CHONDRITES AND THEIR COMPONENTS: RECORDS OF EARLY SOLAR SYSTEM PROCESSES

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Introduction: Based on the bulk chemical and O-isotope compositions, mineralogy, and petrography, chondrites are divided into 14 groups (carbonaceous (CCs): CI, CM, CR, CV, CK, CO, CH, CB; ordinary: H, L, LL, R; enstatite: EH, EL) and 2 grouplets (K and G). Chondrites consist of three major components: refractory inclusions [Ca,Al-rich inclusions (CAIs) and amoeboid olivine aggregates (AOAs)], chondrules, and fine-grained matrix. Here, I will review recent progress in understanding disk and asteroidal processes recorded by chondrites and their components.

Refractory inclusions, hereafter CAIs, are the oldest (4567.3±0.16 Ma) Solar System (SS) solids [1] formed by evaporation, condensation and aggregation in a gas of approximately solar composition in a hot ($T_{ambient}$ > 1300K) disk region exposed to irradiation by solar energetic particles, probably near the protoSun. Subsequently, some CAIs were melted during transient heating events, possibly by shock waves generated by disk gravitational instability [2]. In type ≤3.0 chondrites, CAIs show large variations in $(^{26}Al/^{27}Al)_0$, from $<5\times10^{-6}$ to $\sim5.25\times10^{-5}$ [3]. These variations and the low initial abundance of ^{60}Fe in SS [4] suggest late injection of ^{26}Al into the protosolar molecular cloud (PMC) by a wind from a nearby Wolf-Rayet star [5]. Although there are multiple generations of CAIs, the ^{26}Al heterogeneity precludes determining the duration of CAI formation with ^{26}Al-^{26}Mg system [6]. The abundance of CAIs in chondrites can be explained if they were episodically ejected from near the Sun to the outer SS and then spiraled inwards due to gas drag [7]. In type ≤3.0 chondrites, most CAIs have uniform $\Delta^{17}O$ of ~ –23‰; however, there is a large range of $\Delta^{17}O$ among CAIs (from ~ –40 to ~ –5‰), suggesting the coexistence of ^{16}O-rich and ^{16}O-poor reservoirs in the disk during CAI-forming epoch [8–10]. The observed variations in $\Delta^{17}O$ may be explained if three major O-bearing species in the SS (CO, H_2O and silicate dust) had initially different O-isotope compositions, with H_2O and silicate dust being ^{16}O-depleted relative to both the solar wind $\Delta^{17}O$ of –28±2‰ and even more ^{16}O-enriched CO [11]. O-isotope compositions of CO and H_2O could have resulted from CO self-shielding in the PMC and outer PPD [12]. The nature of possibly ^{16}O-depleted dust remains unclear: it could have been inherited from the MC [11] or initially ^{16}O-rich dust experienced O-isotope exchange in the PPD during FU Orionis outbursts [13] or in spiral density waves [14].

Chondrules: Porphyritic chondrules, the dominant textural type in most chondrite groups, formed by incomplete melting of isotopically diverse solids, including CAIs, fragments of chondrules of earlier generations, and fine-grained matrix during localized transient heating events in different dust-rich disk regions [15]. These observations are consistent with melting of dust-balls by planetesimal bow-shocks [16] and with collisions between chondritic planetesimals [17]. Magnesian non-porphyritic chondrules in CBs formed in an impact-generated gas-melt plume that resulted from high-velocity (>20 km/s) asteroidal collision 4562.49±0.21 Ma [18,19]; at least one of the colliding bodies was probably differentiated [20]. Chondrule formation postdated CAIs and lasted the entire life-time of PPD [21]. The age gap between CAIs and chondrules remains uncertain due to a disagreement of the U-Pb and Al-Mg ages of individual chondrules [21, 22]. Although there are probably multiple mechanisms of chondrule formation, mineralogic and isotopic signatures of chondrules formed by a specific mechanism, except those of CB chondrules, remain elusive.

Matrix: Dust in ISM is dominated by Mg-rich amorphous silicates. In contrast, matrices in the most primitive, type 3.0 chondrites are dominated by amorphous Fe-Mg silicates and crystalline forsterite and enstatite, suggesting thermal processing of primordial MC dust in PPD, most likely during chondrule and CAI formation. A degree of the thermal processing and the abundance of primordial MC material in chondrite matrices remain controversial [13, 23].

Chondrite Accretion Regions: Based on the dichotomy of the whole-rock $\Delta^{17}O$ and nucleosynthetic isotopic variations for Cr, Ti, and Mo, it is suggested that CCs and non-CCs accreted inside and outside proto-Jupiter, respectively [24]. According to the Grand Tack model [25], both chondrite populations were injected into the main asteroid belt during Jupiter's migration. Timing of this migration may have been recorded by CB chondrite-forming event [26].

Aqueous/Metasomatic Alteration: Most chondrites experienced aqueous/metasomatic alteration. Old ^{53}Mn-^{53}Cr ages of aqueously-formed carbonates, fayalite, and kirschsteinite (2.5–5 Myr after CV CAIs) provide the upper limits on the accretion ages of their host asteroids [27–29]. These ages and the inferred conditions of aqueous alteration are consistent with ^{26}Al being their major heating source of hydrated asteroids [30]. $\Delta^{17}O$ of minerals precipitated from aqueous fluids (e.g., magnetite, carbonates, fayalite) correspond to $\Delta^{17}O$ of these fluids. In COs, CVs, and OCs, fluid-rock interaction resulted in mineralogically-controlled O-isotope exchange in CAIs and chondrules [31, 32].

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