POST-METAMORPHIC BRECCIATION IN TYPE 3 ORDINARY CHONDRITES: E.R.D. Scott, T.J. McCoy, and K. Keil, Planetary Geosciences, Department of Geology and Geophysics, SOEST, University of Hawaii, Honolulu, HI 96822.

Type 3.1-3.9 ordinary chondrites can be divided into two kinds: those in which the compositions of chondrule silicates are entirely consistent with metamorphism of type 3.0 material [1-3], and those in which the compositional heterogeneity appears to be too extreme for in situ metamorphism [4]. We present petrologic data for three LL3 chondrites of the second kind, Ngawi, ALH A77278 (both type 3.6) and Hamlet (type 3.9), and compare these data with results for the first kind of LL3-4 chondrites [1]. Given that chondrules form in the nebula and that metamorphic equilibration occurs in asteroids, our new data imply that Ngawi, A77278, Hamlet and many other type 3 ordinary chondrites [4] are post-metamorphic breccias containing materials with diverse metamorphic histories: they are not metamorphic rocks or special kinds of 'primitive breccias' [5]. We infer also that metamorphism to type 3.1-3.9 levels produces very friable material that is easily remixed into breccias and lithified by mild shock. Thus, petrologic types and subtypes of chondrites indicate the mean metamorphic history of the ingredients, not the thermal history of the rock. The metamorphic history of individual type I or II, porphyritic chondrules in type 3 breccias is best derived from olivine and pyroxene analyses and the data of McCoy et al. [1] for unbrecciated chondrites. The new chondrule classification scheme of Sears, DeHart et al. [6, 7] appears to provide less information about the original state and metamorphic history of individual porphyritic chondrules and should not replace existing classification schemes.

Olivine compositions in type IA and IIA chondrules. The detailed study of mineral compositions and zoning in type IA and IIA chondrules in LL3.0 [2, 3] and LL3.3-5 [1] chondrites and the analogous petrologic and theoretical studies of CO3 chondrites [9, 10] give us considerable confidence that we can identify mineral compositions in these chondrite types that are inconsistent with metamorphic equilibration in type 3 chondrites. Figures 1a and 1b show how the mean olivine compositions in 31 type IA and 28 type IIA chondrules vary with the metamorphic subtype in type 3-4 chondrites that show no evidence for post-metamorphic brecciation [1]. The corresponding data for ALHA 77278 (Fig. 1c and d) and Ngawi (Fig. 1e and f) show vastly greater scatter than shown by Parnallee, although all three are nominally LL3.6 chondrites. We suggest that the compositional data in Ngawi and ALH A77278 scatter because these chondrites are breccias composed of at least four distinct types of material including type 3.0, 3.3, 3.6, and 4 material; subtype uncertainty is ±0.2. The compositional zoning of olivine within individual chondrules in these chondrites is also consistent with this origin. Analogous data for Hamlet suggest it is largely type 3.8-4 material with a small amount of type 3.6 material.

Other petrologic evidence. Metallographic cooling rates. Data for taenite grains in the type 3 chondrites studied by McCoy et al. [1] plot coherently on Wood plots indicating cooling through 400 °C at rates of 1-1000 °C/Myr [11]; there are insufficient taenites in Semarkona to derive a metallographic cooling rate. Our data for taenite grains in Ngawi, A77278 and Hamlet plot incoherently, although individual grains are zoned consistently with slow cooling. We infer that taenites in these chondrites cooled at rates of 10-1000 °C/Myr in different locations prior to lithification, as suggested for many fragmental and regolith breccias [12, 13]. Clasts. We found several type 3.9-5 chondritic clasts in Ngawi; Sears et al. [14] infer from CL studies that there are also type 3.1 clasts in Ngawi. An equilibrated clast has been described in Hamlet [15], but none have been found in A77278. Matrix rims on chondrules. In Ngawi and A77278, there is a good relationship between the petrologic subtype of individual chondrules inferred from the data in Fig.1 and the nature of the matrix rim around the chondrule [16]. Thus type 3.0 chondrules have Semarkona-like, opaque matrix rims, type 3.6-4 chondrules have recrystallized matrix rims like those in Parnallee and Bo Xian, and type 3.3 chondrules are intermediate in nature.

Discussion. The diversity of olivine compositions in Ngawi and A77278 cannot be due simply to the differing response of their chondrules to metamorphism. Sears et al. [17, 6] suggest that chondrules in Dhajala and other type 3 chondrites show diverse degrees of equilibration because the mesostasis of unequilibrated chondrules was more resistant to devitrification. We did not find any relationship between mesostasis texture and olivine heterogeneity to support this hypothesis. We infer that the three LL chondrites that we have studied are precisely analogous to the fragmental and regolith breccias of higher mean petrologic type [e.g., 12, 13]. The only difference is that the type 3 breccias have a lower abundance of clasts and clastic material in their matrices and have generally not previously been recognized as breccias. We infer that this is due to the difficulty in recognizing brecciation in chondrites [8], that metamorphism produces friable type 3 material, and that the breccias were lithified by shock. Except for Ngawi, which contains solar-wind gases [18], we cannot preclude the possibility that mild metamorphism (to <300 °C) occurred after final lithification. By calling these rocks post-metamorphic breccias, we only imply that lithification of the breccias occurred after peak metamorphic temperatures had been reached.

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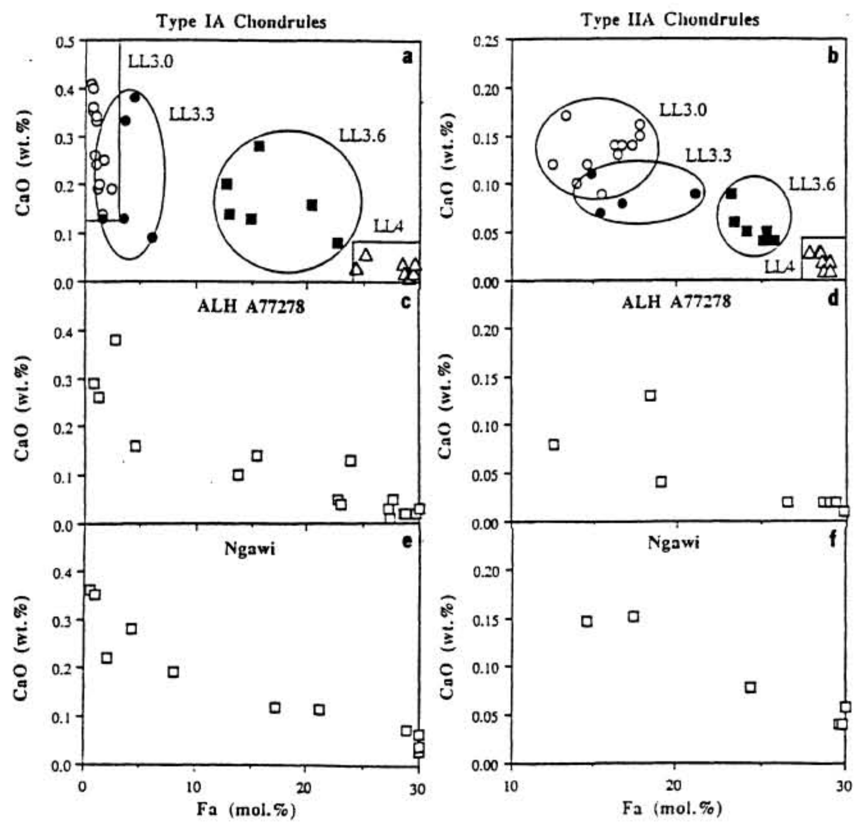

Fig.1. Mean compositions of olivine in type IA and IIA chondrules. (a) and (b) show data for Semarkona (LL3.0) and three LL3-4 chondrites (ALH A81251, Parnallee, and Bo Xian) that appear to have formed by simple metamorphism of Semarkona-like material; data from [1-3]. Our corresponding data for ALH A77278 (c and d) and Ngawi (e and f) show a wide scatter implying that these chondrites which are nominally type 3.6, like Parnallee, are actually breccias composed of at least four kinds of ingredients of type 3.0, 3.3, 3.6 and 4.