UNDERSTANDING THE SIGNIFICANCE OF LUNAR SAMPLE DATA FOR INTERPRETING LUNAR IMPACT HISTORY N.E.B. Zellner[1], T. Swindle[2], J.W. Delano[3], [1]Department of Physics, Albion College, Albion, MI 49224 (nzellner@albion.edu), [2]University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, [3]New York Center for Studies on the Origin of Life, Department of Earth and Atmospheric Sciences, University at Albany (SUNY), Albany, NY 12222.

Introduction: The lunar impact flux is not well-undestood but is driving models of solar system and planetary formation. It is also being used to support observational and experimental data that could be interpreted as supporting ideas about the cometary delivery of terrestrial water (i.e., Comet Hartley) and the origin of life (i.e., hot origin of life). A variety of lunar samples are being investigated to study the timing of lunar impacts, including lunar impact glasses [e.g., 1, 2, 3], lunar melt rocks [e.g., 4, 5, 6, 7], lunar meteorites [e.g., 8], and lunar zircons [e.g., 9]. In particular, these samples are being used to address whether or not the Moon experienced a late heavy bombardment (LHB) or terminal lunar cataclysm between 3.8 and 3.9 billion years ago (Ga) [e.g., 10], but they can also give us insight into the nature and timing of impact events throughout the age of the Solar System [e.g., 1, 3, 11]. It is important, though, to place the magnitude of the impact events, whether cataclysmic or not, into the overall context of impact rate over time and to interpret the data so that the impact flux is neither overinflated nor underreported.

Lunar Sample Studies: We have looked at the ages of lunar samples from various investigators in order to try to reconcile the impact glass, meteorite, and breccia data records. These data include impact glass data from the Apollo 12, 14, 16, and 17 landing sites [1, 2, 3, 12, 15], lunar meteorite data [8], asteroid meteorite data [13], and impact melt data [4, 5, 6, 7]. Reconciling the data sets is important because if impacts were occurring in the inner solar system during specific epochs, all of these samples should be formed in these events.

Old Ages: As early as 1973, lunar sample ages indicated that several of the large basins on the Moon were formed in ~200 Ma between 3.8 and 4.0 Ga [20]. Since then, other investigators have found support for the LHB in Ar/Ar ages of impact melts from the Apollo 15 and 17 landing sites [5, 6] and in U/Pb or Rb/Sr ages of lunar highland samples [10], for example. This supposed LHB has been interpreted as being responsible for impact sterilization of the Earth [16] and for the hyperthermophilic last universal common ancestor of life [e.g., 17]. More recent investigations into lunar zircon shock ages [9] and ages of melt rocks from the Apollo 16 and 17 landing sites [7, 21], though, indicate that old impacts did occur, and recent orbital data is influencing our reinterpretation of the number of large impact basins [18] and the sources of Apollo samples [19].

Young Ages: Several authors [3, 14, 15] have reported that a large number of impacts have occurred in the last 500 Ma and that this is consistent with an increase in the meteoroid bombardment of the inner Solar System. While these data are consistent with an increase in the recent impact flux, they do not require that explanation [3, 15]. Published ages of 25 glass samples from the Apollo 14, 16 and 17 landing sites [1, 2, 12], as well as unpublished data from the same authors, do not show this recent rise in impact flux, though young ages with large uncertainties in those ages are represented.

Data Analyses: To attempt to reconcile the age data from the different sample sets, ideograms reflecting the probable age distributions of these sample were created (Figure 1), with 2σ uncertainty in the ages across all data sets. When possible, multiple samples formed in the same event (i.e., impact glasses [2] or melt rocks [7]) were removed from the data set so that the impact flux was not overinflated. Additionally, ages with uncertainties $\geq$50% of the age were removed from the data sets because those ages are not especially useful. Finally, in the case of the Apollo 14 glasses [14], all ages $\geq$ 3000 Ma were removed since we do not know if these are volcanic glass ages or impact glass ages.

A background continuum for impacting objects was defined so that signficant impact events above that background flux would become more apparent (Figure 2). The average of the "overall" curve is 0.07005 and the standard deviation of the points is 0.042451.

Discussion: With a more consistent treatment of the data, Figure 1 shows that the ideograms of ages from multiple lunar samples do follow similar patterns, but differences also exist. For example, the lunar impact glasses show an impact event about 2800 Ma while the meteorites do not. Additionally, only the Apollo 12 impact glasses show an increase in the recent lunar impact flux, strengthening the argument that these glasses were produced in local cratering events.

Figure 2 shows the same data as in Figure 1, but with the background continuum, defined as the average probability (over all data sets) that a sample would have a particular age, removed. Anything above one standard deviation above the average could be considered “significant”. The LHB barely breaches the 1-StDev mark, while the recent impact flux really does seem to be significant, if the Apollo 12 data can be believed to represent a global flux. Removing the Apollo 12 data greatly affects this curve, however.

Conclusion: Lunar samples can address the complex question of what the lunar impact flux has looked like over time. Taking into account the ‘everyday’ background impact flux that the Moon has experienced over time is important so that the significance of prominenat peaks in ideograms and histograms of impact sample ages is appropriately interpreted.

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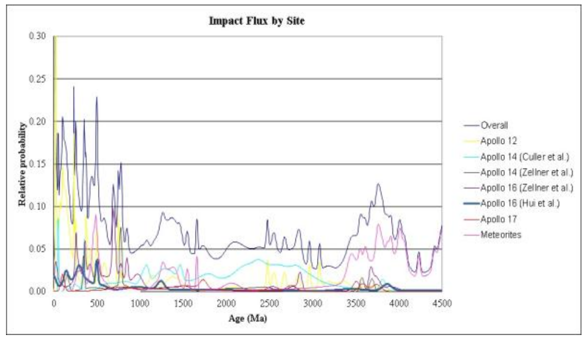

Figure 1. Ideogram of ages of lunar impact glasses and asteroidal meteorites. Note that the averaged flux (i.e., the “Overall” curve) is dominated by the Apollo 12 impact glass ages.

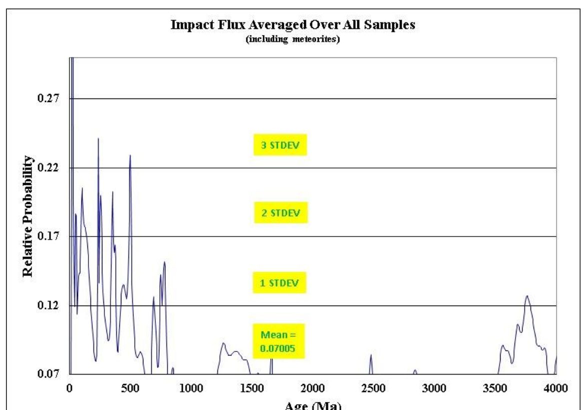

Figure 2. Ideogram of the averaged impact flux, with the continuum flux substracted out. Any event above 1 StDev can be considered “significant”. Again, the recent flux is dominated by the Apollo 12 data.