

## Reduction of FeO-rich chondrules in Kakangari and enstatite chondrites

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Kakangari (K) is a unique chondrite [1] whose bulk chemical composition is similar to enstatite (EC) and ordinary chondrites (OC). However, its high matrix abundance is more comparable to carbonaceous chondrites (CC). K chondrules have oxygen isotopic compositions indistinguishable from EC chondrules [1], suggesting that there might be a genetic relationship between the chondrules in these two chondrite groups.

We studied a suite of Kakangari chondrules [2] and noticed that they are similar to EC3 chondrules [3,4] in the following aspects: (a) no typical FeO-rich type II chondrules are present, (b) most chondrules are pyroxene-rich and (c) many chondrules contain SiO<sub>2</sub>. These characteristics make K and EC chondrules more similar to each other than to OC and CC chondrules. However, there are also major differences [e.g. 5] which imply that EC chondrules formed in a more reducing environment. For example, most chondrule silicates are more Mg-rich in EC ( $0.1 < \text{Fa} < 2.8$ ,  $0.4 < \text{Fs} < 2.2$  [3]) than in Kakangari ( $2.5 < \text{Fa} < 5.5$ ,  $3 < \text{Fs} < 16$  [2]) and their sulfide mineralogy is different (Mg-, Mn-, Ca-bearing sulfides in EC chondrules vs. troilite only in K chondrules).

Even though no typical FeO-rich type II chondrules are present, ubiquitous FeO-rich silicates have been observed in EC chondrules [e.g. 6-8]. Their characteristics and chemical compositions are very similar to FeO-rich pyroxenes and olivines in K chondrules [2]. In both K and EC chondrules, FeO-rich silicates show clear evidence that they have undergone solid-state reduction (e.g. reverse zoning, Ni-poor metal and troilite blebs, presence of SiO<sub>2</sub> [2,6-8]). This reduction must post-date the first chondrule forming event.

[7] proposed a multi-stage model for EC chondrules that contain FeO-rich pyroxenes. These chondrules were originally formed in an oxidizing environment and then underwent solid-state reduction in a more reducing nebular environment. Furthermore, [8] showed that oxygen isotopic compositions of FeO-rich and FeO-poor silicates in an EH3 chondrite have the same oxygen isotopic compositions.

We suggest that FeO-rich K chondrules originated from similar FeO-rich precursor material and underwent a similar, but less extensive reduction event. Subsequently, the evolutionary paths of FeO-rich K and EC chondrules diverged.

### References

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## *In situ* characterizing the structural and chemical evolution of biopolymers during advanced fossilization: From Nature to experiments

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The Biogenic origin of fossil organic matter (OM) contained in metamorphic rocks is usually not easy to assess. Diagenetic and metamorphic processes are indeed responsible for the transformation of primary biogenic OM, leading to the loss of original chemical and structural information. However, it has been observed that morphological, textural and chemical bio-signatures might be preserved in some contexts [1]. To understand the conditions leading to such preservation, we have investigated the evolution of reference carbonaceous biocompounds (e.g. sporopollenin, lignin and cellulose) during pyrolysis using Raman and near edge x-ray absorption fine structure (NEXAFS) spectroscopy at the  $\mu\text{m}$  down to the nm scale. We hence describe and constitute a reference dataset for the differential evolutions of these precursors during carbonification and graphitization. Using the same techniques, we have *in situ* characterized, at multiple length scales, fern-related spores and vascular tissues within diagenetic rocks from Alsace (France) and within high grade metamorphic rocks of the same Triassic age (230 Ma) from the western Alps (France)<sup>1</sup>. Biogenic OM as well as associated various carbonates minerals were mapped at the micrometer scale using Raman imaging. Ultrathin sections were prepared by Focused Ion Beam milling for further structural and chemical imaging of OM/minerals down to the nanometer scale with Transmission Electron Microscopy and Scanning Transmission X-ray Microscopy. In particular, the chemical nature of the carbon functional groups composing these OM and their spatial distribution were documented at a submicrometer scale using high spatial ( $\sim 25$  nm) and energy ( $\sim 0.1$  eV) resolution NEXAFS spectroscopy. Altogether, by combining microscopic and spectroscopic imaging techniques, we evidence in these samples systematic textural, chemical and mineralogical heterogeneities which are interpreted as remnants from primary biological structures. Such a multiscale characterization approach sheds new light on the fossilization processes of biogenic OM during advanced diagenesis and metamorphism, and allows for reconstructing their biological heritage which is of particular interest for the study of soft bodied fossils.

### References

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