THE ORIGIN OF THE APOLLO 16 'SOIL-LIKE' BRECCIAS: CLUES REVEALED BY NOBLE GASES.

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Introduction: Regolith breccias are surficial soil, rock and mineral fragments that were consolidated into a lithological unit. Consolidation of these materials, into breccias, preserves exposure-burial dependent characteristics arising from space weathering effects. Thus, regolith breccias can serve as a probe of regolith evolution processes in a local area, informing us about parameters such as regolith reprocessing rates at the time of consolidation.

Regolith breccia samples collected by the Apollo 16 mission have so-far been grouped into 'ancient', and 'young' regolith breccia groups (consolidated between ~3.8 – 3.4 Ga and ~2.5 – 1.7 Ga, respectively), and a further possible 'soil-like' regolith breccia group (hypothesized to have consolidated <2 Ga) [1-3]. Noble gas measurements support the distinctions between the 'young' and 'ancient' regolith breccia groups but, so far, no noble gas measurements have been reported for the 'soil-like' regolith breccias.

Samples and Methods: We visually identified 10 'soil-like' breccia samples from the Apollo 16 sample suite. The samples represent a range of surface exposure (i.e., maturity), based on reported I_s/FeO indices [1], and textural classification types [4]. The samples were step heated, and the concentrations and, following cryogenic separation, the isotopic ratios of each noble gas element were analysed using a Thermo Fisher Helix multi-collector mass spectrometer. Heavy (Kr, Xe) and light (He, Ne, Ar) noble gas measurements were made on separate chips of different masses (He, Ne, Ar ~0.1 mg; Kr, Xe ~3 mg), from the same parent sample chip.

Discussion: The soil materials comprising the 'young' and 'ancient' regolith breccias are characterised as being immature (i.e., show evidence of lower exposure to lunar surface space weathering processes than more mature samples) [2]. The modern soil materials collected from the Apollo 16 landing site are more mature, and subsequently have accumulated higher noble gas concentration (due to greater abundances of solar wind implanted isotopes) [5]. The aim of this study is address outstanding questions related to how the 'soil-like' regolith breccias fit into the overall regolith breccia suite, and whether the timing of the formation of the 'soil-like' regolith breccias could expand our understanding of an as-yet under represented period of lunar history.

Noble gas concentrations. Eight 'soil-like' breccias studied here are more comparable to those noble gas concentrations reported for Apollo 16 soils (i.e., higher), than the 'ancient' and 'young' regolith breccias (which tend to be gas poor) [2,5]. Two further samples allocated appear texturally to be impact melt samples (rather than regolith breccias), this was supported by their gas-poor nature.

Cosmic ray exposure ages. Cosmic ray exposure ages were calculated using literature bulk sample chemical compositions [4] and the theoretical cosmogenic nuclide surface production rate model of [6]. We assume that cosmogenic nuclide production occurred on the lunar surface (i.e., at 0 g cm^{-2}) in order to compare our results with data within the literature. However, we note that our Ne isotopic data suggest average burial depths equivalent to within 10 g cm^{-2} for most samples. Therefore, while the majority of cosmic ray exposure occurred on or near the lunar surface (100× the duration of exposure at depths greater than 10 g cm^{-2} [7]), a period of exposure at greater depths cannot be ruled out. The 'soil-like' regolith breccias show CRE ages of T_3 = 2 - 5 Myr, T_{21} = 2 - 16 Myr, T_{38} = 30 - 150 Myr, and T_{126} = 10 - 35 Myr, and the impact melt breccias have short CRE durations (<100,000 years across all noble gas isotopes).

Ar antiquity ages. Using the calibration of [3] and reported sample bulk chemistries [4], we calculated $^{40}Ar_{(parent-less)}/^{36}Ar_{(trapped)}$ antiquity ages for each regolith breccia [3,8] (see [6] for details). Model-dependent antiquity ages have large uncertainties, but they can still establish an estimated timeline between the formation of the youngest and oldest breccias. Two samples show higher antiquity ages of 2.33 and 2.51 Ga, four samples formed between 1.76 to 2.04 Ga, and two samples show ages of 0.86 and 1.33 Ga. These are consistent with ages reported for the Apollo 16 'young' regolith breccias, suggesting that the breccias were consolidated predominantly within the lower Eratosthenian period.

Summary: In summary, our new data support the proposition of [1], that these regolith breccias formed from soils that resemble soils found at the Apollo 16 landing site (i.e., they formed from mature, gas rich, regolith).

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References: [1] Jerde E.A., et al. (1987) *17th LPSC, Part 2., Journal of Geophysical Research*. *92*, B4, E526-E536. [2] McKay D.S., et al. (1986) *17th LPSC, Part 2, Journal of Geophysical Research*. *91*, B4, D277-D303. [3] Joy, K.H., et al. (2011) *Geochimica et Cosmochimica Acta*, 75(22), [4] Curran N. (2017) *PhD Thesis, University of Manchester* [5] Curran N.M., et al. (2020) *Planetary and Space Science*, *182*,104823. [6] Hohenberg C.M., et al. (1978) *Proceedings of the 9th LPSC*, 2,2311–2344 [7] Nottingham, M.C., et al. (2022) *Meteoritics and Planetary Science*, *57*, 603-634. [8] Eugster et al. (2001) *Meteoritics and Planetary Science*, *36*,1097-1115.