SUN → EARTH → CRUST → LIFE: QUANTIFYING THE ELEMENTAL FRACTIONATIONS THAT LED TO LIFE ON EARTH. A. Chopra[1] and C. H. Lineweaver[1], [1]Planetary Science Institute, Research School of Astronomy and Astrophysics and Research School of Earth Sciences, Australian National University, ACT, Australia, aditya@mso.anu.edu.au

One way of answering the question 'What is life?' is to look at the ingredients**.** Oxygen, carbon, hydrogen and nitrogen, make up 96.8 ± 0.1% of the mass of life (based on humans and bacteria) [1]. Phosphorus and sulfur together make up 1.0 ± 0.3%. The remaining 2.2 ± 0.2% is dominated by potassium, sodium, calcium, magnesium and chlorine, while 0.03 ± 0.01% is attributed to trace elements such as iron, copper and zinc.

Carl Sagan popularized the idea "We are all star stuff" based on the seminal B^2FH paper [2]. Since then others such as Davies and Koch [3] noted similarities between the composition of humans and bacteria on one hand and the Earth's crust and oceans on the other. They identified the common source of these elements as being big bang and stellar nucleosynthesis. We present correlations between elemental abundances in life [4,5], the bulk Earth, the Earth's crust [6], and the Sun [7] using the most recent and complete data sets in literature and discuss the implications on life in the universe. Fig. 1. is one such comparison between the elemental abundances in the Sun and life on Earth, the two ends of the link: Sun → Earth → Crust → Life.

The elemental composition of planets, moons and asteroids reflects to a large extent the composition of the Sun, except that relative to the Sun, all are depleted in the most volatile elements hydrogen, helium and the noble gases. When the Sun formed from the solar nebula, volatile elements were swept away by the solar wind from the region of the solar nebula where terrestrial planets formed. Rocky planets like Earth, accreted from the fractionated nebular condensate whose composition in refractory (but not volatile) elements closely resembles the solar composition [7].

Input from chondritic material and a late-veneer of volatile elements due to the impacts of comets and other objects from beyond the snow-line led to a crust which exhibits elemental abundances more like the Sun depleted in volatile elements than the bulk Earth which includes the core enriched in refractory elements like iron.

The process of formation of a star like the Sun, out of a collapsing molecular cloud polluted by earlier stellar processes, is observed wherever there are molecular clouds. The associated process of terrestrial planet formation is probably common in the universe and it is likely that the elemental abundances of the surfaces of extrasolar habitable planets will also follow cosmic abundances as represented by the Sun.

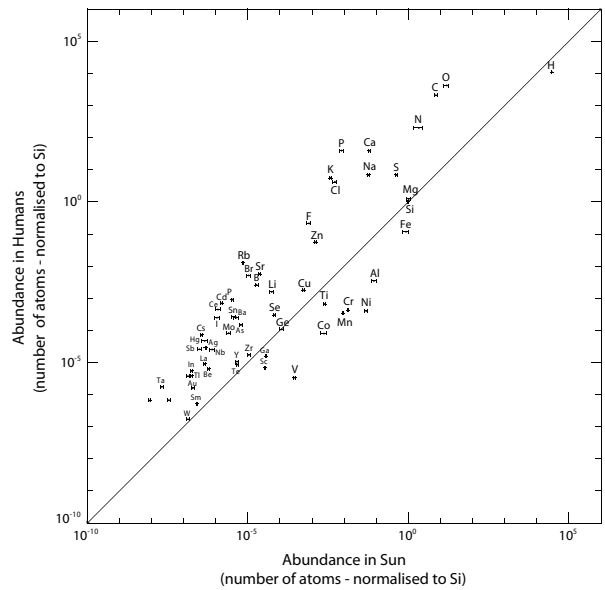

Fig. 1. The positive correlation between elemental abundances (by number of atoms) in life (as represented by humans [4]) and the Sun [7]. The high abundances of volatile elements such as hydrogen, helium and the noble gases in the Sun result in the remaining elements being offset from the 1-to-1 diagonal line towards the left on the x-axis. The abundances are normalized to silicon. Modified from [1].

Bowen [8] drew attention to the correlation that life on Earth is based on the most abundant elements in the environment. Life does not reside in the mantle or the core of the Earth and so its elemental abundances are more reflective of abundances in the crust (specifically the biosphere) than abundances in the bulk Earth.

Since, the abundance of most elements in life forms and their environments on Earth follow cosmic abundances, perhaps extraterrestrial life will also exhibit elemental abundances similar to those found in life on Earth.

Alternatively, if extraterrestrial life is to be found on planets and moons with environments where elemental abundances are different to those found on Earth, it may be possible to predict the elemental abundances and metabolic processes of the extraterrestrial life based on the observed elemental fractionation between: a) the Sun and the bulk Earth, b) the bulk Earth and the crust, c) the crust and the biosphere, and d) the biosphere and life forms.

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