ESTIMATION OF PETROLOGIC SUBTYPES OF UNEQUILIBRATED ORDINARY CHONDRITES FROM SYSTEMATICS OF CHROMIUM DISTRIBUTION IN FERROAN OLIVINE.

T. E. Bunch[1], J. H. Wittke[1], A. J. Irving[2] and S. M. Kuehner[2] [1]Geology Program, SESES, Northern Arizona University, Flagstaff, AZ 86011 (tbear1@cableone.net), [2]Dept. of Earth & Space Sciences, University of Washington, Seattle, WA, 98195.

Introduction: The numerical subdivision of individual chondrite classes was pioneered by Van Schmus and Wood [1] as the now familiar Type 1 through 6 categories. Among these, Types 3, 4, 5 and 6 reflect progressive metamorphism in anhydrous chondrites, as applied most frequently to ordinary chondrites, yet also to certain carbonaceous chondrites (especially of the CO, CK and even CR classes) and to R chondrites. An important refinement of this scheme was made by Grossman and Brearley [2], who recognized that decimal subtypes could be assigned to Type 3 (i.e., unequilibrated) chondrites by utilizing the statistics of fayalite (Fa) contents in constituent olivine.

For subtypes between 3.0 and 3.2, Grossman and Brearley went even further and presented a logical scheme based on chromium distribution in ferroan olivine for subdivision of these highly unequilibrated ("primitive") specimens into Types 3.00, 3.05, 3.10 and 3.15. These authors [2, 3] also noted that the Cr content in ferroan olivine declines progressively in specimens judged *independently* (on the basis of range in Fa contents) to be assigned to Types 3.3 through 3.9. This trend has a sound theoretical basis, in that Cr^{2+} substituting for Mg, Fe and Ca in the octahedral sites of olivine would be expected during metamorphic heating to be driven by solid state diffusion progressively into the matrix (and presumably into recrystallized chromite grains), as the initially very wide range in Fa content contracted towards a narrow median value (expressed ultimately in Types 4-6).

We have attempted to place this classification scheme on a more robust footing by examination of many more unequilibrated chondrite specimens (over 120 in the past 10 years), and by developing more precise microprobe techniques for analysis of Cr in olivine.

Electron Microprobe Techniques For Quantitative Analysis of Minor Elements in Olivine: By using longer peak counting times (40-100 seconds), careful attention to background measurement, and even double spectrometer counting, we have found that we can achieve a practical limit of detection of 0.02 wt.% Cr_2O_3 in olivine. Selection of olivine grains in a polished specimen and avoidance of chromite inclusions are aided greatly by back-scattered electron images.

New Results for LL and L chondrites: Among the many ordinary chondrite specimens that we have studied from Northwest Africa, we have selected typical examples of Type 3 LL and L chondrites which demonstrate the systematic changes in both the range of fayalite contents and the Cr contents in ferroan olivine. We (and others) have also found a similar pattern for H chondrites, but our database for those specimens is not as extensive.

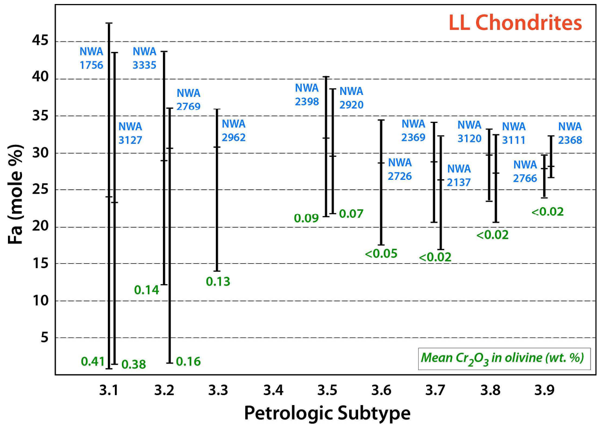
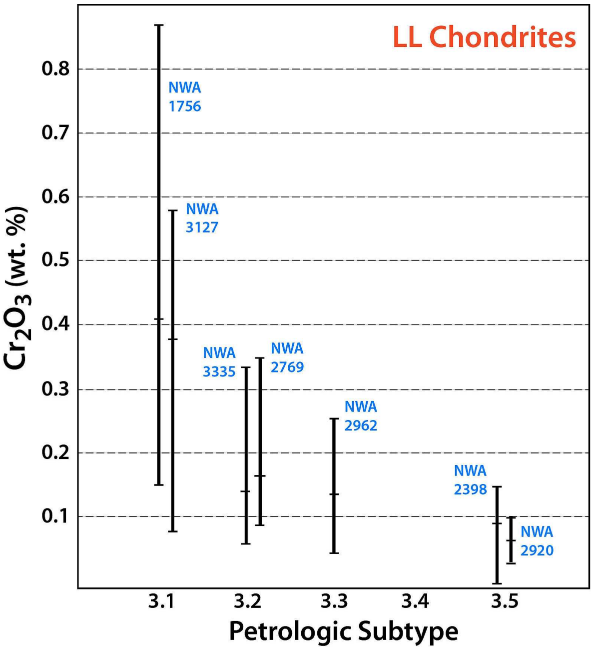


Figure 1. *Variation of Fa content (above) and Cr content (below) in olivine in Type 3 LL chondrites and designation of subtypes.*



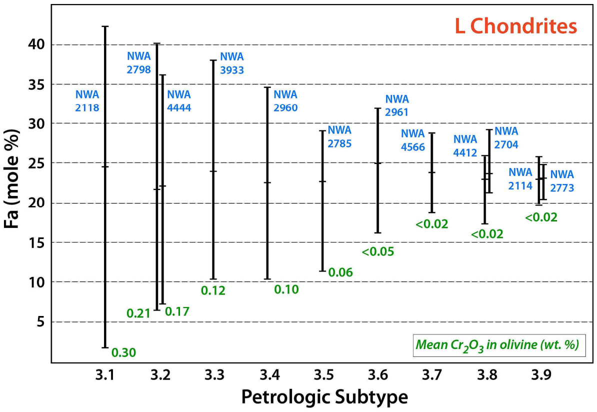
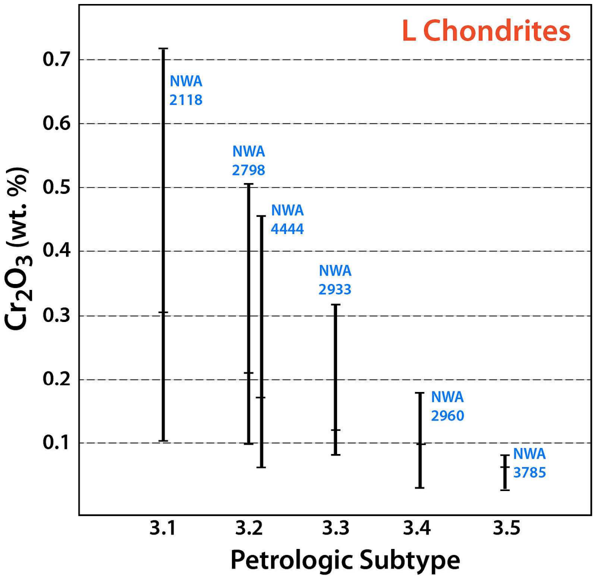


Figure 2. *Variation of Fa content (above) and Cr content (below) in olivine in Type 3 L chondrites and designation of subtypes.*



Recommendations: On the basis of our new data and the previous findings of [2], we recommend the following guidelines for assigning subtypes to unequilibrated LL and L chondrites:

*Subtypes ***3.0-3.2*** As diagrammed in [2, figure 15]

*Subtypes 3.3-3.6 have a wide range in Fa contents; Cr_2O_3 contents in ferroan olivine change as follows:

3.3 0.02-0.30 wt.%
3.4 0.02-0.20 wt.%
3.5 0.02-0.11 wt.%
3.6 0.02-0.05 wt.%

*Subtypes 3.7-3.9 have undetectable Cr in ferroan olivine (but still measurable Cr in the most magnesian olivines within chondrules). Subdivision of these is accomplished by utilizing the range in Fa contents for a representative sampling of <u>all</u> olivines in a specimen as follows:

3.7 21-33 (LL), 19-28 (L)
3.8 24-32 (LL), 20-27 (L)
3.9 26-30 (LL), 21-26 (L)
4.0 28 ± 1 (LL), 24 ± 1 (L)

We emphasize that this scheme is necessarily subjective to some degree, but we believe that it can be used to assign decimal subtypes within ± 0.1. Depending upon factors such as intrinsic heterogeneity in the meteorite (including the possibility of clasts of different subtypes mixed together, unequilibrated crystal cores, etc.), and also attention to quantitative Fa and Cr analyses, different classifiers may arrive at slightly different subtype estimates for the same specimen. However, as long as it is recognized that subtype assignments are estimates, then we believe that their designation is of value in classification, and certainly this is preferable to merely designating most unequilibrated chondrites as Type 3.

One advantage of the proposed scheme is that it requires significantly less analysis time (and expense) than (perhaps more precise) methods utilizing the range in Fa contents of constituent olivine. This is because in unequilibrated chondrites the range of Fa contents is very large (spanning from 0.2 to more than 50 mole% in some cases), and thus it may be necessary to conduct at least 50 point analyses of (presumably) statistically relevant olivine grains per specimen. In contrast, a reasonable estimate of subtype can be obtained by analysis of the Cr contents in as few as 10 ferroan olivine grains.

There is no reason why the scheme outlined here cannot be extended to other anhydrous chondrites, including the growing list of specimens which cannot be assigned to the H, L or LL categories. Such specimens have some hallmarks of typical ordinary chondrites [e.g., 3, 4], but they differ either in having anomalous oxygen isotopic compositions, or else having metal contents that are much lower than expected from their silicate mineral or oxygen isotopic compositions.

References: [1] Van Schmus W. and Wood J. (1967) *Geochim. Cosmochim. Acta* **31**, 747-765 [2] Grossman J. and Brearley A. (2005) *Meteorit. Planet. Sci.* **40**, 87-122 [3] Grossman J. (2004) *Lunar Planet. Sci.* **XXXV**, #1320 [4] Rumble D. et al. (2007) *Lunar Planet. Sci.* **XXXVIII**, #2230 [5] Bunch T. et al. (2010) *Lunar Planet. Sci.* **XLI**, #1280.