Heterogeneous Metal Grains: Compositionally and texturally heterogeneous metal grains in L6 Bruderheim are unlikely to have survived solid-state diffusion during prograde metamorphism [22]; these authors favored hot accretion followed by low-temperature annealing. However, Bruderheim is a fragmental breccia of shock stage S4 [23] containing partly melted metal grains and opaque veins; heterogeneities in metallic Fe-Ni grains are due to postmetamorphic shock.

Misshapen Chondrules: A small proportion of chondrules in Tieschitz are nonspherical and seem to have molded themselves around one another while they were at least partly molten, possibly on the surface of a hot asteroid [24]. However, it is now clear that these conjoined objects are adhering or enveloping compound chondrules that fused in the nebula [25]; most are probably siblings that collided shortly after forming in the same heating event. Objects adjacent to the compound chondrules are separated by intervening matrix material; because matrix material is fine grained, porous, highly disequilibrated, and unmelted [26,27], any complementarity in shape between adjacent objects and compound chondrules is either due to coincidence or jostling during chondrite compaction.

Natural Remanent Magnetization (NRM): The orientations of the stable NRM in OCs were found to be random at scales of ~1 mm^3 [28]. Because metamorphic heating would erase the random magnetization, these authors opted for hot accretion. However, most OCs appear to be fragmental breccias that contain scattered metal and silicate grains of aberrant compositions that were incorporated into their hosts after metamorphic equilibration [29,30]; by analogy to some CM chondrites that contain millimeter-sized clasts that experienced different degrees of aqueous alteration [31], it is plausible that OCs are also brecciated on millimeter-sized scales. Such fine-scale brecciation could account for the random orientations of the stable NRM.

References: [1] Dodd R. T. (1969) *GCA, 33*, 161–203. [2] McSween H. Y. et al. (1988) in *Meteorites and the Early Solar System*, 102–113, Univ. of Arizona, Tucson. [3] Haack H. et al. (1992) *GRL, 19*, 2235–2238. [4] Hutchison R. et al. (1980) *Nature, 287*, 787–790. [5] Keil K. and Fredriksson K. (1964) *JGR, 69*, 3487–3515. [6] Heyse J. V. (1978) *EPSL, 40*, 365–381. [7] Scott E. R. D. et al. (1986) *Proc. LPSC 17th*, in *JGR, 91*, E115–E123. [8] Ashworth J. R. (1980) *EPSL, 46*, 167–177. [9] Ashworth J. R. et al. (1984) *Nature, 308*, 259–261. [10] Göpel C. et al. (1994) *EPSL, 121*, 153–171. [11] Jones R. H. and Brearley A. J. (1988) *Meteoritics, 23*, 277. [12] Brearley A. J. and Jones R. H. (1988) *Eos Trans. AGU, 69*, 1506. [13] Brearley A. J. and Jones R. H. (1993) *LPS XXIV*, 185–186. [14] Watanabe S. et al. (1985) *EPSL, 72*, 87–98. [15] Robinson P. et al. (1977) *Am. Mineral., 62*, 857–873. [16] Dodd R. T. (1981) *Meteorites: A Petrologic-Chemical Synthesis*, Cambridge. [17] Taylor G. J. (1987) *Icarus, 69*, 1–13. [18] Bevan A. W. R. and Axon H. J. (1980) *EPSL, 47*, 353–360. [19] Scott E. R. D. and Rajan R. S. (1981) *GCA, 45*, 53–67. [20] Scott E. R. D. and Rajan R. S. (1981) *GCA, 45*, 1959. [21] Willis J. and Goldstein J. I. (1981) *Nature, 293*, 126–127. [22] Smith D. G. W. and Launspach S. (1991) *EPSL, 102*, 79–93. [23] Stöffler D. et al. (1991) *GCA, 55*, 3845–3867. [24] Hutchison R. et al. (1979) *Nature, 280*, 116–119. [25] Wasson J. T. et al. (1995) *GCA, 59*, 1847–1869. [26] Scott E. R. D. et al. (1984) *GCA, 48*, 1741–1757. [27] Nagahara H. (1984) *GCA, 48*, 2581–2595. [28] Morden S. J. and Collinson D. W. (1992) *EPSL, 109*, 185–204. [29] Scott E. R. D. et al. (1985) *Proc. LPSC 16th*, in *JGR, 90*, D137–D148. [30] Rubin A. E. (1990) *GCA, 54*, 1217–1232. [31] Rubin A. E. and Wasson J. T. (1986) *GCA, 50*, 307–315.

VARIATIONS OF CHONDRITE PROPERTIES WITH HELIOCENTRIC DISTANCE.

A. E. Rubin and J. T. Wasson, Institute of Geophysics and Planetary Physics, University of California, Los Angeles CA 90095-1567, USA.

There are 12 well-established chondrite groups distinguishable by significant compositional hiatus among their compositional and petrographic characteristics. Because each group represents a different parent asteroid, formed in a distinct nebular region (and/or at a particular time), it is plausible that chondrite properties varied in a smooth fashion with heliocentric distance (HD).

Oxidation State: Thermodynamic calculations indicate that the equilibrium FeO/(FeO + MgO) ratio increases with decreasing nebular temperature. Because the nebular temperature gradient decreased with HD, at all times inner nebular regions had a lower oxidation state than more distant regions. If the time of agglomeration increased with HD, outer-solar-system materials generally would have acquired more ferroan compositions. By these criteria we infer that enstatite chondrites formed closer to the Sun, OCs at intermediate HD, and R chondrites and carbonaceous chondrites still farther from the Sun.

Oxygen Isotopic Composition: The nearer the Sun, the higher the nebular temperature and the larger the fraction of infalling interstellar material that evaporated; this resulted in greater equilibration with nebular gas and greater isotopic homogeneity. Because the Earth, Moon, and EH-EL chondrites lie on the terrestrial fractionation (TF) line on the standard three-O-isotope diagram, and martian meteorites ($\Delta^{17}O \approx 0.36‰$) and eucrites ($\Delta^{17}O = -0.40‰$) lie close to this line, we infer that the mean nebular (i.e., solar) O-isotopic composition was on or near the TF line. At >1 AU the absolute value of $\Delta^{17}O$ increased. We infer that EH and EL chondrites formed at a HD <1 AU; H, L, and LL chondrites (mean $\Delta^{17}O = 0.73‰$, 1.07‰, and 1.26‰) formed appreciably beyond Mars' distance of 1.5 AU (probably near 2.5 AU at the 3:1 Jupiter-period resonance); R chondrites ($\Delta^{17}O$ ~2.9‰) and CR, CM, CO, CV, and CK chondrites ($\Delta^{17}O$ ~ −1.6‰, −2.3‰, −4.5‰, −3.4‰ and −4.5‰) formed at still greater HD. Episodic accretion of ^{16}O-poor and ^{16}O-rich materials to the nebula may account for positive $\Delta^{17}O$ values for OC and R chondrites and negative values for carbonaceous chondrites.

Refractory Lithophile Abundance: It is plausible that chondrite refractory lithophile abundances (RLA) reflect the efficiency with which refractory precursor grains settled to the nebular midplane. High temperatures in the inner nebula caused most presolar refractory grains to evaporate; fine refractory condensates formed during subsequent nebular cooling. At greater HD, refractory residues survived, perhaps reaching millimeter to centimeter sizes. The resultant gradient in RLA is reflected in the modal abundance of CAIs. By these criteria, EH and EL chondrites (which have CI- and Mg-normalized mean RLA of 0.88 and 0.78, and CAI abundances of ≤0.1 vol%) formed closest to the Sun, OCs (~0.90; ~0.1%) formed farther away, R chondrites (0.95; <0.1%) formed farther still, and CR, CM, CO, CV, and CK chondrites (≥1.00; ~1–5%) formed at the greatest HD.

Matrix/Chondrule Modal Abundance Ratio: Because matrix material in type-3 chondrites contains appreciable nebular dust (a probable chondrule precursor component), chondrites with high matrix/chondrule modal abundance ratios probably agglomerated in nebular regions where the efficiency of chondrule production was low. Plausible chondrule-formation mechanisms (e.g., lightning) decrease in efficiency with increasing HD; hence, chondrites with high matrix/chondrule ratios formed at greater HD than chondrites with low ratios. Most of the interchondrule silicates, kamacite, and sulfides in EH3 chondrites may represent reprocessed chondrule fragments. If so, the actual chondrule abundance of EH3 chondrules is ~90 vol%. Chondrite groups can thus be ranked in order of increasing matrix/chondrule ratio: EH: 0.1; OC: 0.2; R (Carlisle Lakes): 0.9; CO: 0.9; CR: 0.9; CV: 1.0; CK (Ningqiang): 2.3; CM: 4.

Degree of Chondrule Melting: Droplet chondrules (BO, RP, C) formed by the complete melting of precursor materials, in contrast, surviving relict nuclei in porphyritic chondrules indicate incomplete melting. Chondrite groups ranked in order of decreasing abundance of droplet chondrules probably reflect increasing HD and a probable decrease in the efficiency of chondrule melting: EH (17%), OC (16%), R (~8%), CV (6%), CM (~5%), CO (4%), CK (<1%), CR (<1%).

Because chondrite groups are ranked in the same basic order for variations in five distinct properties, an underlying factor such as varying HD is probably responsible.

REFRACTORY INCLUSIONS IN THE CO3-LIKE CHONDRITES MACALPINE HILLS 88107 AND MACALPINE HILLS 87300.

S. S. Russell[1], A. M. Davis[2], and G. J. MacPherson[1], [1]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington DC 20560, USA, [2]Enrico Fermi Institute, University of Chicago, 5640 Ellis Ave, Chicago IL 60637, USA.

MacAlpine Hills 87300 and MAC 88107 are similar, ungrouped car-