NATURE AND TIMING OF A PERVASIVE REDUCTION EVENT ON L-CHONDRITE PARENT BODY.

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Introduction: BSE images [1] show that at least 17% of L6 chondrites (15/88) exhibit prominent reduction features: (a) 4-5-µm-thick dark bands along grain boundaries and internal fractures in olivine and orthopyroxene up to 0.4 mol% lower in Fa or Fs than grain centers, (b) 4-12-µm-thick dark bands (probably poorly crystalline pyrrhotite) along grain boundaries and internal fractures in troilite that average 0.4 wt.% less Fe than grain centers, and (c) 2-5-µm-thick continuous or discontinuous dark rinds of low-Ni metallic Fe around taenite grains. Major reduction features in L6 chondrites occur in Cactus Springs (CS), Guangnan (GN), Muroc Dry Lake (MDL), NWA 1857, Osceola (OS), Thamaniyat Ajras (TA), and Viñales. Minor reduction is evident in Bluewing 035, NWA (184, 428, 429, 988, and 6811), Pinto Mountains, and Songyuan. Only 1/70 surveyed L3-5 chondrites (i.e., L4 NWA 8144) exhibits (minor) reduction. To ascertain if the reduction was caused by shock, we determined $^{40}Ar/^{39}Ar$ ages of CS, GN, MDL, NWA 1857, OS, and TA. In heating experiments, plateau ages can be assigned if three or more consecutive steps are indistinguishable from adjacent ones at the 95% confidence level and together account for ≥50% of the total $^{39}Ar_K$ released.

Results: Cactus Springs has a five-step plateau age of 4037±9 Ma, accounting for 100% of $^{39}Ar_K$ released. Guangnan has an integrated plateau age of 155.69±0.64 Ma, accounting for 75% of $^{39}Ar_K$ released. MDL has its first two low-temperature steps indicating an $^{40}Ar^*$ loss event 2600-2700 Ma ago. NWA 1857 has its first three low-temperature steps indicating an $^{40}Ar^*$ loss event ~1200 Ma ago. Osceola has a plateau age of 469.1±2.2 Ma, accounting for ~50% of $^{39}Ar_K$ released. Thamaniyat Ajras has a plateau age of 4543±3 Ma, accounting for ~85% of $^{39}Ar_K$ released.

Discussion: Pervasive fine-scale L6 reduction features suggest the reductant was a fluid, possibly CO [1]. Because the reduction event is nearly exclusively in type-6 samples, it must have occurred in the L asteroid after maximum metamorphic temperatures were reached and minerals had coarsened to their present sizes. The variations in Ar-Ar ages reflect stochastic collisions affecting those L6 chondrites exhibiting major reduction. No single impact event (e.g., the disruption of the L asteroid ~470 Ma ago [2]) caused widespread reduction in the L-chondrite parent body.

In each ordinary-chondrite (OC) group, mean olivine Fa values increase with petrologic type [3], indicating a positive correlation between metamorphic grade and oxidation state. This may be due to mobilization of water derived from heating accreted ice or from dehydrating phyllosilicates that had formed during early-stage aqueous alteration. The total amount of H_2O^+ (indigenous water) decreases among L-chondrite falls during metamorphism: L3+L4 (1.00±0.70 wt.%; n=8); L5 (0.30±0.30 wt.%; n=12); L6 (0.25±0.30 wt.%; n=32) [4]. H_2O^+ is present in every measured L3 and L4 fall; it is absent in 33% of L5 falls and 34% of L6 falls. As metamorphism proceeds, water is gradually used up by oxidation reactions or is lost from the asteroid. If the initial water was enriched in heavy O isotopes [5], metamorphic loss of water would cause the higher OC petrologic types to develop lower $\delta^{18}O$ and $\delta^{17}O$, anticorrelating with Fa (e.g., L4 = Fa24.0, $\delta^{18}O$=4.79‰, $\delta^{17}O$=3.55‰; L6 = Fa25.1, $\delta^{18}O$=4.60‰, $\delta^{17}O$=3.46‰) [6]. Approximate metamorphic temperature ranges are: L3 (260-600ºC), L4 (600-700ºC), L5 (700-750ºC), L6 (750-950ºC) [7,8].

A potential reductant is C derived from the suite of C-rich aggregates and C-rich chondritic clasts in OC [9]. These objects are composed of fine-scale intergrowths of poorly graphitized C, amorphous C, metallic Fe-Ni, and minor chromite [10]; they range up to ~1 mm in size and constitute up to several volume-percent of some type-3 OC. The extent of graphite oxidation ($C + ½O_2 \rightarrow CO$) at various temperatures is likely to depend on oxygen fugacity. Under terrestrial-surface redox conditions, the proportion of graphite that would be oxidized at temperatures corresponding to OC petrologic types [11] can be estimated: type 3 (0-4%), type 4 (4-11%), type 5 (11-17%), type 6 (17-26%). We suggest that, during progressive OC thermal metamorphism, there are two competing redox reactions: (1) mobilization of water (derived from ice or phyllosilicates within the matrix), causing oxidation of silicates, oxides, and metallic Fe-Ni and (2) concomitant oxidation of graphite, resulting in reduction of these same components. After peak metamorphic temperatures were reached in L6 chondrites, ~75% of the water had been used up or lost; the remaining water facilitated continuing graphite oxidation so that, after this point, overall reduction effects exceeded those of oxidation. L3-5 chondrites were much less affected by reduction due to their lower metamorphic temperatures. Thamaniyat Ajras has a precise (±0.7‰) plateau age of 4543±3 Ma; the major reduction of this meteorite provides the timing of Ar closure during post-metamorphic cooling. It seems likely the L6 reduction event occurred at this time.

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