Cover Letter for “*Volcanic Lightning and Prebiotic Chemistry on the Early Earth*” by Jeffrey L. Bada, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92024, jbada@ucsd.edu

This is a Matters Arising submission to *Nature Communications* which was received on 12 September, 2022. It is presently under consideration. The manuscript is related to the recent paper by Pan, Z., Mao, F., Rosenfeld, D, et. al., "Coarse sea spray inhibits lightning." *Nature Communications* 13.1, 1-7 (2022).

Abstract: Based on the paper by Pan et al., on the early Earth >4.2 Ga with limited exposed land areas, coupled with an ice covered ocean, lightning could have been rare. This presents a conundrum because lightning is considered to be an important energy source needed for the synthesis of prebiotic compounds required for the origin of life. Lightning occurrence during eruptions on wide spread volcanic islands coupled with their associated release of reduced gases provides a solution.

The manuscript has 1030 words including references (#13) and has one Figure. It has not been submitted or presented elsewhere.

Matters Arising Contribution 9-12-2022

Volcanic Lightning and Prebiotic Chemistry on the Early Earth

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Abstract: Based on the paper by Pan et al., on the early Earth >4.2 Ga with limited exposed land areas, coupled with an ice covered ocean, lightning could have been rare. This presents a conundrum because lightning is considered to be an important energy source needed for the synthesis of prebiotic compounds required for the origin of life. Lightning occurrence during eruptions on wide spread volcanic islands coupled with their associated release of reduced gases provides a solution.

Pan et. al.[1] recently reported that lightning is rare over the oceans because of sea salt spray interactions. The sea salt caused depression of lightning is reflected in the average global lightning[2] of 44 ± 5 flashes/sec (fls^{-1}), with the land/ocean occurrence being 10:1. However, on erupting volcanic islands, lightning can be much more intense. For example, the huge eruption on January 15, 2022 of Hunga Tonga–Hunga Ha'apai, a submarine volcano 65 km (40 mi) north of Tongatapu on Tonga's main island, produced enormous volcanic lightning[3] with a stunning >400,000 flashes in total, with 200,000 flashes (56 fl s^{-1}) during the most active hour!

Continental, island and coastal regions constitute 88% of the total global lightning on the modern Earth[4]. However, in the Hadean eon (>4.2 Ga) there was likely only a limited amount (~20%) of exposed sub-arial continental area[5]. The Hadean was thus truly a 'water world'. If the same sea salt caused interference existed then, global lightning could have been significantly less than today. Also, because of reduced solar luminosity, the early oceans could have been ice covered[6]. Lightning over the Arctic and Antarctica today is infrequent[7]. Thus, it's possible there was a significantly reduced level of overall global lightning on the early Earth.

This presents a conundrum: Lightning is considered to have played a role in the synthesis of organic compounds considered essential for the origin of life[8]. If lightning on the early Earth was relatively rare, this could in turn have limited the production of prebiotic organic compounds. However, there were likely sub-arial volcanic islands present where lighting would have been common[9]. As shown above, the Hunga Tonga-Hunga Ha'apai eruption had a peak fl^{-2} somewhat greater than that over the entire Earth during its most vigorous hour of the eruption. The occurrence of volcanic island lightning scales with the island size[9], with the maximum being in the 10^2 to 10^3 km^2 range, perhaps similar to those on the early Earth.

The island volcanoes also would have expelled water and reduced gases such as carbon monoxide, hydrogen sulfide and hydrogen[10,11]. With the ash, water, reduced gases and lightning, important prebiotic reagents such as hydrogen cyanide, phosphide, aldehydes and ketones as well as some complex compounds could have been generated[8,12]. The discharged water would have produced lakes, pools and ponds on volcano flanks[12]. These prebiotic reagents would have been rinsed off by precipitation and accumulated in these water reservoirs. There, with periodic evaporative concentration, prebiotic syntheses would have taken place, producing important compounds such as amino acids and nucleobases[8,12].

Volcanic islands today tend to be short-lived.[13] Whether this was the case on the early Earth is unknown. Nevertheless, eventually the accumulated prebiotic products would have rinsed off into the oceans during island subsidence. There, further prebiotic molecular evolution could have taken place. Where and when the emergence of life took place in this scenario requires further refinement of the underlying mechanisms and processes. But one thing is certain: "Thunder is good, thunder is impressive; but it is lightning that does the work. *Mark Twain*".

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Figure: A small eruption of Mount Rinjani, with volcanic lightning on the island of Lombok in Indonesia. Photo credit: Oliver Spalt, Taken from Wikimedia Commons.