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The iron redox states of hydrous carbonaceous chondrites and Bennu/Ryugu returned samples

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Chemical and isotopic studies indicate that the different types of hydrous carbonaceous meteorites have distinct origins. Consequently, their iron speciation (e.g., valence state, mineralogy) could reflect different redox environments interspersed in the early solar system, if partially preserved during later parent-body processes. This should be the case since some of these primitive materials are unequilibrated; iron being accommodated in oxides, silicates, sulfides, and even metals in some samples. In this study, we combine synchrotron Mössbauer spectroscopy and X-ray diffraction to characterize iron-bearing phases in CMs exhibiting various degrees of parent-body alteration (Murchison, Paris, and Asuka 12236), C2-ungrouped (Tagish Lake and Tarda), a recently-found CI meteorite (Oued Chebeika 002), and the sample returned from the asteroid Bennu, following the previous work on Ryugu and classical CI samples [1].

Murchison CM contains Fe-rich serpentine and tochilinite, whereas "less-altered" CM samples host metals and poorly-crystalline phases that are more Fe^{3+}-rich than the matrix of Murchison. The C2-ungrouped samples contain iron in magnetite, sulfides, carbonates, and phyllosilicates, but no Fe hydroxides. The C2-ungrouped samples have a higher proportion of oxidized iron than Ryugu sample which represents fresh CI materials, whereas the ratio Fe^{3+}/Fe_{Total} of phyllosilicates appears similar to that of Ryugu. The Mössbauer spectra of OC 002 CI and Bennu include lines from sulfides. This is consistent with typical spectra of Ryugu samples [1], but differs drastically from Orgueil and Alais CI. This supports a previous suggestion [1]: the formation environments of CI materials should have been more oxygen-depleted than previously estimated based on the analysis of CI meteorites that have likely been oxidized on Earth.

The sum of results implies that the variations in the iron speciation of those hydrous chondritic materials cannot be explained by a single oxidation process such as aqueous alteration on parent bodies, but rather suggests distinct formation conditions in different regions of the outer solar system.

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[1] M. Roskosz et al., *MAPS* 59.8 (2024): 1925-1946.