LL6 GALIM (a) AND EH GALIM (b): REDOX REACTIONS IN A HEAVILY SHOCKED POLYMICT BRECCIA; Alan E. Rubin, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA.

Seven pebbles of centimeter size were recovered from a meteorite shower observed near the town of Galim in Cameroon in November, 1952. The main lithologies of the pebbles were described by Christophe Michel-Lévy and Bourot-Denise [1]. At least three (and probably six) of the pebbles constitute Galim (a), a heavily shocked (shock stage S6) LL6 chondrite; one pebble constitutes Galim (b), an impact-melted EH chondrite containing fragmental chondrules and euhedral enstatite grains. Because both the LL6 and EH stones are unweathered, they are almost certainly from the same fall, indicating that Galim is a polymict breccia. Galim (a) contains reversely zoned chromite grains with appreciably lower FeO/(FeO+MgO) ratios than those in typical LL5-6 chondrites. Galim (b) lacks graphite, Si-bearing kamacite, Ti-bearing troilite and other sulfides (e.g., niningerite, oldhamite) characteristic of EH chondrites. It appears that Galim (b) was an EH clast that was oxidized during shock melting while in contact with its LL host; Galim (a) was reduced, during either the same shock event or subsequent thermal metamorphism.

Galim (b). Galim (b) contains some apparently unrecrystallized chondrules and was classified as EH3 by Prinz et al. [2]. However, many of the phases present in EH3 chondrites are not present in Galim (b) including forsterite, Ti-bearing troilite, Si-bearing kamacite, graphite, niningerite, daubréelite and oldhamite [1]. In addition, taenite and tetrataenite, which are absent from EH3 chondrites, occur in Galim (b) as accessory phases [1]. Christophe Michel-Lévy and Bourot-Denise [1] determined the bulk Mg/Si atomic ratio of Galim (b) to be 0.80; this is similar to that of enstatite chondrites (EH: 0.73; EL: 0.88) and less than that of ordinary chondrites (H: 0.97; L: 0.92; LL: 0.92).

The high degree of shock experienced by Galim (b) is illustrated by the elongated veins of kamacite (≤2.5 mm long) and troilite (which forms a series of veins >6 mm in length). Some of the troilite veins contain small dendrites of kamacite; the spacings between the dendrite arms (~1.5 μm) correspond to a cooling rate of $\sim 2\times10^5$ °C s^{-1} in the temperature interval 1400-950 °C (cf. Scott [3]). The texture of Galim (b) is similar to that of Abee [4,5] except for the absence of clasts and dark inclusions. Most of the chondrules in Galim (b) are fragmental; many have been invaded by metal-sulfide melts. Some chondrules are rimmed by kamacite. Kamacite globules range in diameter from 25 to ~400 μm; euhedral enstatite grains (4-125 μm in length) occur within the globules. Larger enstatite grains (≤200 μm) have been partly resorbed and invaded by kamacite and troilite; they appear to be laths dislodged from radial pyroxene chondrules. Many chondrules served as nucleation sites for euhedral enstatite grains growing into adjacent metallic melt. In addition, the interiors of some radial pyroxene chondrules enclose large patches of kamacite containing euhedral enstatite grains. Troilite occurs mainly in patches in the interstices between silicate grains; schreibersite occurs at the interface between kamacite and silicate.

Although the present Si concentration in kamacite is very low (≤0.01 wt.%), one kamacite globule is surrounded by a thin silica-rich rind [1]. It seems likely that this rind formed via oxidation of Si-bearing kamacite during shock melting. During this event, Si was oxidized from kamacite; some Fe was also oxidized, leading to the formation of accessory Ni-rich metal. It is likely that some of the oxidized Fe entered pyroxene; this is consistent with the 1.4 wt.% FeO in a typical enstatite grain and the 6.1 wt.% FeO in pyroxene in the rim around a silica-rich chondrule [1]. (The relatively high and variable FeO content of pyroxene in EH3 chondrites [2] is not appropriate for comparison because much of the enstatite in Galim (b) crystallized from a shock melt.) Among sulfides in Galim (b), Ti was oxidized from troilite, whereas other sulfides were quantitatively destroyed: Mg was oxidized from niningerite, Ca from oldhamite and Cr from daubréelite. Graphite was probably also oxidized, escaping as CO_2(g).

Galim (a). Galim (a) is a highly recrystallized, heavily shocked (shock stage S6) LL6 chondrite. Only rare relict barred olivine and porphyritic olivine chondrules are discernible. Three types of shock veins occur: (1) abundant metal-troilite veins 0.4-20 µm thick, 1-4000 µm long; (2) centimeter-length networks of black glassy shock veins containing 0.5-µm-size blebs of metal and troilite; and (3) rare short veins of chromite inside silicate grains. Chromite also occurs as trails of blebs in recrystallized melt pockets. Silicates exhibit significant darkening due to the presence of abundant opaque blebs, veins and vein networks inside silicate grains. Although a few olivine grains exhibit extreme mosaicism, most have undergone solid-state recrystallization; these 15-30-µm-size grains form 120° triple junctions and are essentially strain free.

Olivine and low-Ca pyroxene compositional profiles show that these grains are generally unzoned. However, chromite grains are reversely zoned (i.e., they have been reduced): the atomic FeO/(FeO+MgO) ratios at chromite grain edges are up to 8% relative lower than grain cores. Furthermore, as first pointed out by Christophe Michel-Lévy and Bourot-Denise [1], chromite compositions are considerably more reduced than typical LL-chondrite chromites: my data show that the mean atomic FeO/(FeO+MgO) ratio in chromite cores is 0.85 ± 0.02 (n=5) in Galim (a) *vs.* 0.92 in typical LL5-6 chondrites [6]. The chromites were recrystallized and reduced during shock heating or subsequent thermal metamorphism.

Discussion. It seems likely that Galim (b) was a clast of a normal EH3 or EH4 chondrite that was significantly oxidized during shock melting while in contact with its LL host. The Galim (a) host was shocked to stage S6 during the same shock event; it was reduced during this event or, possibly, during subsequent thermal metamorphism. This model is analogous to that invoked by Kallemeyn and Wasson [7] for reduced chondritic inclusions (olivine Fa $\leq$5 mol%) with LL-chondrite bulk composition within the Cumberland Falls aubrite. The Cumberland Falls inclusions contain reversely zoned olivine grains, consistent with reduction. Furthermore, olivine in the inclusions is more reduced than associated low-Ca pyroxene, consistent with the greater rapidity of Fe-Mg diffusion in olivine.

References: [1] Christophe Michel-Lévy M. and Bourot-Denise M. (1988) *Mineral. Mag.* **52**, 519-525; [2] Prinz M. et al. (1984) *Lunar Planet. Sci.* **15**, 653-654; [3] Scott E.R.D. (1982) *Geochim. Cosmochim. Acta* **46**, 813-823; [4] Rubin A.E. and Keil K. (1983) *Earth Planet. Sci. Lett.* **62**, 118-131; [5] Rubin A.E. et al. (1995) *Lunar Planet. Sci.* **26**, 1197-1198; [6] Bunch T.E. et al. (1967) *Geochim. Cosmochim. Acta* **31**, 1569-1582; [7] Kallemeyn G.W. and Wasson J.T. (1985) *Geochim. Cosmochim. Acta* **49**, 261-270.