

THE METAMORPHIC EVOLUTION OF MATRIX AND OPAQUE MINERALS IN CO CHONDRITES.

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Introduction: The CO3 chondrites form a metamorphic/alteration sequence analogous to that of the type-3 ordinary chondrites [1-4]. We have investigated metamorphically induced changes in mineralogy and texture in the CO group using the x-ray mapping techniques of Grossman [5]. We find a variety of previously unknown or poorly documented effects in these meteorites that indicate mobility of some elements at a scale of hundreds of micrometers, and underscore the complex nature of CO metamorphism and alteration.

Methods and samples: CO3 chondrites studied include Y-81020 (subtype 3.0 [6]), ALHA77307 (3.1), Kainsaz (3.2), Felix (3.4), Lancé (3.4), Warrenton (3.6) and Isna (3.7) (subtypes from [3]). X-ray maps were prepared for two to four 1×1 mm regions of each chondrite for 10 elements: Na, Mg, Al, P, S, Ca, Cr, Mn, Fe, and Ni. Areas were selected to include large opaque grains as well as chondrules rich in metal. We present the results for S, P, and Cr.

Results: sulfur. The distribution of S undergoes dramatic changes with increasing metamorphic grade. The matrix of Y-81020 is rich in sulfur; it shows a striking compositional and textural resemblance to matrix in LL3.0 Semarkona (Fig. 1). The matrix of ALHA77307 is also S-rich (it contains numerous small sulfide grains [7]), but is more homogeneous than that of Semarkona or Y-81020. There is a significant change above subtype 3.1 reflected in the low S content of the matrix in Kainsaz (Fig. 1) and all higher-petrologic-subtype CO chondrites. Thin rings of FeS enclose many metal grains in Y-81020 and ALHA77307. The FeS rings are thicker and more numerous in Kainsaz and Lancé. Sulfide is coarsest in the highest petrologic subtypes.

Phosphorous: Nearly every metal grain (both inside chondrules and in the matrix) in every CO3 chondrite is rimmed by Ca phosphate. In those grains that are also rimmed by sulfide, the sulfide is outside the phosphate. Phosphate rims surround some magnetite grains in ALHA77307 and some coarse metal-sulfide assemblages in Kainsaz. Some metal grains in the lowest petrologic types are P-bearing or peppered with tiny phosphate grains. Na-rich and Ni-rich phosphates surround some metal and magnetite grains in Y-81020 and ALHA77307, perhaps related to what was observed in Y-82094 by [8]. Phosphate rims around metal grains in types 3.0 to 3.4 tend to be con-

tinuous. Ca-phosphate rings in the highest petrologic types are not continuous; they resemble necklaces of coarse, discrete grains.

Chromium: A significant number of metal grains in types ≤3.1 are Cr-bearing or rich in tiny Cr-rich inclusions. Many metal grains are surrounded by rings of chromite; in many cases these rings occur between an inner phosphate ring and an outer sulfide ring. Starting with type 3.2, chromite also surrounds some olivine grains in chondrules.

Discussion: This work and literature reports on equilibration of CO inclusions [1,2,9] indicate that many elements (e.g., Na, Mg, Si, P, S, Ca, Cr, Mn, Fe, Co, and Ni) have been partially redistributed in CO chondrites during metamorphism/alteration. Apparently, over a narrow temperature range between that of subtypes 3.1 and 3.2, sulfide leaves the matrix and migrates to metal grains, some of which may have had thin sulfide coatings. It is clear that sulfur was transported hundreds of micrometers and across chondrule boundaries during mild metamorphism.

Although the P was once dissolved in metal, it migrated to the grain surface and reacted with an external source of Ca to form phosphate [10]. Almost all of the metal in CO chondrites (both inside and outside chondrules) was probably originally P-bearing. Even the least-equilibrated CO3 chondrites experienced sufficient heating to oxidize much of this P, and to mobilize it and any other elements (e.g., REE) that may reside in the phosphate.

The oxidation of Cr out of metal grains to form chromite rings apparently occurs over a wider temperature range than is the case for the formation of phosphate rings, but the process is fairly complete by subtype 3.4. The origin of the chromite rims around olivine grains is unclear, but may involve removal of Cr from the outer portions of normally zoned olivines.

The mineralogy of low-petrologic-type CO chondrites differs from that in higher petrologic types in an analogous manner to the way Semarkona differs from more-equilibrated type-3 ordinary chondrites. In addition to the presence of unusual phosphates, the low-subtype CO chondrites contain carbides and magnetite in association with other opaque minerals. Because carbides and magnetite in Semarkona most likely formed by secondary fluid-rock reactions, similar processes probably operated on the CO parent body.

Conclusions: We confirm that Y-81020 is among

the least-metamorphosed CO chondrites, and that it is probably more primitive than ALHA77307 as suggested by [3]. Although classified as subtype 3.2, Kainsaz exhibits much more extensive metamorphic redistribution of elements than lower subtypes, suggesting that it might be better classified as a higher subtype. All sulfide grains in types CO3.2 and higher probably have a metamorphic component; even the CO3.0 chondrites have experienced some metamorphism. Chondrule compositions in all CO3 chondrites

have been modified by these parent-body processes.

References: [1] McSween (1977) *GCA* **41**, 477; [2] Scott and Jones (1990) *GCA* **54**, 2485; [3] Sears et al. (1991) *Proc. NIPR Symp. Ant. Met.* **4**, 319; [4] Rubin (1998) *MPS* **33**, 385; [5] Grossman J.N. (1996) *LPS XXVII*, 467–468; [6] Shibata (1996) *Proc. NIPR Symp. Ant. Met.* **9**, 79; [7] Brearley (1993) *GCA* **57**, 1521; [8] Shibata and Matsueda (1994) *Proc. NIPR Symp. Ant. Met.* **7**, 110; [9] Russell et al. (1998) *GCA* **62**, 689; [10] Rubin and Grossman (1985) *Meteoritics* **20**, 479.

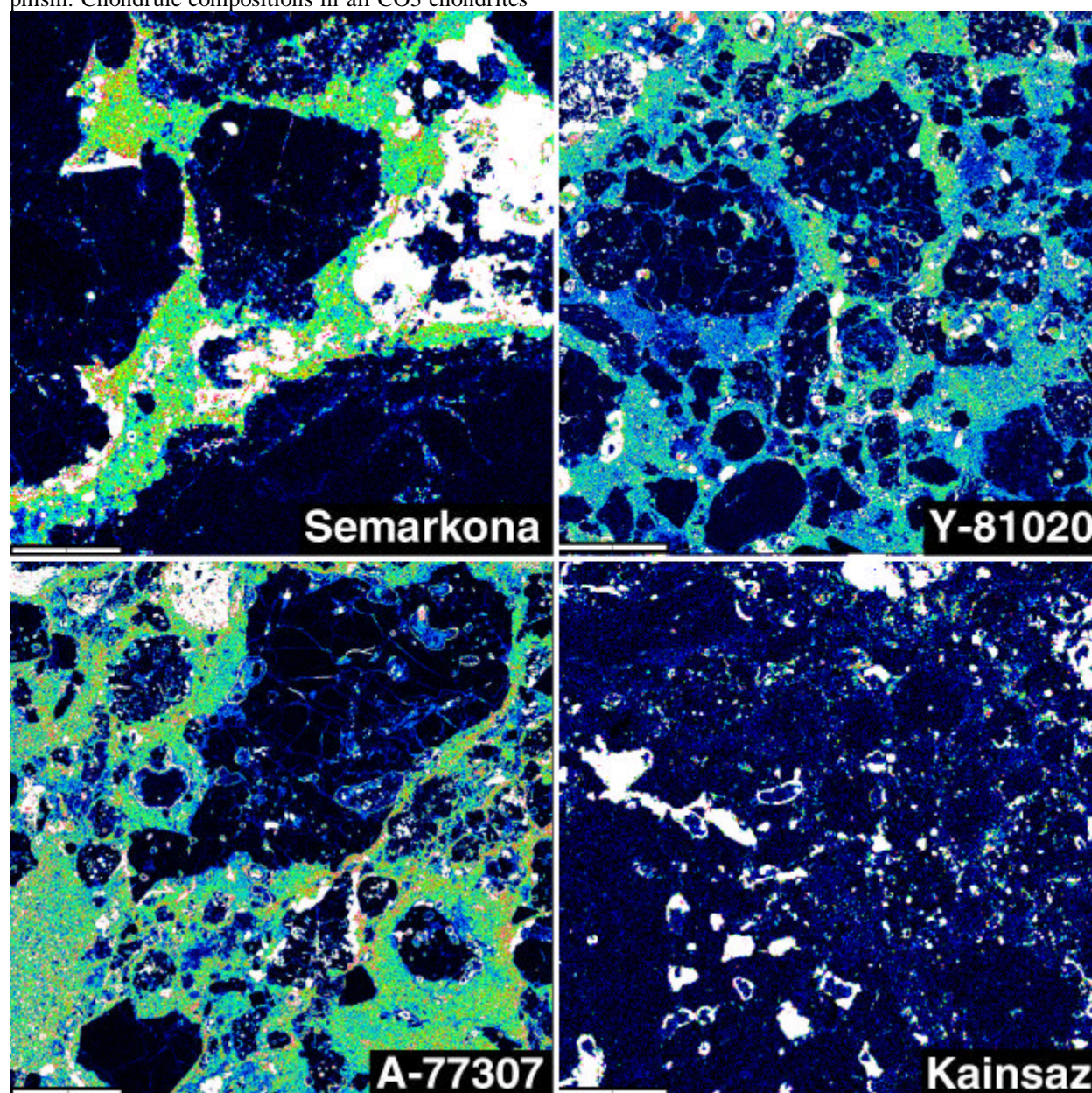


Figure 1. Sulfur x-ray maps of matrix-rich regions of Semarkona (LL3.0) and three CO chondrites. Large sulfide grains, mostly FeS, appear white. Sulfur-poor matrix in Kainsaz appears blue, whereas sulfur-rich matrix in the other meteorites appears mostly green. Silicates appear black. The matrices of Semarkona and Y-81020 have variable sulfide concentrations, while that in ALHA77307 is much more uniform. The more-metamorphosed CO chondrites (Felix, Lancé, and Isna) all have low-S matrices resembling that in Kainsaz. Scale bars are 200 μm .