U-Pb ISOTOPIC SYSTEMATICS OF FERROAN ANORTHOSITE 60025; W.R. Premo and M. Tatsumoto, U.S. Geological Survey, Denver, Co. 80225

Preliminary U-Pb isotopic data from separates of ferroan anorthosite 60025 confirm its antiquity at -4.42 Ga. Three Pb-Pb isochron ages involving different sets of mineral separates vary by only 20 million years, but indicate derivation of the sets from isotopically distinct magma sources. If this anorthosite was a monomict cumulate product formed during the Moon’s early primary differentiation stage, then residual liquids of crystallizing magmas were evolving isotopically, even at the cm-scale, over the duration of the crystallization period. Another explanation is that this sample is simply a polymict breccia and that the Pb isotopic results are a result of subsequent mechanical mixing of mineral assemblages from various cumulate piles formed coevally at -4.42 Ga from isotopically distinct magma sources.

In our ongoing search for early lunar Pb isotopic compositions, we have analyzed Apollo 16 anorthosites 67075 and 62337 [1] and Apollo 17 high-Mg suite cumulates (troctolite 76535 [2], norite 78235 [3], and dunite 72415 [4]). The U-Pb isotopic systematics have been better behaved in the high-Mg suite rocks than in the anorthosites that have shown evidence of mineral assemblages of mixed parentage [1,5]. Our aim in analyzing anorthosite 60025 was to avoid or minimize this problem as it had been considered essentially monomict [6], although recent work by [7] has shown that not only is 60025 polymict, but shows textural evidence of at least two episodes of deformation. Of the five splits studied by [7], the four mineral splits appeared monomict, whereas the whole-rock split was considered polymict. Previous isotopic work indicated that this anorthosite was quite primitive [8], a claim that was apparently confirmed by the U-Pb isotopic age of 4.51 ±0.01 Ga on three plagioclase separates [9]. However, a Sm-Nd internal isochron age of 4.44 ±0.02 Ga was determined using plagioclase, olivine, and mafic mineral separates [10], creating some doubt about the anorthosite’s true age. It was pointed out by [2] that the use of slightly evolved initial Pb values (corresponding to a source μ value of ~35) to correct the U-Pb data of [9] can result in an U-Pb age of 4.44 Ga. The need to resolve the age and isotopic nature of this anorthosite is paramount to furthering our understanding of processes of ferroan anorthosite formation as well as the magmatic history of the early Moon.

Our analytical procedures are not very different than those used in [2,3]. The original subsample of three pieces weighed approximately 1.28 gm and was shaken in a sealed quartz vial until no further disaggregation occurred. The largest chip was removed and treated as a separate split (025C), and was further crushed, sieved, and magnetically split into four separates; hand-picked plagioclase (PL-3), a 150-μm, non-magnetic separate (PL-4), a 150-μm, non-magnetic separate (PL-1), and a magnetic separate (M-2). Two other chips from the shaking were analyzed as whole-rocks (WR-1 and WR-2). The remainder of the shaken material was considered loose matrix (025M) and was subsequently sieved and magnetically-split as well (a 150-μm, non-magnetic separate (PL-2) and a magnetic separate (M-1)). All of these fractions were subjected to alcohol washing and three dilute acid leachings (two HBr and one HNO3) designed to remove terrestrial contamination and strip the grain surfaces of any adsorbed Pb component [11]. The Pb isotopic results from only the residues of these separates (washes and leaches will be analyzed soon) are shown in Figure 1 and compared to results from other anorthosites.

The residues (solid circles and triangles) of 60025 do not form an array, but are instead scattered inside of a triangle defined by CDT [13], anorthosite 15415 [14], and the radiogenic Pb composition of each separate, typically near 4.4 Ga (Fig. 1). However, three arrays or isochrons, defining ages -4.41 to 4.43 Ga, can be constructed using the 60025 Pb data. PL-3 & 4 that represent the cleanest plagioclase separates from the large chip, 025C, lie on the same array as the three plagioclase separates from [9], yielding a 207Pb/206Pb age of 4431 ±15 Ma (short dashed line, marked 2). Another array, connecting PL-1 & 2 that are both very fine-grained plagioclase separates, one from the chip and the other from the loose matrix, defines a 207Pb/206Pb age of 4409 ±65 Ma (long dashed line, marked 1). The two magnetic separates, M-1 & 2, do not lie on either of these arrays, but plot below and indicate a younger age of 4316 ±65 Ma. An apparent isochron connects M-2 (from the chip), the mafic fraction from [9], and WR-2, yielding a 207Pb/206Pb age of 4222 ±10 Ma (94% prob. of fit; dot-dashed line). It is not obvious why these three separates should align so well, although M-2 and the mafic fraction of [9] are similar separates and WR-2, the larger of the two, may have contained a larger proportion of radiogenic-Pb-rich minerals. Nonetheless, it is possible that this array forms a pseudochron that just perches defines the correct age. The two whole-rock separates, WR-1 & 2, plot between the plagioclase and magnetic separates, indicating that they are mixtures of the different Pb components.

The U-Pb isotopic results (not shown) are not complete at present, but preliminary results from four of the separates indicate clear discrepancies in the use of initial Pb values from one separate to the next for correction of the U-Pb data. This problem appears to support our contention that these separates were derived from isotopically
distinct sources. However, some consolation, the use of initial Pb values calculated assuming a source, single-stage Pb evolution between 4.56 and 4.44 Ga and a value of 35 (indicated by line #2) does produce a U-Pb concordia upper-intercept age of 4.433 Ga and a lower-intercept age of 230 Ma. Assuming this lower-intercept age as the time of some isotopic disturbance to all the material in 60025, an upper-intercept age of 4330 ±13 Ma is defined for the mafic fraction of [9] that agrees well with the Pb-Pb age of 4.32 Ga for M-1.

Our interpretation of these preliminary results is tentative at present, but the data would strongly suggest that plagioclase in 60025, although geochemically very similar [7], is derived from isotopically different sources (μ -100 and μ -35), but at essentially the same time (geologically speaking). The magnetic minerals may or may not be mixtures of 4.42 Ga and younger material. If some were formed at 4.42 Ga with the plagioclase, then they were derived from yet another isotopically distinct liquid (μ -1). Certainly M-1 contains material that is younger than the plagioclase and may have been derived from a source with μ -12 at 4.32 Ga. The variability in source-μ values is not uncommon for ancient (>4.0 Ga) lunar rocks [2,15]. An example is illustrated in Figure 1 with the magnetic separates from anorthosite 67075 that indicate a 207Pb/206Pb age of 4422 ±50 Ma and a source-μ value of -250 that is clearly different than that of ~350 for 67075 plagioclase separates [1]. Although the source-μ values are different, the age is very similar to an unpublished Sm-Nd internal isochron age of 4.45 ±0.1 Ga for 67075. The same general pattern was obtained for separates from troctolite anorthosite 62237 [1]. We tentatively suggest that either early cumulates were formed in a magma environment that allowed isotopic reequilibration or mixing over the duration of the crystallization period, or these anorthosites are mechanical mixtures of geochemically-similar, but isotopically different, mineral assemblages. Perhaps early bombardment played a role in the mixing process, although intuitively it would seem that later impacting events caused brecciation in this sample as is the rule in most lunar samples.