SHOCK FEATURES IN ACAPULCOITES AND LODRANITES: IMPLICATIONS FOR THE ORIGIN OF PRIMITIVE ACHONDRITES. Alan E. Rubin, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA. (aerubin@ucla.edu)

Introduction. Acapulcoites and lodranites constitute two related groups of "primitive achondrites" [1-3] that possess recrystallized textures, chondritic mineralogy, planetary-type rare gases, and approximately chondritic bulk compositions. They are widely considered to have formed by partial melting of chondritic material [4-10]. Although Kallemeyn and Wasson [11] suggested that acapulcoites could have been heated during collisions on their parent asteroid, McCoy et al. [8] ruled out this mechanism because acapulcoite olivine grains typically exhibit either sharp optical extinction or undulose extinction (without associated planar fractures), characteristic of unshocked (S1) or very weakly shocked (S2) rocks. However, because it is possible that post-shock annealing processes could heal damaged olivine lattices [12,13] in asteroidal materials and make the samples appear less shocked than they once were [14-16], it is worthwhile to search for relict shock features in acapulcoites and lodranites.

Results and Discussion. I studied nine acapulcoites (ALH77081, S1; ALH84190, S3; Dhofar 1222, S2; GRA98028, S1; LEW86220, S2; MET01195, S1; MET01212, S1; NWA 725, S1; Superior Valley 014, S2) and four lodranites (EET84302, S1; GRA95209, S1; LEW88280, S1; MAC88177, S5). The two MET acapulcoites are probably paired.

A key clue to the petrogenesis of acapulcoites is the presence of relict chondrules in five of these meteorites. Yanai and Kojima [17] identified a few recrystallized BO chondrules in Y74063; McCoy et al. [8] reported a single 1300×1900-µm-size relict RP chondrule in Monument Draw. I now report that GRA98028 contains ~6 vol.% relict POP and PP chondrules ranging in apparent diameter from 400 to 700 µm. Dhofar 1222 contains ~4 vol.% relict RP, GOP and PO chondrules ranging in apparent diameter from 300 to 1400 µm; NWA 725 contains ~3 vol.% relict POP, BO, PO and GOP chondrules ranging in apparent diameter from 300 to 900 µm. There are no known examples of relict chondrules in lodranites. [Chondrule textural types: BO = barred olivine; RP = radial pyroxene; PO = porphyritic olivine; PP = porphyritic pyroxene; POP = porphyritic olivine-pyroxene; GOP = granular olivine-pyroxene.]

Acapulcoites vary significantly in their modal abundances of metallic Fe-Ni and troilite. Those rocks containing abundant relict chondrules (GRA98028; NWA 725; Dhofar 1222) have greater abundances of opaque phases (30-40 wt.%) than typical acapulcoites (13-20 wt.%). Also containing abundant opaques (~40 wt.%) is LEW86220, which is relict-chondrule free and texturally intermediate between acapulcoites and lodranites [8,10]. Most acapulcoites contain 4-7 wt.% troilite, similar to the abundances in OC falls (5-6 wt.%); however, the relict-chondrule-bearing acapulcoites contain higher troilite abundances (18.5, 11.9 and 7.3 wt.% in GRA98028, NWA 725 and Dhofar 1222, respectively). Graphite occurs as lumps and branching laths within a few metal grains in some acapulcoites (i.e., Acapulco [4], ALH77081 [18], and MET01195). The lodranite GRA95209 contains small graphite grains and one coarse (1020×1340 µm) graphite grain within a large (3.6×6.8 mm) grain of metallic Fe-Ni.

Acapulcoites have been significantlfy heated and partly melted. They are characterized by recrystallized textures consisting of equigranular silicates [8]. Many grain boundaries converge at 120° triple junctures, indicating a high degree of textural equilibrium. However, the extent of melting in some acapulcoites was low enough to allow the preservation of relict chondrules.

Clues to the identification of the melting mechanism can be found in the preservation of relict shock features [19] in acapulcoites. These features include veins of metallic Fe-Ni and troilite in Monument Draw [8] and other acapulcoites; ubiquitous polycrystalline kamacite [8]; polycrystalline troilite in many samples; rapidly solidified metal-troilite assemblages in ALH84190 and ALH77081; metallic Cu in NWA 725 and Dhofar 1222, irregularly shaped troilite grains within metallic Fe-Ni in GRA98028, MET01195 and LEW 86220, rare chromite veinlets within mafic silicates in NWA 725 and Superior Valley 014, and rare chromite-plagioclase assemblages in NWA 725.

The preservation of numerous relict shock features in acapulcoties indicate that these rocks were probably heated by impacts. Lodranites formed in a similar manner to acapulcoites but suffered more extensive heating, loss of plagioclase and loss of a low-temperature Fe-Ni-S melt [7-10].

The precursors of acapulcoites seem to have been CR-like carbonaceous chondrites. This is consistent with the chondritic mineralogy of acapulcoites (major olivine, pyroxene, plagioclase and metallic Fe-Ni), the occurrence of relict chondrules and planetary-type noble gases [4], CI-level abundances of refractory lithophiles and refractory siderophiles [11] (as in CR chondrites [20]), the mean modal abundance of metallic Fe-Ni (17 wt.% vs. ~16 wt.% in Renazzo [21]), and O-isotopic composition ($\Delta^{17}O$ = -0.85 to -1.22‰ [22] vs. -0.96 to -2.42‰ in CR chondrites [23]).

Acapulcoites suffered reduction, presumably during heating. The highest mean Fa value in an acapulcoite (Fa 13.1 in NWA 2627) is a lower limit of the mean Fa content of the chondrite precursors of acapulcoites. Graphite was probably the reducing agent, producing metallic Fe at the expense of FeO and causing reverse zoning in mafic silicate grains in some acapulcoites and lodranites [24]. The amount of FeO available for incorporation into olivine and low-Ca pyroxene decreased during reduction and resulted in lower mean Fa and Fs values than in the original precursor rock. Because diffusion of Mg and Fe in olivine is more rapid than in pyroxene, olivine in reduced rocks tends to equilibrate faster and achieve a higher *mg* number [(Mg×100)/(Fe+Mg)] than low-Ca pyroxene (e.g., Fa 6.8 and Fs 8.1 in Dhofar 1222; Fa 6.1 and Fs 7.5 in NWA 725). Loss of FeO caused the FeO/MnO ratios in acapulcoite olivine to decrease. Equilibrated H chondrites have olivine FeO/MnO ratios of 32 to 38; acapulcoite olivines have ratios of 16 to 18 [8]. Another consequence of reduction is an increase in the orthopyroxene/olivine (opx/ol) ratio. Although H chondrites have modal opx/ol ratios of ~0.74, some acapulcoites have much higher opx/ol modal ratios: e.g., Monument Draw, 1.7 [8].

Shock heating was followed by rapid cooling, a process that allowed planetary-type noble gases to be retained. The low shock stages of most acapulcoites and lodranites indicate that most of these rocks experienced post-shock annealing, presumably resulting from burial beneath hot, impact-comminuted materials. The annealing process repaired damaged olivine crystal lattices, lending acapulcoites and lodranites the appearance of unshocked rocks.

Some samples were subsequently shocked again; several acapulcoites reached shock-stage S2 levels, ALH84190 reached S3, and the MAC88177 lodranite reached S5.

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