Survey of Large Igneous-Textured Inclusions in Ordinary Chondrites

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Abstract

The inventory of early solar system objects includes large, igneous-textured inclusions that occur uniquely in ordinary (O) chondrites. In order to better understand and characterize the formation processes of these inclusions, which may have implications for our models of early solar system processes, polished thin sections of inclusions from nine inclusions have been examined with optical light microscopy (OLM). Five inclusions were further investigated with scanning electron microscopy, and chemical data for olivines in six inclusions were collected with an Electron Microprobe.

Texturally, the inclusions fall into one of three distinct categories: porphyritic, fine granular, and skeletal. Texture was determined to be unrelated to host type and unrelated to whether the inclusion is a drop-formed mass or a clast. Chemically, the olivines are eqilibrated in some inclusions but unequilibrated in others. This was unrelated to host classification and petrographic type.

Background

Ordinary chondrites (O-chondrites) are a class of stony meteorites that derive from undifferentiated parent bodies. Uniquely among meteorites, approximately 4% of O-chondrite samples contain "large igneous-textured inclusions". These inclusions are:

· igneous in texture; they crystallized from a melt
· highly depleted in metal & sulfide relative to host meteorite
· up to an order of magnitude larger than chondrules
· highly variable in texture, mineralogy, and bulk composition
· variable in shape; can be angular, subrounded, or rounded

Their relationship to other early solar system material is unclear. They probably have diverse origins. Models proposed for their formation are:

· shock melting of ordinary chondrites with an associated loss of metal and sulfide
· melting of vapor-fractionated condensate mixtures
· chondrule formation involving a larger melt production volume than typical for chondrules
· igneous differentiation occurring within planetesimals sampled by ordinary chondrite parent bodies.

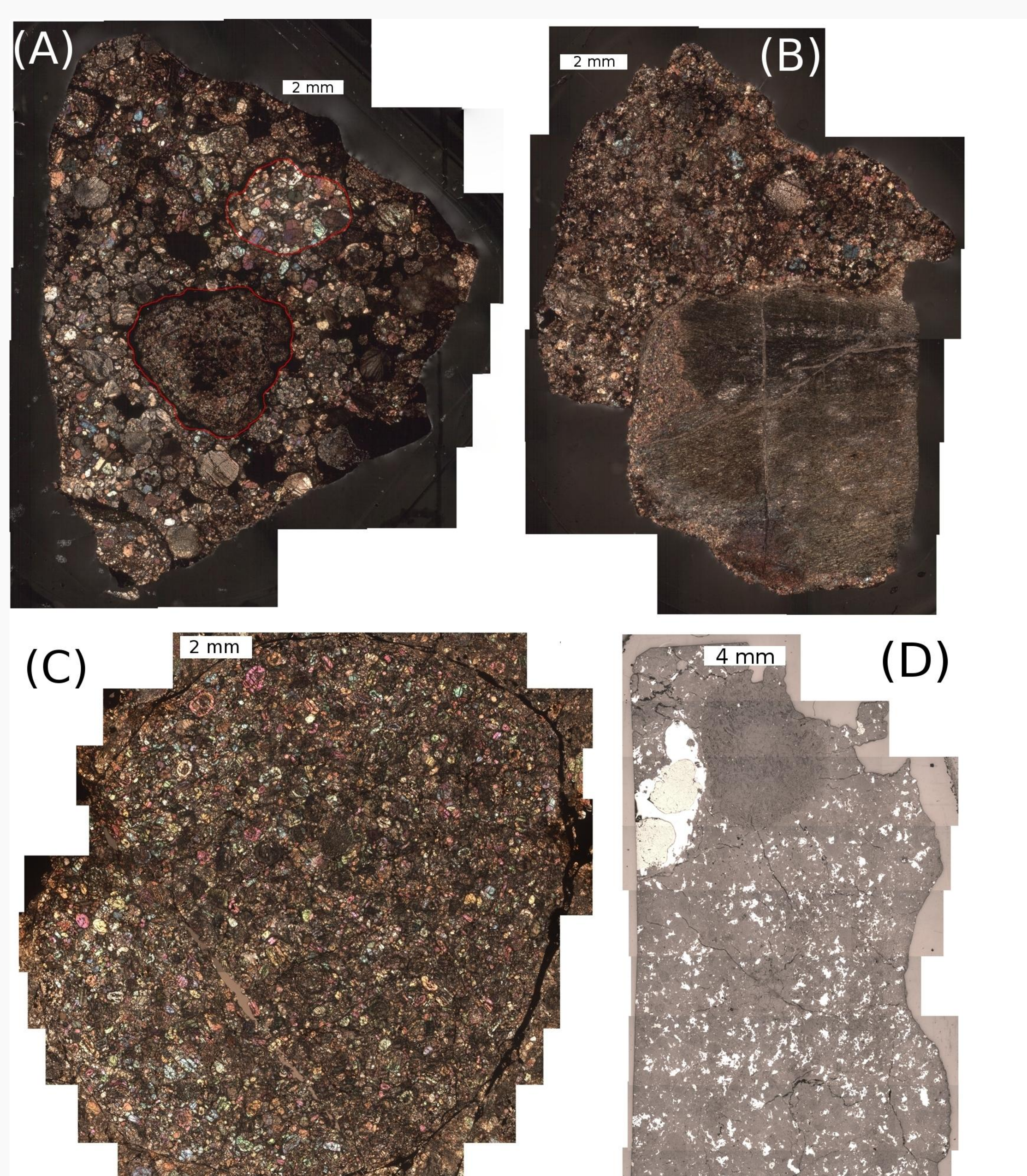

Figure 1: Examples of five large igneous inclusions, viewed with cross polarized light. (A) Sample NWA 7869 contains two very different large inclusions, outlined in red. (B) Sample NWA 7871 contains an exceptionally large inclusion. (C) One of several documented inclusions in sample NWA 4859. (D) Sample NWA 7873 contains a large metal-sulfide blob in close proximity to an inclusion.

Results and Discussion

An initial question investigated was whether or not there appeared to be a connection between host meteorite classification and inclusion properties. Such a relationship could have implications for our understanding of parent body formation environments.

Petrographically, the inclusions were determined to fall into one of three distinct textural categories: porphyritic, fine granular, and skeletal olivine. Mean grain sizes are on the order of 100 um for both microporphyritic and fine granular inclusions, with microporphyritic inclusions showing a much wider range of grain sizes. The largest grains in the microporphyritic inclusions are on average ~0.25 mm, with the grains of the mesostasis <100 microns. Skeletal olivine textures are defined as being dominated by olivine crystals that are an order of magnitude longer across one direction than the other (e.g., 1 mm x 100 um). No relationship between shape, texture and host classification is noticeable among these samples. From this, it follows that the conditions and formation processes that created the inclusions were not isolated or unique, as they appear to have affected more than one parent body.

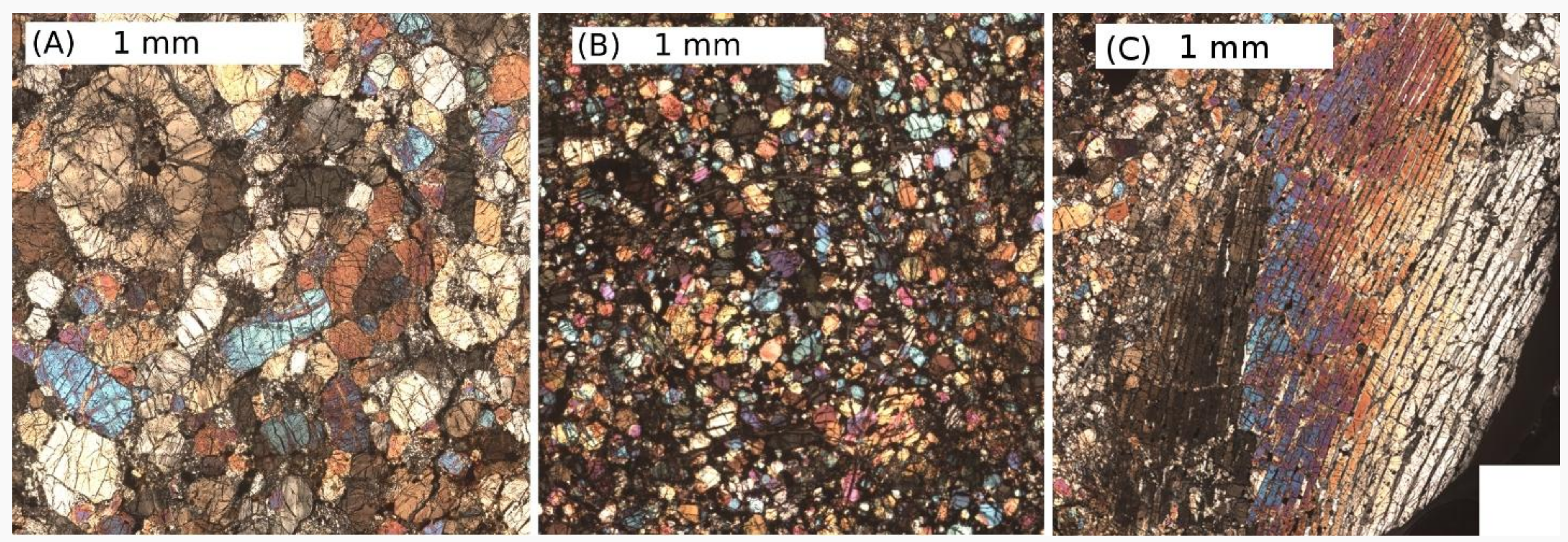

Figure 2: Examples of the textural differences observed in the inclusions. (A), the inclusion in the Palo Verde Mine meteorite has a microporphyritic texture. (B) is an example of fine granular texture, and (C) is skeletal. Note particularly the variation of grain size in (A) vs the relative uniformity of grain sizes in (B). The obvious difference in texture implies different crystallization histories.

Table 1: Characteristics of inclusions. (*) denotes that the edges of these inclusions grade into a microporphyritic texture, which suggests that it is the true original edge of the inclusion. †This meteorite contains multiple inclusions, only one of which has yet been included in this study. At least one of the other inclusions has skeletal texture.

Host	Texture	Size	Shape	Grain Size (Mean, Range)	Olivine Chemistry (Fa)
NWA 7869 (1), L3	fine	~5.0 mm diameter	rounded	0.07 mm (0.025 - 0.10 mm)	16.5 (EMPA, uneq.)
NWA 7869 (2), L3	microporphyritic	~ 3.5 mm diameter	rounded	0.3 mm (0.1 - 0.7 mm)	23.2 (EMPA, uneq.)
NWA 7870, L4	skeletal*	~5.0 mm diameter	rounded	0.3 mm x 0.03 mm	24.1 (EMPA, eq.)
NWA 7871, L6	fine*	9.4 x 9.8 mm	subrounded	0.035 mm (0.02 - 0.04 mm)	24.9 (EMPA, eq.)
NWA 7872, L3	skeletal*	2.3 x 4 mm	angular	0.6 mm x 0.025 mm	24.4 (SEM, eq.)
NWA 7873, H5-6	skeletal*	6.0 x 8.0 mm	subrounded	0.6 mm x 0.06 mm	12.6 (SEM, uneq.)
NWA 869, L3-6	fine	13.1 x 3.7 mm	angular	0.13 mm (0.11-0.16 mm)	-
Palo Verde Mine, L6	microporphyritic	4.4 x 6.7 mm	subrounded	0.23 mm (0.05 - 0.7 mm)	24.5 (EMPA, eq.)
NWA 4859 (1)†, LL5	microporphyritic	~16.0 mm diameter	rounded	0.26 mm (0.06 - 0.8 mm)	28.4 (EMPA, eq.)

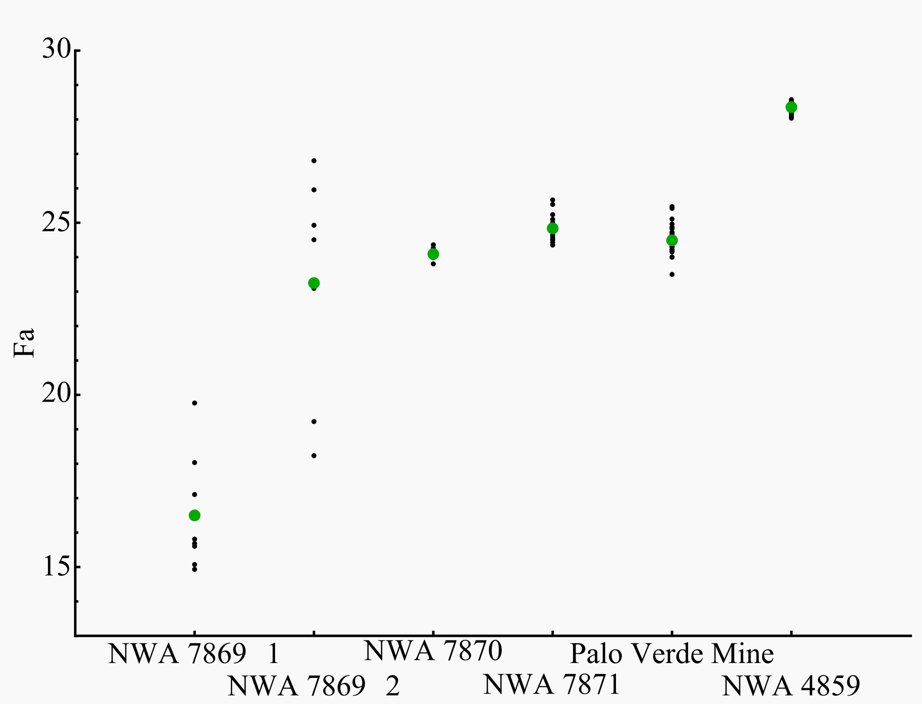

Figure 3: The observed distribution of olivines in six inclusions, obtained with an electron microprobe. The two inclusions in NWA 7869, an L3, are both unequilibrated, while the other four are equilibrated.

Chemically, some inclusions were found to have equilibrated olivine, while others were uneqilibrated. This was also unrelated to host classification, as well as unrelated to host petrographic type. Of the two unequilibrated hosts studied, one had two unequilibrated inclusions, while the other had one equilibrated inclusion. Several eqilibrated hosts had equilibrated inclusion, while one equilibrated host had an unequilibrated inclusion. This implies that the inclusions became incorporated with host meteorite at different times; an equilibrated inclusion must have been thermally altered before incorporating into an unequilibrated host. Average Fa values for the inclusions are given in table 1.

Also noted is that olivines in unequilibrated inclusions were more likely to be zoned, with magnesian cores and ferrous rims, than olivines in equilibrated inclusions.

Methods

Polished thin sections of nine inclusions have been examined with optical light microscopy (OLM) using a Leica DM 2500 petrographic microscope at Portland State University. Petrographic data such as texture, grain sizes and shapes were collected for the inclusions and their hosts in order to facilitate comparisons. Five inclusions have been investigated with scanning electron microscopy (SEM) on a Zeiss Sigma FE-VP SEM at Portland State University. Backscatter electron micrographs were obtained in order to provide additional petrographic data, and olivine composition was determined using a silicon-drift energy dispersive X-ray (EDX) detector integrated with an Oxford Instruments AZtec X-ray analytical system. Olivine crystals of six inclusions were investigated with electron microprobe analysis (EMPA), performed with a Cameca SX-100 electron microprobe located at Oregon State University, and remotely operated from Portland State.

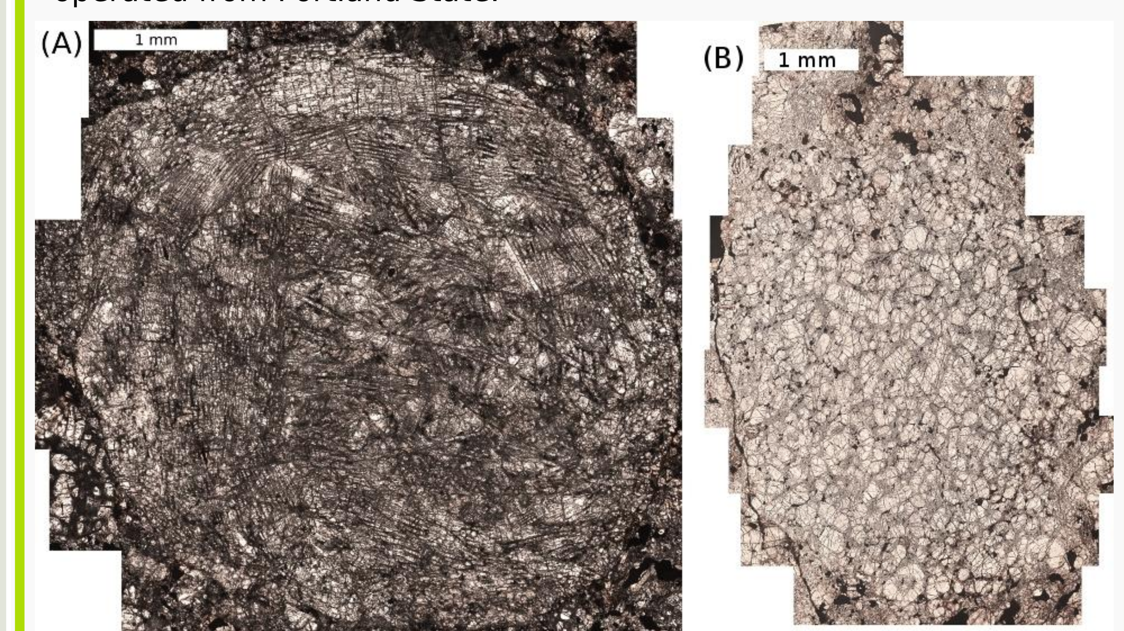

Figure 4: Examples of inclusions with notably different shapes (A) is from sample NWA 7870, an L4. Its rounded shape suggests a formation process analagous to chondrules (crystallization of a free-floating droplet). (B) is from Palo Verde Mine, an L6. Its angular left edge suggests that it is a fragment of a larger object.

Future Work

The work presented here is a subset of a larger project that aims to better understand the origins of these inclusions. Additional samples will be examined with the techniques described here and added to the survey. Bulk composition of all inclusions will be determined through modal reconstruction, and samples will be analyzed with an electron backscatter diffraction system (EBSD). This system will enhance the understanding of the samples by allowing independent, quantitative measurements of grain sizes, textures, and mineral proportions.

References

[1] J. Bridges, R. Hutchison, A survey of clasts and large chondrules in ordinary chondrites, Meteoritics and Planetary Science 32 (1997) 389–394.

[2] A. Ruzicka, G. Snyder, L. Taylor, Mega-chondrules and large, igneous-textured clasts in Julesberg (L3) and other ordinary chondrites: Vapor-fractionation, shock-melting, and chondrule formation, Geochimica et Cosmochimica Acta 62 (8) (1998) 1419–1442.

[3] A. Ruzicka, G. Snyder, L. Taylor, Geochemical and isotopic evidence bearing on the origin of large, igneous-textured inclusions in ordinary chondrites, Antarctic Meteorite Research 13 (2000) 19–38.

[4] R. Binns, An exceptionally large chondrule in the Parnallee meteorite, Mineralogical Magazine 36 (1967) 319–324.

[5] R. Hutchison, Meteorites: A Petrologic, Chemical, and Isotopic Synthesis, Cambridge University Press, Cambridge, UK, 2004.

[6] R. Dodd, E. Jarosewich, Olivine microporphyry in the St. Mesmin chondrite, Meteoritics 11 (1976) 1–20.

[7] R. Fodor, K. Keil, Carbonaceous and noncarbonaceous lithic fragments in the Plainview, Texas chondrite: origin and history, Geochimica et cosmochimica Acta 40 (1976) 177–189.

[8] N. Jamsja, A. Ruzicka, Shock and thermal history of NWA 4859, an annealed impact-melt breccia of LL-chondrite parentage containing unusual igneous features and pentlandite, Meteoritics and Planetary Science 45 (2010) 828–849.

[9] M. Weisberg, M. Prinz, C. Nehru, Macrochondrules in ordinary chondrites: constraints on chondrule-forming processes, Meteoritics 23 (1988) 309–310.

[10] R. Hutchison, C. Williams, V. Din, R. Clayton, C. Kirschbaum, R. Paul, M. Lipschutz, A planetary, H-group pebble in the Barwell, L6, unshocked chondritic meteorite, Earth and Planetary Science Letters 90 (1988) 105–118.

[11] A. Ruzicka, D. Kring, D. Hill, W. Boynton, R. Clayton, T. Mayeda, Silica-rich orthopyroxenite in the Bovedy chondrite, Meteoritics 30 (1995) 57–70.

[12] A. Ruzicka, M. Hutson, C. Floss, A. Hildebrand, Large silica-rich igneous-textured inclusions in the Buzzard Coulee (H4) chondrite, 43rd Lunar & Planetary Science Conference, Abstract 1630.

[13] A. Ruzicka, M. Hutson, C. Floss, A. Hildebrand, Large silica-rich igneous-textured inclusions in the Buzzard Coulee chondrite: Condensates, differentiates, or impact melts?, Submitted to Meteoritics and Planetary Science.