DETERMINING COSMOGENIC CONTRIBUTIONS IN APOLLO SAMPLES WITH NOBLE GAS MEASUREMENTS.

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Introduction: It is generally accepted that the Moon formed as a result of the collision between proto Earth and a potentially Mars-sized impactor, Theia [e.g., 1]. The origin and composition of Theia can be constrained by comparing isotope variations in lunar samples to terrestrial and meteorite data. Previous studies showed a striking similarity in O, Si, Ti and Zr isotopes between the Earth’s mantle and the Moon [2-5]. Based on these observations, two hypotheses can be advanced: the Moon mainly formed from the Earth’s mantle or Theia originated from the inner solar system and was isotopically similar to the Earth [5-8]. Genetic relationships between solar system objects can be traced by using nucleosynthetic isotope variations. For example, 39Cr variations have a nucleosynthetic origin, while 53Cr is also produced by the decay of the short-lived radionuclide 54Mn. Both types of variations are well characterised in solar system materials [9]. Therefore, high precision Cr isotope data have the potential to further tighten the constraints on the moon-forming scenario [5]. However, the lunar surface is exposed to galactic cosmic rays (GCR) that cause cosmogenic reactions, which can strongly affect the Cr isotope composition of lunar samples. These effects need to be corrected [10]. All four Cr isotopes can be affected by spallogenic reactions on Fe and Ni isotopes, in addition to spallation and neutron capture reactions on Cr itself. The dominant GCR-induced reaction is still debated [11-13], but likely depends on several factors such as chemical composition of the rock, shielding conditions, and the duration of exposure. Thus, knowledge of the different cosmogetic contributions is essential to precisely determine the Cr isotope composition of the Moon. Noble gases are sensitive to cosmogenic reactions and can be a useful tool to constrain these contributions; 4He, 23Ne and 38Ar are easily detectable products of spallation, while additional excesses in 80,82Kr and 129Xe can be produced by neutron capture on 79,81Br and 128I [14]. Previous noble gas studies of Apollo samples rarely report a complete dataset of all He to Xe isotopes. Moreover, the cosmic ray exposure (CRE) ages, if published, are calculated using various analytical techniques, variable and potentially outdated production rates and/or different isotopic systems. To address these shortcomings, we performed a systematic high-sensitivity study of noble gas compositions (He to Xe) in lunar samples with the goal to quantify the GCR effects. Based on the results, we will quantify the different cosmogetic noble gas components and select the least affected samples as best candidates to determine the nucleosynthetic Cr isotope compositions of the Moon.

Samples and Method: We analysed 18 Apollo samples including 14 basalts, two anorthosites, one norite and one sample of lunar orange soil. Noble gas compositions were measured on an in-house-built mass spectrometer (“Albatros”) at ETH Zürich. Noble gases were extracted from 1 to 10 mg bulk samples wrapped in commercial Al-foil, in one heating step at ~1700°C. All noble gases (He to Xe) were separated and analysed following the method of [15]. We verified total degassing of the samples by occasional measurements of a “re-extraction” at ~1750°C, which were found to be comparable to blank measurements. Instrumental mass fractionation and sensitivity were monitored using various well-known calibration gases (He-Ne, Ar and Kr-Xe mixtures) and corrected.

Results: The samples yielded 21Ne/22Ne ratios ranging from 0.05 to 0.90 and 20Ne/22Ne ratios from 0.81 to 12.14. Out of 18 analysed samples, 8 show a trapped Ne-Solar Wind (SW) component in addition to cosmogenic Ne. After deconvolution of these two components and calculating the amount of cosmogenic 21Ne and 4He, all samples define a positive correlation between 4He/21Ne and 22Ne/21Ne. Furthermore, for 12 samples, the determined cosmogenic 4He concentrations correlate with published exposure ages, mostly calculated based on Ne, Ar and Xe. Both correlations indicate no 4He loss by diffusion [16]. Thus, the new He and Ne data can and will be used for the calculation of new CRE ages. The measured 36Ar/38Ar ratios range from 0.65 to 4.95, while the accepted cosmogenic 36Ar/38Ar ratio in meteorites is ~0.65 [17,18]. In total 9 samples show noticeable amounts of trapped Ar. After deconvolution, all samples yield cosmogenic 38Ar that roughly positively correlates with cosmogenic 4He and 21Ne. This indicates that, for at least noble gases, the neutron capture contribution is negligible.