Deciphering mafic and felsic lunar magmatic events: Insight from zircon

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Microstructural studies of zircon grains from lunar breccia samples, combining high resolution imaging together with in-situ U-Th-Pb analyses, has allowed us to distinguish primary zircon, formed by igneous crystallisation in plutonic rocks, and secondary, impact-related, features in zircon grains. Dating of these grains can be used to identify multiple igneous and impact events. For example, a single impact melt breccia from the Apollo 17 landing site contains grains that record more than 3 igneous events in addition to 3 distinct impact events, indicating that the region sampled by this breccia probably significantly exceeds the area of the landing site. As a result, the study of primary zircon ages in the available samples can be used to investigate the temporal distribution of plutonic magmatism on the Moon, even though these samples were collected from the relatively small areas covered by the lunar landing missions.

The study of primary zircons containing inclusions of rock-forming minerals or zircons preserved in lithic clasts found in lunar breccias also provides an opportunity to place temporal constraints on the different types of plutonic magmatism on the Moon. U and Th concentrations of these zircon grains vary systematically allowing clear separation of zircons formed in mafic rocks, such as anorthosite, norite, and gabbro-norite, from those formed in felsic rocks (i.e. granophyre and felsite). This chemical variation can be used to determine plutonic hosts of zircon grains found as mineral clasts in the breccia samples and as loose grains in lunar soils, expanding significantly the number of zircons with known origin.

A comparison of ages of zircons originating from mafic and felsic host rocks suggests a possible age difference between these two chemical rock groups. If confirmed by further analyses this would indicate that the two current explanations for the formation of felsic rocks on the Moon, (i) as residual melt left after extreme fractionation of basaltic magma or (ii) as a result of liquid immiscibility during late stages of fractionation of basaltic melts, are incorrect. Both mechanisms imply close temporal relationships between mafic and felsic rocks, which does not appear to be supported by the available U-Pb ages.

Silicon isotopes as a tracer for silicate utilization in the Peruvian upwelling

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Natural stable isotopes are a powerful tool in marine sciences to investigate biological processes, such as present and past nutrient utilization. In this study we present the first dissolved silicon isotope data in the upwelling area off Peru, where one of the world's largest Oxygen Minimum Zones (OMZ) is located. Samples were recovered during "FS Meteor" cruises M77/3 and M77/4 in 2009. Silicic acid is the most important component required for the growth of diatoms, which dominate the primary productivity in this region. Stable silicon (Si) isotopes are fractionated during diatom growth in that the lighter isotopes are preferentially incorporated into diatom frustules with a fractionation factor of -1.1‰. The Si isotope composition of dissolved silicic acid of the corresponding surface waters is therefore left isotopically heavier. The silicon isotope composition, $^{30}Si/^{28}Si$ is given relative to a reference standard (NBS28) and expressed in the $\delta^{30}Si$ notation. Dissolved Si isotope signatures of seawater provide a measure for the degree of utilization of silicic acid but are also influenced by water mass mixing. Surface waters on the shelf off Peru are mainly fed by the Peru Chile Undercurrent ($\delta^{30}Si$=1.5‰), which consists of water masses ultimately originating from the western and Central Pacific. In areas and during phases of intense upwelling the fractionation of Si isotopes was observed to be weaker due to upwelling driven supply of less fractionated Si ($\delta^{30}Si$=1.8‰) from water depths of 50 to 150m, whereas under weak upwelling conditions the surface waters are heavier ($\delta^{30}Si$=2.8‰) due to more complete utilization of the available dissolved silicic acid. The distribution of the dissolved silicon isotope compositions correlates strongly with particulate biogenic silicate (opal) concentrations in that the highest opal concentrations in surface waters on the shelf reflect the lowest $\delta^{30}Si$ values thus the strongest upwelling intensity. The most extreme $\delta^{30}Si$ values in surface waters ($\delta^{30}Si$=3.2‰) are observed offshore where silicic acid is limited. Furthermore we compare $\delta^{30}Si$ data with the dissolved nitrogen isotope distribution, which, in addition to nitrate utilization, is also influenced by denitrification and annamox processes in the OMZ. Combined silicon and nitrogen isotope compositions can thus help to disentangle different fractionation processes within the nitrogen cycle.