White paper report for the Nomenclature Committee on the composition of olivine and pyroxene in equilibrated ordinary chondrites.

Jeff Grossman and Alan Rubin

In August, 2006, the Nomenclature Committee voted to allow associate editors of the Meteoritical Bulletin to approve, on behalf of the committee, equilibrated ordinary chondrites that meet certain conditions. These conditions are (or should be):

1) The person or team doing the classification is sufficiently experienced, in the eyes of the editors, to be trusted.
2) The meteorite is classified as only H, L, or LL, without any modifiers such as "anomalous", and without being described as transitional between two classes.
3) The petrologic type is 4, 5, or 6; indications that a meteorite is brecciated are OK as long as type 3 material is not included (i.e., 4-5, 4-6, or 5-6); meteorites with transitional petrologic types are OK as well as long as the classes are 4, 5, or 6 (i.e., 4/5 or 5/6).
4) The type specimen requirement of 20 g or 20%, whichever is less, is satisfied. The repository should be acceptable, beyond a reasonable doubt, in the opinion of the editor.
5) The meteorite is classified using methods that have previously been accepted by the Nomenclature Committee. At the current time, these methods include: (a) measurement of the composition of olivine and/or pyroxene by electron microprobe; (b) measurement of the index of refraction of olivine by the oil-immersion method; (c) measurement of magnetic susceptibility; (d) measurement of the bulk composition by INAA, XRF, or wet chemistry.

In implementing the 5th condition, it is necessary for the Committee to develop acceptable ranges for the various parameters in each group of ordinary chondrites. Here we consider what the appropriate ranges of mol% fayalite in olivine (Fa) and mol% ferrosilite in low-Ca pyroxene (Fs) should be in each group of ordinary chondrites.

A number of papers in the literature have attempted, since at least the 1960s, to define the ranges of silicate compositions in each group. It should be noted that to this day there is no generally accepted reference on the subject. Keil and Fredriksson (1964 [JGR 69, 3487-3515]), henceforth KF64, did the best early study, looking at a total of 86 chondrites, and measuring both olivine and low-calcium pyroxene compositions. Rubin (1990 [GCA 54, 1217-1232]), henceforth R90, examined 134 ordinary chondrites, but only considered olivine composition. Brearley and Jones (1998 [Rev. Min. 36]), henceforth BJ98, present graphical data for both olivine and pyroxene taken from many earlier sources. All of these papers come to similar but distinctly different conclusions about the ranges of mineral compositions in the three groups ordinary chondrites.

To update the previous work, here we make a grand compilation of olivine and pyroxene compositions extracted from MetBase, which in turn has relied heavily on data that the Nomenclature Committee has published in the Meteoritical Bulletin. We have extracted all of the ordinary-chondrite mean Fa and mean Fs data, and screened it by removing all samples of petrologic type 3, as well as removing all data reported only to the nearest integer (this has the effect of removing all the determinations by oil immersion and at the Smithsonian as well as a large amount of other data). The resulting data set contains ~4600 H chondrites, ~2950 L chondrites, and ~570 LL chondrites. Of the total of 8179 samples, 90% contain both olivine and pyroxene compositions. This data set is 30× larger than any which has previously been used for this purpose.

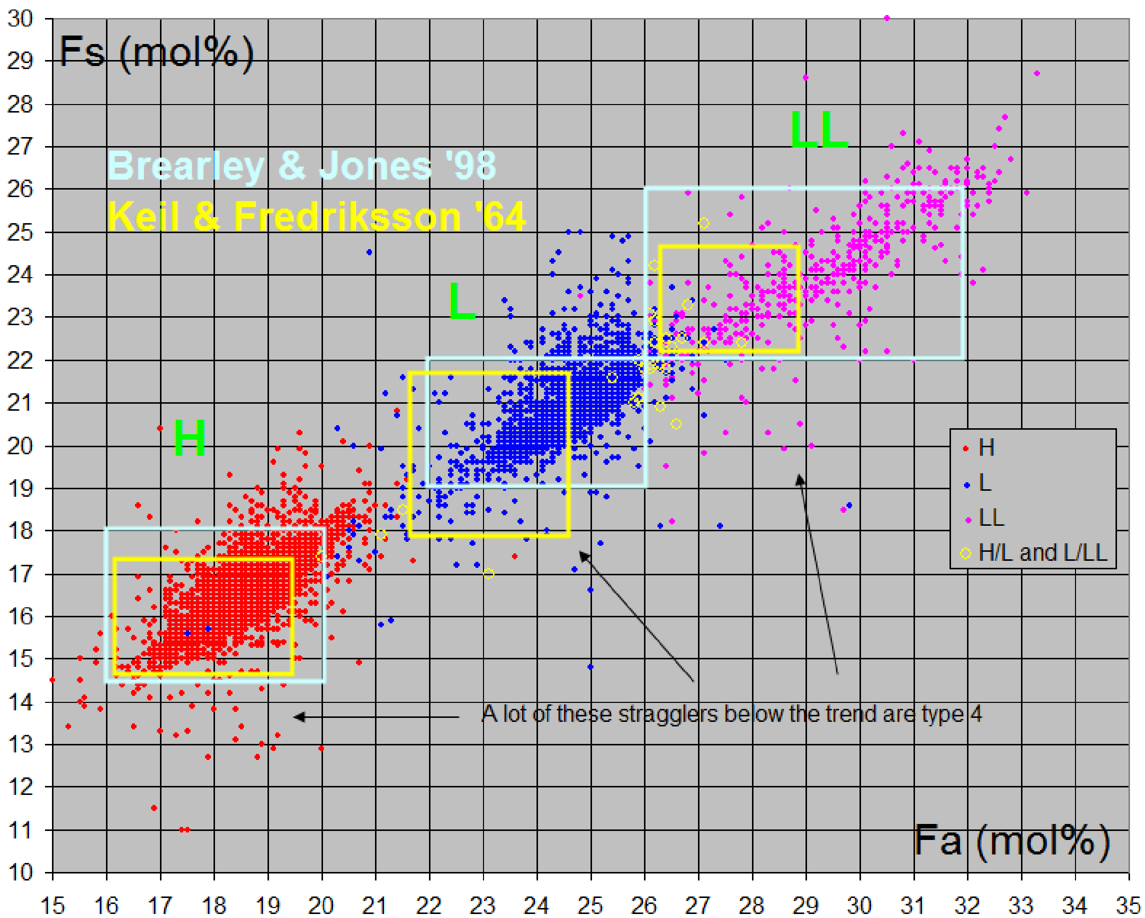

Figure 1, above, plots Fs vs Fa in >7300 ordinary chondrites, with the symbol color showing the *reported* classification. Also shown are the recommended ranges for each chondrite group as given in KF64 and BJ98. Note that there is no way to know the criteria that was used by each classifier to decide which group a meteorite belonged to. Several observations can be made from this plot:

- KF64 used too small a data set, so their ranges exclude a large fraction of ordinary chondrites.
- BJ98's ranges are better, but seem to miss the tails of the H and LL groups, and cut off a significant fraction of the range of Fs in all of the groups.
- There are a lot of straggling points, especially below the intergroup trend. Analysis of the data set shows that more than half of these points below the general trend come from type 4 members of the data set. This should not be

surprising as it is well-known that pyroxene is not fully equilibrated in many type 4 ordinary chondrites (it is especially common for enstatite grains to survive in what were once low-FeO chondrules).

- There has been a lot of ambiguity in how to classify meteorites at the border of the H/L and L/LL groups. Some meteorites that were classified as transitional are well within the accepted ranges, and there is significant overlap among the groups as classified in the literature.
- There does seem to be a significant gap between H and L, but the gap between L and LL is not so obvious.

The decision about the proper place to draw the lines between the ordinary chondrite groups for the purpose of the Meteoritical Bulletin is tricky. Since there is no standard way to classify chondrites, we have to accommodate differences of opinion in the community, which in turn are at least partially based on the literature cited above. We do not want to be in a position of doing research by committee, announcing to the world that we have decided to enforce our own standards of classification over all others, although we can certainly make recommendations. But, we do want to be able to expose poor classifications which are beyond any reasonable interpretation of the literature. We also would like to have all reasonable classifications eligible to be approved by the editors, and not have a large number of borderline cases being forwarded to the entire committee, who in turn may not know what to do about them.

Consequently, we recommend that the committee adopt fairly broad operational ranges of Fa and Fs in each ordinary chondrite group for use in the editorial approval process. At the same time, we can publish data from this white paper on our web site (or even as peer-reviewed paper!) with our recommendations on where the exact borders between groups should be.

Figures 2 and 3, below, show histograms of the Fa and Fs contents, respectively, in the ~6000 type 5 and 6 OCs extracted from MetBase. In these figures, no attempt has been made to show how meteorites were actually classified. The point is to look for the proper place to draw the boundaries between groups, knowing full well that many of the meteorites near the boundaries have been either misclassified or classified inconsistently. The recommended ranges of KF64, BJ98, and R90 (who only measured olivine) are shown on these plots for reference.

<u>The lower boundary of H</u>:

At the low end of Fa and Fs, H chondrites vaguely give way to reduced ordinary chondrites, which have anomalously low amounts of FeO. A reasonable place to set the "operational" boundary between routine H chondrites and interesting ones would probably be around Fa16.0/Fs14.0. Such a boundary would also accommodate the low end of BJ98, which some workers might use. We should probably set the "recommended" lower end of the H chondrite range at Fa16.5/Fs14.5, where the histograms trail off to near zero.

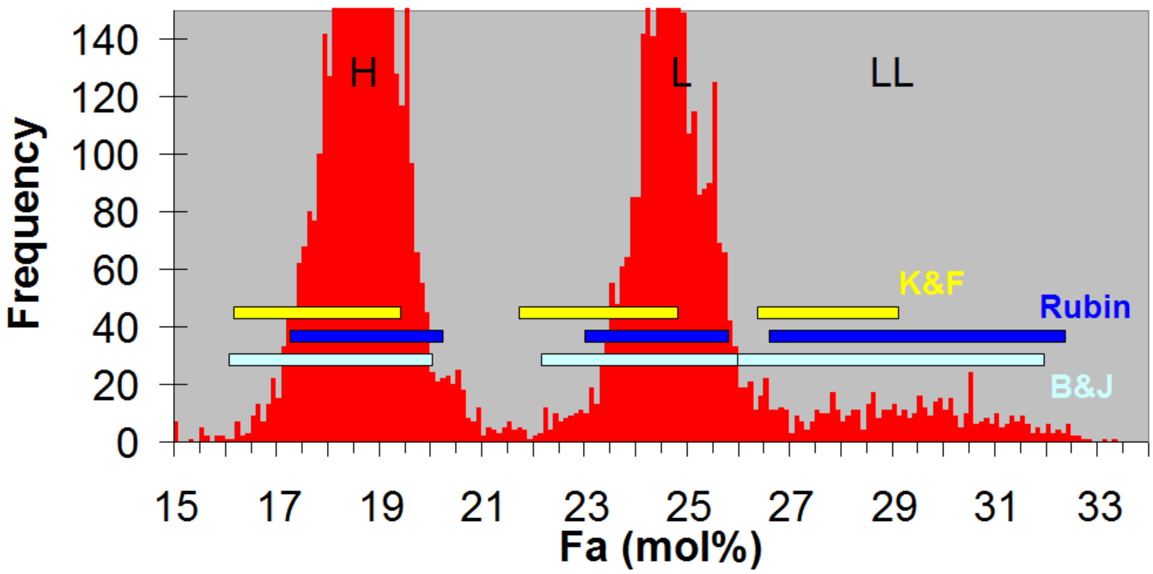

Figure 2

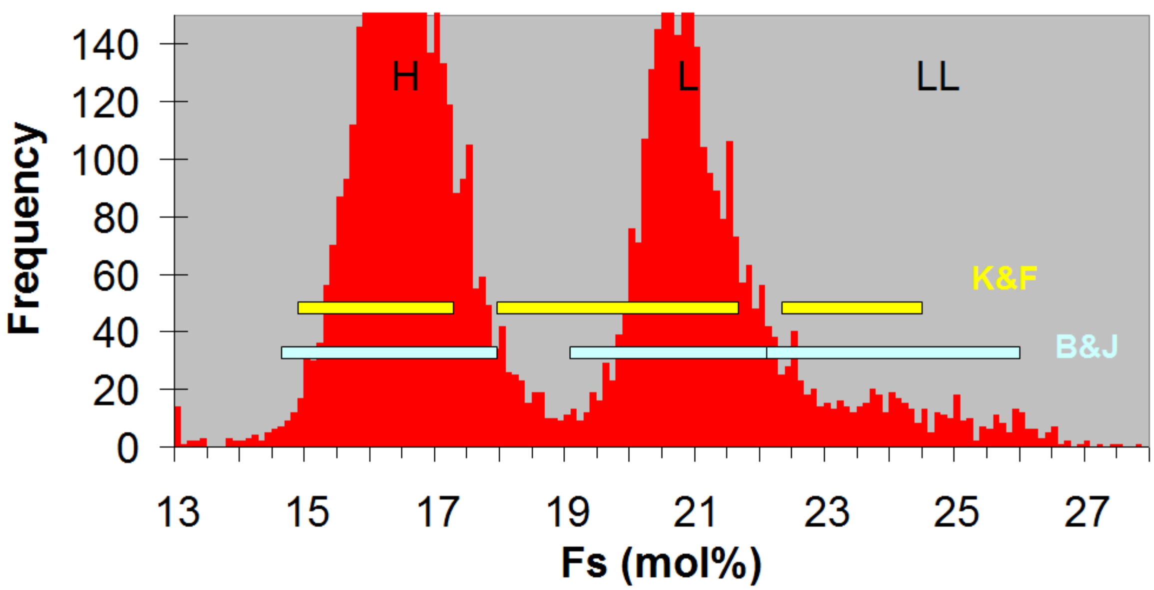

Figure 3

<u>The H/L boundary</u>:

All three literature data sources plotted on Figs. 2 and 3 agree that there is a gap between H and L chondrites in their olivine composition. However, it also appears that all three sources have set the high end of the H-chondrite distribution slightly too low and have also set the low end of the L-chondrite distribution too low. We should probably set both our operational and recommended value for the high end of the H chondrite distribution to be at Fa20.8/Fs19.0. This encompasses both the actual tail of the distribution as well as the recommended values in R90 and BJ98. The lower end of the L distribution is more difficult to set. All three literature compilations set this boundary well to the left of the actual tail in the L chondrite distribution. We have no choice but to set our operational values to accommodate these, using Fa22.0/Fs19.0. This leaves a gap of 1.2 mol% Fa, between Fa20.8 and Fa22.0 in which we would expect workers to adopt an "H/L" classification. At the same time, we can adopt a recommended lower end for L chondrites at Fa23.0/Fs19.0.

The L/LL boundary:

The boundary between L and LL chondrites has really never been clearly defined anywhere in the literature. On most diagrams, such as Fig. 1 above, or the plot of Co in kamacite vs. Fa in R90, and even in O isotope diagrams, there is no hiatus between the groups. R90 defined a transition zone between Fa25.8 and 26.6, which can be seen in Fig. 2, in which meteorites are arbitrarily called "L/LL," but are really not suspected of being a separate group. BJ98 simply define an arbitrary cut off between L and LL at Fa26, which is right on the sharp edge of the L peak. Probably, the best operational boundary for the Nomenclature Committee to use in decision-making would have a slightly overlapping range between the two groups, i.e. L chondrites could be as high as Fa26.6/Fs23.0 and LL chondrites could be as low as Fa25.8/Fs22.0. This way, we could accommodate the whole range of current practices. Our recommendation for the real cutoff should probably be Fa27/Fs23, representing a hint of a hiatus in the distributions.

The upper LL boundary:

R90 and BJ98 recommend a similar upper limit to LL at Fa32-32.5. The distribution actually tails off to zero at Fa33/Fs27, so this should be both our operational and recommended limit.

Summary table and figure:

Group	R90 Fa	BJ98 Fa	Rec. Fa	**Oper. Fa**	BJ98 Fs	Rec. Fs	**Oper. Fs**
H lower	17.3	16.0	16.5	**16.0**	14.5	14.5	**14.0**
H upper	20.2	20.0	20.8	**20.8**	18.0	19.0	**19.0**
(gap)	yes	yes	yes	**yes**	yes	no	**no**
L lower	23.0	22.0	23.0	**22.0**	19.0	19.0	**19.0**
L upper	25.8	26.0	27.0	**26.6**	22.0	23.0	**23.0**
(gap)	yes	no	no	**overlap**	no	no	**overlap**
LL lower	26.6	26.0	27.0	**25.8**	22.0	23.0	**22.0**
LL upper	32.4	32.0	33.0	**33.0**	26.0	27.0	**27.0**

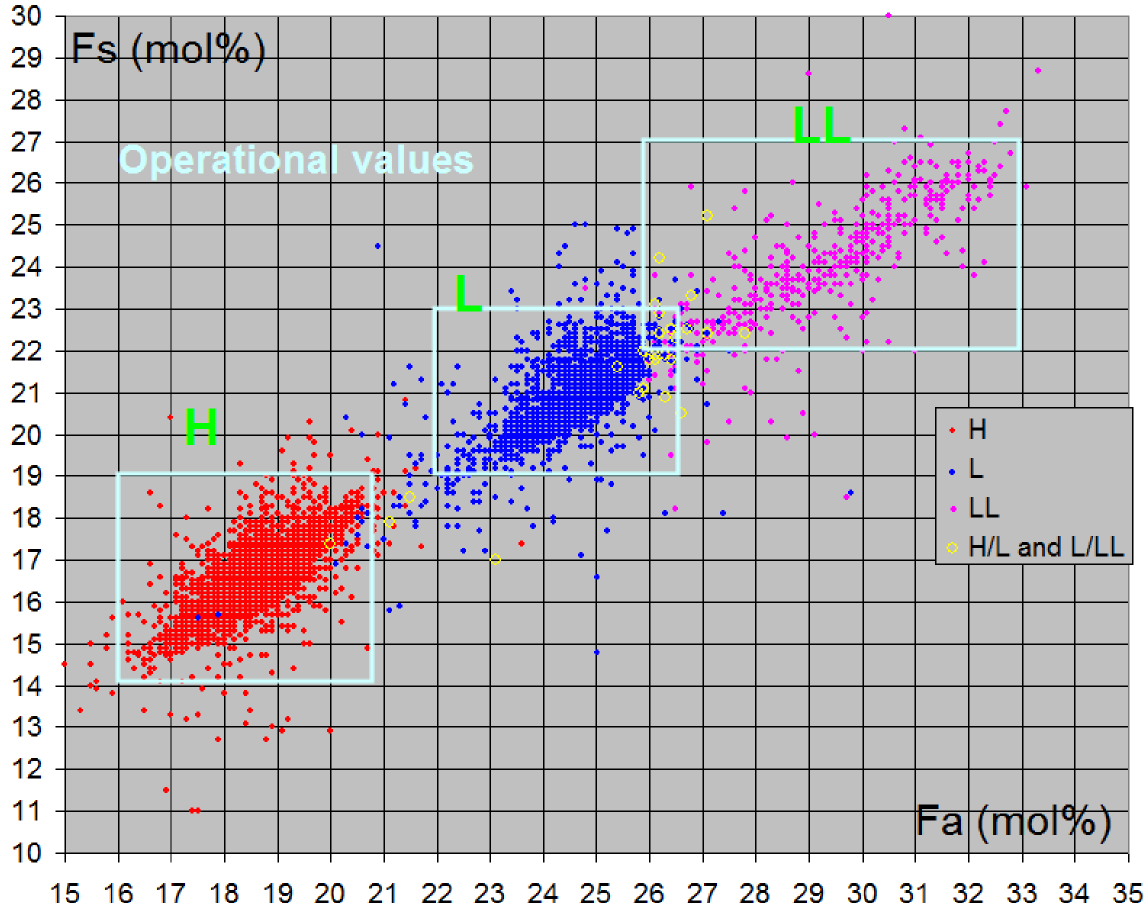

Figure 4. Graphical display of operational values recommended for the Nomenclature Committee.

In practice, then, the editor will compare the range of Fa and Fs to the operational values in this chart and make sure they agree with the classification. This can be done by a calculation in excel. For type 4 chondrites, low Fs values can be ignored. If reported values are outside the operational ranges, the editor would have the option of calling it to the attention of the submitter or referring the meteorite to the entire committee.