論文の内容の要旨

Mineralogical and geochemical study of quenched angrite meteorites: Implication for crystallization process and shock history of ancient igneous rocks in the solar system
（急冷したアングライト隕石の鉱物学的・宇宙化学的研究：太陽系最初期の火成岩の結晶化過程及び衝撃進化の解明）

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Angrites are basaltic achondrites that are depleted in volatile elements and enriched in refractory elements. Most angrites show either quenched or slowly-cooled textures, with quenched angrites having older crystallization ages compared with the slowly-cooled angrites. Quenched angrites often contain Mg-rich olivine xenocrysts with homogeneous cores with variety of Fo#, Ca and Cr contents. However, the origin of olivine xenocrysts is still unclear as well as the formation process of igneous body of quenched angrites. In this study, I performed mineralogical and geochemical study of quenched angrites in order to clarify the crystallization process and shock history of the angrite parent body (APB).

Northwest Africa (NWA) 7203 is a quenched angrite, showing mineralogical features typically not present in other quenched angrites. NWA 7203 exhibits textures whose grain size varies from <10 μm to ~3 mm, while other quenched angrites show only single textures. Mg-rich olivines ($\sim Fo_{64}$) were found only in fine-grained lithologies. I propose that crystallization of NWA 7203 started in the fine-grained lithologies with Mg-rich olivine grains acting as seeds for crystallization. Coarse-grained lithologies were subsequently formed under conditions of slower cooling.

Quenched angrites except a possible cumulate sample (NWA 8535) exhibit three kinds of textures: dendritic, relatively coarse-grained, and anorthite spinifex. Dendritic samples are NWA 1296 and NWA 7203, and they contain dendrites consisting of olivine and anorthite. Relatively coarse-grained samples are Sahara 99555, D'Orbigny and Asuka-881371. Anorthite spinifex samples are NWA 1670, Lewis Cliff (LEW) 87051 and NWA 12774, and they contain extremely elongated anorthites. These textural varieties are considered to be caused by the difference of cooling rates. I estimated cooling rates from atomic diffusion recorded in olivine xenocryst (or early phenocryst) with chemically homogeneous core. The cooling rates are estimated as >300 ^{o}C/hr for fine-grained lithology of NWA 7203, 100 ^{o}C/hr for D'Orbigny, 50 ^{o}C/hr for Asuka-881371, 3 ^{o}C/hr for NWA 1670 and 3.5 ^{o}C/hr for NWA 12774, respectively, corresponding to textural varieties.

Bulk chemical compositions of quenched angrites show strong correlations for some elements as pointed out by Mikouchi et al. (2004), and the trends can be explained by incorporation of variable amounts of Mg-rich olivine xenocrysts into the common parent melt of quenched angrites. The incorporated degrees of olivine xenocrysts are estimated as about 0 % for NWA 1296, Sahara 99555, NWA 7203 and D'Orbigny (considered as 'pristine angrite magma'), 20 % for Asuka-881371 and NWA 1670, and 40 % for LEW 87051 and NWA 12774. REE patterns of quenched angrites also support mixing of 'pristine angrite magma' and olivine xenocrysts.

Modal abundances of olivine xenocrysts are estimated 0% for Sahara 99555 and NWA 7203, ~0% for D'Orbigny, 14% for Asuka-881371, ~11% for NWA 1670 and 13% for NWA 12774. From EPMA analyses, Fo# of the most Mg-rich olivine phenocrysts are Fo_{64} for NWA 1296, NWA 7203 and D'Orbigny, Fo_{65} for Sahara 99555, Fo_{72} for Asuka-881371, Fo_{80} for LEW 87051, Fo_{84} for NWA 12774, and Fo_{85} for NWA 1670, respectively. From the bulk chemical compositions, modal abundance of olivine xenocrysts and the most Mg-rich olivine phenocrysts of quenched angrites, I conclude that olivine xenocrysts are dissolved into ‘pristine angrite magma’, which made the melt composition more Mg-rich, but some of olivine xenocrysts remain unmelted.

To clarify the origin of olivine xenocrysts, I measured both oxygen isotopic ratios of olivine xenocrysts and phenocrysts in NWA 12774. The oxygen isotopic ratios of olivine xenocrysts and phenocrysts in NWA 12774 are identical to AFL, meaning that the olivine xenocrysts in NWA 12774 crystallized in APB, not in other asteroidal sources.

I suggest that quenched angrites came from a single igneous body where bulk chemical compositions and cooling rates change depending on burial depth because textures, cooling rates and bulk chemical compositions of quenched angrites are correlated with each other. I propose the formation process of the igneous body of quenched angrites as follows. (a) The parent melt was produced by the partial melting of the quenched angrite source mantle and trapped mantle olivine grains as xenocrysts during its ascent. (b) The magma flow containing the Mg-rich olivine xenocrysts was erupted onto the surface of APB. (c) Rapid cooling of the lava flow and sinking and melting of the olivine xenocrysts started. (d) Subsequent lava flow came and overlay on NWA 7203 during crystallization. (e) Cooling rates were faster near the surface and slower at a lower part, producing the angrite textural varieties.

The stratigraphy of the igneous body of quenched angrites suggested in this study is similar to that of terrestrial komatiites. When I compared the uppermost layer of each igneous body (chilled margins), QA1 and A1, the finest grain size in each igneous body and fastest cooling rates are similar. The second shallowest layers, QA2 and A2, are similar in terms of the random mineral orientation and cooling rates. The third shallowest layers, QA3 and A3, contain oriented minerals and show similar cooling rates. On the other hand, mineral sizes of spinifex textures are different. The bottom layers, QB and B, are peridotite with a cumulate texture. Although bulk chemical compositions, mineral combinations and several characteristics are different between quenched angrites and komatiites, textural variations, and cooling rates of quenched angrites are comparable to komatiites.

Geological settings of komatiites are considered as continuous eruption from fissure (Hill et al., 1995). The formation process of quenched angrites might be similar to that of komatiites, and if so, a similar eruption event might have occurred at the surface of APB. Taking NWA 7203 into consideration, quenched angrites known until now might originate from an igneous body far from the eruption site because of its textural difference produced by cooling rate change when a subsequent lava flow overlay the earlier surface.