POSSIBLE UNDER-SAMPLING OF METEORITES INFERRED FROM A NEW DATABASE OF METEORITE AND TERRESTRIAL ROCK P. K. Ness[1] and H. Miyamoto[2], [1]The University of Tokyo 113-0033 Japan (pkness@u-tokyo.ac.jp), [2]The University of Tokyo, 113-0033 Japan (hm@um.u-tokyo.ac.jp).

Introduction: Reflectance-spectroscopic observations of both meteorites and asteroids indicate that no class of meteorites has an exact asteroid counterpart [1] in a literal sense. Although recent studies confirm that space-weathering can be partly responsible for mismatches between measurements and observations, it remains unclear whether counterparts of many classes of meteorites match with asteroid classes. This raises the question as to whether any meteorites types could be under-sampled.

To answer this specific question, we compiled a database of elemental abundances of both meteorites and terrestrial rocks from peer-reviewed papers. Similar efforts have been made by other researchers [e.g. 2-7] for a variety of purposes including classification of meteorites. Thus, we utilized these databases as references and expanded to include a wider range of elements and petrologic types for the above purpose.

Method: Currently, our meteorite database comprises 28,742 chemical abundances from 2,112 meteorites from 121 peer-reviewed papers published between 1953 and 2010, which cover 78 atomic elements and 20 major chemistry analyses. Our terrestrial-rock database is composed of 71,245 chemical abundances compiled from 2,848 rocks, from 66 peer-reviewed papers published between 1982 and 2011.

We sourced the most recent meteorite abundances on the assumption that it could improve data quality and precision [8-10]. We selected the first value for each atomic element of each meteorite from journals in preference to mean abundances (we note that taking individual values is much more common for analyses of terrestrial rocks, where samples are analyzed once).

We converted abundances into consistent units (%, ppm, ppb) and converted major chemistry compounds into their atomic elements using atomic mass ratios as per [6,7,8]: this increased abundances by 20%. We checked data against original publications to reduce input and conversion errors which affected 2.27% of abundances. Descriptive statistics were then compiled.

Weathering and alteration could explain increased scatter: in order to minimize this as an issue we selected terrestrial rocks from areas less susceptible to chemical weathering. The meteorite database includes Antarctic (falls, finds) and non-Antarctic meteorite (falls) including a few (around 50) non-Antarctic desert finds.

We compiled laboratory precision errors only for meteorites and terrestrial rocks from listed/tabulated data. We calculated weighted average precision errors for major petrologic types, and utilized straight averages for statistical tests: Type-2 errors could increase due to a sample-size bias.

We refer to scatter as the range, extent, or irregular spread of data in a plot; whereas, dispersion is the variation of data in relation to the average value, i.e. whether data are closely/loosely, spaced or packed. The term regression refers to the relationships (correlation) between x and y values in a plot.

Results: Plots of SiO_2-MgO, and Al/Si-Mg/Si indicate that large L-, LL-, H- and C-chondrites sample size from our database have broad scatter, similar to terrestrial rocks, in that dispersion decreases (data are more closely packed) towards the center of the distribution (Fig 1, 2). Jarosewich [2] data has fewer meteorite abundances, with much less (around 60%) scatter for L- and H-chondrites. The dispersion of Nittler et al. [3] eucrites is almost identical to diorites from Earth.

LH-chondrites abundance trends (e.g. SiO_2-MgO plots) tend to change with increase in sample size. In comparison, meteorite petrologic types with few samples can plot in small clusters or have much neater linear trends and higher correlations. This indicates that sampling bias could be an issue where meteorite petrologic types contain few samples.

Outliers can affect means and ranges if sample size is small. For instance, Fe and individual metal abundances of Cumberland Falls can offset aubrite means.

Less than 2% of meteorites are misclassified, which suggests that misclassified meteorites have limited influence on means and ranges where sample size is large. In Fig 1 the H-chondrite Elsinora and the L6-chondrite, Forksville plot as outliers to other H- and L-chondrites but ranges and means are not affected. However, these particular MgO values may be in error.

Results of statistical tests suggest terrestrial rocks can have more scatter and better precision than meteorites: therefore, precision errors do not explain differences in scatter. The laboratory precision of terrestrial rocks is 0.75% lower than meteorites (6.68%) for both double and single sided T-tests at 95% CL. Once spurious terrestrial rock precision values Os, Au, Pd, Ir, Pt are removed, they have 1.01% better precision at 99%

CL: however, for meteorites only Ca fails both T and F-tests on precision errors at 99% CL.

Systematic errors do not affect standard deviations of meteorites at +99% CL: R^2 is low (0.59%), so could be explained as random noise. However, we did find PGE abundances of terrestrial rocks with systematic sampling errors that could account for increased scatter.

Discussion: The regressions of LH-chondrites for SiO_2-MgO plots tend to change with increase in sample size: therefore, it is possible for sampling biases to skew or offset meteorite abundance means for small sample sizes. Meteorites with less scatter or dispersion than terrestrial rocks might not cover the full compositional range of their asteroid counterparts (Fig 1, 2).

Scatter and dispersion in major chemistry plots of C-, LH-chondrites, and eucrites is similar to terrestrial rocks: but, gaps in dispersion of LH-chondrites (Fig. 1, 2) suggest that a) there could be other ordinary chondrite types not yet sampled, or b) a number of LH-chondrite sub-groups might be incompletely sampled.

The broad scatter of C-chondrites suggests that they are not under-sampled as a class, which likely rules out asteroid forming processes as a major cause for reduced scatter in meteorite petrologic types. However, individual subgroups could be under-sampled (Fig. 2): CM- have many more samples than CI-chondrites and are likely more representative of the solar nebula.

In our databases, meteorites contain more pre-1990 chemical abundances than terrestrial rocks, and 0.75% higher precision but plots have the same/less range in scatter (Fig. 1): Terrestrial rocks are more altered than meteorites, but calculated major chemistry precision errors are better.

Laboratory and systematic errors affect few chemical abundances, so are not the main causes of scatter. However, laboratory errors account for 30% of variability in meteorites/rocks abundances: a few spurious values can distort means and ranges of small data sets. For example, Cumberland Falls Fe, FeO, SiO_2 and metal abundances, reported by Kallemeyn and Wasson [11] and Wiik [4] are outside Keil's [12] ranges.

Conclusion: We conclude that statistical characteristics (e.g. scatter, dispersion) of LH, C-chondrites, eucrites and some iron meteorite bulk chemical abundances can change with sample size. These meteorites are likely the only petrologic types which reflect the entire range of chemistry of their asteroid counterparts. Smaller data sets often have less scatter and better regression coefficients: suggesting sampling bias can exist for small data sets. These findings are scientifically important because they explain why researchers have difficulty assigning rock types to asteroids. The implication is that bulk samples from asteroids are required for complete understanding of the evolution of both asteroids and the way solar systems form.

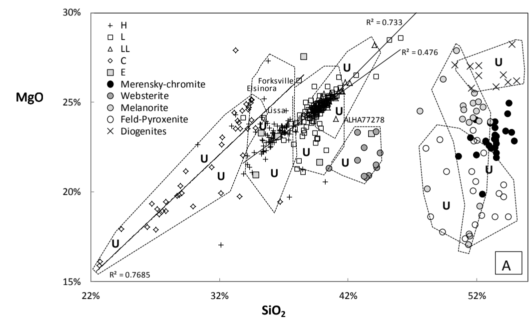

Fig. 1. SiO_2-MgO plots for major meteorite groups and terrestrial rocks. U indicates a blank area of plots, which may be caused by a limited number of samples.

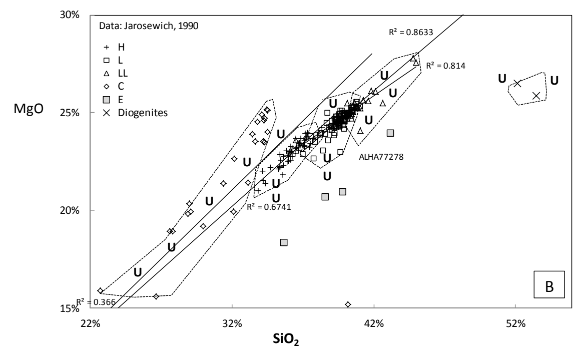

Fig. 2. Jarosewich [2] data tend to have better correlations and less data points, with larger gaps (U) in groups. Where scatter (extent) is reduced, under-sampling could make it more difficult to classify all possible asteroid analogs.

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