A Pervasive Reduction Event on the L-chondrite Parent Asteroid

Alan E. Rubin

Department of Earth, Planetary & Space Sciences and Institute of Geophysics & Planetary Physics *UCLA*

I surveyed 157 L chondrites and found that some samples exhibit prominent reduction features in olivine, low-Ca pyroxene, sulfide and metallic Fe-Ni. These features occur in 14 of 87 L6 chondrites (16%), but only one of 70 L3-5 chondrites (1.4%). Among L6 chondrites, samples exhibiting major reduction include Cactus Springs, Guangnan, Muroc Dry Lake, NWA 1857, Osceola and Thamaniyat Ajras; minor reduction is evident in Bluewing 035, NWA 184, NWA 428, NWA 429, NWA 988, NWA 6811, Pinto Mountains and Songyuan. Minor reduction also occurs in L4 NWA 8144.

In the recent Osceola L6 fall (24 January 2016), there are 4-5-µm-thick reduction rims (dark bands in BSE images) on many olivine and orthopyroxene grains and along most fractures within these grains (Fig. 1). A typical large olivine grain in Osceola has a composition of Fa23.6±0.2 in the center and Fa23.2±0.1 in the reduction rim. Unlike reduction rims on ureilite olivines, there are no small blebs of low-Ni metallic Fe at the mafic-silicate grain margins in reduced L chondrites.

In many Osceola troilite grains (FeS; Fe/S = 1.67), grain margins and fractures are lined with a 4-12-µm-thick band of pyrrhotite ($Fe_{1-x}S$; Fe/S = 1.65) (Fig. 2). Although pyrrhotite is typically found in oxidized chondrites (wherein the Fe deficit was caused by oxidation of Fe from troilite during parent-body aqueous alteration), this may be the first known instance where pyrrhotite formed from troilite by reduction of Fe^{+2} and removal of the resultant metallic Fe.

There are 2-5-µm-thick BSE-dark rinds of low-Ni metallic Fe around taenite grains in Osceola and Cactus Springs (Fig. 3). The rinds were probably derived from Fe^0 reduced from Fe^{+2} in silicate and sulfide.

Because the reduction process affected type-6 L chondrites nearly exclusively, the reduction event must have been either syn- or post-metamorphic; the silicate and sulfide grains had coarsened to their present sizes and fractured prior to reduction. Because organic matter in type-3 ordinary chondrites probably cannot survive metamorphism to type-6 levels, it seems plausible that the reductant was introduced from outside the L-chondrite parent body, e.g., by a C-rich projectile. The reduction event was wide-spread and likely caused by a major impact, possibly the same one that disrupted the L-chondrite asteroid ~470 Ma ago.

The pervasiveness of reduction in Osceola, Cactus Springs and related L6 chondrites suggests that the reductant was a fluid, perhaps CO. Possible reduction reactions include: $Fe_2SiO_4 + 2CO = 2Fe + SiO_2 + 2CO_2$ and $FeSiO_3 + CO = Fe + SiO_2 + CO_2$. I found no free silica in these meteorites; it seems possible that the excess silica combined with olivine to make small amounts of additional low-Ca pyroxene.

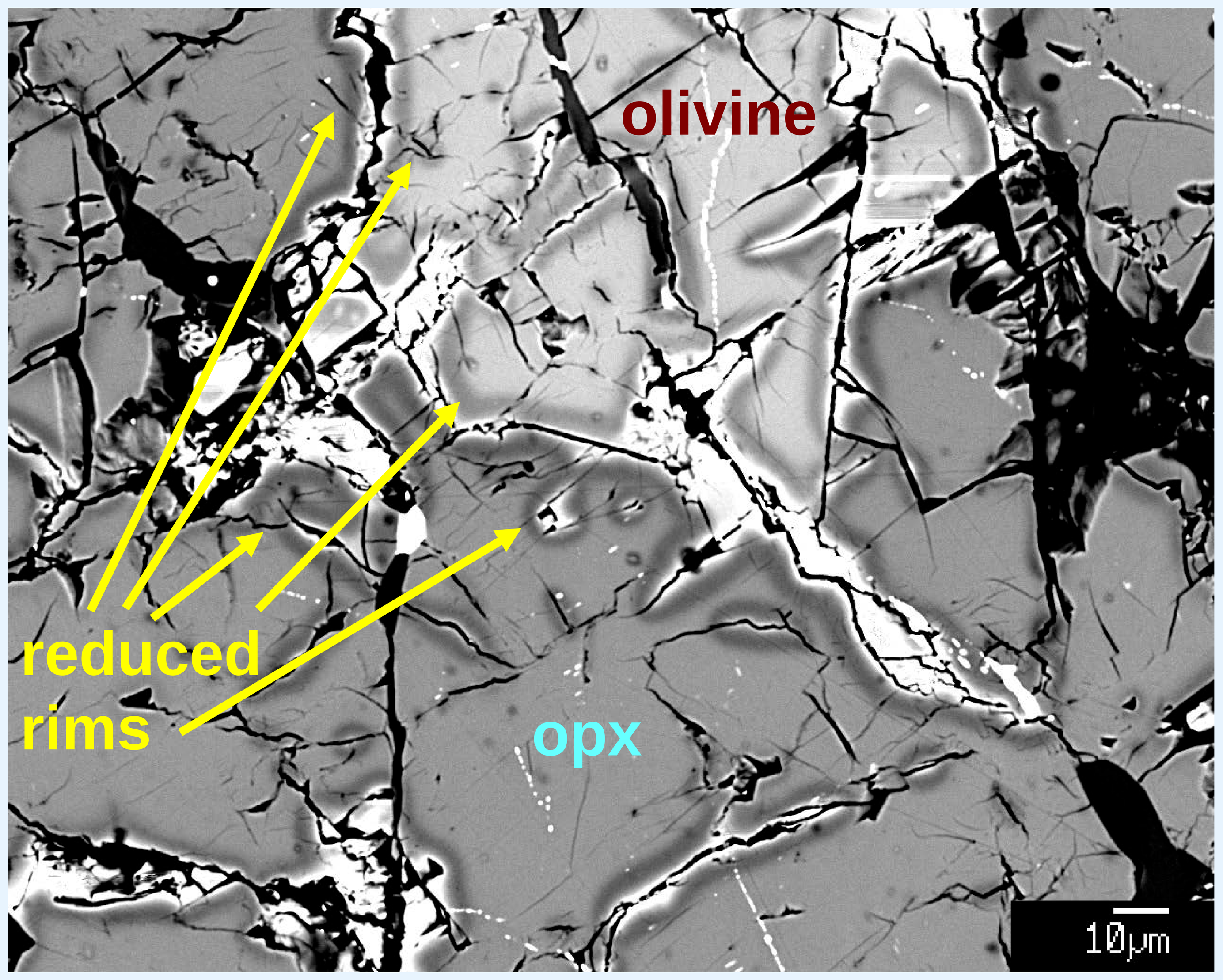

Fig. 1. Olivine (light gray) and ortho-pyroxene (opx) (medium gray) grains with reduction rims (dark gray) in L6 Osceola. BSE image.

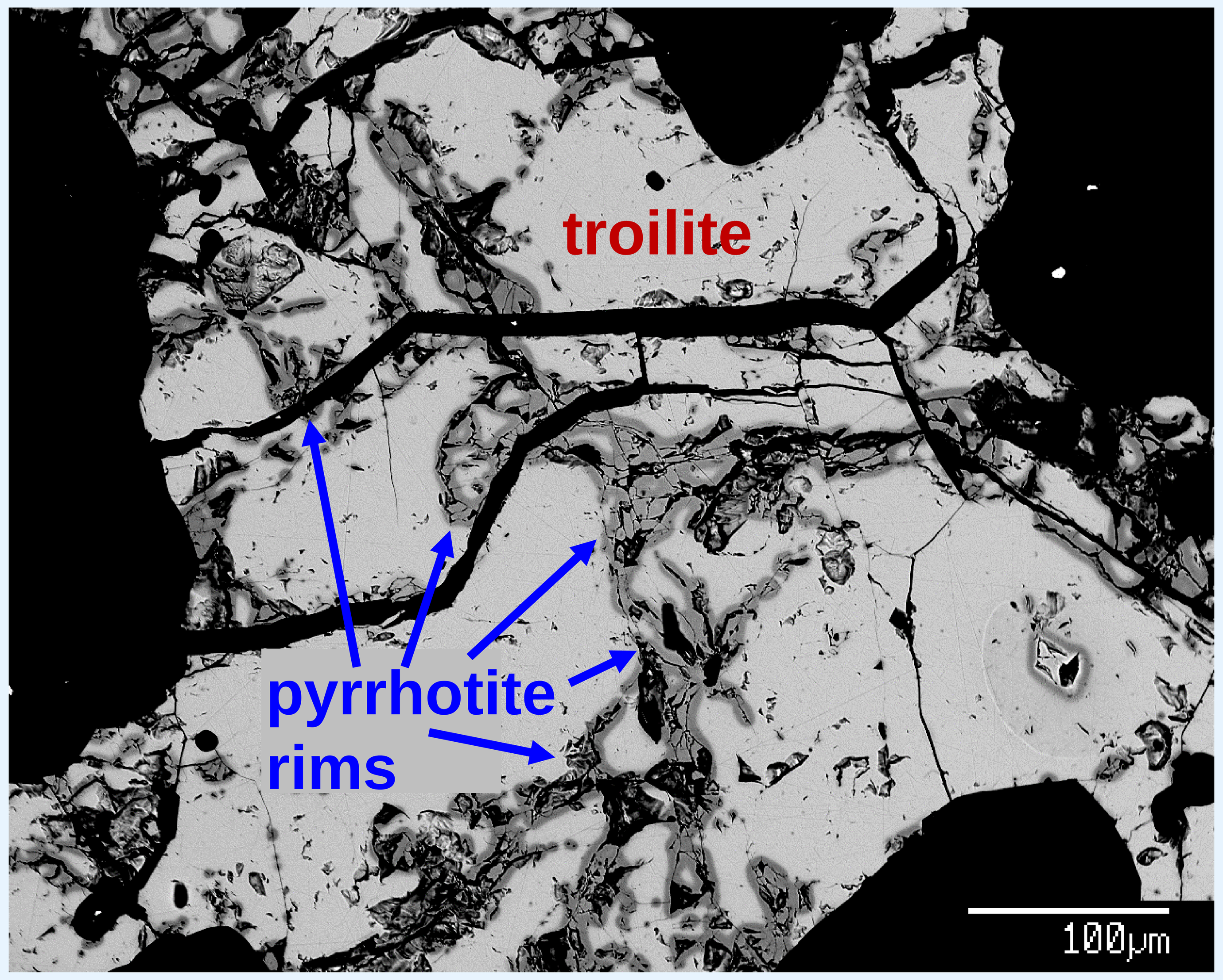

Fig. 2. Portion of a large troilite grain (light gray) with pyrrhotite (dark gray) lining rims and fractures in L6 Osceola. BSE image.

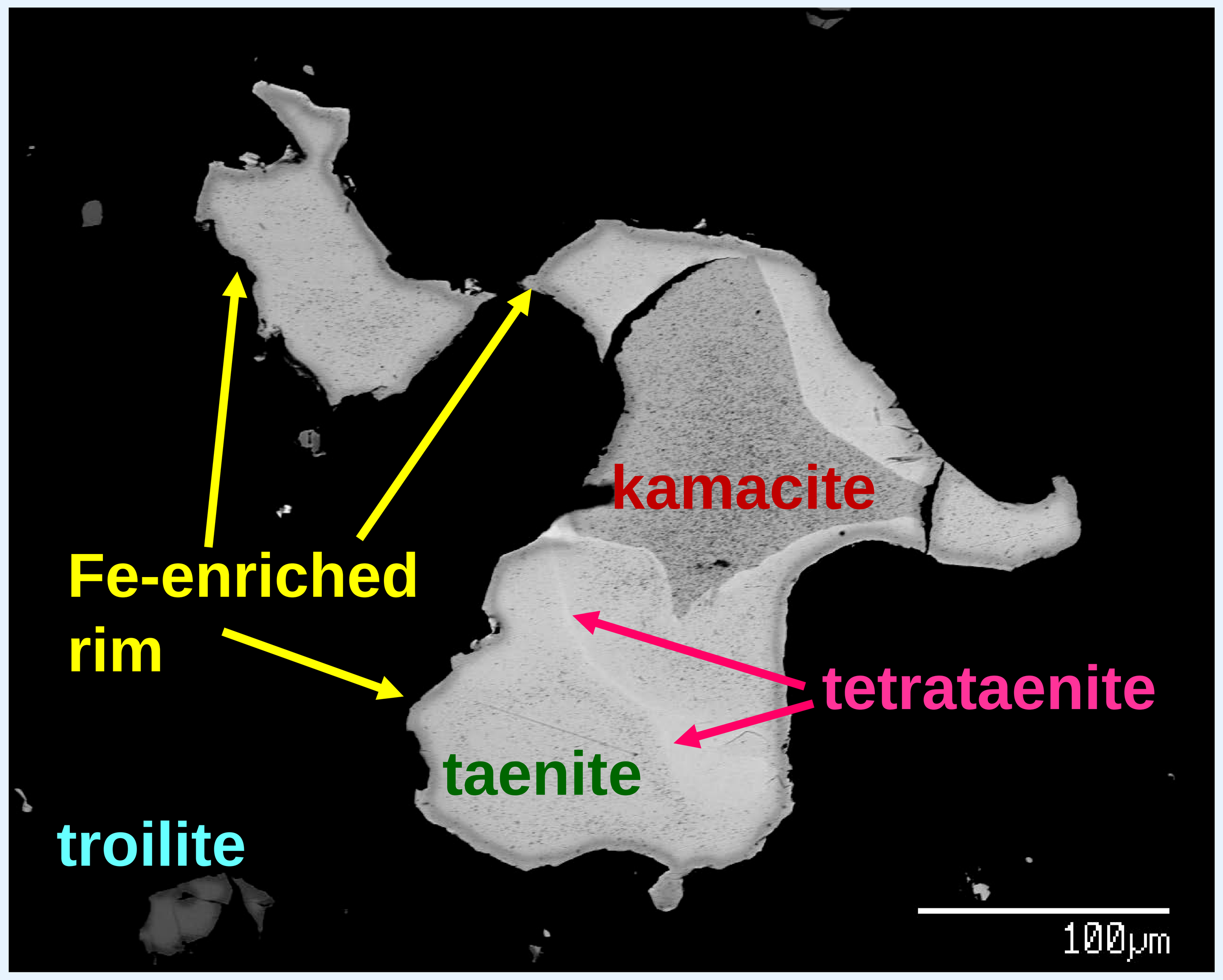

Fig. 3. Metallic Fe-Ni grain in L6 Cactus Springs consisting of kamacite, taenite and tetrataenite surrounded by a ~5-µm-thick Fe-enriched rim. The rim formed from reduced Fe liberated from mafic silicates and sulfide. BSE image.