A Record of Organic Bearing Fluids on Early Planetesimals in the Unclassified Carbonaceous Chondrite Ningqiang

H. G. Changela[1], Y. Lin,[1] L. Gu[1], J. Hao[1], X. Tang[1], X. Xia,[2] J. Li[1] J. Wang[3]
[1]Institute of Geology & Geophysics, Chinese Academy of Sciences IGGCAS, Beijing, China [2]Guilin University of Technology, Guilin, China. [3]Canadian Lightsource, Saskatoon, Canada

Introduction: Records of abiotic fluid-based organic systems provide constraints on the physical chemistry of organic material (OM) in the early Solar System prior to the occurrence of life on Earth. Organic fluids synthesized on Earth based on simple carbon, hydrogen, oxygen and nitrogen chemistry provide an account of the formation of labile organic compounds pertinent towards the building blocks of life [1]. Macromolecular organic compounds with affinities to the major fraction of total organic carbon (TOC) delivered to Earth – insoluble organic matter (IOM) – have also been synthesized [e.g. 2]. Here we report a unique record of organic fluids in the early Solar System in the unclassified carbonaceous chondrite (CC) Ningqiang.

Chondrites are samples of early planetesimals. Microanalytical studies of soluble and insoluble organic bulk meteorite separates coupled with the characterization of OM *in situ* provide a comprehensive account of chondritic OM. Most chondritic TOC is in the form of IOM [3]. In the CI, CR, CM chondrites, although their organic mass fractions are minor to trace in bulk [4] their volumetric distributions are ubiquitous in CI, CR, CM matrices at the nano-scale [5]. Micron to submicron organic particles are ubiquitously distributed across CI, CM and CR matrices. They are mostly surrounded by either submicron (Fe, Mg, Al) hydrated amorphous silicate or phyllosilicate grains. A diffuse organic component carboxylic-richer but aromatic-poorer OM than organic particles also occurs within volumes of amorphous silicates and phyllosilicates which majorly constitute the mineralogy of CI, CM and CR matrices [5]. The morphology, distribution and molecular composition of OM in the other CV, CO, CK, CH, CB chondrites is less clear than the CI, CR and CM carbonaceous groups that are more abundant in TOC.

Sample and Methods: Ningqiang is an anomalous CC with CV and CK affinities that landed in the Shanxi Province, China in 1983. Its OM abundance is however uniquely in similar amounts to the CM and CR chondrites [6]. Ningqiang is a soft, crumbly meteorite. Approximately 50 % of the meteorite is fine grained porous matrix around harder chondrules and CAIs. It is thus a challenging sample for obtaining a flat, polished surface of matrix. Raman-SEM-NanoSIMS-STXM-TEM was coordinated on hand polished fresh chips of Ningqiang, as well as a thin section embedded under vacuum conditions aiming to confine EPOXY only a few mm in boundary of the section. Raman Spectroscopy was performed on the thin section and a fresh chip at Guilin University of Technology, China, with a Renishaw *Invia* 514 nm laser source. Electron microscopy and isotopic imaging was performed at IGGCAS with a Zeiss *Auriga* Dual Beam FIB-SEM and a Cameca NanoSIMS 50L respectively. In order to obtain a large coverage of polished surface for NanoSIMS, an unconventional ~40 x 15 x 1.5 µm FIB section was extracted from an observed matrix region of one of the chips. After NanoSIMS, the FIB section was further thinned down to electron and soft X-ray transparency (100-150 nm) for Scanning transmission X-ray microscopy (STXM) at the Canadian Light Source, Beamline 10 ID-1. TEM was perform at IGGCAS and JEOL, Beijing with the JEOL 2100 and JEOL JEM F200 respectively.

Results and Discussion: Unlike organic particles [7] surrounded by mostly amorphous silicate and phyllosilicate grains containing diffuse OM in the CIs, CRs and CMs [5], the OM in Ningqiang occurs as a network or groundmass of material around mostly fine scaled fayalite grains (Fig. 1). Secondary phases occur in this organic groundmass such as sulphides (Fig. 1a) replacing these Fe-rich olivines also containing minor Mn and Cr, minor phosphates and Na-bearing phases. Fe and Fe, Ca-rich pyroxenes also occur. Thus the simplest explanation for the formation of this network of OM is by fluids. The organic material also contains nano sulphides and chromites. Raman mapping on both the thin section and chip display identical Raman spectra ubiquitously across matrix and chondrule rims with spectra consistent with the elevated thermal histories in recorded in OM from other chondrites [8]. Carbon XANES measured by STXM shows the characteristic 3-band aromatic/olefinic (C=C) – carbonyl/phenol (C=O) – carboxyl/ester (COOH) functional chemistry of IOM but with more absorption due carboxyl/ester functional groups than organic particles in e.g. the CR chondrites. Although Raman and C-XANES displays some differences between Ningqiang and e.g. CR OM, $CH_2/^{12}C$ ratios compared between Ningqiang and the CR chondrite GRV 0121710 [9] measured the same way by NanoSIMS, are similar.

Conclusion: The Ningqiang carbonaceous chondrite records a unique account of organic material reported in any CC. Its organic inventory mostly occurs as a network or groundmass surrounding secondary mineralogy in its matrix. This suggests the role of fluids contained under the Ninqiang parent body leading to its formation.

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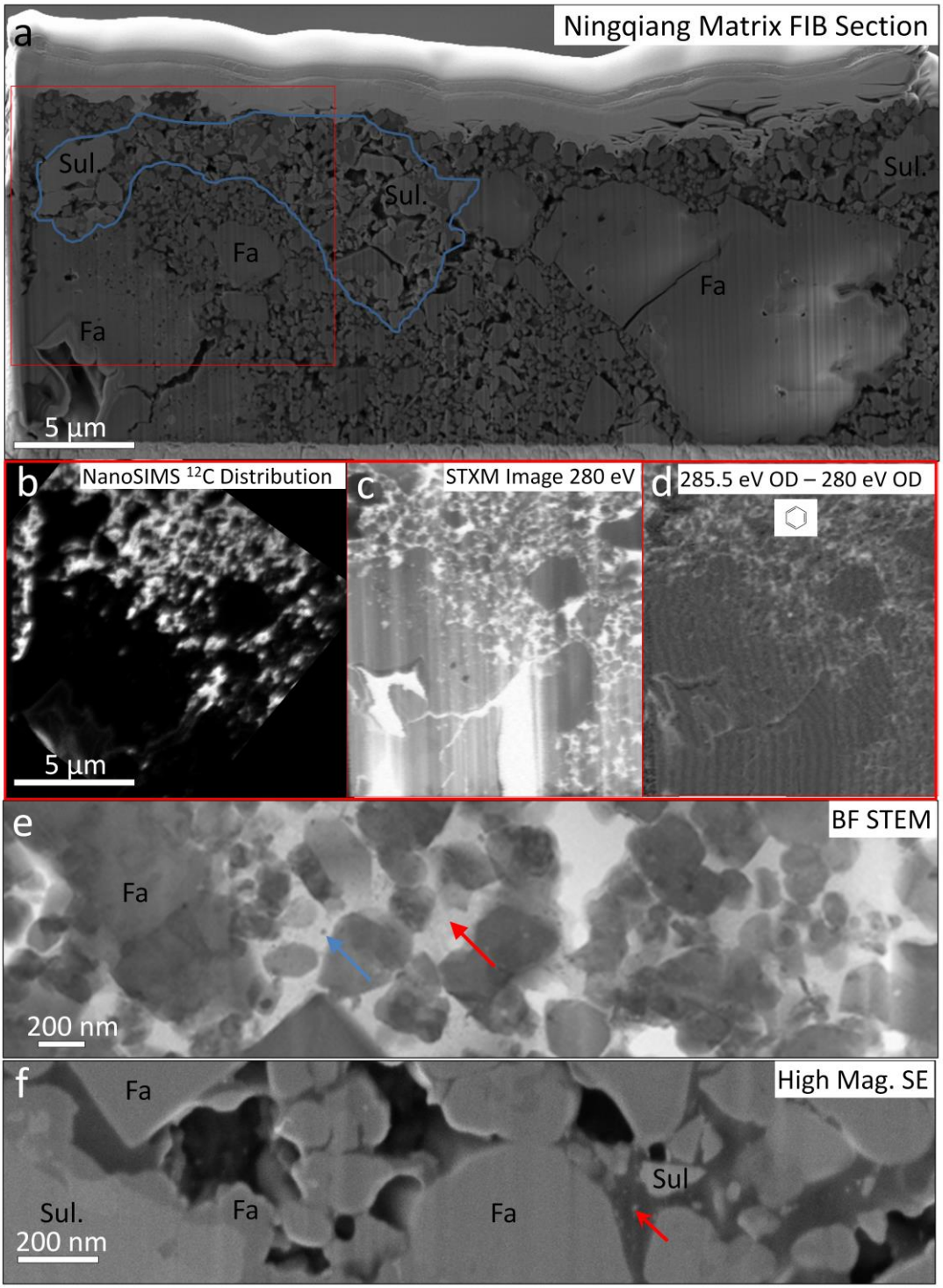

Figure 1. (a) SEM SE image of an atypical large FIB section extracted from a fresh chip of Ningqiang matrix. Grey grains are mostly fine grained fayalites. The red rectangle shows the region of the maps in the lower images. The blue outline shows brighter sulphides replacing the Fe-rich olivine grains that are networked by the darkest grey organic material. (b) NanoSIMS ^{12}C map in the red rectangle region from (a) showing the distribution of carbon networked around the fine fayalite grains. (c) Single energy 280 eV image of the red rectangle in (a). (d) Aromatic carbon map (285.5 eV - 280 eV optical density) corresponding with the NanoSIMS ^{12}C map distribution. (e) BF STEM image of a region of another matrix FIB section from a fresh chip of Ningqiang showing the light grey organic network or groundmass in closer detail (red arrow indicates the grey scale of organic network) surrounding the fine grained, mostly fayalites. Nano sulphides and chromite grains also occur in the organic network as very fine dark specs in the organic groundmass (e.g. blue arrow) (f) SEM SE image of another FIB section from a fresh chip of matrix. The organic groundmass now is in dark grey. The red arrow points towards both the organic network surrounding the mineralogy as well as the nano sulphides or chromite grains.