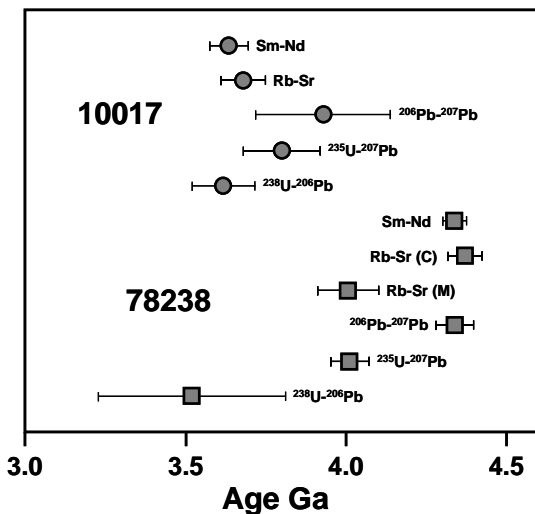


**DISTURBANCE OF U-Pb ISOTOPIC SYSTEMATICS IN LUNAR SAMPLES: MARE BASALT 10017 AND NORITE 78238.** J. Edmunson, A. M. Gaffney, L. E. Borg, Institute of Meteoritics, University of New Mexico (MSC03 2050, 1 University of New Mexico, Albuquerque NM 87131-0001, Edmunson@unm.edu).

**Introduction:** Many lunar samples record some degree of disturbance to their U-Pb isotopic systematics [e.g., 1,2]. This disturbance may be reflected in Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ ,  $^{238}\text{U}$ - $^{206}\text{Pb}$ , or concordia ages that are discordant among the U-Pb systems as well as with more robust Sm-Nd and Rb-Sr ages. Both mare basalt 10017 and norite 78238 fail to yield consistent geochronologic results among their Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ , and  $^{238}\text{U}$ - $^{206}\text{Pb}$  isochrons, and some of these ages have questionable geologic meaning (Fig. 1). These samples are ideal for examination of disturbances to their U-Pb systematics because they potentially encompass the range of disturbances to the U-Pb system in lunar samples. Samples 10017 and 78238 are geochemically distinct, have a 700 Ma difference in age, and were analyzed in the same lab with the same procedures during the same time period. The same mineral fractions analyzed for U and Pb in both samples were also used to define the Sm-Nd and Rb-Sr ages, allowing direct comparison between the Sm-Nd, Rb-Sr, and U-Pb systems. Therefore, any difference in the behavior of the U-Pb isotopic systems, and inconsistencies between the Sm-Nd, Rb-Sr, and U-Pb ages determined for the samples, is likely to be a lunar phenomenon.



**Figure 1:** Different ages obtained using the Sm-Nd, Rb-Sr, and U-Pb isotopic systems for mare basalt 10017 (circles) and Mg-suite norite 78238 (squares). The Sm-Nd ages obtained for both samples are interpreted to represent the crystallization ages. Note the different ages obtained with the Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ , and the  $^{238}\text{U}$ - $^{206}\text{Pb}$  isotopic systems. C = crystallization age, M = metamorphism age.

**Background:** The high K, high Ti mare basalt 10017 is a fine-grained vesicular rock dominated by clinopyroxene and plagioclase, with up to 20% ilmenite and <1% interstitial glass [3]. This sample was dated by Gaffney et al. [4] using the Sm-Nd, Rb-Sr, and U-Pb isotopic systems. The Sm-Nd crystallization age for 10017 is  $3633 \pm 60$  Ma.

Norite 78238 is part of the Mg-suite and contains ~50% plagioclase and ~50% orthopyroxene [5]. This sample was dated with the Sm-Nd, Rb-Sr, and U-Pb isotopic systems as part of a continued study by Edmunson et al. [6]. The Sm-Nd age, interpreted to be the crystallization age of 78238, is  $4334 \pm 37$  Ma. Edmunson et al. [6] concluded that the Rb-Sr isotopic system of 78238 was partially reset during a metamorphic event at  $4003 \pm 95$  Ma.

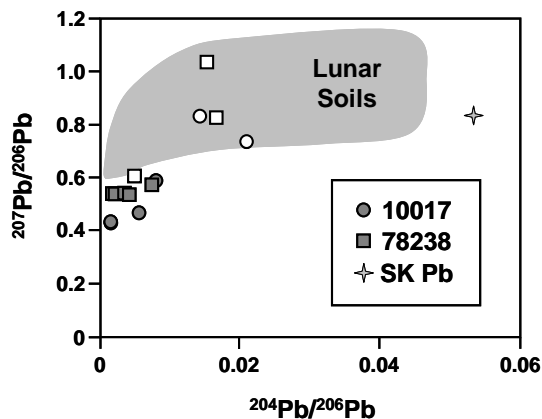
**Observations:** Fig. 1 illustrates the ages obtained for 10017 and 78238. Note that for both samples, the ages decrease in the order: Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ ,  $^{238}\text{U}$ - $^{206}\text{Pb}$ . Also note the overlap in the U-Pb system ages for 10017, and the extreme difference between U-Pb system ages for 78238. Fig. 1 also shows concordant ages obtained for 10017 from the Sm-Nd, Rb-Sr, and  $^{238}\text{U}$ - $^{206}\text{Pb}$  systems, whereas the relatively young age obtained with the  $^{238}\text{U}$ - $^{206}\text{Pb}$  system for 78238 does not appear to have geologic significance.

Initial Pb isotopic compositions and source  $\mu$  ( $^{238}\text{U}/^{204}\text{Pb}$ ) can often be determined from U-Pb system isochrons. For example, the 10017  $^{238}\text{U}$ - $^{206}\text{Pb}$  isochron yields a source  $\mu$  of  $80 \pm 36$  assuming single-stage growth from CDT [7] at 4558 Ma to 3633 Ma. The 10017  $^{235}\text{U}$ - $^{207}\text{Pb}$  isochron yields a source  $\mu$  of  $61 \pm 37$  and is consistent with the  $^{238}\text{U}$ - $^{206}\text{Pb}$  estimate. For 78238, the error of the  $^{238}\text{U}$ - $^{206}\text{Pb}$  isochron does not allow a reasonable source  $\mu$  to be defined ( $\mu = 0$  to 547). However, the  $^{235}\text{U}$ - $^{207}\text{Pb}$  isochron for 78238 yields a calculated source  $\mu$  of  $94 \pm 43$ , consistent with the  $\mu$  calculated from the Pb-Pb isochron of  $72_{-15}^{+25}$ .

Concordia diagrams were employed to further understand the U-Pb systematics of 10017 and 78238. Surprisingly, 10017 did not yield a concordant age due to scatter in the data, proximity of the data to the concordia curve, and the variability in possible Pb initial isotopic compositions. Conversely, a best-fit Tera-Wasserburg concordia for 78238 yielded an age of  $4249 \pm 83$  Ma assuming single-stage growth in a  $\mu = 25$  reservoir between 4558 (CDT) and 4334 Ma. The best-fit  $\mu$  of 25 differs greatly from the previous  $\mu$  calculations.

**Discussion:** For both 10017 and 78238, different ages are obtained with the Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ , and  $^{238}\text{U}$ - $^{206}\text{Pb}$  systems. The disturbance producing the difference in ages must have occurred after isotopic homogenization by melting and crystallization. The Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ , and  $^{238}\text{U}$ - $^{206}\text{Pb}$  ages show similar systematics in both 10017 and 78238 (i.e., Pb-Pb >  $^{235}\text{U}$ - $^{207}\text{Pb}$  >  $^{238}\text{U}$ - $^{206}\text{Pb}$ ). However, the crystallization ages of 10017 and 78238, defined by their Sm-Nd ages, are concordant with different U-Pb systems ( $^{238}\text{U}$ - $^{206}\text{Pb}$  and Pb-Pb, respectively). Therefore, it is necessary to evaluate the role of post-crystallization events for U-Pb systems in the context of Sm-Nd and Rb-Sr ages. Two such post-crystallization events are contamination by lunar or terrestrial Pb and thermal metamorphism.

When represented in a Tera-Wasserburg Pb-Pb diagram [8], mineral fractions from both 10017 and 78238 show evidence for incorporation of lunar surface Pb (Fig. 2). The fractions of 10017 that lie closest to the  $^{207}\text{Pb}/^{206}\text{Pb}$  axis (whole rock and ilmenite) have  $^{207}\text{Pb}/^{206}\text{Pb}$  ratios that are higher than expected for the corresponding Sm-Nd age of the sample (i.e., an isochron in Fig. 2 through the 10017 points should intersect the  $^{207}\text{Pb}/^{206}\text{Pb}$  axis at 0.33). Therefore, these fractions may have incorporated lunar surface Pb into trace phases such as sulfides and mesostasis. In contrast, the deviation of the plagioclase mineral fractions in 78238 towards high  $^{207}\text{Pb}/^{206}\text{Pb}$  ratios and away from whole rock and terrestrial Pb compositions is a strong indicator that plagioclase in 78238 incorporated lunar soil. Unlike 10017, the plagioclase fractions of 78238 do not lie along a linear array with the remaining 78238 mineral fractions.



**Figure 2:** Tera-Wasserburg Pb-Pb plot showing the relationship between 10017 (circles), 78238 (squares), soils characterizing lunar surface Pb [8], and the Stacey and Kramers estimate of terrestrial Pb [9]. Data points with white interiors represent plagioclase-dominated fractions.

The large spread in the measured  $^{238}\text{U}/^{204}\text{Pb}$ ,  $^{206}\text{Pb}/^{204}\text{Pb}$  and  $^{207}\text{Pb}/^{204}\text{Pb}$  ratios of the individual mineral fractions from both 10017 and 78238 (not shown) indicates that terrestrial Pb, if present after blank corrections, is not a significant contributor to the isotopic composition of the mineral fractions.

Models for post-crystallization disturbances to the U-Pb isotopic systematics of lunar materials must explain the spread in Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ , and  $^{238}\text{U}$ - $^{206}\text{Pb}$  ages as well as the relationship between U-Pb systems and their Sm-Nd and Rb-Sr counterparts. One can assume the natural present-day  $^{238}\text{U}/^{235}\text{U}$  ratio of 137.88, measured in lunar samples by Chen and Wasserburg [10]. It is possible to modify the Pb isotopic composition after crystallization by loss of Pb at some time in the past. Elemental U and Pb can be fractionated in a crystalline rock by volatilization or diffusional loss of Pb. Preliminary results from theoretical models indicate that episodic loss of Pb during an impact or thermal metamorphism event some time after crystallization creates the spread in U-Pb and Pb-Pb ages in the order Pb-Pb >  $^{235}\text{U}$ - $^{207}\text{Pb}$  >  $^{238}\text{U}$ - $^{206}\text{Pb}$ . This order is observed in both 10017 and 78238. Unfortunately, the relationship between the U-Pb systems and the Sm-Nd and Rb-Sr systems for 10017 and 78238 has not been clarified.

Reproducing the time-dependent, complex U-Pb systematics of 10017 and 78238 requires a model that combines post-crystallization loss of Pb with contamination by lunar and terrestrial Pb. As the comparison of 78238 and 10017 demonstrates, there is no single U-Pb system isochron that reliably provides the crystallization age for all samples. Rather, the U-Pb systematics for any given lunar sample must be evaluated in the context of a more robust geochronologic system, such as Sm-Nd or Rb-Sr, in order to assign geochronologic significance to the various Pb-Pb,  $^{235}\text{U}$ - $^{207}\text{Pb}$ , and  $^{238}\text{U}$ - $^{206}\text{Pb}$  ages. When Sm-Nd and Rb-Sr systematics are applied to the U-Pb systems, it is then possible to extract useful petrogenetic information, such as source  $\mu$ , from some lunar samples.

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