METAMORPHIC CONDITIONS WITHIN THE VILLALBETO DE LA PEÑA L-CHONDRITE PARENT BODY BASED ON PETROLOGIC AND UV LASER FLUORINATION OXYGEN ISOTOPIC STUDIES ON AN UNIQUE FRAGMENT. K.A. Dyl[1], A. Bischoff[2], K. Ziegler[3], K. Wimmer[4], E.D. Young[1,3], [1]Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095 (kdyl@ucla.edu), [2]Institut für Planetologie, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany, [3]Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90095, [4]Suedendstr. 1, 86695 Nordendorf, Germany.

Introduction: Villalbeto de la Peña, originally classified as an L6 ordinary chondrite [1], is a well-characterized fall over Spain from 2004. A piece of this meteorite found in 2005 revealed a large, dark fragment of largely feldspathic composition, prompting its potential reclassification as a polymict breccia [2]. Shock veins intersect the clast, indicating an early incorporation into the parent body (Figure 1).

Compositional and oxygen isotopic analyses across the host-inclusion boundary were performed to elucidate the relationship between the clast and the L6 ordinary chondrite host. The results were used to explore metamorphic conditions on the parent body. We find that the inclusion is unrelated to ordinary chondrite material, and that coexisting geochemical trends cannot be explained by "dry" diffusion. We hypothesize that the presence of a volatile phase better explains the geochemical data.

Petrography of Inclusion: The dark fragment found in Villalbeto de la Peña is approximately spherical and 2 cm in diameter. Micron-scale Cr-rich spinel, kamacite, and troilite are interspersed through a feldspathic matrix of andesine composition (~An_{50}). The inclusion is surrounded by a rim exhibiting a recrystallization texture.

Electron microprobe analyses of feldspar across the inclusion reveal a compositional gradient from rim to core. Feldspar found in the recrystallized rim records Na-rich compositions (~An_{10}) indistinguishable from plagioclase grains in the host meteorite [1,2]. A profile of increasingly anorthite-rich compositions is clearly observed, and plateaus at ~500 μm.

Isotopic Analyses: Oxygen isotopic data were obtained for the bulk meteorite, bulk inclusion, and across the boundary between the two.

CO_2 Laser Fluorination: High-precision infrared laser-heating fluorination with an analytical precision of ±0.02 ‰ for $\Delta^{17}O$ was used to analyze mg-sized aliquots of both the host material and the included fragment. $^{18}O/^{16}O$ and $^{17}O/^{16}O$ ratios of the released and purified O_2-gas were measuerd by dual inlet gas source mass spectrometry (ThermoFinnigan Delta-Plus).

UV Laser Ablation Fluorination: This technique was employed to measure the isotopic gradient across the rim and interior of the black fragment. Due to matrix effects from the compositional gradient and micron-sized secondary phases in the feldspar, this technique was uniquely suited for this study. A 213 nm Nd-YAG laser was used to ablate individual spots in the sample, a fragment containing both host meteorite and inclusion, in the presence of purified F_2 gas. The sample was ablated in 600 μm lines parallel to the host-inclusion interface with a radius of 100 μm. A He-carrier flow system injected O_2 sample into a Thermo Finnigan 253 mass spectrometer for analysis. Precision is on the order of 0.2 to 0.3 ‰ in $\delta^{18}O$ and $\delta^{17}O$.

Figure 1: Hand specimen of the Villalbeto de la Peña meteorite showing the cm-sized black fragments. A shock vein is cutting through the black fragment indicating its formation after the incorporation and annealing of the black fragment.

Results: Oxygen isotopic results are summarized in Figure 2. Data obtained from both fluorination techniques are consistent, and show that Villalbeto de la Peña has an oxygen isotopic composition with $\Delta^{17}O \approx$ 1.1 ‰, consistent with L6 ordinary chondrite. The bulk inclusion, however, records a $\Delta^{17}O \approx -0.55$ ‰. This confirms that the fragment is unrelated to the bulk meteorite; the winonaite Tierra Blanca and the anomalous silica-bearing iron meteorite LEW 86211 are the only other meteoritic material exhibiting a similar oxygen isotopic composition [3,4]. The profile obtained from in situ ablation reveals a clear isotopic gradient, indicating that exchange occurred. The gradient in $\Delta^{17}O$ extends 1000-1500 μm into the inclusion.

Discussion: We investigated whether the two exchange reaction profiles observed in the fragment, that of albite-anorthite substitution ($NaSiCa_{-1}Al_{-1}$) and the oxygen self-diffusion (e.g., $^{18}O^{16}O_{-1}$), were consistent with solid-state diffusion between the host and fragment during thermal metamorphism on the L6 chondrite parent body.

Diffusion in Feldspar Under "Dry" Conditions: In the simplest case, we assume the diffusion occurred via no facilitation from a secondary phase ("dry" conditions) along growth or grain boundaries. Models of thermal metamorphism on the L chondrite parent body give peak temperatures of 1000-1273 K over ~60 Ma of cooling [5]. By plotting the diffusion lengthscale for both exchange reactions at temperatures of type 6 metamorphism, we can compare the predicted diffusion of the two species with our data.

Since cation diffusion in feldspar is rate-limited by the diffusion of silicon into the tetrahedral site, diffusion of silicon into feldspar can be used to approximate the coupled substitutions [6]. Experimentally determined diffusion parameters for silicon in labradorite (An_{67}) and oxygen self-diffusion in anorthite (~An_{90}) were used to plot the expected lengthscales of diffusion as a function of time [6,7].

Lengthscales of diffusion were calculated at two temperatures corresponding to expected upper and lower bounds estimated for type 6 chondrites [5]. These results are summarized in Figure 3. Red data correspond to the lower bound of ~973K while black data represent the upper bound of ~1273K. Silicon diffusion in feldspar is shown as solid lines; oxygen-self diffusion appears as dashed lines.

The calculations above illustrate that the chemical and isotopic signatures recorded are inconsistent with "dry" diffusion, given the extent of $NaSiCa_{-1}Al_{-1}$ exchange exhibited in the inclusion. We see, as expected, that oxygen self-diffusion occurs over a longer lengthscale than that of silicon (~three times farther); however, we see no evidence for the widespread oxygen isotopic re-equilibration predicted from these diffusion calculations.

Diffusion in Feldspar Under "Wet" Conditions: The presence of a secondary volatile phase is an alternative explanation for the alteration and subsequent reaction and exchange of this inclusion. The presence of two different reaction fronts – a recrystallization front (the rim) and diffusion front into the interior-suggests a more complex history of metamorphism. Evidence for aqueous alteration in chondrules of metamorphosed L chondrites has been previously reported [8]. Furthermore, crystals of halite have been found in H6 chondrites, suggesting the presence of an aqueous brine [9]. After further characterization of this inclusion, we will use more rigorous models under "wet" conditions in an attempt to reconcile the chemical and isotopic profiles.

Conclusions: We conclude that the exotic clast present in Villalbeto de la Peña records alteration signatures from a volatile phase on the L chondrite parent body. Future work on this inclusion will more rigorously model the complex albitization reaction front and simultaneous oxygen isotopic exchange with the goal of characterizing conditions of metamorphism as well as the composition of the proposed volatile phase.

References: [1] Llorca A. et al. (2005) *Meteoritics & Planet. Sci., 40*, 795–804. [2] Bischoff A. et al., *in prep*. [3] Clayton R. N. and Mayeda T. K. (1996) *GCA, 60,* 1999-2017. [4] Clayton R. N. et al. (1991), *GCA, 55*, 2317-2337. [5] Bennett M. E. and McSween H. Y. (1996) *Meteoritics & Planet. Sci., 31,* 783-792. [6] Cherniak D. J. (2003) *EPSL, 214*, 655-668. [7] Ryerson F. J. and McKeegan K. D. (1994) *GCA, 58,* 3713-3734. [8] Grossman J. N. et al. (2000) *Meteoritics & Planet. Sci., 35,* 467-468. [9] Zolensky M. E. et al. (1999) *Science, 285*, 1377-1379.

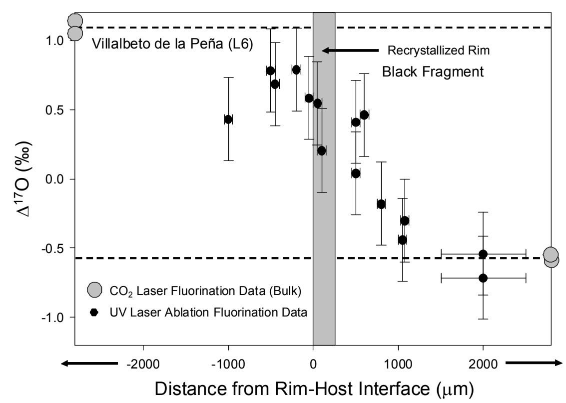

Figure 2: $\Delta^{17}O$ vs. distance in μm across the host-fragment interface. Gray area approximates region of recrystallization. Large grey circles represent bulk analyses and contain no spatial information.

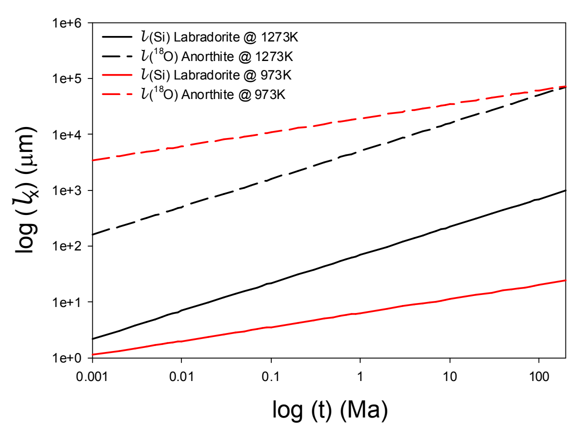

Figure 3: Characteristic diffusion lengthscales (l_x) in feldspar plotted as a function of time for T=973 K and T=1273 K under "dry" conditions. Silicon data was obtained for labradorite [6], and anorthite data was used for O [7].