

OXYGEN ISOTOPIC COMPOSITIONS OF CHONDRULES IN UNEQUILIBRATED CHONDRITES: FURTHER PETROLOGICAL INTERPRETATIONS J.L. Gooding^{1,2}, T.K. Mayeda⁴, R.N. Clayton^{3,4}, K. Keil², T. Fukuoka^{5,6}, and R.A. Schmitt⁵.

¹Dept. of Geology and Institute of Meteoritics, Univ. of New Mexico, Albuquerque, NM 87131 USA ... ²SN2, NASA/Johnson Space Center, Houston, TX 77058 USA ... ³Dept. of Geophysical Sciences and ⁴Enrico Fermi Institute, Univ. of Chicago, Chicago, IL 60637 USA ... ⁵Dept. of Chemistry and Radiation Center, Oregon State Univ., Corvallis, OR 97331 USA ... ⁶Dept. of Chemistry, Gakushuin Univ., Tokyo 171, Japan.

Introduction. In a previous report (1), we described the first measured $^{18}\text{O}/^{16}\text{O}$ and $^{17}\text{O}/^{16}\text{O}$ ratios in petrologically characterized individual chondrules from unequilibrated ordinary chondrites. However, important developments since that time justify further discussion of the data and their interpretation. Firstly, new oxygen isotopic analyses of additional individual chondrules (2,3) have confirmed the three-isotope trend observed previously (1). Secondly, new oxygen isotopic analyses of whole-rock equilibrated H- and L-chondrites (3) have led to refinement in the position of the H-L mixing line and its contrast with the apparent chondrule trend. Thirdly, further study of correlations between oxygen isotopic and chemical/petrological compositions of the chondrules has led to refinement of our interpretations regarding chondrule origins. We infer that both mixing and fractionation processes were involved in chondrule formation but that petrological correlation with these two isotopic effects may not be the same in the porphyritic and nonporphyritic chondrule groups.

Isotopic Mixing and Fractionation Factors. On a three-isotope plot (Fig. 1), the chondrule data lie along a moderately well-defined trend line of slope 0.8. However, data for a larger suite of (petrologically uncharacterized) chondrules indicates a trend of slope -1 (2,3). The chondrule trend line is appreciably different than the whole-rock equilibrated chondrite H-L mixing line as most recently defined (3; Fig. 1) although the former still intersects the latter near the average H-chondrite composition. Given the properties of the three-isotope plot (4), the isotopic composition of each chondrule can be attributed to the combined effects of (a) mixing of two end-members (with one highly enriched in ^{16}O) along a slope-1 line, and (b) mass fractionation along a slope-1/2 line by isotopic exchange between the evolving chondrule and an external reservoir. Assuming that the H-L mixing line is the dominant graphical control of (a), the mixing (m) and fractionation (f) vectors can be assigned magnitudes, relative to an arbitrarily selected reference point (r), of

$m^{18} = 2\delta^{17}\text{O}_r - \delta^{18}\text{O}_r - 2\delta^{17}\text{O}_r + \delta^{18}\text{O}_r$, and $f^{18} = 2\delta^{18}\text{O}_r - 2\delta^{17}\text{O}_r + 2\delta^{17}\text{O}_r - 2\delta^{18}\text{O}_r$. Using a reference point ($\delta^{17}\text{O}_r = 2.60\text{‰}$, $\delta^{18}\text{O}_r = 4.00\text{‰}$) on the H-L mixing line just below the H-chondrite composition, m^{18} and f^{18} were computed for each chondrule. For nonporphyritic chondrules (DH-4, DH-5, HG-2, SE-9, SE-12), m^{18} shows a very strong inverse correlation with f^{18} (correlation coefficient, $r = -0.95$) whereas the corresponding covariation among porphyritic chondrules (HG-1, HG-24, HG-25, SE-10, SE-13) is significantly weaker ($r = -0.76$).

Isotopic/Petrological Correlations. Most of the tests performed to identify correlations between isotopic and petrological parameters found trends of questionable statistical significance, probably reflecting both the compositional heterogeneity among the chondrules and the small number of samples analyzed. In general, though, for most trends, the isotopic/petrological correlations were greater in strength for nonporphyritic than for porphyritic chondrules. A particularly striking example is the correlation of m^{18} with bulk Ir/Au ratio which yields $r = +0.99$ for nonporphyritic chondrules but only $r = +0.19$ for porphyritic chondrules. Among porphyritic chondrules, though, correlations between m^{18} and total bulk Fe ($r = -0.58$) or total bulk rare-earth

OXYGEN ISOTOPIC COMPOSITIONS OF CHONDRULES

Gooding, J.L. et.al.

elements (REE) ($r = +0.65$) were both stronger than the corresponding correlations between $\delta^{18}\text{O}$ and the same petrological parameters. The case for m^{18} vs. bulk ratio $(\text{CaO} + \text{Al}_2\text{O}_3)/\text{MgO}$ is similar although less clear.

Implications for Chondrule Formation. Oxygen isotopic compositions of chondrules were apparently controlled by mixing, with fractionation producing second-order effects. Isotopic mixing might have occurred either by exchange between chondrule droplets and a ^{16}O -depleted external gaseous reservoir (2) or by actual petrological mixing of different solid precursor materials prior to chondrule melt formation (1). Petrological mixing (e.g., mafic with felsic materials) might be consistent with the observed weak correlations of m^{18} with total REE and $(\text{CaO} + \text{Al}_2\text{O}_3)/\text{MgO}$, respectively. However, the basis of the m^{18} vs. Ir/Au correlation among nonporphyritic chondrules remains unclear. A point of major importance, though, is that different isotopic/petrological trends may exist among nonporphyritic chondrules relative to porphyritic chondrules. Such differences would serve to further emphasize the possible petrogenetic contrast between the two groups, as previously suggested (5,6).

References: (1) J.L. Gooding, K. Keil, T.K. Mayeda, R.N. Clayton, T. Fukuoka, and R.A. Schmitt (1980) *Meteoritics*, 15, 295. (2) R.N. Clayton, T.K. Mayeda, J.L. Gooding, K. Keil, and E.J. Olsen (1981) *Lunar Planet. Sci. XII*, 154-156. (3) R.N. Clayton and T.K. Mayeda (1981), unpublished data. (4) R.N. Clayton, N. Onuma, and T.K. Mayeda (1976) *Earth Planet. Sci. Lett.*, 30, 10-18. (5) J.L. Gooding, K. Keil, T. Fukuoka, and R.A. Schmitt (1980) *Earth Planet. Sci. Lett.*, 50, 171-180. (6) J.L. Gooding and K. Keil (1981) *Meteoritics*, 16, 17-43. (7) F. Robert, L. Merlivat, and M. Javoy (1979) *Nature*, 282, 785-789. (8) R.N. Clayton, T.K. Mayeda, and N. Onuma (1979) *Lunar Planet. Sci. X*, 221-223.

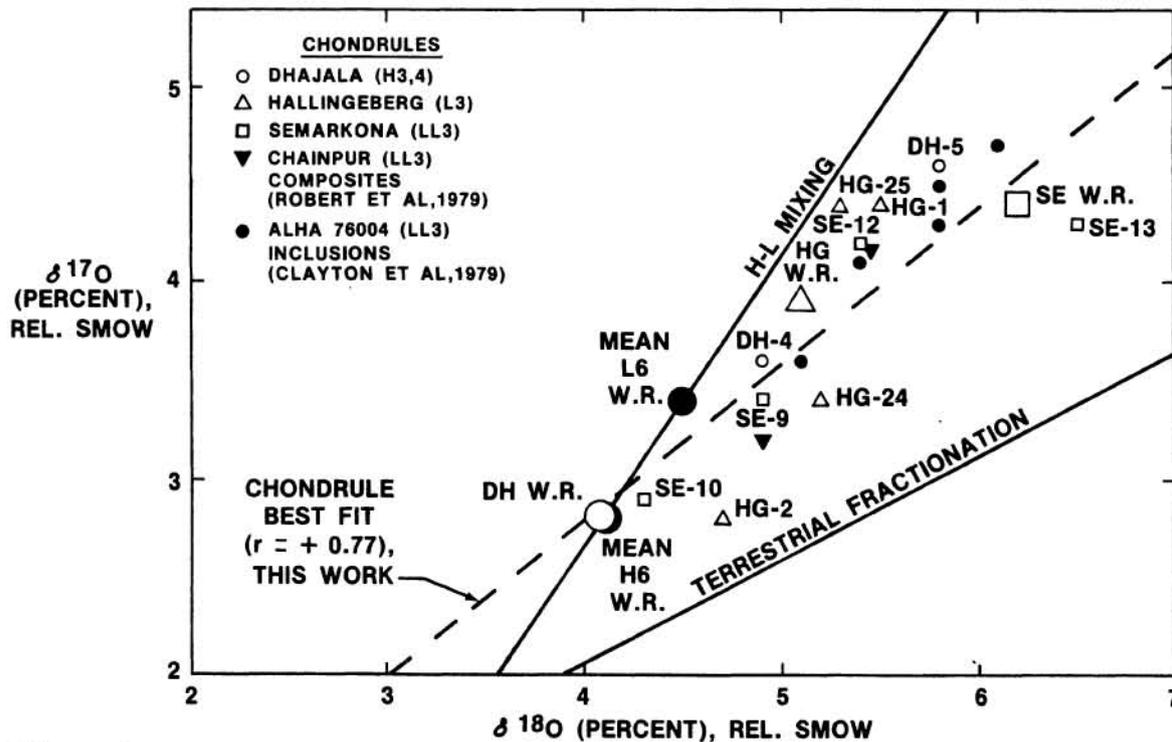


Figure 1. Three-isotope plot of Dhajala (DH), Hallingeberg (HG), and Semarkona (SE) chondrule and whole-rock chondrite (W.R.) compositions compared with compositions of chondrule composites (7) and individual inclusions (8).