In Situ U-Pb Dating of Lunar Breccia 15455: Impact Resetting and Growth of Zircons at 4.2 Ga.

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Introduction: In early dating studies of lunar impactites, ages > 4.0 Ga were relatively scarce. The abundance of ages between 3.95 and 3.85 Ga led to the hypothesis of a spike in the impactor flux in the inner solar system at around this time (lunar cataclysm or late heavy bombardment, e.g. [1-5]). However, interpretations of these age data may be biased because of resetting of chronometers in impact ejecta by subsequent heating events and biased sampling at Apollo landing sites caused by the proximity of the young Imbrium basin (e.g. [6-8] and references therein). Here we provide new in-situ U-Pb age data on zircons from petrologically well-characterized domains in the cataclastic noritic breccia 15455 [e.g. 9-10] to obtain new constraints on the significance of multiple heating episodes on the age record of lunar zircons.

Materials and Methods: To identify Zr-phases and to map the mineralogy of thin sections 15455,27 and 15455,28, Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) has been applied at the Institute of Mineralogy and Economic Geology at the Rheinisch-Westfälische Technische Hochschule Aachen. Zr-phases have been further investigated under the optical microscope and by Micro-Raman Spectroscopy (MRS) to investigate their structural order. Back Scattered Electron (BSE) and Cathodoluminesecence (CL) imaging of Zr-bearing phases have been performed on selected grains for textural analysis at the Geoforschungszentrum Potsdam (GFZ). U-Th-Pb concentrations and isotope ratios have been measured using the secondary ionization mass spectrometer (SIMS) CAMECA IMS 1280 HR at the GFZ. In total 11 analyses with a spot size of ~4 µm have been obtained on 7 zircon grains in three sessions over three days. Data has been calibrated against the zircon reference matieral 91500 [11] bracketing each session with at least 4 measurements. Calibrations for each session, using the empirical relationship between Pb/U vs. UO_2/UO, yielded a reproducibility of 2.04% to 1.54% (1 sd.).

Results: The thin sections expose domains in the cataclastic norite which were intruded by a 3 mm thick dark vein of former impact melt. The vein consists of fine-grained bytownite-rich, olivine- and enstatite-bearing groundmass (max. 300 µm ø) and three clasts (1 mm–3 mm ø) of varying lithology, degree of shock and extent of assimilation by the melt: A plagioclase clast (70-100% An), a bytownite clast (70-90% An, only ,27) and a troctolite clast. Accessory FeNi, pink spinel, SiO_2 (≤ 100 µm ø), augite, K-feldspar, labradorite (≤ 50 µm ø) ilmenite, ferrosilite (≤ 10 µm ø), disseminated troilite and apatite grains (≤ 4 µm ø) have been identified in the vein. In addition, a Ca-Al-Mg-Si phase, likely glass, is abundant in and around the troctolite clast. The norite host is dominated by an anothite matrix that contains fractured enstatite phenocrysts (max. ø 500 µm). Locally (e.g. Fig. 1), silica-diopside (Si-Di) aggregates occur (≤ 500 µm ø) associated with troilite, apatite, baddeleyite (Bd), zircon (Zr) and chromite (Chr) (≤ 20 µm ø). The Si-Di aggregates occur across the whole norite lithology. Some are located adjacent to or in contact with the intruding vein or along bytownite rich shear zones. Accessory phases are not limited to the aggregates and also appear isolated in the norite but smaller in size. Ilmenite (≤ 50 µm ø) and Fe metal (≤ 10 µm ø) also occur dispersed in the norite. For further petrographic details of section 15455,28 see also [9]. In BSE (less clear in CL) images, the majority of zircon grains have a granular texture with granules ranging from less than 1 µm to 6 µm diameter (Figure 1).

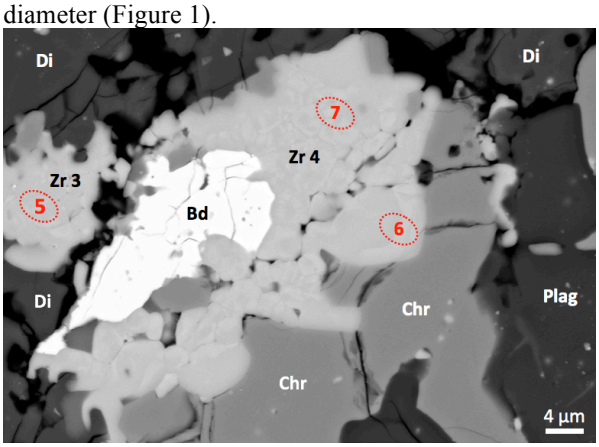

Figure 1: BSE image showing remnant baddeleyite (Bd) surrounded by granular zircon (Zr) in a Si-Di aggreagate near the melt vein associated with chromite (Chr). Red ellipses mark SIMS spots. Di: diopside, Plag: plagioclase.

Some (<6 µm) dispersed zircon grains do not show a granular texture. Zircon granules are euhedral and tend to form aggregates that reach 20 µm in diameter (Fig. 1). These grains have irregular grain boundaries controlled by the shape of the granules. Four zircon grains are associated with baddeleyite, which is partly (Fig. 1) or completely surrounded by zircon. Further-

more, the baddeleyites show fractures that do not extend into surrounding zircon. The size of the baddeleyite is mostly proportional to the size of the zircon present, ranging from 4 µm to 20 µm. MRS spectra of zircon grains and granules show asymmetric stretching of the full width at half maximum of the v3(SiO_4) band (19–33 cm^{-1}) and a shift to lower wavenumbers (966-1007 cm^{-1}). The shift is pronounced where baddeleyite is present. SIMS analysis have been performed in granular zircon cores, homogeneous zircon rims, granule cores and zircon adjacent to baddeleyite. No significant common Pb has been observed. The $^{207}Pb/^{206}Pb$ ages display a narrow range between 4154 and 4210 Ma (Fig. 2), yielding a mean $^{207}Pb/^{206}Pb$ age of 4190 ± 16 Ma (2sd, n=11).

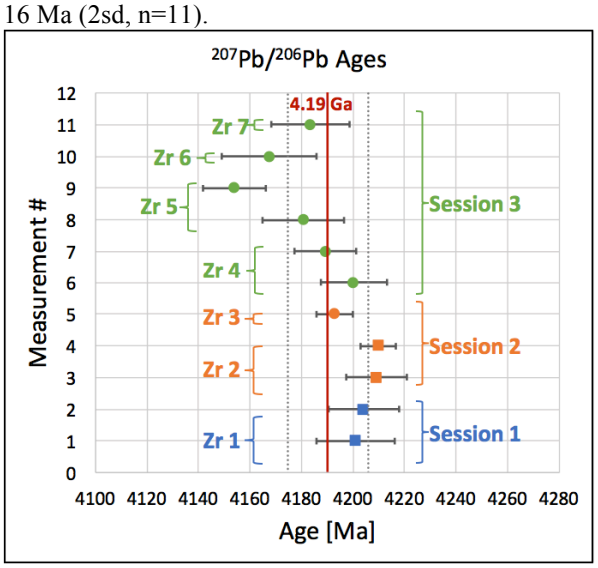

Figure 2: $^{207}Pb/^{206}Pb$ ages obtained in-situ on lunar zircons. Squares show data for zircons in thin section 15455,27, circles show data for thin section 15455,28. Error bars are 2sd. Different sessions and the different zircons are indicated.

Duplicate analysis in homogeneous rims of zircon 1 (measurements 1-2) with less pronounced granular texture, surrounding a 20 µm ø baddeleyite grain, are concordant and yield an age of 4202 ± 13 Ma (2sd). A 5 µm ø zircon grain in ,27 close to the melt vein and the core of a large granular zircon in a Si-Di aggregate adjacent to the melt vein in ,28 both yield a concordia intercept age of 4206 ± 11 Ma (2sd). Except for one measurement during session 3, five results are reverse discordant. A Tera-Wasserburg (TW) concordia intercept of five of the datapoints (n=3 core of granular zircon, n=2 homogeneous rim of granular zircon) yields an age of 4205 ± 15 Ma (2sd). The datapoint not considered (#10) shows a larger deviation from other measurements of this session in terms of its $^{207}Pb/^{206}Pb$ age and correlation within the TW-concordia. The mean $^{207}Pb/^{206}Pb$ age, the concordia and (TW-) concordia-intercept ages agree within error. From this data we infer a closure of the U-Pb isotope system of zircon at ~4.2 Ga. U, Th, Pb concentrations vary from 163 to 341, 54 to 231 and 261 to 729 ppm respectively. Th/U ratios measured range from 0.298 to 0.846. The U-Th concentrations and ratios tend to be elevated for zircons near or in contact with the melt vein. Alpha-doses calculated after Nasdala et al. (2001) combining MRS and SIMS data vary from 4.4 to 10.8 10^{15}/mg.

Discussion and Conclusion: Previous studies ([10] and references therein), who also analyzed granular zircons separated from sample 15455, interpreted the granular texture to be indicative of zircon growth in an impact related environment in a crater floor bedrock adjacent to an impact melt body. The previous SIMS analyses of large granular zircons (ø 30 µm) obtained by mineral separation methods yielded an age of ~4.33 Ga. In the present study, no ages older than ~4.21 Ga were obtained. Possible interpretations of the different results include either that 15455 comprises unrelated lithologies with different ages or that analyzed zircons of the present study underwent significant impact-related lead-loss at ~4.2 Ga. The petrological evidence from this study suggests impact-induced recrystallization and complete resetting of the U-Pb system of previously existing zircon and possibly growth of new zircon grains from pre-existing baddeleyite. The new age data on 15455 supports recent studies (e.g. [7], [10], [13], 14]) indicating the occurrence of a major impact event or a series of events at 4.2 Ga.

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