Results and discussions: 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, benzaldehydes, benzoic acid, dibenzofuran, pyroles, pyridines, benzonitrile, and thiophenes. Of the distributions of compound groups in the pyrolysis products, the abundances of PAHs were similar for all IOM, but are almost absent in CV, CO, OC, and Tagish Lake. This difference likely indicates modification of the IOM structure during thermal alteration on the parent bodies. Some pentagonal ring containing PAHs might have been incorporated into the molecular condensation during thermal alteration. 

Introduction: Pyrolysis Gas Chromatography-Mass Spectrometry (Py-GC-MS) is a common method for analyzing insoluble organic matter (IOM) from carbonaceous chondrites [1-4] especially for IOM derived from the primitive carbonaceous chondrite CI, CM2, and CR2. In this study, the established technique has been extended to 23 kinds of IOM from CI, CM2, CR2, CO, CV, ordinary chondrites and Tagish Lake. The aim is 1) a comprehensive identification of compositional characteristics of pyrolyses from IOMs within and across meteorite groups and 2) elucidation of modification mechanisms of IOM during alteration/metamorphism on the meteorite parent bodies.

Experimental: The chondritic meteorites analyzed were CM2 (Murchison, ALH83100, Cold Bokkefeld, Kivasvara, Bells, Murray, Mighei), CR2 (MET01070, GRO95577, EET92042, Al Rais), CI (Ivana), Tagish lake, CV (Kaba, Mokoia, Vigaran, Leoville, Allende, MET00430), CO (Kainzach, ALH77003), and ordinary (OC) (Tieshitz, Krymka). The IOM was purified by CsF/HF demineralization of each meteorite powder. ~0.5 mg of IOM were loaded into quartz capillary tubes. Flash heating (610°C for 10 s) was performed under helium atmosphere using CDS 1000 Pyr-GC-MS (Agilent 6890).

Fig. 1. Relative compositions of different types of PAHs identified from the representative 12 IOM by pyrolysis-GC-MS.
The relative abundances of O-containing compounds in different groups (e.g., pyridines, methylpyroles, and benzonitrile) varied regardless of chondrite groups. Pyridines were relatively abundant in two CR2 and Murchison. Benzonitrile was detected from IOM in every meteorite group. Most IOM from CV, CO, OC, and Tagish Lake, and a few IOM from CM and CI contained only benzonitrile. The resistance of benzonitrile to thermal alteration might be explained by reaction of organic acids or benzaldehyde with ammonia to nitrile [11]. In this study, the ratios of benzoic acid to benzonitrile for CM, CR, and CI were > 1 while those for CV, CO, OC, and Tagish Lake were < 1 or 0. Likewise, the ratios of benzaldehyde to benzonitrile for CM, CR, and CI were > 2 while those for CV, CO, OC and Tagish Lake were < 2. This evaluation shows that benzonitrile could be a reaction product of benzoic acid or benzaldehyde in the IOM structure with ammonia, ammonium salts or pyridine on the parent bodies during the progress of the thermal alteration.

The relative abundances of S-containing compounds (alkylated thiophenes (C1 – C3)) and alkylated benzothiophenes (C1 and C2)) were determined for IOM from CR, CI, and CM chondrites (Fig. 3). The abundance of these compounds reflect enrichment of alkyl C of IOM from these chondrite groups. In contrast, only C1-thiophene and benzo thiophene dominate the pyrolysates from CV, CO, OC and Tagish Lake, probably reflecting the loss of alkyl C during progress of parent body alteration. The disappearance of dibenzo thiophene from these chondrites may be due to thermal cracking of the compound to benzothiophene, biphenyl, benzene, and dimerization [12].

**Conclusion:** The molecular distribution in 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.