THERMAL PROCESSING AND ACCRETION OF SILICATE DUST INTO CHONDRITES AND COMETS. Edward R. D. Scott and Alexander N. Krot. Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Manoa, Honolulu, Hawai'i 96822, USA. (escott@hawaii.edu)

Chondrite matrix minerals: The most abundant matrix minerals in chondritic meteorites—hydrated phyllosilicates and ferrous olivine—formed predominantly in asteroids by fluid-assisted metamorphism. These minerals probably formed from materials like the matrix minerals in three less altered carbonaceous chondrites (Acfer 094, ALHA77307, and Adelaide), viz., μm and nm sized grains of forsterite and enstatite, and amorphous, ferromagnesian silicate [1-2]. The matrix of K chondrite, Kakangari, also contains enstatite and forsterite but has albite and anorthite rather than amorphous silicate [3]. Compositional and structural features of enstatite (ortho-clino intergrowths) and forsterite (high Mn, as in some AOA olivine) suggest that they formed as condensates that cooled below 1300 K at ~1000 K/h. Most amorphous silicates are likely to be solar nebula condensates also, as matrix, which is nearly solar in composition, is unlikely to be a mixture of genetically unrelated materials with different compositions. Here we focus on matrix-chondrule relationships, clues to accretion from chondritic components, and comparisons between matrix, chondritic IDPs and cometary silicates.

Matrix-Chondrule Relationships: Limited oxygen isotopic data for matrix suggest that most crystalline and amorphous matrix silicates formed in the ^{16}O-poor region with chondrules and not in the ^{16}O-rich CAI formation region. Matrix and chondrules are chemically complementary ensuring that the bulk chondrite composition is near solar [4]. Some low-Ca pyroxene crystals in chondrite matrices cooled through 1300 K at ~1000 K/h, a rate comparable to that experienced by chondrules. This suggests that the heating process that vaporized dust to form matrix grains also melted grain aggregates to form chondrules. Shocks, which are the most promising mechanism for melting mm-sized aggregates, also vaporize dust [5]. The presence in matrix material of many volatile elements at near-solar concentrations, implies that matrix silicate dust is unlikely to have condensed at ~0.05 AU [6]; it probably formed under low ambient temperatures >2 AU from the protosun near chondrules.

The absence of melted matrix particles and the chemical uniformity of rims around different types of inclusions and chondrules show that matrix grains accreted together to form rims long after the chondrules cooled. Mineral compositions in igneous rims on chondrules show that the material that accreted to chondrules and was later melted, or was partly molten when it accreted, was chemically similar to the enclosed chondrules [7]. For low-FeO, type I chondrules, the igneous rims are made of low-FeO silicates and may largely have been derived from material that resembled the magnesian silicate component of matrix. For the FeO-rich chondrules (type II), the igneous rims are made of ferrous silicates and may have been derived largely from dust that resembled the amorphous component.

Accretion of chondritic materials: The only chondrule-poor chondrites are CIs, which are rich in organics and water. If dry silicate dust had accreted into planetesimals in the inner solar system, we should expect to find tough chondrites made of metamorphosed matrix without chondrules. This suggests that chondrule formation triggered planetesimal accretion in the inner solar system.

The first cohesive, silicate aggregates in the inner solar system, probably formed by sintering of dust above 1200 K. In the chondrule-forming region, silicate aggregates were melted and collisions between partly melted objects promoted agglomeration into mm-sized chondrules. In the CAI-forming region, forsterite dust and refractory grains accreted into porous amoeboid olivine aggregates [8]. AOAs probably formed from fractal aggregates as a result of surface-area reduction during sintering above 1300 K. Forsterite-poor, refractory dust was presumably sintered into fine-grained CAIs by welding of fractal aggregates.

Mixtures of matrix grains accreted to form rims on chondrules by compaction of fractal aggregates [9]. Matrix silicates, although present in the chondrule-forming regions, did not accrete permanently to cold chondrules until silicate dust from chondrule-forming regions was mixed with presolar grains and solar-system refractory dust. What triggered rim formation? Permanent accretion of rims may have required the presence of sticky organics and ices to glue grains together, or increased impact speeds during chondrule accretion to compact the rimming fractal aggregates.

Although data are sparse, matrix rims on CAIs appear indistinguishable from those on chondrules, even though CAIs may predate chondrules by 1-2 Myr [10]. Presumably early-formed rims on CAIs that were acquired during turbulent mixing [9] were easily eroded. We hypothesize that sticky organics were concentrated near the mid-plane and only abundant during the final stages of accretion.

Presolar grains, refractory dust, organics, and ice. These escaped destruction by shock heating during chondrule formation. Three explanations can be advanced: 1) stochastic survival from shock heating, 2) survival near the disk periphery where pressures were too low for efficient shock heating, or 3) survival at the midplane in meter-sized ice-rich bodies or planetesimal fragments that drifted sunwards. However, the similar concentrations of presolar grains in different kinds of primitive chondrite matrices [huss] is puzzling, The proportion of dust that escaped thermal processing during chondrule formation would decrease with increasing heliocentric distance but large stochastic variations might be expected.

Chondritic IDPs and cometary dust: Crystalline and amorphous silicates in cometary comas [11] and chondritic IDPs [12] resemble silicates in the matrices of the three least altered, C chondrites. Silicate portions of primitive C chondrite matrices, chondritic IDPs, and comets are all largely composed of forsterite and enstatite with Fe/(Fe+Mg) <0.05 and amorphous, and heterogeneous Fe-Mg-Si-O material. Chondrite matrices and chondritic IDPs both contain sub-μm, Mn-rich forsterite and enstatite crystals [13]. IDPs, like primitive matrices, contain enstatite crystals with ortho-clino intergrowths characteristic of rapid cooling at ~1000 K/h from 1300 K [14]. Amorphous particles in chondrite matrices are chemically heterogeneous, may contain rounded grains of metal and sulfide [1] and may be related to GEMS (glass with embedded metal and sulfide) found in IDPs. However, GEMS are 10 × smaller and typically have more magnesian glass [12].

C (4-45%) and presolar grains (~900 ppm) are ~10-100 × higher more abundant in chondritic IDPs than in chondrite matrices [15, 16]. Components in IDPs, unlike chondritic units, accreted hierarchically: matrix units formed matrix aggregates, aggregate IDPs, and cluster IDPs [20]. Nevertheless, the overall resemblance suggests that similar processes helped to form the crystalline silicate particles in the matrices of carbonaceous chondrites and the chondritic IDPs, as well as some fraction of the amorphous particles. Crystalline silicates, which are almost absent (≤0.2%) in the diffuse interstellar medium [17], are abundant in long-period comets (up to 30-50%; 11]. This is generally attributed to thermal equilibration of amorphous silicate precursors in the hot inner regions of the solar nebula and transport outwards by turbulent diffusion [e.g., 18]. Although substantial mixing between the hot inner region and the cool exterior of the solar nebula was needed to mix traces of refractory dust from the CAI-formation region into chondrite matrices and IDPs (Fig. 1), we infer that many crystalline silicates in IDPs formed by condensation in localized heating processes, like matrix grains in chondrites. Nebular shocks, invoked to form magnesian silicates at 5-10 AU by annealing amorphous silicates [19], may also have vaporized and recondensed silicates.

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Fig. 1. Schematic diagram showing how presolar silicate dust, which is largely amorphous (≥99.8%), may have been thermally processed in the nebular disk [21].