Dinosaurs, Trace-metals and Hydrocarbons: Decrypting the Metallome of Life

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Abstract

The evolution of life on Earth has given rise to the endless forms most beautiful that weave a complex web of origin, diversification and extinction. Unraveling genomes and reconstructing molecular phylogenies can now measure the evolutionary distance between living species. However, the fossil remains that litter deep time and record the evolution of all life on Earth are not so easy to characterize.

The DNA that so defines life is a fragile molecule, unable to resist even the gentlest ravages of geological time. The molecule of life is only recovered from rare samples no older than 1 million years, but only in rare and exceptional circumstances. The proteome might be the next logical focus, as proteins are more robust and might leave tantalizing evidence for the very building blocks of life. Here the frustration is also evident to those who study such ancient molecules, as anything older than 10 million years is hard to identify. However, the breakdown of organic material through time can yield hydrocarbons that provide unequivocal evidence that such molecules can survive, albeit in an altered state, through deep time. Hydrocarbons in crude oil are composed mostly of alkanes, cycloalkanes and several aromatic hydrocarbons with additional organic compounds containing nitrogen, oxygen and sulfur, and dilute amounts of trace-metals (iron, nickel, copper, zinc and vanadium). The composition of crude oil is a chemical ghost of past life that might well be echoed in fossils.

The very atoms that construct biological materials can and do survive the sands of time, else we would not find fossils, but can these atoms be imaged to relay information about the original organism? Recent work has shown that there are elemental biomarkers that we can identify and map in both living and extinct organisms (plants and animals). Such biomarkers are powerful tools when unlocking the puzzle of organismal biology, physiology and the very biosynthetic pathways that built, regulated and drove the evolution of life. For the very first time, synchrotron-based imaging techniques are allowing us to piece together the complex relationships between trace-metals, rare earth elements and the discrete tissue types that comprise life, both past and present.

The fragile paradigm that fossils merely represent shadows of past life clearly has to shift, not with the promise of DNA or intact proteins, but the fundamental building blocks of life, including organometallic complexes and the breakdown products of original proteins. Through the analysis of exceptionally preserved fossils from different ages and contrasting preservational environments, we have begun to chemically resolve and map such discrete elemental biomarkers. These results are permitting us to develop a model for degradation of biological tissue, improve our ability to use biomarkers to resolve discrete biosynthetic pathways, and possibly begin to ask new questions on the evolution of life on Earth. This elemental “Rosetta stone” can help us translate the chemical residues that survive in fossils to an intelligible record that provides detailed information on tissue types, composition, trace metal inventories and their distribution through deep time. While the genome

and proteome leave scant evidence to resolve the biology of life, the metallome has the potential to push back our understanding of life by billions of years!