis, as some suggest there is, in rocks at 3.8 billion years before present, that means that you got from no life to photosynthesis i.e quite complicated life in 100 million years, which is like Michael Schumacher going down the Hangar Straight - it's just not hanging around.

[Melvyn Bragg] Shall we then speculate on ... how this might have happened? What formations inside? How the thing got going in the first place? Richard Dawkins, we've talked about [the starting molecules for life] not being DNA, but possibly RNA could have been the cause of it. Can we bring that in?

[18:58]
[Richard Dawkins] Yes. DNA is what Graham Cairns-Smith has called a "high tech replicator". It needs a lot of machinery, rather like needing a Xerox machine to actually make a copy of a piece of paper. So it almost certainly wasn't DNA.

[Melvyn Bragg] And there's a Catch 22 in the DNA.

[Richard Dawkins] There is a Catch 22. DNA is needed to make protein and protein in the form of enzymes is needed to make DNA... That is the Catch 22 of the origin of life - and it's very difficult. We have these two fundamental properties of molecules that you need - replication, which DNA is brilliant at, and catalysis, which proteins are brilliant at. And you seem to need both and it's not clear how you can get one without the other. RNA seems to have some of the properties of both. RNA is a good replicator, though not as good as DNA. RNA can act as an enzyme, can act as a catalyst. And so the hope of the RNA world theory is that RNA might have actually done both jobs and then later the job of replicating was, as it were, handed over to the really streamlined high-tech version, DNA.

[20:10]
[Melvyn Bragg] Linda, can you spell out RNA for listeners like myself who are not familiar with these letters?

[Linda Partridge] Ribonucleic acid. It's one of the two main nucleic acid molecules that occur in modern organisms. And as Richard says, it has this extraordinary property, it can act as a genetic template to direct its own replication, but it can also behave like modern day proteins do, as a catalyst that makes chemical reactions far more likely to occur easily in cells. And in fact, this is one of the areas where there's been a lot of experimental work on the origin of life because it's possible to evolve in the test tube RNA molecules that can do all kinds of chemical jobs that in cells now are done by proteins. So it's very plausible that this whole RNA world existed, I think.

[Melvyn Bragg] Richard Dawkins, can you tell us what might then have happened (before we move on to complexity) ... in your view, (and it is speculation, you make it quite clear), how, in your view, the first very early forms came into being which allowed natural selection to begin?

[21:14]

[Richard Dawkins] A major step in the subsequent evolution under natural selection was the formation of something like the first cell. Because when you had the first cell that meant that a membrane of some sort, a wall, separated units of self replication and kept their chemical products together instead of having them streaming around free in the soup. And I think that enabled the possibility of building up complex collections of molecules which work together with each other, which is what a cell is, as opposed to just having them streaming out into the sea and having a very indirect effect on the replication success of the competing entities. So the first cell wall seems to me to be a very crucial step. Living cells are conventionally nowadays, conventionally divided into two main types eukaryotic and prokaryotic. Prokaryotic cells are bacteria, of various kinds, eukaryotic cells are those are the cells of all the rest of us. They're enormously larger than prokaryotic cells. They're much more complicated. They have a nucleus within the cell which contains the genetic material separated off from the rest of the cell. The rest of the cell is filled with complicated systems of membranes, including mitochondria, which we now know are themselves originally derived from bacteria. So at a moment in history when several different kinds of bacteria, it is now thought, came together to form a kind of social unit, a bigger cell, which was a combination of different kinds of bacteria.

[Melvyn Bragg] Richard Corfield?

[23:07]
[Richard Corfield] Just to give you some perspective on the time, by the time the eukaryotes evolved, you're at effectively 2 billion years before present - you're half of the way, pretty much towards where we are now. So the evolution of the eukaryotic cell is actually quite a complicated, long-term thing in terms of natural selection. It's a major platform from which life could then step up on the way to multicellularity.

[Melvyn Bragg] Linda, you wanted to come in. Can you take this forward to the further developments from this eukaryotic cell? What happened, as it were, after that?

[23:43]
[Linda Partridge] Well, one of the things about it, just before moving on to that, and very quickly, is that this may really have been one of the very improbable steps in the evolutionary tree, I think, because it turns out that eukaryotes are almost certainly derived from a very basic fusion of two quite separate bacterial lineages one of which brought in the information transfer and processing machinery in the cell and the other of which brought in the metabolic bits, the things that actually do things within the cell. And they seem to have had quite separate evolutionary origins, which makes a lot of sense of why there have been such conflicting results. If evolutionary biologists try and ask the question, where did the eukaryotes come from? What are they most closely related to? Well, the answer is they're closely related to several things, because essentially the eukaryotic cell is a committee of separate bacterial lineages. But the next big event, of course, was the evolution of multicellularity - cells coming together to form more complex organisms. And the evidence on that is that it's happened more than once. It happened separately in the plant, animal and fungal lineages, and also several lines gave rise to multicellular algae from single-celled forms. So that seems to be quite a common, easy step to take.

[Melvyn Bragg] So by going for the cells, as it were, Richard Dawkins we're finding commonality right across the planet, whichever way you cut it?

[Richard Dawkins] Yes. Well, the new findings that Linda's just been talking about of two separate genomes merging is immensely exciting. That's quite a new thing, which I'm still trying to digest. But, yes, after multicellularity, then you have the evolution of life as we've known it for a long time, and life as Darwin would have known it: big, big life, life that you can see, creatures that swim and walk and fly and climb, all that seems to have come about through the modularity, the building up of lots and lots of cells, each cell having fundamentally the same structure but modified for different particular purposes in a kind of society of cells.

[Melvyn Bragg] A point that has been raised, and it was raised a long time ago by Fred Hoyle was that life or the beginnings of life or the things that could make life begin came from asteroids, came from extraterrestrial sources. What's your view about Richard Golden?

[Richard Corfield] Well, carbonaceous chondrites, particular types of meteorite are so called because they have carbon compounds on them and in fact, the basic building blocks of life, amino acids and probably nucleic acids. What came before them, the things that they themselves are formed from, are available in stardust, in outer space. There's nothing particularly unique about the basic chemicals of life. It's just the way they were put together on this planet. If you take that one step further and say, was life seeded from outer space - the Panspermia theory - well, it may have been, but that doesn't help you very much because it means that you just have to go somewhere else to figure out how it started in the first place.

[Melvyn Bragg] Linda?

[26:49]
[Linda Partridge] Yes, [I] quite agree with all of that. And even if life did in fact evolve here and didn't come from outer space, some of the information that gave rise to it may have come from elsewhere. And there's plenty of evidence that the early Earth received a large amount of organic input from outside, from more widely in the solar system. And sometimes the sorts of molecules that come have a particular handedness to them, which doesn't tend to happen when they're formed under the conditions that prevailed in the early Earth. And that handedness may well have acted as a source of information for modern biological systems.

[Melvyn Bragg] Once [natural selection] got going, Richard Dawkins, ... once there was the ability to enter into Darwinism as it were, was it inevitable..[to have] the massive multiplication of species and so on?

[27:38]
[Richard Dawkins] Well, that's very interesting. I think that there may have been more than one very difficult step to get over. It's already been mentioned that the formation of the "eukaryocracy", the eukaryotic cell, with all that followed from that, could have been a very, very difficult step. And it could be that there's all sorts of beginnings of life elsewhere, none of which reach that point. There could be other major steps - multicellularity might have been a difficult step. I don't think in fact it was because, as

Linda says, it happened many times, so we know that multicellularity is not that difficult. But maybe intelligent life, maybe the sort of life that is capable of language, of technology and of broadcasting itself by radio to other planets, maybe that's a very, very difficult step indeed. And that may be the answer to the riddle of as Enrico Fermi said, "where are they?" Why haven't we received radio communications from outer space? It could be that there's plenty of life out there, but only we have reached the technology threshold.

[Melvyn Bragg] Well, thank you very much, Linda Partridge, Richard Corfield and Richard Dawkins.
