Extensive pyrolysis survey of chondritic meteorites: Organic molecular indicators of secondary process

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[Introduction] Pyrolysis Gas Chromatography-Mass Spectrometry (Pyr-GC-MS) is a common method for analyzing insoluble organic matter (IOM) from carbonaceous chondrites especially for IOM derived from the primitive carbonaceous chondrite CI, CM2, and CR2. In this study, the established technique has been extended to 24 kinds of IOM from CI, CM2, CR2, CO, CV, ordinary chondrites and Tagish Lake. Our aim is to identify compositional characteristics of pyrolysates from IOM that are distinct within and across meteorite groups and to see whether one can deduce organic reaction mechanisms that modified IOM during alteration/metamorphism as a consequence of secondary processes.

[Methods] The IOM was purified by demineralization of each meteorite powder. IOM were loaded into quartz capillary tubes. Flash heating was performed under inert atmosphere using Pyr-GC-MS.

[Results and discussion] Over 170 compounds were identified from IOM in CM2, CR2, and CI chondrites, while one third or less of these compounds were identified from IOM in Tagish Lake, CV, CO, and OC chondrites. The common molecules included a series of PAHs and hetero-atom (O, N, S) containing aromatic compounds such as phenols, ketones, pyrroles, pyridines, and thiophenes. It is noted that in the CI1, CM2, and CR2 chondritic IOM a large fraction of the pyrolysate is observed in the chromatograms as an unresolved complex mixture (UCM). Such UCM can be formed under a hydrothermal condition. CR2 and CI showing continuous hump in their chromatograms have experienced relatively high temperature aqueous alteration compared to CM. The pyrolysate yield was plotted against bulk H/C, Raman spectroscopic parameter D- and G-band widths. That all of plots exhibit reasonable correlations is a simple reflection of the fact that pyrolyzable fraction of IOM is derived from the labile carbon and must decrease as thermal metamorphism transforms this fraction through molecular condensation. This trend in the pyrolysate yield clearly distinguishes between primitive CR, CI, CM IOM and the more thermally altered OC, CO, CV chondrites. The orderly variation of a ratio of 2- / 1- ring PAHs in pyrolysates reflects even within a small change of H/C for CR, CI, CM appears to indicate the different conditions that the meteorites experienced. In addition, an increase of relative abundance in alkylated benzenes with increasing 2- / 1- ring PAHs is seen in order of Bells - Kivesvaara - Mighei - Murchison - Cold Bokkeveld. The ranking is somewhat similar to that of aqueous alteration degree evaluated by mineralogical studies. It should be noted that two- and more ring PAHs in pyrolysate are not necessary original constituents of macromolecule, and rather, that they are secondary products resulted from non-aromatic structures, particularly hetero atom bound-branched alkyl moieties between aromatic moieties. These moieties are probably susceptible to formation by photo-irradiation of alkyl carbons with ices. Thus, a linear relationship between 2- / 1- ring PAHs and alkylbenzenes appears to be reflected by the progress of photochemistry accompanied with low temperature aqueous alteration, mainly for CM2. The total abundance of O-containing compounds in pyrolysates of IOM from CM, CI, and Tagish Lake chondrites was plotted with that of S-containing compounds. An increase of both compounds was seen in order of Murchison - Mighei - Cold Bokkeveld - Ivuna - Bells except that Tagish Lake was not in a range of the sequence. This distribution roughly corresponds to the degree of aqueous alteration degree among carbonaceous chondrites. Thus, a large portion of oxygen- and sulfur- containing compounds in pyrolysates from chondritic IOM could be resulted from the progress of aqueous alteration. Therefore, the molecular distributionin the pyrolysate of IOM, in many cases, provides a robust signature of meteorite group and may provide unique information on chemical history of the respective meteorite parent bodies.