A half century in the study of isotopic biosignatures: Tribute to the late Dr. Harmon Craig

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The idea of using stable isotope compositions of light elements, particularly of the element carbon, as biological signatures (biosignatures) dates back to the dawn of stable isotope geochemistry. In the wake of the discovery of large variations in $^{13}C/^{12}C$ ratios among various carbon-bearing materials including plants, contentious debates ensued between Kalervo Rankama and Harmon Craig in the early 1950’s whether the origin of graphitic carbon in ancient rocks (biogenic or abiogenic) can be uniquely identified by its isotopic compositions.

During the last half-century, we have made great strides in understanding biogeochemical processes in modern and ancient terrestrial, and extraterrestrial environments. Recent developments of novel analytical techniques (continuous-flow, secondary-ion, and MC-ICP mass spectrometry) and the birth of new geosciences fields (geomicrobiology, astrobiology) has prompted resurgence in the application not only of conventional light stable isotopes, but also of those of metal and other intermediate elements.

This year marks the golden anniversary of the classic paper by Dr. Harmon Craig titled "*The Geochemistry of the Stable Carbon Isotopes*" GCA 3, 53-92 (1953). How much progress have we really made? Recent debates on the origin of graphitic carbons from Early Archean (3.5 – 3.8 Ga) metasediments are very much reminiscent of the Rankama-Craig debate. Several studies on natural gases, organic compounds, and others clearly demonstrated that their isotopic compositions alone are not a unique criterion for biogenic origin. Recent developments in our understanding of isotope biosignatures will be discussed as a tribute to the late Dr. Harmon Craig, whose contributions to this subject of primary importance, among many others, stand tall even after half a century.

Anhydrobiosis, a Capacity for long-term survival of hostile environmental conditons

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With its current thin atmosphere of a mean atmospheric pressure of 560 Pa, the surface of Mars provides an extremely cold and dry climate, and does not allow the presence of liquid water which is considered as one of the prerequisites for life to appear and evolve on a planet. However, the recently observed “gullies” in the inner walls of impact craters on Mars are interpreted as geologically young erosionally landforms produced by a combination of groundwater seepage, surface runoff, and debris flow. Therefore, the appearance of local interim “wet” areas on the surface of Mars cannot be excluded. On Earth, several organisms have developed a strategy of desiccation tolerance, called anhydrobiosis, for surviving unfavorable dry interim conditions. Examples of such anhydrobiotic organisms are the slime mold *Dictyostelium*, cysts of the brine shrimp *Artemia salina*, dry larvae and adults of several species of nematodes, and microspores of *Selaginella lepidophylla* which is known as resurrection plant or "Rose of Jericho". These anhydrobiotic organisms generally possess good reserves of high energy compounds (e.g., ATP) and of membrane stabilizers (e.g. trehalose) which enhance survival following drying and rehydration. Among the microorganisms, bacterial endospores have been considered as the hardiest forms of life on Earth. In the dormant state, spores undergo no detectable metabolism and exhibit a high degree of resistance to inactivation by various physical insults including extreme desiccation. The high resistance of *Bacillus* endospores is mainly due to two factors: (i) a dehydrated, highly mineralized core, the cytoplasm, enclosed in a thick protective envelop, the cortex and the spore coat layers, and (ii) the stabilization of their DNA through saturation with small, acid-soluble proteins whose binding greatly alters the chemical and enzymatic reactivity of the DNA. In the presence of appropriate nutrients including liquid water spores respond rapidly by germination and outgrowth, resuming vegetative growth. Hence, spore formation represents a strategy by which a bacterium escapes temporally and/or spatially from unfavorable conditions: spores exhibit extreme longevity and can be relocated e.g., by wind and water, to remote areas. Through this high resistance against environmental extremes, especially desiccation, bacterial endospores are suitable model systems for studying the possibility that microorganisms might adapt to an extremely dry environment with short intervals of humid phases, as they might have existed on Mars.