Ecole doctorale Sciences Chimiques / ED 250

Thesis subject : Hydrothermal alteration of organic matter and minerals in astrophysical objects: asteroids and icy satellites

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This phD project concerns the origin and chemical evolution of the extraterrestrial organic matter in past or present aqueous environments of solar system bodies. This thesis is in line with the preparation of future space missions that will explore the solar system bodies and especially carbon-rich asteroids or icy satellites (such as JUICE and Europa clipper). Primitive bodies of our solar system, such as comet and asteroids are organic-rich and their studies can give significant information on the nature of the organic matter delivered to planets and satellites of the solar system. While comets are believed to remain unmodified since their formation 4.5 billion years ago, carbon-rich asteroids are known to have been altered by secondary processes, typically hydrothermal alteration. The recovery of meteorites on earth and their analysis give precious information on the final composition of the organic matter after this alteration. Besides these interplanetary objects, icy satellites such as Europe, Enceladus, can be reservoirs of a large organic matter that would be processed in aqueous environment and may be favorable for the emergence of life. The evolution of the organic matter in the primitive bodies (such as asteroids) and in the icy satellite are essential to understand what kind of molecules can be involved and available for the emergence of living systems. Furthermore, a large part of matter in primitive objects is inorganic (minerals, salts) and has to be taken into account next to the organic one.
The thesis aims to experimentally constrain the behavior of organic and mineral phases, representative of the one accreted in primitive object at the dawn of the solar system, during secondary alteration in asteroids and icy satellites.

Our astrochemistry team at PIIM has developed since many years experimental devices to simulate the evolution of the organic matter in the solid phase from the molecular cloud to the early phases of the solar system. This is the primary processes that will transform atoms or simple molecules (such as CO, CO2, CH3OH, NH3) observed in the interstellar medium into complex organic compounds such as nitrogen heterocycles, sugars, aliphatic compounds and many others. It has been shown that this chemistry occurs mainly in the solid phase of the interstellar medium, starting from interstellar ices. Experimental conditions are constrained by astronomical observations of the dust grains in the interstellar medium and protoplanetary disks. Basically, an astrophysical ice analog, typical of the environment studied is formed at low temperature (minimum 10 K), and submit to different energetic processes (photon irradiations, thermal reactions). After warming to 300 K, an organic-rich

residue is obtained. Analysis of this residue reveal a close connection with the organic matter found in meteorites. These experiments lead to new discoveries on the chemistry that occurs during the first stage of the solar system formation and have opened new routes to understand the diversity of the organic compounds found in primitive objects.
This primary alteration is an important step to build up the complex network of organic matter evolution from the interstellar medium to the solar system bodies. This work will be the first part of this thesis. Recently, a mineral phase was associated to the ice analog to better simulate the dust grain in the interstellar medium. Futures experiments are request to fully understand the interaction and inter-evolution of both phases during these primary processes and to form an organic-rich mineral residue. The second key step will be to understand the evolution of such organic-mineral residue during the secondary alteration in the primitive bodies. Based on a new experimental setup build up recently in the laboratory, this secondary alteration will be explored as a second and complementary part of this thesis. We will investigate the evolution of organic compounds and organic residue in hydrothermal environment with minerals simulating asteroids or icy satellites. The complementary of primary and secondary processes for the evolution of the organic matter will lead without doubts to new discoveries about the chemical pathways of organic matter evolution in astrophysical environments.

Several analytical techniques will be used to analyze organic and the mineral phases after alteration. Our team is currently using infrared spectroscopy and mass spectroscopy to monitored and characterized ice analog samples, as well as gas-chromatography coupled to mass spectrometry (GC-MS) for the volatile organic compounds, specially developed for understanding the chemistry of the ice analogs. Same techniques will be used for the characterization and formation of organic mineral residues. Additional technics, such as GC- MS, liquid–chromatography coupled to mass spectrometry (LCMS) and Raman spectroscopy, available in the laboratory will be used to analyze the organic matter ex-situ, especially after hydrothermal alteration. At the Aix-Marseille University, we will have the opportunity to characterize our samples with technics such as X-ray diffraction and high resolution electron microscopy (MET). For some samples, we will also take advantage of the synchrotron facility in France (SOLEIL) for X-ray spectroscopy (STXM-XANES). In collaborations, other analyses are available, such as high resolution mass spectrometry FT-ICR (Fourier-transform ion cyclotron resonance mass spectrometry) or NMR.

The student, coming preferentially from a research master on chemistry or physico- chemistry or astronomy/planetology should have a strong knowledge on analytical chemistry, experimental chemistry and a large interest for astrochemistry and planetology.

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