EVIDENCE FROM METEORITES FOR MULTIPLE POSSIBLE AMINO ACID ALPHABETS FOR THE ORIGINS OF LIFE.
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Introduction: A key question for the origins of life is understanding which amino acids made up the first proteins synthesized during the origins of life. The canonical set of 20 – 22 amino acids used in proteins are all α-amino, α-hydrogen isomers that, nevertheless, show considerable variability in properties including size, hydrophobicity, and ionizability. Abiotic amino acid synthesis experiments such as Miller-Urey spark discharge reactions produce a set of up to 23 amino acids, depending on starting materials and reaction conditions, with significant abundances of both α- and non-α-amino acid isomers. [1]. These two sets of amino acids do not completely overlap; of the 23 spark discharge amino acids, only 11 are used in modern proteins (Figure 1). Furthermore, because our understanding of conditions on the early Earth are limited, it is unclear which set(s) of conditions employed in spark discharge or hydrothermal reactions are correct, leaving us with significant uncertainty about the amino acid alphabet available for the origins of life on Earth. Meteorites, the surviving remnants of asteroids and comets that fall to the Earth, offer the potential to study authentic samples of naturally-occuring abiotic chemistry, and thus can provide an alternative approach to constraining the amino acid library during the origins of life.

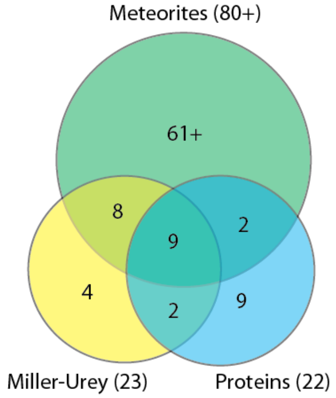

Figure 1. Relationship between amino acids found in meteorites, used in contemporary biology (proteins), and produced in Miller-Urey spark discharge experiments.

Results and Discussion: More than 80 amino acids of extraterrestrial origin have been unambiguously identified in meteorites. These amino acids range from two to ten carbons in length and possess considerable structural diversity, including 11 amino acids found in proteins, and more than 70 not found in contemporary biology [2; Figure 1]. However, much of our understanding of meteoritic amino acids has been shaped by analyses of the Murchison CM2 chondrite and meteorites that are closely related [3, 4]. Because the parent bodies of meteorites accreted at approximately the same time as Earth but in a range of locations in the solar nebula, they sampled a variety of chemical conditions including differences in amino acid precursor compositions (water, hydrogen cyanide, ammonia, aldehydes/ketones etc.) and parent body conditions (mineralogy, thermal and aqueous alteration etc.). There are 45 distinct groups of meteorites, allowing us to analyze samples that experienced a variety of nebular conditions [3].

Over the past decade, we have determined the amino acid contents of meteorite groups not previously analyzed [1, 6-8]. These analyses have revealed a number of trends, including the effects of parent body alteration conditions on amino acid abundances and structural diversity. Perhaps most notably, the predominance of α-amino acids observed in Murchison-like meteorites is not representative of meteoritic amino acids in general. These findings have important implications for types and amounts of amino acids delivered to the early Earth by meteorites. In addition, to the extent that parent body conditions on a given meteorite are relevant to local environments on the early Earth, the amino acids likely to be produced in a range of conditions can be constrained. Our results suggest that there may have been a multitude of regions on Earth with discrete amino acid alphabets for the origins of life on Earth.

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