

Anhydrous phases preserved in CI chondrites

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Introduction: CI chondrites are considered to be the most chemically primitive rocks in the Solar System, because their bulk composition (except for volatiles) is similar to that of the solar photosphere [e.g. 1]. Ryugu is also known to be an asteroid composed of materials very similar to CI chondrites [e.g. 2-6]. The nature and origin of the precursor materials of the CI chondrites are however poorly understood because CI chondrites experienced pervasive aqueous alteration, as attested by their abundant secondary phases (i.e., phyllosilicates, magnetite, and carbonates) [e.g. 7]. Isolated anhydrous silicates, chondrules, and CAIs are rare in CI chondrites and Ryugu [6-12]. These phases and objects are a part of the precursors of CI chondrites and retain direct information about the material accreted on the CI parent body(ies). However, there has been no comprehensive study of these minor anhydrous phases in CI chondrites. It is important to understand the formation history of CI chondrites in order to compare with that of the Ryugu samples in more detail. Here, we report in-depth petrographic and mineralogical descriptions of anhydrous phases that survived heavy aqueous alteration of CI parent body(ies).

Samples and methods: We studied polished sections of the CI chondrite Ivuna and Orgueil in reflected light using an optical microscope and by conventional and field-emission scanning electron microscopes (SEM) at Kyoto University. Quantitative analysis of the chemical compositions of the anhydrous phases and matrix phyllosilicates was performed at NIPR using an electron microprobe.

Results and discussion: Both Ivuna and Orgueil meteorites contain a lithology with a high concentration of anhydrous minor phases represented by olivine. Therefore, we call the lithology “olivine-rich lithology”. Because most areas of these meteorites contain few olivine crystals, we call them “major lithology”. Phyllosilicate-rich matrix of the olivine-rich lithology is enriched in Fe, Na and K compared to the major lithology. Mode of olivine (<50 μm across) in the olivine-rich lithology is about 2%. Their forsterite mol% ranges from 62.3 to 99.5. The FeO vs. MnO and FeO vs. Cr_2O_3 diagrams seem to show two different trends, which may suggest two different origins of olivine in the CI chondrites. Pyroxene (<15 μm across) is less abundant than olivine. They are low-Ca pyroxenes and their En mol% is >95 and their Wo mol% is <5.8 but the majority has <1.2. We identified the first well-preserved porphyritic olivine chondrule in Ivuna. The mesostasis of the chondrule has been replaced by abundant magnetite. P-bearing (up to 0.96 wt.%) Fe, Ni-metal (~10 μm) is included in the phenocrystic olivine, and Fe-phosphide is present on the surface of the chondrule. We also identified refractory oxide minerals such as spinel, perovskite, and hibonite, strongly suggesting a link to CAIs. One Fe, Cr-sulfide (S: 40.2 wt.%, Cr: 34.0 wt.%, Fe: 15.0 wt.%, Zn: 3.5 wt.%) was observed in Ivuna. The chemical composition suggests that it is daubr elite or zolenskyite. These minerals are found in enstatite chondrites and form in highly reducing environments. Some pyrrhotite and pentlandite rarely contain Ir-Os-Pt alloys up to about 200 nm. Based on their chemical composition, their formation temperatures range from ~1900 to ~1600 K. Although CI chondrites are generally thought to have accreted in areas far from the sun [13], our results clearly show that materials formed in extremely high-temperature and/or very reducing environments also incorporated in CI chondrite parent body(ies).

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