U-Th-Pb ANALYSIS OF BADDELEYITES IN SHERGOTTITE METEORITES. N. R. Hays[1], M. J. Drake[1], G.G. Gehrels[2], [1]Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd., Tucson, AZ, 85721, USA (nhays@olympic.edu), [2]Department of Geosciences, University of Arizona, 1040 E 4th St., Tucson, AZ, 85721, USA.

Introduction: While there is little disagreement about the Martian origin of shergottite meteorites, the petrologic history of the rocks is in debate. Rb-Sr and Sm-Nd ages of basaltic shergottites consistently yield young ages (~150-450 Ma) [e.g. 1-3]. Other shergottite sub-groups also yield young ages [e.g. 4, 5, 6]. In contrast to these results, Pb-Pb isochron analyses yields ages on order of 4.05 Ga. [7, 8]. While many researchers interpret the young ages as timing initial formation of the rocks and the Pb-Pb isochron data as a marker of Martian mantle evolution, Bouvier *et al* [8] infer that the older ages represent crystallization and the young ages are recording some resetting event. Additional analyses may provide some resolution to this debate.

As the debate centers around the potential metamorphic resetting of chronometers, analysis of the more resilient accessory phases, such as baddeleyite (ZrO_2), may shed light on the petrographic history of these meteorites. In addition to being resistant to metamorphic processes, baddeleyite can contain abundant U and negligible common Pb, making it a good candidate for successful U-Pb dating. [9]

Ion microprobe analyses of Shergotty phosphates have been performed and are, in general, consistent with young ages [10]. Preliminary *in-situ* baddeleyite analyses were performed by Herd *et al.* [11] which also were consistent with the young ages. Herein, we present further *in-situ* analysis of baddeleyites in three subgroups of shergottites (basaltic, lherzolitic and olivine-phyric).

Methods: Thick sections of 9 different shergottite meteorites were analyzed: ALH 77005, EETA 79001, LAR 06319, LEW 88516, NWA 2646, NWA 2986, RBT 04261/04262 and Y793605. For each sample, X-ray maps were made using the CAMECA SX-50 microprobe operated at the Lunar and Planetary Laboratory at the University of Arizona. These maps were used to locate baddeleyite grains. Mineral identification was confirmed with energy-dispersive spectrometry. Silicate compositions were analyzed with wavelength-dispersive spectrometry using a voltage of 15 keV and a current of 20 nA and reflected-light images were made of each crystal.

In-situ U-Th-Pb isotopic data were collected using laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS) at the Arizona LaserChron Center using a New Wave UP193HE Excimer laser operating at a wavelength of 193 nm. Spot diameters of 6 µm were used for baddeleyite analyses. LA-MC-ICP-MS methods are similar to those described in Gehrels et al [13]. Ablated material is carried with helium gas in the plasma source of a Nu HR ICPMS with a flight tube of sufficient width that U, Th, and Pb isotopes are measured simultaneously. All measurements are made in static mode, using 3 x 10^{11} ohm Faraday detectors for ^{238}U, ^{232}Th, ^{208}Pb, ^{207}Pb, and ^{206}Pb, and an ion counter for ^{204}Pb. Ion yields are ~0.5 mV per ppm. For each analysis the laser was operated for 30 pulses at 4 Hz.

Results: The number of baddeleyite grains located in the samples varied widely. No grains were located in LEW 88516 while 39 grains were found in RBT 04262. A total of 117 grains were located in eight of the nine thick sections. The baddeleyite grains in these samples were very small, ranging from ~2 µm up to ~ 20 µm in the largest dimensions. Only four baddeleyite grains within RBT 04262 and five grains within NWA 2986 were of sufficient size to analyze with LA-MC-ICP-MS. Results of these analyses can be found in Table 1.

Despite the ability for baddeleyite to take up uranium, concentrations of U and Th in the samples were small. For RBT 04262, the average U concentration in baddeleyite was ~50 ppm, with a range of 28 to 67 ppm. Pb concentrations averaged 3 ppm, with a range from 1 to 4 ppm. For NWA 2986 the average U concentration is ~350 ppm, with lead concentrations comparable to those found in RBT 04262. Unfortunately, most of the Pb in both samples is common Pb with large measurement uncertainties. These uncertainties in the common Pb correction propagate through to large errors in the final age, but at the very least allow for calculation of a maximum age for each analysis, if it is assumed that all of the ^{206}Pb present is radiogenic rather than common. These maximum ages range from 100 ± 9 Ma to 526 ± 48 for RBT 04262 and from 187 ± 50 to 1236 ± 430 Ma for NWA 2986.

Discussion: For these ages to be interpreted as the crystallization ages of the meteorites, three complications must be addressed; the origin of the baddeleyite grains, the size of the grains, and the risk of age resetting due to a magmatic or metamorphic event.

It has been suggested that baddeleyite in shergottites formed as the result of zircon decompo-

sition [7]. This would mean that any age determined from analysis of the baddeleyites would simply date the decomposition effect rather than the crystallization of the meteorite. However, for the baddeleyites analyzed herein, there is no evidence of the decomposition process. For example, the high-silica glasses associated with zircon decomposition [13] were not found in RBT 04262. Thus, it is reasonable to interpret these baddeleyite grains as late-stage minerals, formed during the crystallization of these meteorites from magma.

The limitations caused by the small grain size of baddeleyites in these samples can also lead to ambiguity in interpretation. With grains this small, it is possible that analyses could be contaminated by the unintentional ablation of surrounding materials. To avoid this, only the largest grains, with cross-sections larger than the beam size, were analyzed. As such, it is unlikely that the ages determined from the U-Pb analysis of these baddeleyites could be the result of contamination by surrounding minerals.

The last complication is the risk of dating a resetting event with these internal ages, rather than the magmatic age of the rock itself. However, shock experiments and analysis of terrestrial baddeleyites indicate that the grains retain accurate U-Pb age data through high degrees of shock metamorphism [9, 15]. Baddeleyite is simply less susceptible to resetting. Thus, ages determined from U-Pb analysis cannot simply be dismissed as timing some alteration process. Much more likely is that the ages determined for baddeleyite formation also date the magmatic crystallization of the meteorites.

Conclusion: The baddeleyite ages determined herein are young (100 – 526 Ma and 187 – 1236 Ma for RBT04262 and NWA2986 respectively). This is consistent with ages determined for oxides, olivine and pyroxene [e.g. 1-3]. Thus, the interpretation that internal chronometers can be used to infer the age of igneous crystallization is reasonable. The baddeleyite results indicate that shergottites are young (100-1236 Ma) and that the 4.05 Ga ages determined by Bouvier *et al.* [7] do not date the formation of these meteorites.

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TABLE 1.
Baddeleyite U-Pb Isotopic Data

Sample Name	U (ppm)	$^{206}Pb/^{204}Pb$	U/Th	$^{206}Pb^*/^{207}Pb^*$	± (%)	$^{207}Pb^*/^{235}U^*$	± (%)	$^{206}Pb^*/^{238}U$	± (%)	**Max Age (Ma)**	± (%)
NWA 2986	197	835		2.1289	5.6	8.6741	36.4	0.1339	36.0	**502**	34
	66	752	1.1	2.1206	4.6	23.5745	40.6	0.3626	40.3	**1236**	35
	125	2049	5.3	1.0278	2.9	35.1728	24.0	0.2622	23.8	**931**	21
	486	1490	3.2	6.2350	6.8	2.1660	27.5	0.0979	26.7	**373**	25
	914	1373	32.7	2.3179	4.4	2.8486	27.7	0.0479	27.4	**187**	27
RBT 04262	63	10635	0.4	5.6013	2.2	0.5356	9.4	0.0218	9.1	**100**	9
	67	2885	0.4	2.4237	1.6	3.3185	9.1	0.0583	9.0	**263**	9
	28	4899	0.1	1.6305	1.4	10.1476	9.7	0.1200	9.6	**526**	9
	58	2203	0.6	2.1877	1.9	4.3365	11.4	0.0688	11.2	**309**	11