

Early stages of aqueous alteration in the primitive hydrous asteroids inferred from mineralogical and petrological observation of pristine hydrous carbonaceous chondrites

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論文内容要旨

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学位論文の 題目	<p>Early stages of aqueous alteration in the primitive hydrous asteroids inferred from mineralogical and petrological observation of pristine hydrous carbonaceous chondrites.</p> <p>始原含水炭素質コンドライト隕石の岩石鉱物学的観察から推定される含水始原天体の初期水質変成環境</p>		

論文要旨

Part I.

Transmission electron microscope (TEM) observation of the least altered grains from Paris CM 2.9 chondrite clarified the formation process and sequence of various minerals during incipient aqueous alteration. (1) Primary silicates and amorphous silicates in matrix were not altered to serpentine. The crystallinity of the silicates is heterogeneous. (2) Calcites are the first phase to precipitate from fluids. Some calcites precipitated with sulfates (bassanite and Na-sulfates). (3) In the periphery of calcites, Fe-pure tochilinite, serpentine, and minor TCIs (or TCIs-like poor-crystalline phase) formed together. There are abundant empty spaces in it. These three minerals exhibit stacked structure and tochilinite is the first phase formed among these minerals.

These observation indicates that there was the initial large fluid in the periphery of the calcite and it caused the incipient aqueous alteration; that is, slight reaction with nearby matrix amorphous silicates and precipitation of calcite and its peripheral minerals. The absence of serpentine in matrix indicates that the aqueous alteration occurred at almost 0 ° C for very short durations. The sequence of the minerals in periphery of calcites reflects the changes of fluid conditions. The initial fluids had CO_3^{2-} and was supplied several cations from nearby matrix minerals. The CO_3^{2-} -bearing alkaline fluid precipitated calcites. Some fluids are sulfur-rich precipitated sulfates with calcites. The further reaction of the fluid with organic matter caused reducing condition of the fluid and tochilinite precipitated. The consumption of Fe and S and further reaction of the fluid with matrix minerals changed the fluid composition into Mg and Si-rich resulting in the formation of TCIs and serpentine at the surface of tochilinites. The short duration of fluid reaction with matrix materials is due to the exhaustion of fluids. The exhaustion was caused by (1) extremely low abundance of fluids in the Paris parent body and/either, (2) sublimation of ice which were formed by re-freezing of fluids with decreasing temperature of the parent body. Therefore, it is suggested that the Paris chondrite came from the surface of the hydrous parent body and the aqueous alteration in it is unequilibrated.

Part II.

Fine-grained lath-shaped dmisteinbergite, a hexagonal form of $\text{CaAl}_2\text{Si}_2\text{O}_8$, was found in a compact type A Ca-Al-rich inclusion (CAI) in the Allende CV_{oxA} chondrite. Based on the textural and crystallographic evidence derived from scanning and transmission electron microscope observations, the following mineralogical alterations processes were found to have occurred in the CAI. (1) Melilite changed to grossular. High densities of vesicles in the grossular indicate that hydrogrossular was the primary alteration phase and it was dehydrated by later metamorphism. (2) Dmisteinbergite formed from hydrogrossular through a reaction with Si-rich fluid. (3) Nano-sized biopyribole and grossite formed within dmisteinbergite. (4) Dmisteinbergite transformed to anorthite. (5) Both anorthite and dmisteinbergite were altered to nepheline by reactions with Na-rich fluids. (6) hydrogrossular was dehydrated to grossular. Hydrogrossular, dmisteinbergite, anorthite, and nepheline in the CAI seems to have formed in the course of metasomatism that occurred in the Allende parent body. Except for the hydrogrossular dehydration and completion of nepheline and sodalite formation, these reactions occurred at moderate temperature (200–250°C) in high pH fluids (pH 13–14) according to past experimental studies. Episodic changes in fluid composition seem to have occurred before reactions (2), (4) and (5), because these reactions were not completed before the next reaction started. Higher temperature is required for reactions (5) and (6) to occur. Our observation of the CAI suggests that it experienced multiple episodes of metasomatism as temperatures were rising in the Allende CV_{oxA} parent asteroid.

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論文審査の結果の要旨

本論文では太陽系の始原物質である炭素質隕石に対し、詳細な透過電子顕微鏡による観察を行い、太陽系固体物質の形成および初期進化過程を明らかにした。特に原始惑星系円盤の雪線以遠で形成された水を含む小惑星内部で、水が関与する水岩石反応（水質変成）により、円盤に浮遊していた太陽系の原材料が、小惑星に集積後どのように化学的、鉱物学的に変化していくことを追跡することに成功した。

博士論文の第一章では、Paris CM コンドライトの最も変質していない粒子を透過型電子顕微鏡で観察し、初期の水質変成における各種鉱物の形成過程と順序を明らかにした。(1)原始惑星系円盤由来の無水ケイ酸塩とアモルファスケイ酸塩は不均一に変質が進んだ。大部分はすぐには含水化（蛇紋岩化）しなかった。(2)流体から様々な鉱物が沈殿したが最初に析出したのは方解石である。一部の方解石は硫酸塩と一緒に析出した。(3)方解石の周辺にはトチリナイト、蛇紋岩、および両者の混合層と一緒に形成される。これらの観察結果は、方解石の周辺に流体が存在し、それが初期の水質変成を引き起こしたことを示している。蛇紋岩が形成されていないことから、水質変成は低温短時間で起こったことを示している。方解石の周辺鉱物の配列は、流体条件の変化を反映している。その後、流体と有機物との反応により、流体が還元状態になり、トチリナイトが析出し、その結果 Fe と S が消費された。流体が鉱物と反応する期間が短いのは、流体が枯渇したためと考えられる。その原因は、(1) Paris の母天体である小惑星に存在する流体の量が極端に少ないこと、(2) 母天体の温度低下に伴って流体が凍結してできた氷が昇華したこと、のいずれかであると考えられる。

第2章では、Allende CV コンドライトに含まれる太陽系最古の物質（Ca-Al-rich inclusion : CAI）が小惑星内部の水質変成によりどのように物質変化していくかを詳細に調べている。CAI の中に六角形のドミスタインベルグ石（ $\text{CaAl}_2\text{Si}_2\text{O}_8$ ）を発見した。走査型電子顕微鏡および透過型電子顕微鏡による観察を行い、この CAI 内部では連続的な交代変質作用が起こっていることを明らかにした。(1)メリライトがグロシュラーに変化した。(2)Si を多く含む流体との反応により、グロシュラーからドミスタインベルグ石が生成した。(3)ドミスタインベルグ石の中には、ナノサイズの共生鉱物が同時に形成された。(4)ドミスタインベルグ石の一部はアノーサイトに変化。(5)アノーサイトとドミスタインベルグ石の両方が、Na に富む流体との反応によりネフェリンに変化した。これらの反応は高 pH の流体（pH13-14）中で 200-250°C の温度範囲で起こったと推定される。本論文の CAI の観察では、Allende 隕石の母天体の C 型小惑星内部の温度上昇に伴って、CAI が複数回の交代変成作用を経験したことが示唆された。

これらの隕石詳細観察により得られた知見は、先行研究と比較し大きく進化しており、このことは榎戸氏が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示している。したがって、榎戸氏提出の博士論文は、博士（理学）の学位論文として合格と認める。