SOILS AIN'T SOILS: THE PRESERVATION OF SOLAR WIND IN METAL GRAINS FROM THE LUNAR REGOLITH. T. R. Ireland[1], P. Holden[1], M. D. Norman[1], J. Mya[1], and M. Asplund[2], [1]Planetary Science Institute and Research School of Earth Sciences, The Australian National University, Canberra ACT 0200 Australia, [2]Planetary Science Institute and Research School of Astronomy and Astrophysics, The Australian National University, Canberra ACT 0200 Australia.

Introduction: The discovery of ^{17}O and ^{18}O enrichment in lunar metal grains indicates a source of oxygen hitherto unrecognised in the solar system [1].

This oxygen has a concentration profile that is consistent with implantation from an energetic source and so we interpreted it as representing the solar wind, the most likely source in that it continually irradiates the exposed lunar surface with high-energy particles. This interpretation has met a mixed reaction for two reasons. First, another recent study of oxygen isotope compositions from lunar metal grains came to a very different conclusion [2], and second, this composition is not apparent in meteoritic materials from which interpretations of an ^{16}O-rich Sun [3] or an isotopically normal Sun [4-6] are commonly proposed. To address issues concerning preservation of oxygen isotope signatures in different soils, we have extended our analyses to lunar metal grains from two more recently exposed soils. Possible scenarios under which a solar composition that differs from the composition of the planetary disk will also be discussed.

Oxygen isotopes: Oxygen compositions are generally reported as $\delta^{17}O$ and $\delta^{18}O$ where measured $^{17}O/^{16}O$ and $^{18}O/^{16}O$ are expressed in delta notation relative to the respective ratios in standard mean ocean water. Mass dependent isotope fractionation causes dispersion along a slope 0.5 line (TFL). Deviation from the TFL is measured by the parameter $\Delta^{17}O$ that is the fractional deviation of $^{17}O/^{16}O$ from the appropriate terrestrial value (as determined from the $^{18}O/^{16}O$ value). In meteoritic materials, dispersion is commonly found along a slope 1.0 line that has been interpreted in terms of ^{16}O excess.

Oxygen in Lunar Metal Grains: The analysis of metal grains from the lunar surface constitutes a natural GENESIS experiment in that a target-element-free substrate is analysed for the implanted composition. Because it is a natural experiment there are many circumstances under which the experiment can fail, including contamination, non-uniform-exposure, or diffusion loss of the signal. But the advantage is a potentially longer time exposure with better signal/noise.

In our first series of experiments on a recent lunar soil (10084) we found an oxygen profile in two grains that was exactly as expected for solar wind, viz. a shallow implantation profile for which the concentration decayed with depth. The oxygen in the top few tens of nanometers appears to be contaminated with normal (i.e. terrestrial-lunar composition), but once this rim is sputtered through the composition has a constant $\Delta^{17}O$ (+26 ‰), i.e. is enriched in ^{17}O and ^{18}O relative to ^{16}O. Several other grains had thick oxide rims and analysis of these was discontinued after thirty ratios were measured and these were normal.

In contrast to our experiments, Hashizume and Chaussidon [2] found that all grains from lunar regolith breccia 79035 had relatively thick oxide rims. The oxygen isotope compositions of these layers typically lie on or close to the terrestrial mass fractionation line. The source of the oxygen in these rims appears to be chemical alteration rather than implantation. Hashizume and Chaussidon focused their attention on a small subset of grains that showed decreasing $\Delta^{17}O$ with depth and whose maximum deviation from terrestrial (+lunar) is around -20 ‰. The exotic composition lies off the slope unity ^{16}O fractionation line and is interpreted as an isotopically mass fractionated composition coming from a ^{16}O rich source. The depth of this component at around 600 to 1600 nm requires very high energy (order MeV) such as found for solar energetic particles.

The metal grains analysed in these two studies [1,2] have very different histories. Sample 10084 [1] was chosen because it is a recently exposed lunar soil for which 96% of feldspar grains have high track densities, and the soil has the highest concentration of ^{36}Ar recorded from the lunar surface. Sample 79035 [2] is a lunar regolith breccia with a compaction age of 1-2 Gyr that was chosen because of appropriate concentration profiles of C and N isotopes in silicate grains associated with low-D hydrogen. Therefore, there are good reasons for the selections of both of these samples and the disparate results are perplexing.

However, there are also a number of unresolved issues with the selection and analysis of metal grains from various lunar regolith samples. On the basis of the C and N isotope results, Hashizume et al. [7, 8] note that recently exposed lunar soils preserve a number of isotopic compositions related to various inputs, including planetary, and they also note the presence of different C and N isotopic components in different soils. The regolith breccia on the other hand has been indurated close to the lunar surface some 1-2 Gyr before present, and so the preservation of solar wind will be different for different elements in different mineral matrices. Regolith breccias by definition have also experienced more complex histories including heating and shock beyond those obtained for unindurated surface soils.

While bulk soil characteristics are supportive of certain exposure histories, it is not clear that any single grain has experienced the history suggested by the average characteristics, or that any grain has experienced the same history as its neighbour. As such, there is a clear need to associate a number of solar wind characteristics on an individual grain-by-grain basis.

New results: We have extended our study of oxygen in lunar metal grains to two more active soils – 61141 from Apollo 16 and 78481 from Apollo 17 in an attempt to further explore the nature of solar wind exposure, and secondly, to find potential discriminants for finding solar implanted oxygen as opposed to oxygen from other sources.

Metal grains were separated from the soil using a Franz isodynamic separator set to a minimal magnetic field setting. The soil was suspended in ethanol and passed through the separator in a vertically mounted burette such that magnetic grains adhered to the wall of the burette. Grains from this fraction were hand picked and individually mounted on gold foil for analysis. At this stage there was a clear distinction between the grains of the two soils: grains from 61141 generally appeared clean and metallic whereas those from 78481 were all tarnished (oxidised) to a degree that it was not clear optically that they were metallic. Isotopic analysis with SHRIMP II followed a multiple collection procedure with a Faraday cup for ^{16}O and two ion counters for ^{17}O and ^{18}O [1]. Terrestrial ilmenites, and ilmenites from the lunar soils were run during the course of analysis.

Consistent with their tarnished appearance, the grains from 78481 showed high ^{16}O count rates that did not decay with analysis (depth). The oxygen isotope composition is indistinguishable from terrestrial.

Grains from 61141 showed initially high ^{16}O count rates that quickly decayed. But these grains also differ from those from 10084 in that the depth profile revealed no implanted component. The oxygen concentration exponentially decayed away from the surface with no indication of a sustained signal from below the surface. The oxygen isotope composition remained normal, albeit with larger uncertainty with depth as the count rate decayed. There was no indication of either ^{16}O-rich, or ^{17}O-^{18}O-rich oxygen.

These data indicate that different soils preserve different signatures despite all being classified as recent soils. The presence of solar wind could be a function of the gardening history of the specific locality and is potentially different for different grain mineralogies (e.g. feldspar vs. ilmenite) depending on density, size, etc. Various maturity indices are proxies for solar wind exposure, but these may or may not be indicative for all types of grain.

There is no indication of a specific planetary oxygen isotope component in these grains that can be distinguished from the terrestrial oxygen isotope composition. However this does not necessarily indicate that the solar composition is the same as planetary.

The solar composition represents the bulk solar nebula, but ascertaining the solar composition from what remains in the planetary disk requires a detailed understanding of the processes and reservoirs involved. The solar composition is enriched in gaseous elements relative to meteorites [9] and it is possible, if not likely, that the gaseous components could have different isotopic compositions relative to the isotopic compositions of the elements in refractory dust [10]. Oxygen is a very special case in this regard with sub equal contributions from gaseous carbon monoxide and refractory silicate dust. Carbon monoxide will be affected by self-shielding in molecular clouds and so variability in oxygen isotope composition is likely. The oxygen composition of the refractory dust on the other hand is potentially dominated by galactic chemical evolution. A difference in composition between the bulk solar nebula, and the most refractory components represented in our planetary system, is therefore not totally unexpected.

Conclusions: These new results are important not so much for what we did find, but what we did not find. There is no indication in any grains for a component that is ^{16}O-rich. Setting aside grains that have thick (>100 nm) oxide layers, there are two types. In grains from Apollo 16 there was no implanted oxygen signal and the oxygen remains isotopically normal with depth. In the grains from Apollo 11, oxygen is uniquely consistent with an implantation origin and its composition is enriched in ^{17}O and ^{18}O.

References: [1] Ireland T. R. et al. (2006) *Nature, 440*, 776. [2] Hashizume K. and Chaussidon M. (2005) *Nature, 434*, 619. [3] Clayton R. N. (2002) *Nature, 415*, 860. [4] Ozima M. et al. (2006) *LPS XXXVII*, Abstract #1130. [5] Nuth J. A. I. et al. (1998) *Earth, Moon, Planets, 80*, 73. [6] Thiemens M. H. (1999) *Science, 283*, 341. [7] Hashizume K. et al. (2000) *Science, 290*, 1142. [8] Hashizume K. et al. (2004) *Astrophys. J., 600*, 480. [9] Asplund M. et al. (2005) ASP Conf. series vol. 336, 25. [10] Ireland T. R. and Asplund M. (2006) MAPS 41, A83.