A combined study of Cr isotope and noble gas compositions of 18 Apollo samples.

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Introduction:

The characterisation of nucleosynthetic isotope variations between planetary bodies in the solar system is a powerful tool to determine their genetic relationship. Each planetary body investigated so far has its own nucleosynthetic composition except for the Moon and Earth. It is generally accepted that a giant collision between proto-Earth and a large impactor, Theia, was at the origin of Moon formation [e.g., 1]. However, the composition and the origin of Theia remains subject to debate. While early simulations concluded that the Moon mostly formed from impactor material [e.g., 1], several isotopic studies revealed strong similarities between bulk silicate Earth (BSE) and the Moon [e.g., 2]. These observations opened the way to two potential explanations: (i) the Moon mainly formed from the Earth's mantle and this either requires a reassessment of the Moon-forming scenario, or (ii) Theia and Earth originated from the same region of the inner solar system and are therefore isotopically similar [2-5]. A recent O isotope study [6] has refuelled this debate and proposes that this similarity is only apparent, and remnants of Theia could be preserved in the deep reservoirs of the Moon [6]. If true, this observation has strong implications on the current lunar formation models. As consequence, the isotopic composition of lunar rocks needs to be further characterized with high precision analyses to define potential discrepancies. The acquisition of high precision Cr isotope data of lunar samples have the potential to untangle these challenges. The ^{54}Cr variations have a nucleosynthetic origin, while ^{53}Cr is also produced by the decay of the short-lived radionuclide ^{53}Mn. Both types of variations are well characterised in solar system materials [7]. However, the lack of atmosphere on the Moon leaves its surface exposed to galactic cosmic rays (GCR). Nuclear reactions induced by this exposure can strongly affect the Cr isotope composition of lunar samples and need correction to obtain the initial lunar isotope composition [4]. The production of cosmogenic Cr depends on several factors such as chemical composition of the rock, lengths of the exposure, location of the sample in the regolith and the nature of the GCR-induced reactions [8-10]. Since the various noble gases are extremely sensitive to GCR irradiation, this study combines He, Ne, Ar, Kr and Xe isotope analyses with ultra-high precision Cr isotope data (< 5 and 7 ppm for ε^{53}Cr and ε^{54}Cr (2SE), respectively) for lunar rocks.

Samples and Methods: We analysed 18 Apollo samples including 14 basalts, two anorthosites, one norite and one sample of lunar orange soil. All isotope measurements were carried out on the same sample aliquots at ETH Zürich. Noble gas compositions were measured on an in-house-built mass spectrometer ("Albatros"). The noble gases (He to Xe) were extracted from 1 to 10 mg bulk samples and analysed following the method given in [11]. For Cr isotopes analyses, 10 to 60 mg of bulk samples were dissolved and purified through a two-column chromatography procedure. The isotopic analyses were performed on a Thermo Scientific Neptune Plus multi-collector inductively coupled plasma mass spectrometer (MC-ICPMS). All chemical and analytical procedures followed the method described in [12].

Results: The samples yield ^{21}Ne/^{22}Ne ratios ranging from 0.05 to 0.90 and ^{20}Ne/^{22}Ne ratios from 0.81 to 12.14. Out of the 18 analysed samples, 8 have a trapped Ne-Solar Wind (SW) component in addition to the cosmogenic component. This trend is confirmed by the data of the other noble gases. All cosmogenic gas concentrations calculated by deconvolution are coherent with literature data, when those are available. Measuring He to Xe isotope compositions and concentrations allows us to use Kr and Xe shielding depth parameters and reassess the exposure ages (T_{CRE}) of the Apollo samples. Generally, T_{CRE} calculated from Ar and Ne are younger than those from Kr and Xe. Thus, this highlights the importance to recheck exposure ages by calculating the ages based on several noble gases. A comprehensive study of the neutron-capture derived noble gases allows us to identify the different GCR reactions experienced by the sample set. Noble gas data combined with Cr isotope data yield a correlation with exposure time and traces the specific GCR-induced reactions involved that are affecting the Cr isotopes variation in lunar samples.

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