Magmatic events recorded in Apollo 14 zircon. F. Thiessen[1,2], A.A. Nemchin[1,3], J.F. Snape[4] and M.J. Whitehouse[1,2], [1]Swedish Museum of Natural History, Stockholm, Sweden (Fiona.Thiessen@nrm.se), [2]Department of Geological Sciences, Stockholm University, Sweden, [3]Curtin University, Perth, WA, [4]Faculty of Earth and Life Sciences, VU Amsterdam, The Netherlands.

Introduction: Zircon ($ZrSiO_4$) is an accessory mineral occurring in a wide range of lunar rocks. Its high closure temperature, around 950-1110℃ [1], makes it an important U-Pb geochronometer for dating magmatic processes. Zircon forms in melt saturated in Zr and hence, the sources of these zircon grains are thought to be magmas enriched in incompatible elements, such as KREEP [2]. Based on these attributes, zircon is used to investigate crystallization ages (magmatic or from an impact melt) of rocks, which also help to constrain the timing and evolution of KREEP magmatism. However, disturbance by impact events may cause partial resetting of the U-Pb system, leading to meaningless ages.

In this study, U-Pb ages were obtained by SIMS for zircon occurring in four Apollo 14 breccias (14305, 14306, 14314 and 14321). A thorough textural and petrological analysis was used to interpret the ages as igneous crystallisation ages, impact ages, or partially reset ages. Moreover, we tried to determine whether zircon grains within different lithic clasts crystallized in a localised plutonic melt, or whether these clasts were formed in a more widespread event involving multiple pools of magma. Additionally, the age distributions were compared to detect similarities and differences among the Apollo 14 breccias.

Sample description: Three samples (14305, 14306 and 14314) were collected near the Apollo 14 landing module and one sample (14321) was collected close to the edge of Cone Crater and within its continuous ejecta blanket. All four samples are described as clast-rich crystalline-matrix breccias and as KREEP-rich [3]. The matrices of breccias 14305 and 14321 appear to consist of more fragmental material, including clasts of crystalline material [4], whereas the crystalline matrices of breccias 14306 and 14314 are mainly composed of plagioclase and pyroxene grains. The various clasts identified in the breccias comprise anorthosites, norites, basalts and impactite clasts.

Analytical Methods: To identify zircon grains and to investigate the texture of the samples, backscattered electron (BSE) images and element maps were acquired by scanning electron microscopy (SEM). The SEM analyses were performed with a Quanta 650 FEG-SEM and accompanying Oxford Instruments Energy Dispersive Spectroscopy (EDS) detector. U-Pb isotopic data was collected using a CAMECA IMS 1280 ion microprobe at the NordSIMS facility, Swedish Museum of Natural History, Stockholm. Cathodoluminescence (CL) images were taken using the ChromaCl2 system. The U/Pb ratios in zircon were corrected against the 1065 Ma zircon crystal 91500 [5]. All ages are stated with 2σ uncertainties.

Results:

14305: Eighteen analyses were performed on seven zircon grains and yielded individual $^{207}Pb/^{206}Pb$ ages ranging from 4058±9 Ma to 4300±13 Ma. The zircon grains are subhedral to anhedral and the majority occur within the matrix. Four grains exhibit sector and oscillatory zoning in CL.

14306: Nine zircon grains were analyzed and the individual $^{207}Pb/^{206}Pb$ ages vary from 4078±10 Ma to 4349±5 Ma. The majority of grains occur as fragments within the matrix, but two grains are located within the same K-feldspar-rich clast.

14314: In total, 60 analyses on 29 grains yielded individual $^{207}Pb/^{206}Pb$ ages ranging from 3936±8 Ma to 4346±12 Ma. Several grains occur as poikilitic zircon grains within lithic clasts (noritic and anorthositic). Two baddeleyite grains are surrounded by aggregates of granular (~1-5 µm) zircon. One grain is the largest of all analyzed zircon with a size of ~430 x 340 µm. It exhibits a dark and a bright CL zone. Seventeen analytical spots were placed within the grain and gave a weighted average $^{207}Pb/^{206}Pb$ age of 3941±5 Ma (MSWD=0.89, P=0.58).

14321: Five analyses on four grains yielded individual $^{207}Pb/^{206}Pb$ ages varying from 4166±18 Ma to 4325±33 Ma. Two grains are located within the matrix, and two grains occur within the same impactite clast.

Magmatic crystallization ages:

Grains within lithic clasts: Three grains are located within two different "anorthositic norite" clasts (approximately 70% plagioclase, 25% pyroxene, and minor amounts of phosphate, K-feldspar and ilmenite). These zircon grains are poikilitic, interstitially grown with plagioclase, and are therefore, interpreted to have crystallized at the same time. A combined weighted average $^{207}Pb/^{206}Pb$ age of all three zircon grains of 4146±3 Ma (MSWD=0.32, P=0.81) was derived, which is interpreted as the crystallization age of the clasts. Furthermore, five zircon grains occur within two noritic clasts. These grains are poikilitic grains with an irregular shape. They yield a combined weighted average $^{207}Pb/^{206}Pb$ age of 4214±4 Ma (MSWD=1.4, P=0.22), which is interpreted as the crystallization age of the noritic clasts. Two grains belong to the same K-feldspar-rich clasts and give a combined weighted average $^{207}Pb/^{206}Pb$ age of 4348±4 Ma (MSWD=1.18, P=0.28). Nevertheless, they occur as small fragments of much larger zircon grains within the clasts and do not show any evidence that they crystallized within it. Their age cannot be unambiguously linked to the crystallization age of the clast.

Cogenetic zircon grains: In addition to zircon occurring within lithic clasts, several zircon grains are part of mineral assemblages (mainly plagioclase, phosphates and pyroxene) and show petrological evidence that they formed cogenetically with their host assemblages. These grains recorded crystallization events at 4166±13 Ma, 4216±5 Ma and 4286±3 Ma.

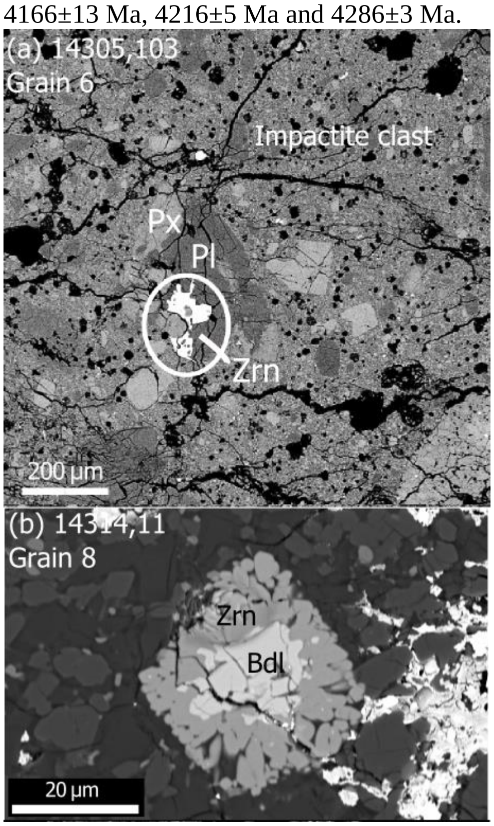

Figure 1. *Backscattered Electron (BSE) images of (a) a poikilitic zircon grain, which is part of a mineral assemblage and located in an impactite clast, and (b) granular zircon surrounding a baddeleyite grain. Abbreviations: Zrn=zircon, Px=pyroxene, Pl=plagioclase, Bdl=baddeleyite.*

Impact event at ~3936 Ma: Two baddeleyite grains are located within the matrix and are surrounded by granular zircon grains, which are thought to have formed as a result of an impact [e.g. 6]. The age of 3936±8 Ma is taken as the best estimate for the time of zircon formation, whereas the baddeleyite grain yielded a minimum $^{207}Pb/^{206}Pb$ age of 4307±12 Ma. The 3936±8 Ma age of the granular zircon is indistinguishable from the age of 3941±5 Ma obtained from the largest zircon grain analyzed in this study. Therefore, the large zircon grain might have crystallized in the same melt sheet which formed the granular zircon or, alternatively, the impact event impact event might have triggered late-stage KREEP magmatism.

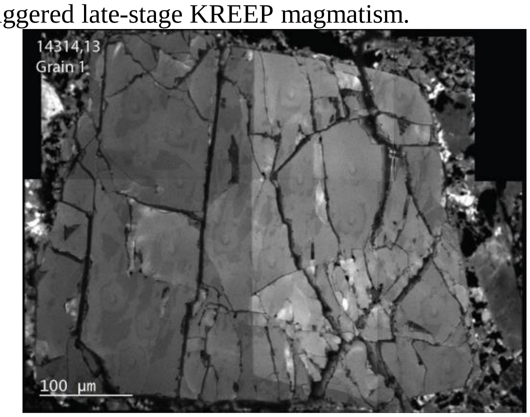

Figure 2. *Cathodoluminescence (CL) image of the largest grain analyzed in this study, exhibiting one dark and one bright CL zone.*

Age distribution: There is a prominent age peak at ~4335 Ma in all four breccias, which is also visible in breccias from different landing sites [e.g. 7]. A minor age peak at ~4210 Ma is seen in the overall age distribution of Apollo 14 breccias [8] and is mainly derived from zircon located within different noritic clasts and from cogenetically grown zircon grains. Therefore, this age peak can be interpreted as a real crystallization event (either igneous or impact-related). There is a possibility that the noritic clasts derive from a single plutonic rock, which was broken into numerous pieces during the impact event which formed the different breccias. If this is the case, then the minor age peak at ~4210 Ma might represent a smaller local magmatic event. Another minor age peak at ~3940 Ma is observed in breccias 14314 and 14321. This peak can be linked to an impact event and might indicate that some of the breccias sampled material from stratigraphically deeper levels (pre-Fra Mauro Formation) and recorded an older impact event than the one that formed the breccias. The latter was possibly the Imbrium impact at 3927±2 Ma as recorded by U-Pb ages of younger Ca-phosphate grains in these breccias [4].

References:

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