Earth impacts and the faint young sun

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The 'faint young sun paradox' is considered in relation to theories on the early earth and a new proposal regarding Earth impacts. This proposal is that large impacts could produce greenhouse gases for millions of years that would help solve the problem of the evolution of life under the young sun. The concept dovetails with proposals that large impacts could stimulate volcanism. Problems with this concept are considered in relation to the time-scale of the faint young sun problem. It is shown that the new proposal is overly optimistic regarding impacts affecting greenhouse gases and that the outgassing effects in any case would only be present for a small portion of the time in which the faint young sun issue exists.

The 'faint young sun paradox' continues to be a challenge to evolutionary ideas on the origin of life on Earth. The problem affects approximately the first 2 Ga of our solar system, by evolutionary reckoning. Creationists have frequently addressed the issue.[1–4] Models of the sun suggest that at about 3 Ga before present the sun's luminosity would be approximately 20% less than today. By 2 Ga before present, solar luminosity would be approximately 15% less.[5] The present paper does not address the period from about 2 Ga ago to 3 Ga ago. That period poses different issues than the period prior to 3 Ga ago because evolutionary models postulate significant changes in Earth's atmosphere. Impacts were not a factor in secular theories in the period from 3 or 3.5 Ga ago to the present. The lower solar luminosities from prior to 3 Ga ago have the potential of causing all water on Earth's surface to freeze for some time. Thus the question that arises is how could life evolve? It is generally believed the first life to evolve was some form of microorganism that lived in water, possibly something similar to the cyanobacteria known to exist today. A hypothesis has recently been put forward suggesting that large impacts in the early earth could help resolve the faint young sun problem.[6]

The new proposal relating impacts to the faint young sun problem has been published in *Earth and Planetary Science Letters* (2016) suggesting that in the period between 3.5 and 4.5 Ga ago large impacts could cause outgassing at the earth's surface that would generate a significant greenhouse heating effect and warm the earth.[6] Earth and planetary scientists have applied a number of different proposed greenhouse heating mechanisms in order to make the early earth warm enough for life to evolve and survive. In the 1970s Carl Sagan suggested that Earth's atmosphere once had higher proportions of gases such as methane, ammonia, and carbon dioxide than today.[7] That was largely abandoned because it required unrealistically high concentrations of the greenhouse gases. In the early period of prior to 3 Ga ago scientists have generally taken the view that the early earth's atmosphere was denser than today, making a greenhouse effect more significant. It is thought that heat would come from other processes as well. For example, the hot surface and mantle of the earth would strongly heat the atmosphere for a long period. But what was Earth's atmosphere believed to be like prior to 3 Ga ago?

The early earth

The earliest history of the earth, by today's evolutionary theories, involves a complex series of atmospheric changes and catastrophic events.[8,9] Sometime between about 50 to 100 Ma after Earth begins to form, a Mars-sized object is believed to have collided with Earth. This ejected material is thought to have formed our moon. The earth's surface was largely molten at the time of the moon-forming impact (allowing the impactor material to mix into Earth's mantle). Before this powerful collision Earth's atmosphere is believed to have been even more dense than Venus's atmosphere is today. It could be argued that the early earth had multiple atmospheres, since it is thought it's first atmosphere was lost due to collisions and after this there were dramatic atmospheric changes due to both impacts and changes in the earth's interior. In the naturalistic concept of the early earth, the atmosphere was of a reducing nature (little or no oxygen) until approximately 2.3 Ga before present.[10,11] By 2.3 Ga ago it is believed there was a dramatic increase in oxygen in the atmosphere. The increase in oxygen levels is believed to have been due to photosynthetic bacteria which lived in liquid water. So evolutionary theories would say the first life must evolve in liquid water when the atmosphere has very little oxygen. It is believed that the surface waters could have had minute concentrations of oxygen (such as in the nanomole range) even if the atmosphere did not.[10] Before the atmosphere changed to having oxygen as it does today, there would have been a long period of perhaps hundreds of millions of years where microorganisms existed. But because of the violent large impacts taking place in Earth's first billion years, scientists now believe that early life could have evolved multiple times only to be wiped out by the harsh conditions.

Though an early reducing atmosphere has long been accepted in the scientific community, this has never been well supported by geological evidence. Creationist geologist S. Austin pointed out that some arguments used to support an early reducing atmosphere have other plausible explanations.[12] In addition, Austin argued that sedimentary rocks known as 'red beds', which contain the mineral hematite, argue for an oxidizing atmosphere. These red beds are often associated with banded iron formations, which have sometimes been used to argue for a reducing atmosphere. A much more recent report from the *Proceedings of the National Academy of Sciences (PNAS)* gave results of a study of hydrogen and oxygen isotopes in serpentine minerals from the Isua Supracrustal Belt of West Greenland.[13] The samples used in this study would be dated by uniformitarian assumptions at 3.8 Ga. The study concluded that oxygen concentrations in the Archean oceans were comparable to today. The study also considered chemical processes affecting hydrogen, methane production by photolysis, and carbon dioxide. They concluded much hydrogen was likely lost to space and this would limit concentrations of methane. This in turn limits the greenhouse effect from methane. The *PNAS* study concluded with this statement about the faint young sun problem.

> "This supports the argument that the combined greenhouse effect of atmospheric CO_2 and CH_4 cannot independently reconcile the faint early sun paradox. Additional forcing, such as a lower Earth-albedo, is necessary to maintain temperate conditions in the early Archaean."[13]

The last sentence in the quote refers to a new idea proposed by some, that during the Archean period Earth's oceans covered significantly more of the surface and the overall darker surface of the earth would more efficiently absorb energy from the sun.[14] Thus some have argued from geological evidence that CO_2 levels were not enough to allow for liquid water. This sometimes prompts scientists to combine multiple mechanisms.

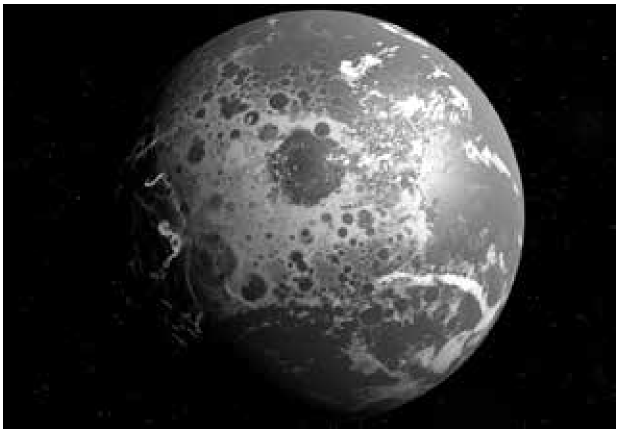

Figure 1. Artistic rendering of the early earth in the late Hadean period, approximately 4 Ga ago by uniformitarian assumptions. Earth's surface shows craters, some molten zones, some ice, and some liquid water.

It has been a common view among scientists that the earliest chemical evidence for life on Earth would be dated at approximately 2.3 Ga old. This comes from discoveries of organic chemicals classed as hopanes and steranes in certain drill cores of Precambrian rocks.[10] But a recent publication now questions this evidence on the basis that such chemicals could be introduced by contamination, even in the more carefully collected samples.[15] Even if there were chemical evidence of life in rocks 2.3 Ga in age, in order to leave this evidence, life would presumably have to exist long before this time. There are also reports of evidence of life prior to 3 Ga ago, such as stromatolites dated at 3.7 Ga ago, suggesting microbial life.[16] It is generally accepted by the scientific community that it was primarily photosynthetic bacteria, which generated most of the oxygen in Earth's atmosphere. This implies that these bacteria had to survive for well over 1 Ga before Earth's atmosphere became oxidizing. The oxygen producing bacteria had to thrive enough so that oxygen would build up to significant concentrations in the atmosphere. So, this implies the faint young sun paradox is a problem that lasts for more than a billion years, since it is still a problem after 2 Ga ago. There continues to be debate about how oxygen-producing bacteria could cause Earth's allegedly thick early atmosphere to switch from a reducing character to having a significant fraction of free oxygen. This is the background for the recent paper by Marchi *et al.* (2016)[6] which proposes that large impacts generated a greenhouse effect in the early earth that kept surface waters from freezing. The period this new idea applies to is after the moon-forming impact and up to approximately 3.5 Ga ago.

The paper by Marchi *et al.* proposes that some large impacts would cause melting of the mantle under the impact site that would lead to millions of years of outgassing from molten material on Earth's surface. The impacts proposed for this are larger than any known identifiable crater sites on Earth today. The largest known impact sites on Earth today, such as Vredforte in South Africa,[17] would be too small to have the intended effect. Another paper by Marchi in 2014 summarized the large impacts in the following way.[18] The number of impactor objects striking the earth larger than 100 km diameter would be in the range of 100 to 150. Impactors of this size would create craters possibly several hundred kilometres in diameter on the earth. The number of impactors larger than 200 km diameter would be from 10 to 30. The paper by Marchi from 2014 also advocates impact-induced melting of material in the mantle and lithosphere that would bring large volumes of lava to the earth's surface.

Effects of impacts

What would be the effects of such impacts? It has been proposed by some that for impacts of this scale there could be melted rock that is much more in volume than that produced by the impact itself. There have been a number of studies simulating the effects of impacts in the early earth. Much attention has been given to estimating the amount of impact melt produced in the crater floor. The impact melt liquefies because it has been shocked and when the extreme pressure releases it leads to the rock melting. Some scientists have proposed a new mechanism in which large impacts could release large quantities of lava for extended periods of hundreds of millions of years. It is argued that a large impact can reduce the pressure on the magma under the crater site enough to cause melting that starts a mantle convection under the crater site. The higher temperatures of the mantle in the early earth are believed to make this more feasible than it would be today. This implies that the crater itself would likely be obliterated by the melted rock that comes from below. Because these would be large craters it is believed a large volume of molten material could come to the surface. The large pool of molten material would stay on the surface for a long period of time, due to being fed by a mantle convection below it. This molten pool would be associated with volcanism at or near the impact site and gases would evaporate from it into the atmosphere. The gases believed to be involved would be carbon dioxide, carbon monoxide, sulfur dioxide, hydrogen sulfide, as well as some methane, hydrogen, and water vapour.

This impact-induced greenhouse concept makes two major assumptions. First, that large impactors would continue striking Earth with some frequency long after the moon-forming impact, and second that impacts can cause volcanism. The Late Heavy Bombardment is believed to have taken place from approximately 4.2 to 3.8 Ga before present, based on lunar crater data. At about 3.85 Ga planetary scientists generally agree that the rate of cratering dramatically decreased.[19] This raises questions about what the realistic time-frame of effects for these impacts would be. According to theories on the early earth, large impacts were frequent from 4.5 to 3.9 Ga ago. This period included impacts of sufficient scale that it's believed they would have more than penetrated Earth's crust and lithosphere. It is also thought that some of these impacts could have completely vapourized all water on Earth's surface. This kind of vapourizing of surface materials would make the atmosphere temporarily very dense but the water and some other material would cool and make its way back to the surface. Even for the moon-forming impact it is suggested that the hot dense material in the atmosphere would largely cool in a period of roughly 1,000 years.[8] One impact could have covered over or overturned another, as crater structures were broken up and impact melt filled craters. Large volumes of molten rock are believed to have filled the largest craters and possibly melted the earliest crystalline minerals and zircon crystals. However, there seems to be no large impact basins known on Earth today in which lava totally filled the crater (like the lunar mare), but it is believed this was common in Earth's first billion years. The research on large impacts on the early earth generally does not include changes in the earth's atmosphere along with effects on Earth's surface and in the mantle. Thus there is much uncertainty on the atmospheric effects in the early earth environment.

Volcanism and impacts

The direct effects of the large impacts above would not last tens or hundreds of millions of years, so this new idea attempts to lengthen the time of the effects by building on controversial ideas that impacts can cause large scale volcanism. This hypothesis suggests that when a large crater is created by an impact, it depressurizes the lithosphere and mantle enough so as to significantly increase the amount of molten material under the crust and lithosphere. By setting off a convection cell in the mantle under the crater site, it is believed that melt can make its way to the surface and cause a large volume of gases to be input into the atmosphere. This concept also goes hand-in-hand with a view that large igneous provinces on Earth (such as the Deccan Traps for example) could come from impacts. I believe that the connection between such large basalt deposits and impacts is questionable. Melosh and Ivanov have argued from their impact physics simulations that large impacts on this scale cannot generate melted rock in the manner suggested.[20]

On the other hand, there are scientists who persist in the view that large basalt deposits could be related to impacts due to the depressurization of the mantle as mentioned above. Even if some volcanism happened at a crater site, it seems unlikely it could last for hundreds of millions of years. In the recent paper by Marchi *et al.* (2016),[6] they summarize their results for atmospheric carbon dioxide this way:

> "These simulations show that impact outgassing could have intermittently sustained a level of atmospheric CO_2 above the inferred minimum condition for liquid water in the early Archean and Hadean … for a cumulative time span of several 10 Myr up to 100 Myr."

The assumption of it lasting this long may come from the assumed volume of molten material and the time required for it to cool. But does it really require tens of millions of years for such a volume of molten material to cool? Water and volatiles present could actually hasten the cooling. Thus, even if some gases were released into the atmosphere, its actual effect on atmospheric temperatures could be relatively short-lived. If Melosh and Ivanov are correct, the depressurization mechanism above would not be effective in generating large volumes of melt. Impacts can have more direct atmospheric effects but they are not long-lived. Thus the depressurization concept has arisen in order to provide a mechanism for a long-term heating and now an outgassing effect at Earth's surface.

There continues to be research by geologists and geophysicists that looks for evidence connecting large basalt deposits with possible impact structures. But this is in sites where there is little or no clear indication of a large crater. On the moon there are abundant indications of volcanism in and near craters but on the moon this is mainly in the form of dikes. The thinner crust of the moon, especially on the near side, makes volcanic dikes possible within craters where some of the crust has been removed and lava came up through fractures. There is also some evidence on the moon that impacts sometimes apparently overturned or excavated basalt rocks from earlier impacts. Thus there may have been essentially multiple generations of mare on the moon.[21] The hypothesized earlier mare rock that were destroyed by later impacts are referred to as cryptomare. The same could be possible on Earth if an impact were large enough. But molten material (or geothermal fluids) coming up through fractures is a different process than this new concept proposed by Marchi *et al.* Molten material coming to the surface via fractures or dikes in a crater also would not be a long-lived process that would continue for tens of millions of years.

From what is best known about the atmospheric effects of impacts, impacts would not normally have a long-term effect on the atmospheric temperature. Most of the ejecta in an impact is in the form of dust and particulates; gases released by impacts are normally very minor. On the other hand, volcanic eruptions often release gases such as sulfur monoxide, carbon monoxide, methane, and other gases that can form hazes in the atmosphere. These hazes can require a few years to clear from the atmosphere, after a volcanic eruption. There are some other short-lived atmospheric effects of impacts but they could not cause long term changes for millions of years. Sometimes acid rain can be produced in the region near an impact, due to the formation of nitric acid in the atmospheric wake of the impactor. Large impacts can also actually cause some of the atmosphere to escape into space. A partial vacuum is created behind an impactor as it ploughs through the atmosphere and this can essentially suck gases into space. So if large impacts caused outgassing, the greenhouse effect might be counteracted to some degree by an atmospheric loss from the impacts.

Life on the early earth

Life is thought to have started on the earth in the period between 3 and 4 Ga ago. Only as impacts became less frequent could there be some areas of Earth's surface where life might have survived. Thus it is thought the earliest life forms would have to be bacteria that could survive in relatively high-temperature waters (prior to 3 Ga). Today scientists have come to a view of the early earth in which Earth is very hot for a long time. This view is mainly a consequence of planetary science considerations on Earth's formation, not from geological evidence. But after the Late Heavy Bombardment ended at approximately 3.8 Ga ago, it is thought Earth's surface would cool. Thus it is in the period between approximately 4.0 and 3 Ga ago that the faint young sun could freeze Earth's surface. It is also believed there would also be much outgassing from the earth's interior from volcanism that would be totally unrelated to impacts. Theories on the early earth generally agree that an outgassed atmosphere would be a reducing atmosphere, not an atmosphere with significant oxygen. Impacts in the early earth thus serve the purpose of thoroughly mixing Earth's rocks and minerals. The early earth is also 'kept hot' in scientific models in order to counteract the early faint sun problem. Yet it is not clear how the atmospheric changes would unfold. Thus a self-consistent early history of the earth from 4 Ga to 2 Ga has not really been worked out by secular scientists.

Tidal heating of the earth, radioactive decay, intense ultraviolet radiation from the sun, and other mechanisms have been considered as solutions to the faint young sun problem. Even at best, none of the mechanisms proposed to keep the earth's surface warm would last for more than a small portion of the 2 Ga of time from 4 Ga to 2 Ga ago. Evidence sometimes conflicts from a secular perspective. For example, some studies have implied that Earth's atmospheric pressure could have been lower than present, perhaps as low as half current pressures.[22,23] One of these studies was looking at nitrogen and argon isotope data believed to be from 3.5 to 3 Ga ago.[23] The other was regarding fossil raindrop evidence believed to be from 2.7 Ga ago.[22] If the atmospheric pressure was less, this tends to make the faint young sun cooling problem worse, but researchers tend to propose a higher proportion of greenhouse gases to warm Earth's surface. This shows how one type of evidence can conflict with another type of evidence. However, from a creation perspective with a young earth, many of the difficulties disappear in a biblical view of Earth history.

Conclusions

Impacts do not solve the early faint sun problem prior to 3 Ga ago in secular scientific models. Firstly, it is not clear that the outgassing mechanism proposed by Marchi *et al.* would be effective in altering Earth's surface temperatures. Serious doubts have been raised for the depressurization mechanism for outgassing from impact sites. The relationship between large impacts and volcanism continues to be debated in the scientific community. But a clear case has not really been made from geological evidence, for known sites on Earth where a crater structure can be causally related to volcanism. Certain sites have been proposed to be caused by an impact, such as the Deccan Traps region in India. But arguing a causal connection between the impact and the volcanism is very difficult. It seems to be simply assumed by those that advocate the concept, mostly on the basis of the assumed coincidence in time between the impact and the volcanic activity.

Secondly, any conceivable atmospheric effects of impacts, even very large ones, could not be expected to endure for adequately long periods of time. This is the case even if one grants the outgassing mechanism proposed by Marchi *et al.*[6] In their own conclusions their proposal would only warm Earth's surface temperatures for approximately 100 Ma at most, per large impact, as quoted above. The early faint sun problem applies to an evolutionary Earth history for about one or one and half billion years, during which Earth's surface could be very cold. So even if an impact could warm temperatures for a time, life would not evolve. Life would not evolve because liquid water is considered necessary for the formation of early microorganisms. The proposed period in which the impacts allegedly led to outgassing is from 4.5 to 3.5 Ga ago. For most of this period, when the impacts could have more of an outgassing effect, the effects of the impacts would be too severe for life to get started on the surface, even if the outgassing mechanism proposed were viable. The possible time window when life could start in this scenario would be from about 3.8 to 3 Ga. But this is also enough time for the effects of the impacts and volcanism to subside and the surface of the earth to freeze. If the impacts slow, so that life could have opportunity to establish itself, then the impact 'solution' to overcome the problem of the cold temperatures of the early faint sun is no longer effective. Thus, whenever the impacts end, the early faint sun problem returns. Even if the impacts and volcanism kept Earth's atmosphere and surface warm enough for liquid water until 3 Ga, there would still be hundreds of millions of years in which Earth's surface waters could freeze after the impacts ended. Thus a frozen surface of the earth makes the evolution of life even less likely. This illustrates the complications introduced by old age uniformitarian assumptions. Instead, we should accept that God created Earth only several thousand years ago and that Earth was made well-suited to life from the beginning. If the sun and Earth are both part of a young solar system which was designed to allow for life from the beginning, the faint young sun problem disappears.

References

1. Spencer, W.R., New science on the young sun, and Earth migration, *J. Creation* **26**(1):6-8, 2012.
2. Oard, M.J., Is the faint young sun paradox solved? *J. Creation* **25**(2):17–19, 2011.
3. Sarfati, J., Our Steady Sun: a problem for billions of years, *Creation* **26**(3):52–53, June 2004.
4. Faulkner, D., The young faint sun paradox and the age of the solar system, *J. Creation* **15**(2):3–4, 2001.
5. Ribas, I., The Sun and stars as the primary energy input in planetary atmospheres, *Proceedings of the International Astronomical Union* **5**(S264): 3–18, 2009.
6. Marchi, S., Black, B.A., Elkins-Tanton, L.T. and Bottke, W.F., Massive impact-induced release of carbon and sulfur gases in the early Earth's atmosphere, *Earth and Planetary Science Letters* **449**:96–104, 2016.
7. Sagan, C. and Mullen, G., Earth and Mars: evolution of atmospheres and surface temperatures, *Science* **177**(4043):52–56, 7 July 1972.
8. Zahnle, K., Arndt, N., Cockell, C., Halliday, A., Nisbet, E., Selsis, F. and Sleep, N.H., Emergence of a Habitable Planet, *Space Science Reviews* **129**(1–3): 35–78, 2007.
9. Lunine, J.I., Physical conditions on the early Earth, *Philosophical Transactions of the Royal Society B* **361**:1721–1731, 2006.
10. Waldbauer, J.R., Newman, D.K. and Summons, R.E., Microaerobic steroid biosynthesis and the molecular fossil record of Archean life, *Proceedings of the National Academy of Sciences* **108**(33):13409–13414, 16 August 2011.
11. Allen, J.F. and Martin, W., Evolutionary biology: Out of thin air, *Nature* **445**: 610–612, 8 February 2007.
12. Austin, S.A., Did the Early Earth Have a Reducing Atmosphere? *Acts and Facts*, (Institute for Creation Research) **11**(7), 1982.
13. French, K. L. *et al.*, Reappraisal of hydrocarbon biomarkers in Archean rocks, *Proceedings of the National Academy of Sciences* **112**(19): 5915–5920, 12 May 2015.
14. Rosing, M.T., No climate paradox under the faint early Sun, *Nature* 464: 744–747, 1 April 2010.
15. Pope, E.C., Bird, D.K. and Rosing, M.T., Isotope composition and volume of Earth's early oceans, *Proceedings of the National Academy of Sciences* **109**(12): 4371–4376, 20 March 2012.
16. Nutman, A.P. *et al.*, Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures, *Nature*, published online 31 August 2016.
17. Reimold, W.U. and Koeberl, C., Impact structures in Africa: A review, *J. African Earth Sciences* **93**:57–175, 2014.
18. Marchi, S. *et al.*, Widespread mixing and burial of Earth's Hadean crust by asteroid impacts, *Nature* **511**: 578–582, 31 July 2014.
19. Chapman, C.R., What are the real constraints on the existence and magnitude of the late heavy bombardment? *Icarus* **189**:233–245, 2007.
20. Ivanov, B.A. and Melosh, H.J., Impacts do not initiate volcanic eruptions: eruptions close to the crater, *Geology* **31**:869–872, 2003.
21. Whitten, J. and Head, J.W., Lunar cryptomaria: Mineralogy and composition of ancient volcanic deposits, *Planetary and Space Science* **106**:67–81, 2015.
22. Som, S.M. *et al.*, Earth's air pressure 2.7 Ga ago constrained to less than half of modern levels, *Nature Geoscience*, 9 May 2016.
23. Marty, B., Zimmermann, L., Pujol, M., Burgess, R. and Philippot, P., Nitrogen isotopic composition and density of the Archean atmosphere, *Science* **342**: 101–104, 2013

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