SIMS PB/PB AGES OF BADDELEYITE AND ZIRCONOLITE IN APOLLO 17 NORITE 78235: IMPLICATIONS FOR SHOCK HISTORIES OF EXTRATERRESTRIAL ROCKS. A. C. Zhang[1], L. A. Taylor[2], R. C. Wang[1], Q. L. Li[3], X. H. Li[3], A. D. Patchen[2], and Y. Liu[2], [1]School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China (aczhang@nju.e.du.cn); [2]Planetary Geosciences Institute, University of Tennessee, Knoxville 37996, USA; [3]Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China.

Introduction: Shock metamorphism is one of the most important processes on the surface of planets and asteroids, which results in disturbance of radiogenetic isotopic systematics (e.g., Rb-Sr, Ar-Ar, K-Ar). Whether shock metamorphism can disturb the U-Pb isotopic systematics of zircon and baddeleyite also has drawn considerable attention [1-4]. However, in shock-recovery experiments, even if the peak pressures are up to 59 GPa for zircon and 47 GPa for baddeleyite, no measurable differences in U-Pb and Pb/Pb ages were observed before and after shock experiments [1,3]. To further understand the effects of impact events on Pb/Pb ages of baddeleyite, we report ion-microprobe dating results on baddeleyite and zirconolite in the unbrecciated Apollo 17 sample (norite 78235), utilizing CL-imaging techniques to distinguish relative ages of analyzed spots.

Analytical methods: Two polished thin-sections of Apollo sample 78235 (78235,37 and 78235,48) were studied. Petrography was studied in back-scattered electron (BSE) imaging mode with the CAMECA SX100 electron microprobe at the University of Tennessee. The CL images of the baddeleyite were prepared at Nanjing University. The U-Pb isotopic compositions of the baddeleyite and zirconolite were determined using the Cameca IMS-1280 SIMS at the Institute of Geology and Geophysics, Chinese Academy of Sciences, in Beijing. The analytical procedures were similar to those described by [5-6]. However, to avoid possible crystal orientation effects of U-Pb ages in baddeleyite, we only discuss the variation of Pb/Pb ages in baddeleyite and zirconolite from 78235.

Results: Norite 78235 is composed mainly of subhedral to euhedral and coarse-grained orthopyroxene and anorthite. Silica, ilmenite, merrillite, apatite, clinopyroxene, baddeleyite, zirconolite, and rutile occur as interstitial phases or in mesostasis. Most large pyroxene grains display their original shapes. Only a few pyroxene grains were shattered to small irregular fragments. Most of plagioclase grains were transformed to maskelynite. Melt pockets are common. In melt pockets, some small relict pyroxene grains are observed, whereas molten pyroxene contains a flow structure--schlieren (Fig. 1). Vesicles of varying sizes are also common in 78235, occurring mainly within molten regions.

In this study, eight baddeleyite grains and one zirconolite grain were dated. Three baddeleyite grains (bd-3, bd-4, bd-8) are included in pyroxene and close to the boundary between pyroxene and surrounding minerals (pyroxene or plagioclase). No brightness variations on CL images of these three baddeleyite grains were observed. The mean Pb/Pb ages for bd-3 and bd-4 are 4333 ±25 Ma and 4326 ±25 Ma, respectively. Grain bd-8 is possibly a bit younger, with a mean Pb/Pb age of 4295 ±30 Ma.

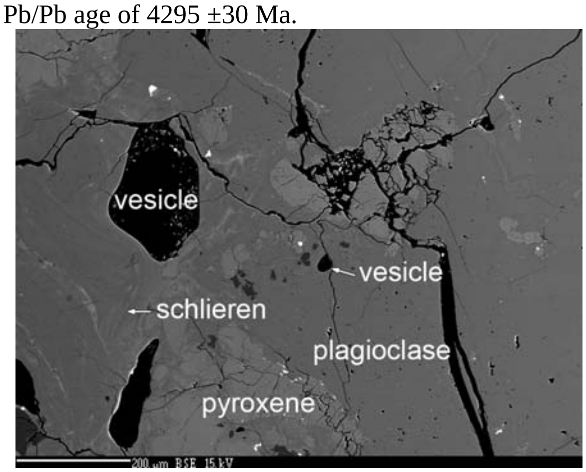

Figure 1. BSE image of a representative region in 78235.

Baddeleyite grains bd-5, bd-6, and bd-7 occur in a common mesostasis and are associated with late-stage pyroxene, silica, plagioclase, and merrillite. No distinct CL variations were observed in these three baddeleyite grains. Grains bd-5 and bd-6 have a mean Pb/Pb age of 4313 ±18 Ma and 4340 ±25 Ma, respectively. However, the Pb/Pb age of grain bd-7 is significantly younger (4253 ±25 Ma).

Baddeleyite grain bd-2 is located in mesostasis and associated with apatite, merrillite, pyroxene, silica, rutile, and zirconolite. It is surrounded by a zirconolite rim. The thickness of the zirconolite rim varies from 2 µm to 6 µm. Grain bd-2 has a mean Pb/Pb age of 4308 ±15 Ma; in contrast, the zirconolite has a much younger Pb/Pb age of 4263 ±25 Ma.

Baddeleyite grain bd-1 is included in plagioclase. Cathodoluminescense imaging revealed that this baddeleyite grain consists of a dark area and a bright area. Dating results obtained a mean Pb/Pb age of 4240 ±20 Ma for the dark area, whereas the bright area has a much older Pb/Pb age of 4324 ±19 Ma.

In summary, baddeleyite and zirconolite in 78235 have a large Pb/Pb age variation from 4220 ±21 Ma to 4347 ±22 Ma, and there are two age peaks at 4318 ±9 Ma and 4252 ±15 Ma, respectively (Fig. 2).

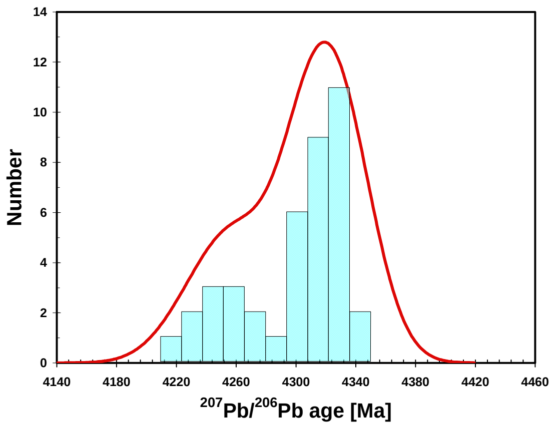

Figure 2. Distribution of Pb/Pb ages of all baddeleyite and zirconolite grains in 78235.

Discussion: Based on the petrographic observations, four major types of shock-induced features could be identified in 78235: 1) fragmentation of pyroxene; 2) transformation of plagioclase to maskelynite; 3) flow structure of molten pyroxene in melt pockets; and 4) vesicles in molten regions. These shock-induced features reflect heterogeneous distribution of shock intensities within 78235, to be expected with shock propagation through a heterogeneous solid. Similar conclusions have also been drawn in previous investigations [7-8]. Sclar and Bauer [7] proposed a model of two discrete shock events to interpret the heterogeneous distribution of shock intensities, whereas Nyquist et al. [8] preferred a model of single shock event for 78235. In the present study, we also prefer the single shock-event model and suggest that *the heterogeneous distribution of shock effects reflect the heterogeneity of post-shock temperatures rather than pressures.* At the same time, based on the classification of shocked basaltic-gabbroic rocks by [9], which have similar mineral assemblages to the 78235 norite, the presence of molten plagioclase glass, with incipient flow structure and vesicles, indicates that the shock pressure could be greater than ~42-45 GPa, but less than ~60 GPa, and the post-shock temperatures could be between ~900 °C and 1100 °C.

In this study, the Pb/Pb age variations in 78235 are not only present among different baddeleyite grains (bd-5, bd-6, and bd-7) located in the same mesostasis, but also present within a single baddeleyite grain (bd-1) and between baddeleyite (bd-2) and associated zirconolite. At the same time, baddeleyite and zirconolite in 78235 have two age-peaks (at 4318 Ma and 4252 Ma), shown in Fig. 2. These age variations in baddeleyite and zirconolite cannot be a result of primary crystallization of the coarse-grained norite cumulate. A later thermal event is required to account for the age variations. *The most likely interpretation is a slight resetting of Pb/Pb ages in baddeleyite and zirconolite during shock metamorphism in 78235.*

Among the two age peaks for baddeleyite and zirconolite in 78235, the older baddeleyite Pb/Pb age at 4318 ±9 Ma is consistent with the crystallization ages obtained by the whole rock and coarse-grained mineral separates from Sm-Nd, Rb-Sr, and Pb/Pb isochron methods in the literature [8, 10-11]. However, the younger baddeleyite and zirconolite Pb/Pb age is much older than theAr-Ar age (4110 ± 20 Ma) for a plagioclase separate [12] and a young Rb-Sr isochron age (4003 ± 95 Ma) [11] in the literature. One scenario for the various ages ([11-12]; this study) would be that norite 78235 samples have experienced at least two shock events at ~4252 Ma, with a less-intense one at ~4110 Ma. This scenario is not in contrast with the above interpretations that the shock-induced petrographic features in 78235 formed by only one major impact event and reflect the heterogeneity of post-shock temperatures.

Conclusions: Our dating results indicate that baddeleyite and zirconolite define two signifycantly different ages at 4318 ±9 Ma and 4252 ±15 Ma, respectively. The older age is interpreted as the initial crystallization age, whereas the younger age reflects a significant impact event, consistent with the shock features observed in 78235. The post-shock temperatures could play a more important role in resetting Pb/Pb ages than shock pressures do.

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