HIGH-PRECISION $\Delta^{17}O$ DATA: QUERYING THE MEANING OF $\Delta^{17}O$ IN THE INNER SOLAR SYSTEM. K. Ziegler[1], J. E. Chambers[2] and E. D. Young[1,3], [1]Department of Earth and Space Sciences, University of California Los Angeles (UCLA), Los Angeles, CA 90095 (kziegler@ess.ucla.edu), [2] Carnegie Institution of Washington, Department of Terrestrial Magnetism, Washington, DC 20015 (chambers@dtm.ciw.edu), [3]Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90095 (eyoung@ess.ucla.edu).

Introduction: The veracity of the standard interpretation that the $\Delta^{17}O$ value of meteorites are unique fingerprints for individual parent bodies can be evaluated in the context of models for planetary accretion [1-3]. We wish to know if high-precision oxygen isotope analysis of meteorites can be understood in the context of these models. The goal is to device ways to filter out the isotopic effects of planet-forming processes in order to relate meteorite oxygen isotope data to theories for the oxygen isotopic evolution of the protoplanetary disk [4].

Current theories for planetary accretion indicate that during growth of planetary embryos (Moon-sized bodies), $\Delta^{17}O$ signatures are acquired locally over a narrow range of AU. Later stage planetary growth involves inter-embryo collisions, and growing planets then acquire $\Delta^{17}O$ signatures representing planetesimals from a much broader range in radial distance from the Sun spanning much of the inner solar system. As evidenced by the different meteorite groups, $\Delta^{17}O$ signatures of planetesimals vary, but what, if anything, do these variations tell us about the structure and the dynamics of the inner solar system prior to and during planet formation?

Planetary Accretion and $\Delta^{17}O$ model: We use a stochastic planet accretion model [2] with an initial population of pre-planetary bodies at circumstellar distances (*R*) from 0.3 to 2.0 AU. The bodies comprise 140 small 'planetesimals' (asteroid-like) and 14 larger 'embryos' (Moon-like). The simulation leads to the formation of a system of four terrestrial planets with characteristics similar to our solar system [2]. We assigned different $\Delta^{17}O$ values to different heliocentric radii to those objects, with the $\Delta^{17}O$ ranging from –3 ‰ to +1 ‰ (corresponding to carbonaceous chondrite whole rock values to ordinary chondrite values), and calculated the $\Delta^{17}O$ of the resulting final four planets. Two extreme cases of $\Delta^{17}O$ distribution are presented: 1) a random and uniform initial distribution of $\Delta^{17}O$, and 2) a very regular, systematic initial distribution following an error function meant to simulate a steep gradient in $\Delta^{17}O$ in the inner solar system.

The random initial distribution leads to planets with $\Delta^{17}O$ values that are different from each other by several tenths of per mil (Fig. 1; up to 0.8 ‰). The reduction in spread in $\Delta^{17}O$ from 4 ‰ to 0.8 ‰ reflects homogenization during accretion. The lack of regular

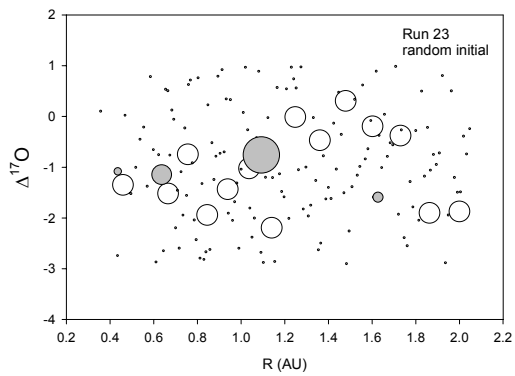

Figure 1. Random distribution of assigned $\Delta^{17}O$ values to planetesimals (black dots) and embryos (black circles) across the inner solar system, and the resulting fours planets (grey, not to scale with planetesimals and embryos).

variation in $\Delta^{17}O$ with *R* is a consequence of the random initial distribution. In contrast, the systematic initial $\Delta^{17}O$ distribution with a steep gradient across the inner solar system creates planets with $\Delta^{17}O$ signatures that mimic the original $\Delta^{17}O$-*R* structure with planets different from each other by about 3 ‰ (Fig. 2).

Although we chose two extreme scenarios for these thought experiments, we can conclude that with disparities in $\Delta^{17}O$ among planetesimals commensurate with the range in chondrite $\Delta^{17}O$, and in the absence of

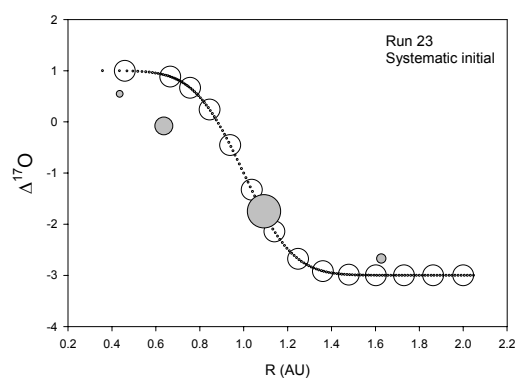

Figure 2. Systematic distribution of assigned $\Delta^{17}O$ values to planetesimals, embryos, and the resulting fours planets (symbols as in Fig. 1).

a strong gradient in $\Delta^{17}O$, planets should have formed with $\Delta^{17}O$ variability on the order of several tenths of per mil . What is more, the chances of forming a planet of the same $\Delta^{17}O$ as one of the 'absorbed' small objects are basically zero (Fig. 1). Conversely, the presence of a strong gradient in $\Delta^{17}O$ of the 4 ‰ over a limited range of R will be mirrored, albeit less strongly, by the $\Delta^{17}O$ of the resulting planets.

Oxygen Isotope Data: Our model results imply that an analytical precision of <0.1 ‰ is required to establish unequivocally the uniqueness of $\Delta^{17}O$ values among smaller parent bodies. Infrared laser-heating fluorination (IR-LF) has an analytical precision of ~0.02 ‰ and can be used for this purpose [5-8].

We obtained new IR-LF oxygen isotope data at UCLA for 11 eucrites (cumulate and basaltic), 2 howardites, 7 pallasites (MG), 5 mesosiderites, and 3 enstatite chondrites (EH3, EL3, and EL6). Our goal is to compare groups using the same procedures in a single laboratory in order to minimize systematic errors. We find that $\Delta^{17}O$ values of mesosiderites (–0.25 ±0.04 1σ ‰), pallasites (–0.22 ±0.03 ‰), and HEDs (–0.23 ±0.05 ‰), with the exception of Ibitira (–0.085 ±0.004 ‰, cf. –0.054 ±0.010 [4]), are indistinguishable from each other at the 0.03 ‰ level, and that enstatite chondrites (–0.01 ±0.01 ‰) are indistinguishable from Earth at the 0.01 ‰ level.

Relative probability plots of the HED, MG pallasite, and mesosiderite data reveal that they form one indistinguishable, narrow $\Delta^{17}O$ population (Fig. 3). If one were to assume a 4 ‰ variation in $\Delta^{17}O$ across the inner solar system (R < 3 AU), one would have to conclude that these bodies come from the same feeding zone over a narrow range of R.

Plotting our terrestrial and E chondrite data with lunar data [8] shows that those groups are indistinguishable from one another (Fig. 4).

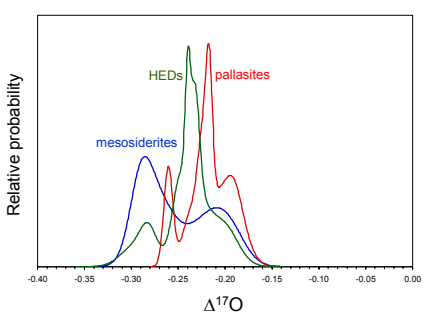

Figure 3. Relative probability of $\Delta^{17}O$ values for pallasites, HED meteorites, and mesosiderites obtained by IR-LF at UCLA.

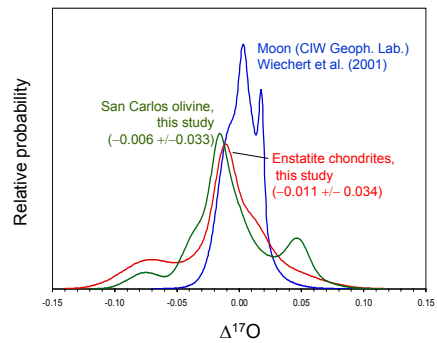

Figure 4. Relative probability of $\Delta^{17}O$ values of San Carlos olivines, E chondrites, and the moon [8; data obtained at CIW Geophysical Lab is offset by 0.02‰ from UCLA lab].

Discussion: In the standard interpretation these data require that MG pallasites, mesosiderites, and HEDs (*sans* Ibitira) derive from the same planetary embryo or from embryos grown in adjacent feeding zones if nebular $\Delta^{17}O$ varied with R (Fig. 2). The interpretation for the E chondrites is more complicated. Our accretion models have shown that it is not very likely to have two objects of the same $\Delta^{17}O$ (Fig. 1), yet we have identical $\Delta^{17}O$ values in objects that have sampled very different scales of the solar system: E chondrites on a planetesimal scale, and Earth and Moon on a planetary scale. If the identical $\Delta^{17}O$ values of Earth and Moon binds them together genetically [9], then either the E chondrites are part of the Earth-Moon system (unlikely) or $\Delta^{17}O$ was the same for R ~ 0.5 to 3 AU. Therefore, if $\Delta^{17}O$ did not vary with R, any observed $\Delta^{17}O$ variability must have been due to heterogeneity in time rather than space.

Conclusions: We conclude: (1) Identical $\Delta^{17}O$ among HEDs, mesosiderites, and MG pallasites suggest that these rocks represent a single feeding zone, or that a $\Delta^{17}O$ of -0.23‰ was typical of the inner solar system at some time; (2) coincidence among E chondrites, Earth, and Moon in $\Delta^{17}O$ requires that $\Delta^{17}O$ was the same for R ~ 0.5 to 3 AU at some time; (3) the $\Delta^{17}O$ of protoplanetary material changed with time rather than position in the inner solar system.

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