A TEXTURAL COMPARISON OF CHONDRULES AND SMELTER-DERIVED DUST: IMPLICATIONS REGARDING FORMATION CONDITIONS

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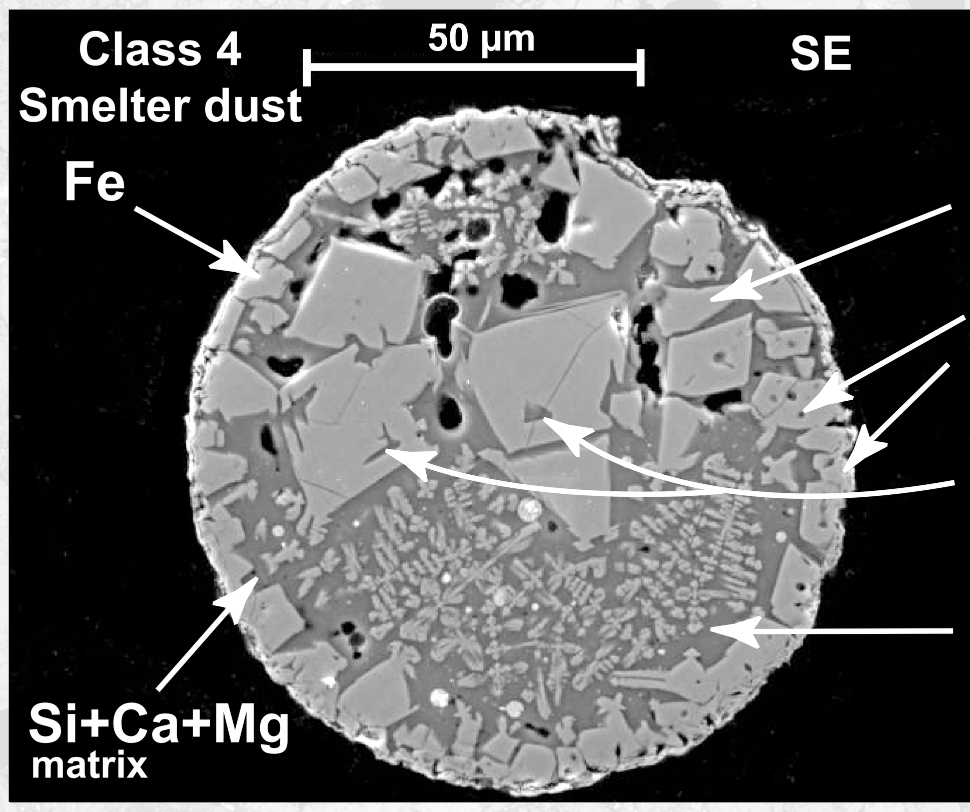
A Textural Comparison of Chondrules and Smelter-derived Dust: Implications Regarding Formation Conditions

Introduction

A comparison of smelter-derived dust particles (RDK), and chondrules in primitive (LL3, L4) ordinary chondrites (RKH), indicates similar crystallization textures, as imaged in back-scattered-electron (BSE) and secondary-electron (SE) modes with a scanning-electron microscope (SEM). An energy-dispersive spectrometer (EDS) system on the SEM allowed qualitative identification of phases. The similarity of textures, first recognized by PAH, allows us to consider implications for the conditions of formation of the dust spherules and the chondrules. Here we compare a class 4 smelter-derived particle [1] from the Horne copper smelter, Rouyn-Noranda, Québec, Canada, and a chondrule from the Saratov (L4) chondrite.

Description, Smelter Spherule



Sectioned Spherule

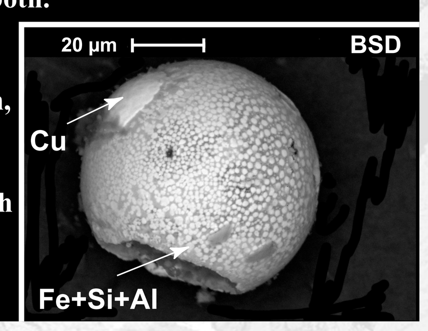
This 100 µm diameter smelter dust particle has

1) porphyritic texture, with euhedral to subhedral chemically homogenous crystals of an iron-rich phase (up to 30 µm) occupying most of the core and

2) smaller euhedral to subhedral chemically homogenous crystals of the same phase concentrated on the rim

Some phenocrysts either contain matrix or have irregular margins or both.

The glassy matrix is rich in silicon, calcium, and magnesium, and encloses iron-rich dendrites and iron-rich phenocrysts.



Whole Spherule

Sphere surfaces range from rough to smooth and often display fine geometric shapes on the exterior. Elements detected on external surfaces include Fe, Fe+Si+Al, Mg, Cu, Ca and Fe+Cu+Si.

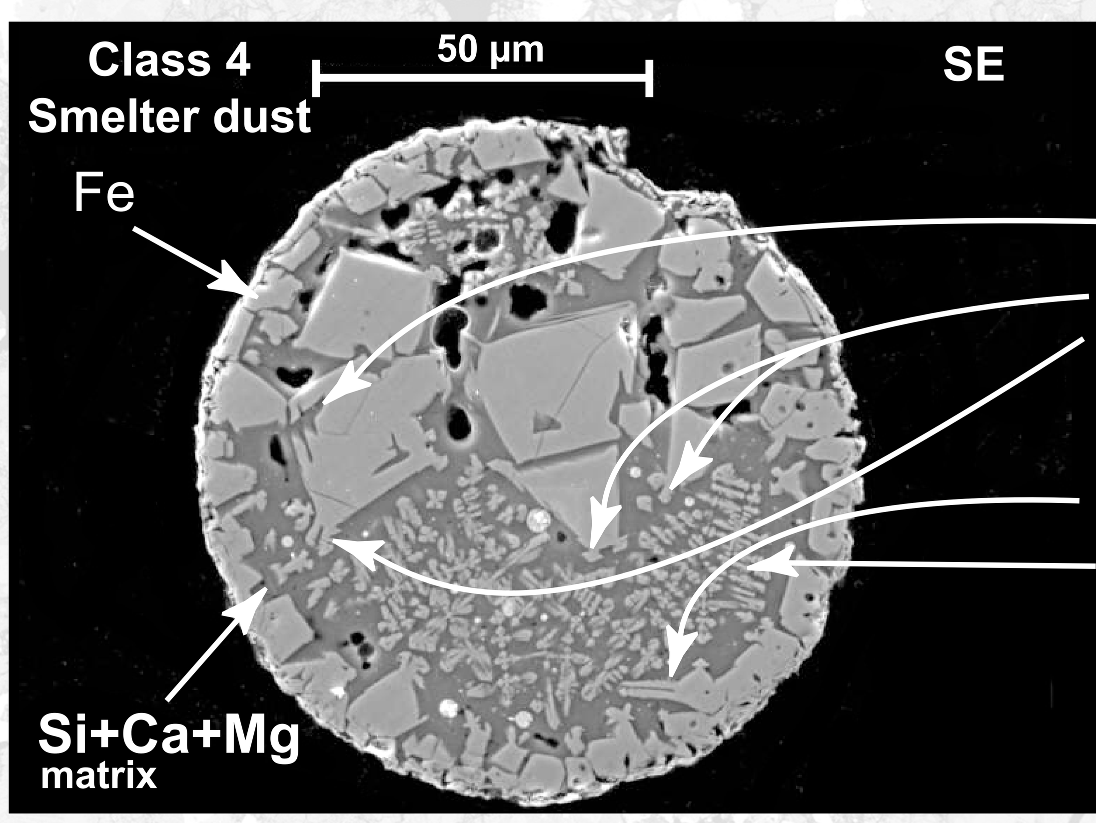
Origin of Smelter Spherule

The examined smelter dust comprises spheres that are chemically heterogeneous agglomerates resulting from high-temperature fusion of flux, mineral feed (which includes sulphides and gangue), and recyclables, that takes place during the production of a molten matte [1]. The dust forms in a reactor gas stream at 1230°C that is quench-cooled in air to about 620°C in 0.6 seconds, and is further cooled to 350°C in 6 seconds [2]. Some dust is recycled into the smelter feed and comes in contact with molten droplets. The resulting textures and mineralogy reflect multi-element and multi-phase complexes with various degrees of crystallinity. Due to the highly oxygenated environment of the blast furnace elements such as Fe probably occur as oxides: FeO, Fe_2O_3, Fe_3O_4, or Fe_2SiO_4 (fayalite), and not as elemental Fe. The processes and textures are similar to those described [3,4] for chondrule melts.

The two-phases in a molten droplet may result from:

1) complete melting with slow re-crystallization with exsolution of relatively large, well-resolved grains in a matrix that forms dendrites in a glassy matrix upon quench cooling; and/or

2) spheres formed by the agglomeration of unreacted to partly reacted dust with molten material that forms dendrites in a glassy matrix upon quench cooling.



The two iron-rich phase textures may be related through partial dissolution and corrosion with the matrix. Supporting evidence includes:
1) embayments in the large Fe phenocrysts and the presence of,
2) "chevron edges" and
3) "ferning" that given time would be further subdivided until a dendritic pattern is complete [5].

Upon quench cooling, large Fe phenocrysts are preserved in a stage of corrosion and the molten droplet forms two phases comprising Fe dendrites and a glassy matrix.

References

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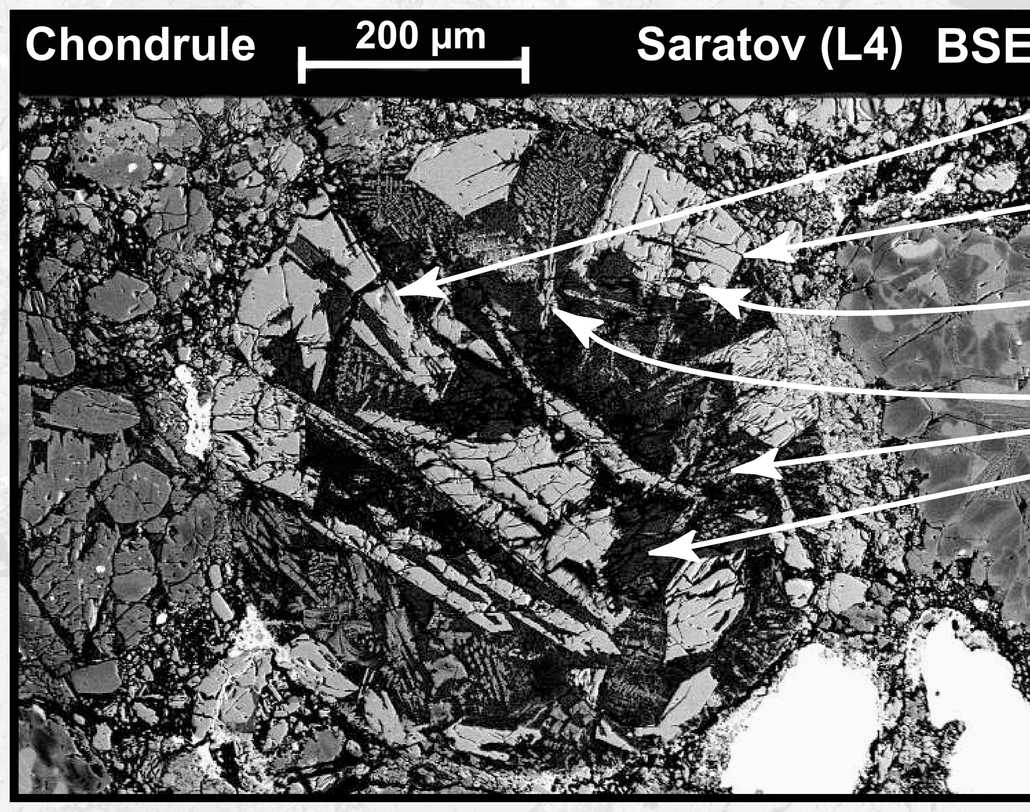
Description, Chondrule



This 600 µm diameter spherule has:
1) A porphyritic texture, with euhedral to subhedral chemically homogenous crystals of olivine (up to 300 µm) occupying most of the core,

2) Similar porphyritic texture, with euhedral to subhedral chemically homogenous crystals concentrated near the rim and truncated by it.

3) Some olivine phenocrysts contain matrix or have irregular margins against it. The crystal-line matrix to the phenocrysts is rich in silicon, calcium, sodium, magnesium and aluminium,

4) and contains olivine spines,
5) two types of dendritic pyroxene (low calcium, and calcic-aluminous pyroxene) and
6) sodic plagioclase grains.

The phenocrysts and dendrites may be related through the olivine spines. The pyroxene dendrites appear to have been derived from the phenocrysts by corrosion through reaction with the matrix, reducing the olivine to reaction remnants in the pyroxene-rich regions.

Despite an order of magnitude difference in size between the smelter derived particle and chondrule illustrated here, they contain analogous textures, and the process of their origin may, in some ways, be similar.

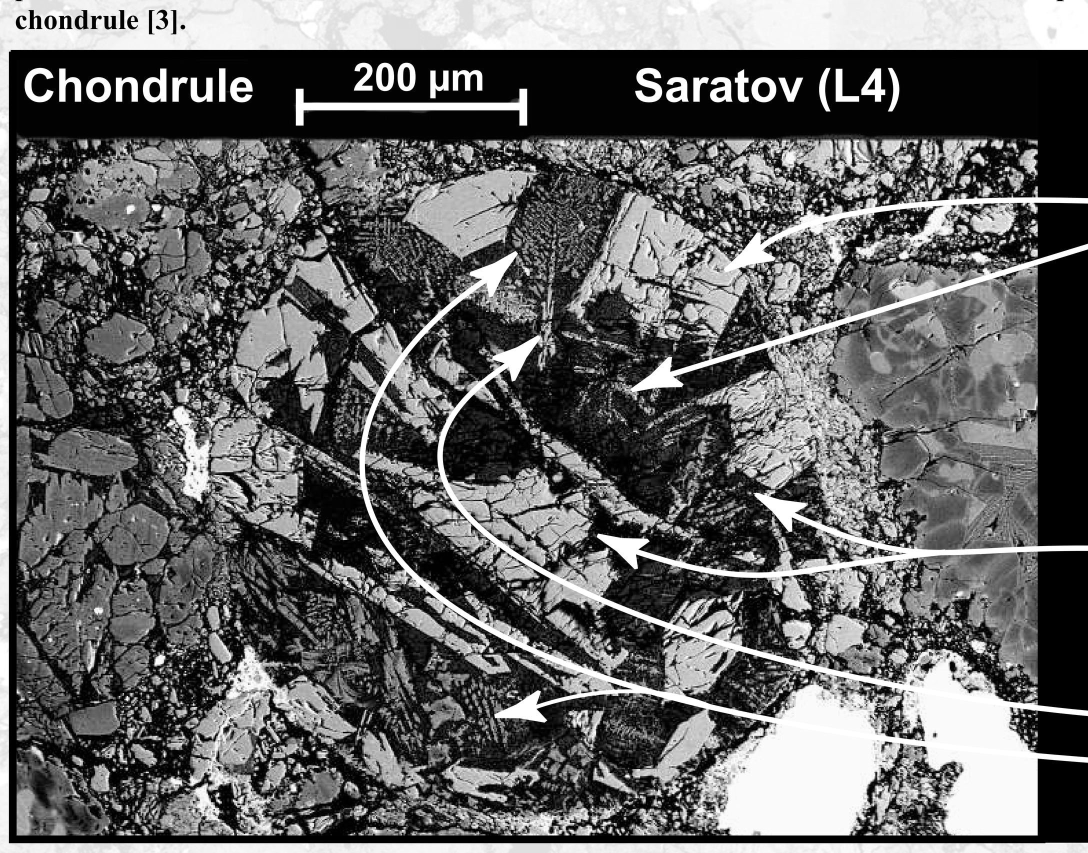
Chondrites and Chondrules

Individual chondrules in primitive chondritic meteorites can record either simple or complex histories resulting from solar nebula processes. Hence, understanding the origin of a single chondrule may or may not be useful in understanding the origin of others. Multi-stage melting and re-melting of pre-solar dust may be reflected in their textures, as well as subsolidus heating, annealing, and recrystallization. Their incorporation in agglomerates within even the best-preserved primitive meteorite samples may have been preceded by aqueous or other alteration, incorporation in a primitive meteoroid or asteroid, and impact brecciation and/or shock melting, generally early in solar system history [6]. Chondrules in primitive chondritic meteorites contain relict, sometimes pre-solar, grains, and their textures are considered to be controlled by the presence or absence of relict nucleation sites within essentially molten silicate +/- metal droplets [3,4]. The relict sites may be all that remains of either pre-solar dust grains, or phases generated in prior chondrule-forming processes. Multiple, and probably rapid, recycling of phases and liquids is suggested by some chondrule textures, while others imply relatively slow cooling during a single melting/ quenching episode.

Textural Interpretation

Crystallization textures in chondrules, as in igneous and metamorphic Earth rocks, may be related to formational process by: (1) experimental laboratory work on synthetic chondrule-like compositions, which seeks to duplicate the mineral phases, their habits, and intergranular textures, and thus derive e.g. P, T, fluid conditions, cooling rates and other parameters that may have existed in nature; (2) comparison with crystallization textures in compositionally similar terrestrial rocks; (3) observations on man-made materials, where the phases may be different (e.g. in alloys) but the textures are analogous.

Based on (1) and (2): Radiating textures of olivine and pyroxene in chondrules result from rapid cooling of material with limited relict nucleation sites, likely from temperatures well above the liquidus, possibly as high as 1900°C [3,4]. Similar textures are observed in laboratory experiments, in volcanic rocks, and in quenched slag from smelters [7]. Porphyritic textures may reflect preservation of numerous relict nucleation sites in such chondrules, in melts that had peak temperatures close to the liquidus [4], or they may result from incorporation of xenocrysts into a molten chondrule [3].



The sharply defined Saratov chondrule shows what may be interpreted *a priori* as both porphyritic and radiating textures.

Porphyritic olivine (Fa23) is contained in a devitrified matrix of skeletal olivine, pyroxene and plagioclase.

Evidence for a reaction between the matrix and primary olivine phenocrysts is shown by:

1) the embayed nature of the larger olivines, and

2) the presence of relict olivine spines in dendritic or trellis pyroxene-rich areas.

Summary & Conclusions

In spite of compositional differences the Saratov chondrule has many textural similarities with smelter-derived spherules.

1) The porphyritic texture of each arose in a similar manner, either by slow recrystallization of the spherule or chondrule, or by incorporation of unreacted dust xenocrysts into molten droplets. The latter is favored in the case of the smelter spherule by estimates of rapid cooling and the documented reintroduction of cooled dust back into the smelter gas stream. It is also favored for the chondrule

2) The dendritic/trellis textures in the matrix of each arose by reaction of the pheno/xenocrysts with the matrix, resulting in corrosion of the larger grains. This interpretation is favored in the case of the chondrule as many chondrules in type 3 and type 4 ordinary chondrites show olivine preserved in a devitrified matrix of pyroxene and feldspar, and derivation of pyroxene from olivine by reaction with a silica-rich matrix is a simple explanation.

As in the spherule, there is some evidence for corner chevron formation and ferning in the chondrule textures, plus olivine spines are preserved. Thus what appears to be quench texture in the chondrule may be evidence for sub-liquidus reactions, i.e. the pyroxene did not result from cooling of the matrix independently of the phenocrysts, but by reaction between matrix and phenocrysts.

3) Estimates of the time-scale for cooling the smelter spherule (1230 °C and quench cooled in air to 600-620 °C in about 0.6 seconds and further cooled to 350 °C in 6.0 seconds [2]) suggest the chondrule textures likewise arose within seconds, in whatever medium they formed.

4) Temperature, the number of nuclei, composition/type of material, and cooling rate have influenced and produced similar textures in both types of particles, even though they formed in radically different environments, and billions of years apart.

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