ON THE USE OF PHASE AND BULK COMPOSITIONS IN CLASSIFYING CHONDRULES FROM SEMARKONA (LL3.0) AND OTHER ORDINARY CHONDRITES.

J.R. Beckett[1,3] and H.C. Connolly Jr.[2]. [1]Division of Geological and Planetary Sciences, Caltech, Pasadena, CA 91125; [2]Department of Physical Sciences. Kingsborough College CUNY, Brooklyn, NY 11235; [3]john@gps.caltech.edu.

Introduction: Two major classification schemes involving phase compositions are in current use for the classification of chondrules (ch) from ordinary chondrites (OC). For Semarkona (Sem), types are defined by separating FeO-poor (I) from FeO-rich (II) and subdividing according to olivine (ol)-rich (A), pyroxene (px)-rich (B) or intermediate (AB) [1-4]. [5] used textures to assign ch types in more equilibrated OC. Groups [6] are defined through cathodoluminescence (CL) into bright (A) and dull (B) CL and subdivided into A1-5 and B1-3 by CL of ol and mesostasis (mes) and for A4/A5 and B1/B2 of mes composition. Groups are nominally applicable to all OC.

Both schemes suffer from a lack of transparency. There is currently no satisfactory way to determine type for most ch originally classified by group nor a robust procedure for determining the group of most ch classified by type. This has led to considerable confusion over the accuracy, range of applicability, and relevance of the two schemes [e.g., 6-7]. We use mean compositions of phases and bulk ch of known type or group to develop suites of diagrams. Each places constraints on some but not all ch. By using multiple figures, it should be possible to reduce the incidence of misclassification and maximize constraints where available data are not tailored to classification in a particular scheme. Where inconsistencies are observed, it should be possible in many cases to isolate the source(s) allowing efficient error checking and a focus on anomalous properties.

Approach: We use ol, low-Ca px, mes and bulk composition data of [1-4] for types and [8-10] for groups. The data sets were culled using agreement of stated and calculated sums for all data. For ol and px, oxide sum (100±2%) and stoichiometry constraints were also imposed. For non-IA Sem ch data of [1-4], bulk wt% FeO (all Fe as FeO) is linearly correlated to average FeO in px, and ol. We used these plots to cull data of [8-10]. For mes and bulk compositions, we used MELTS components SiO_2 (Q), TiO_2 (RU), Al_2O_3 (COR), $MgCr_2O_4$ (PC), Fe_2SiO_4 (FA) $MnSi_{0.5}O_2$ (TE), Mg_2SiO_4 (FO), $CaSiO_3$ (WO), Na_2SiO_3 (N2S), $KAlSiO_4$ (KS), and $Ca_3(PO_4)_2$ (WH).

Chondrule types: Useful constraints on type were obtained from average ol (FeO vs. CaO, MnO), px (FeO vs. CaO, Al_2O_3), mes [TE vs FA, PC, N2S/(WO+RU+COR)], and bulk [Q/(WO+RU+COR) vs. FO/FA; Q vs. TE/(WO+RU+COR), N2S/COR; TE/(FO+FA) vs Q/FA; TE vs. PC/FA; TE/(WO+RU+COR) vs. FO/FA; N2S/(FO+FA) vs. PC/FA; WO+RU+COR vs. PC/FA, Q/FA] compositions. Bulk Fe partitioned among FeO, FeS and alloy also generates useful constraints. We were unable to distinguish consistently between IAB and IB ch and, therefore, generally combined the type into IAB/B.

Bulk compositions are especially valuable indicators of type. For 35 accepted Sem ch bulk compositions from [9], 31 yield internally consistent predictions of a specific type. Two of the other 4 are generally off-scale, one is discrepant on one fig but otherwise consistent (i.e. type resolvable) and one is discrepant on many figs. Ol and px compositions for the same ch generally agree with the bulk predictions. There is a discrepancy of some sort for about 20% of the ch in [9] but almost all are readily resolved so that assignment of type is unambiguous. In general, type is not greatly sensitive to average mes compositions (mes of [1-4] combines all phases in interstitial regions between large crystals). For 22 mes of Sem ch in [10], unambiguous type could be assigned to only 8 based solely on mes.

The diagrams described above all involve Fe and many use Mn and/or Cr in Sem ch. All three elements are mobile during metamorphism [5] and applying the diagnostic diagrams to less equilibrated OC leads to misidentification. More work is needed but based on data of [5,11], use with confidence of most Sem-based figs. is likely restricted to chondrites less equilibrated than 3.3. Thus, phase/bulk compositions and textures, which are related in Sem ch, become decoupled in more equilibrated chondrites. Type is best applied to highly unequilibrated OC and used in evaluating the response of ch to an igneous event.

Chondrule groups: [6] suggest the use of FeO-CaO in ol and normative quartz-albite-anorthite (Q-Ab-An) of mes "glass" to define group when CL is unavailable. However, application to 148 ch of [8-10] in OC of metamorphic grades 3-6 with ol and mes yielded only a 59% correct retrieval of the group. Prediction of group was wrong 32% of the time and only for A1s was the error rate below 20%. Similar results are obtained for a 45 ch subset from Sem. Fig. 1 shows one major source of error. Ol compositions from [8-10] with group defined by CL are plotted with suggested composition fields of [6]. There is considerable overlap of A2 and A5 data and many ch plot outside the suggested ranges of [6]. Similar problems occur for group B ch based on ol compositions and for the Q-

Ab-An diagram for mes. While the composition-based designations of [6] are readily determined and may well be useful in their own right, connections to the CL groups whose names they assume are more tenuous than desirable.

Our approach to groups is similar to that for types, using multiple figures to place multiple constraints on a composition and placing field boundaries conservatively to minimize misidentification. We used A3s only for A vs. B because there were only 3 ch. We also combined A4 and A5 (A45) and B1 with B2 (B12) because the CL is not unique. A modified version of Fig. 1 identifies most A1 and A45 and some A2 ch in [8-10] but makes no attempt to classify all. For mes, we use the ternaries FO-COR-FA, N2S-COR-KS, N2S-COR-FA, N2S-Q-COR, N2S-Q-WO, AND RU-TE-PC to distinguish A from B, the first 4 plus N2S-COR-WO, FA-N2S-KS, and N2S-Q-FA to discriminate among Bs and N2S-COR-WO, N2S-Q-COR, N2S-Q-WO, and (WO+RU+COR)-Q-(FA+FO) to subdivide As. These figs. correctly predict a unique CL group for 77% of the culled data set, 1 of 2 groups for 16 % and are wrong for 5%. The errors and ambiguities arise from two major sources. (1) With data for all meteorites, we couldn't distinguish most A2s from A45s. Restricting attention to Sem, where all but one of the A2s occurs, A2s are easily separated from A45s. For OC type >3.2, "guessing" that A2 or A45 means A45, is correct virtually every time at least for the meteorites studied by [8-10]. Using these recipes increases the correct prediction rate of a specific CL group to 92%. (2) Where predicted group is wrong and for many A45s that plot ambiguously versus A2, mes composition is often consistent with contamination by enstatite. Examination of multiple analyses would likely reduce this problem. We conclude that CL groups can generally be extracted from mes and ol compositions. Bulk (known only for Sem) and px compositions are not very sensitive to group. For bulk and ol of [1-4], we could assign only 18 of 37 to a single CL group, 13 to one of 2, and 1 to A (vs. B). 3 yielded no constraints and 1 was discrepant.

The cause of specific CL signatures is uncertain but [12] found anorthite in mes of A1 ch and attributed the yellow CL to Fe^{2+} in the plagioclase (pl). Fig. 2 suggests that mes of A45 ch from Sem lie on mixing lines between a Na-poor end-member (glass?) and plagioclase (~An30-40). Inferred compositions are more sodic (~An10) for type 4-6 OC and variable for other type 3 OC). If pl is responsible for blue CL, then CL groups are largely constructed from the presence (A) or absence (B) of pl in the mes and its composition (calcic in A1+A2 vs. more sodic in A3+A45). The evolution of ch groups toward A45 with increasing intensity of metamorphism [e.g., 6] is likely a marker for pl. Groups are best used to monitor metamorphic effects on ch and perhaps the evolution of volatile elements during igneous processing. Types and groups are complementary measures of ch properties.

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