HOT ACCRETION OF THE ORDINARY CHONDRITES: THE ROCKS DON'T LIE; R. Hutchison, Mineralogy Department, Natural History Museum, London SW7 5BD, U.K.

Abstract The ordinary chondrites (OCs) comprise three petrographic series, each ranging from type 3 (the UOCs), with distinct chondrules, little crystalline intergrowth and unequilibrated minerals, to type 6 or 7, in which chondrules have largely disappeared into a granular textured fabric with little mineralogical disequilibrium [1]. There are conflicting interpretations of the textural progression. Many believe that the OCs formed by accretion of ‘cold’ silicate chondrules, chondrule fragments, metal, sulphide and fine-grained material, followed by thermal metamorphism [1,2]. A minority argues that the constituents accreted ‘hot’ and that the textural progression resulted from different cooling rates; type 3 cooled rapidly, types 6 and 7 cooled slowly [3,4]. Hot accretion has been attacked by Haack et al. [5], from the premise that chondrules are nebular, and by Rubin [6], who suggests that OCs are ‘brecciated on millimeter-sized scales’ to explain the presence of grains that do not fit the metamorphic model. Some OCs are not post-crystallisation breccias and contain mineralogical evidence that is incompatible with cold accretion and prograde metamorphism.

Introduction Fewer members of the H-group of the OCs suffered shock and brecciation than in the L- and LL-groups, so the H-group was chosen by Hutchison et al. [3] for reappraisal because the elimination of secondary effects is critical in elucidating the thermal history of the primary crystallisation of OCs. Unfortunately this selectivity was not applied by others [e.g. 8,9]. This discussion centres on Kernouve (H6), Barwell (L6) and Tieschitz (H/L3), which suffered no significant post-crystallisation shock or brecciation. There is no direct evidence that chondrules are nebular. In Tieschitz, chondrules or chondrule fragments of silicate, of silicate, metal and sulphide, and of metal and sulphide, are associated with rare igneous fragments. All are coated with opaque, fine-grained rims. They accreted together when igneous activity on a ‘planetary’ object had occurred [7], so we cannot take it for granted that chondrules are nebular.

Rubin [6] discusses seven criteria bearing on the thermal history of OCs. He resorts to late-stage shock and/or brecciation to account for features that otherwise would support hot accretion. A detailed rebuttal will, hopefully, be published elsewhere. Of Rubin's criteria [6], pyroxene thermometry, the significance of polycrystalline taenite, ‘heterogeneous metal grains’ [6,8] and misshapen chondrules in type 3 OCs are treated here.

Chondrules probably are planetary Most silicate chondrules in UOCs have unfractonated refractory lithophile elements, but some do not. Metal-sulphide chondrules are fractionated relative to bulk solar condensables [10]. Very early asteroidal core formation [11] and the former presence of ‘live' 26Al in an igneous object in Semarkona (LL3) [12] are consistent with contemporaneous chondrule-formation [10]. Crystal-liquid fractionation in some chondrules and the existence of differentiated planetary objects when chondrules formed indicate that all chondrules probably are planetary, rather than that some are nebular and others planetary. Observations at sub-micrometre spatial resolution indicate that opaque matrices of UOCs are not dominated by nebular dust [13]. A nebular component in the OCs is probably restricted to a tiny amount of presolar grains [13]. Direct observation, therefore, contradicts the nebular premise of Haack et al. [5].

Pyroxene thermometry Rubin [6] questioned the statements by Hutchison et al. [3] that the Ca content of Ca-poor pyroxenes in ten H3-H6 chondrites is uniformly low throughout the sequence and was controlled by crystallisation from chondrule liquids. The sequence is one of increasing equilibration, so the spread in Ca contents decreases from H3-H6, but the modes for Monroe and Quenggouk (H4), Allegan (H5) and Butsura and Kernouve (H6) lie at 0.5 wt% Ca or below [3]. Failure of Ca-poor pyroxene to equilibrate in response to temperature even manifests itself in LL6-LL7 chondrites [14]. Rubin [6] doubted the interpretation of the experimental result that striated orthopyroxene in Quenggouk (H4)
transforms isochemically to 'normal' orthopyroxene in one week at about 800°C [15]. Striated orthopyroxene is mostly orthorhombic. The experiment shows that only a short time and low temperature are needed to transform the pyroxene typical of H4 to that of H6. This seems incompatible with the duration of a prolonged heating/cooling cycle associated with prograde metamorphism. There may be a problem in producing striated pyroxene from the Ca-poor pyroxene in H3 chondrites, but this may be overcome by the effects of minor elements in determining the pyroxene polymorph precipitated in chondrules [16].

Polycrystalline taenite Bevan and Axon [17] interpreted polycrystalline taenite in metal-sulphide chondrules in Tieschitz as a quench product. Scott and Rajan [18] argued that its presence in H6 chondrites may have been due to shock, but such a 'hot working' origin was disputed by Bevan and Axon [19] and this taenite occurs in Kernouve which is unshocked [20]. Survival of solidification zoning in taenite requires that unshocked H6s were not held above about 900°C. This is compatible with computer modelling [21] which indicates that at cooling rates >1000K/Myr⁻¹, solidification zoning is not erased.

Heterogeneous metal grains Rubin [8] found compositionally 'aberrant' metal grains in various meteorites, and concluded that they must be post-metamorphic xenoliths. One is present in Barwell, which suffered no post-crystallisation brecciation [10]. Barwell and Kernouve [7] also contain 'zoneless plessite' grains [22] produced by rapid cooling through the martensite transformation at about 500°C. This indicates that the normal metallographic cooling model is inapplicable, because it demands homogenisation of metal in the single phase field, followed by slow cooling and kamacite precipitation. Slow cooling should have produced only residual taenite and kamacite, not martensite and plessite.

Misshapen chondrules It has been suggested [23,24] that chondrules that mutually indent had their outlines modified by pressure-induced diffusion at low temperature. In Tieschitz, chondrules are coated by opaque, fine-grained rims which deformed together with their enclosed chondrules. In some chondrules high temperature minerals crystallised after deformation and crystal growth in the opaque rims amounted to only a few micrometres [13]. There is no evidence that chondrules responded to pressure like carbonate spherules in brine [24], nor can indenting chondrules in Tieschitz be compound chondrules, as suggested [6].

Conclusion Disequilibrium among metal and Ca-poor pyroxene in unshocked and/or unbrecciated type 6 OCs is incompatible with prograde metamorphism. Chondrules that indent each other, survival of zoneless plessite and the ease with which striated orthopyroxene (type 4) transforms to orthopyroxene (type 6) favour hot accretion and different cooling rates. If this precludes a nebular origin for chondrules, so be it.