DATING MELT ROCK 63545 BY Rb-Sr AND Sm-Nd: AGE OF IMBRIUM; SPA DRESS REHEARSAL. L. E. Nyquist [1,4], C.-Y. Shih[2], Y. D. Reese[3]. [1]KR/NASA Johnson Space Center, Houston, TX 77058. E-mail: laurence.e.nyquist @nasa.gov. [2]ESCG Jacobs-Sverdrup, Houston, TX 77058. [3]Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058. [4]Center for Lunar Science and Exploration, NASA Lunar Science Institute.

Introduction: Apollo 16 sample 63545 was initially described as one of a group of 19 generally rounded, fine-grained, crystalline rocks that were collected as rake samples [1]. This 16 g "rocklet" was collected at Station 13 on the ejecta blanket of North Ray Crater at the foot of Smoky Mountain [2]. Originally classified as a Very High Alumina (VHA) basalt on geochemical grounds [3], it was later argued to be an impact melt rock [4]. Here we report a Rb-Sr and Sm-Nd isotopic study that shows that some portions of the rock failed to reach isotopic equilibrium on last melting in agreement with the impact melt rock interpretation. Nevertheless, by omitting mineral fractions that are discordant with the majority of the data, we arrive at the time of last melting as 3.88±0.05 Ga ago. This age is in agreement with the $^{39}Ar/^{40}Ar$ plateau age of 3839±23 Ma [5], if the latter is adjusted for the ~1.4-1.8% revision in the age of the hornblende monitor [6]. This investigation was undertaken in part as proof-of-concept for SPA-basin sample return.

Petrology, Sampling, Sm and Nd Abundances : Rock 63545 was one of the rocks originally considered by Hubbard et al. [3] to constitute a group of Very High Al_2O_3 (VHA) "basalts". The major element composition of VHA rocks is characterized by Al_2O_3 in the range ~20-24% and FeO in the range ~5-8% [3]. REE abundances are characterized by La in the range ~50-70 X chondritic. A more comphensive compositional study [7] placed 63545 into sub-group 2M, "low-Sc VHA", or as an aluminous variant of 2NR. Texturally, it was classified as a "subophitic-ophitic-intersertal (clast-free) impact melt rock" [8] and placed into the "aluminous subophitic group by [5]. Photomicrographs of 63545 [4] show a subophitic texture like 63549 [5], but also a fine-grained, recrystallized anorthositic clast.

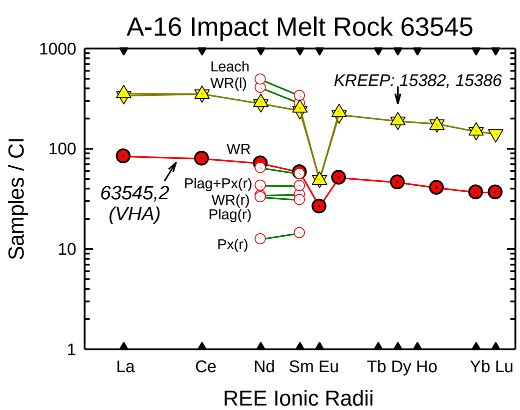

Fig. 1. REE abundances in 63545,2 [3] and mineral separates compared to KREEP basalts 15382 and 15386.

Compositionally "VHA basalts" are grossly similar to KREEP basalts like15382 and 15386, but characterized by higher Al_2O_3 and lower REE abundances. (*cf.* Fig. 1). Because in a melting experiment Delano [5] found plagioclase to be absent from the liquidus of a 63545 composition he concluded that its negative Eu anomaly could not be a result of petrogenesis via partial melting. Delano [4] thus favored an origin via impact-fusion of highlands components, in agreement with modern consensus on the origin of VHA basalts.

Although 63545 is not endogenously igneous in origin, its subophitic texture makes it amenable to mineral separation procedures routinely used to study basalts. A finely powdered sample (258 mg) retained from previous studies was sieved into 200-325 (115 mg) and <325 mesh size fractions. Each size fraction was "washed" in 2N HCl and the wash retained as "Leachates". As for basalts, the leachates were greatly enriched in both Sm and Nd compared to the whole rock, showing LREE-enrichment (Fig. 1). A plagioclase-enriched fraction (Plag(r)) was floated from the 200-325 mesh fraction in heavy liquid of density ρ = 2.85 g/cm^3. A pyroxene-enriched fraction (Px(r)) sank at ρ = 3.32 g/cm^3. An intermediate density fraction with $2.85<\rho<3.32$ g/cm^3 is designated Plag+Px(r). REE abundances of Px(r) were lowest among the fractions and LREE-depleted as expected for pyroxene. Unexpectedly, REE in Plag(r) were greater than in Px(r), and also LREE-depleted compared to the whole rock (WR), suggesting incomplete removal of pyroxene.

Delano [4] described pink spinel, plagioclase, olivine, pyroxene, interstitial glass, minor oxides, and metal in 63545. No electron probe studies were available to him, and we know of none. Phosphates were not described, but are likely contributors to the leachates and should be sought in this rock and in others like it.

Sm-Nd Data: Sm and Nd isotopic data of several fractions do not satisfy an isochron relationship (Fig. 2), implying the mineral grains in them did not come to complete isotopic equilibration. However, WR (unleached, <325 mesh), the two leachates, and Px(r) are collinear within 1 ε-unit and define an age of 3.91±0.10 Ga, and ε_{Nd} = -0.4±0.4 consistent with derivation from LREE-enriched parental materials.

Rb-Sr Data: Whole rock $^{87}Rb/^{86}Sr$ ~ 0.06 is high compared to lunar mare basalts. In contrast to lunar

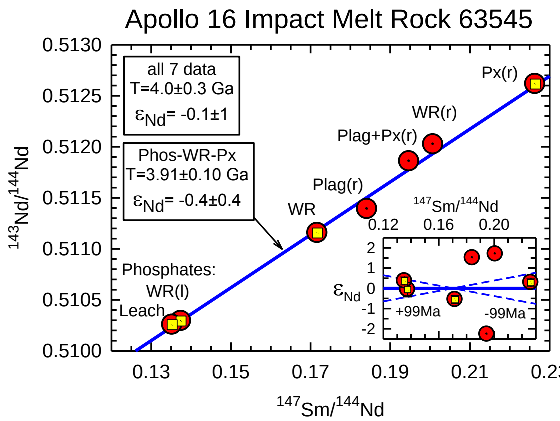

Fig. 2 Sm-Nd isochron diagram for 63545.

basalts, $^{87}Rb/^{86}Sr$ of the plagioclase separate (Plag(r)) was nearly equal to that of the whole rock. The Sr concentration in the Plag(r) separate exceeded that in the whole rock by ~40%, but the Rb concentration was increased proportionally, possibly due to an unseparated late-crystallizing phase (interstitial glass?). The leachates had the lowest $^{87}Rb/^{86}Sr$ ratios. Compared to the whole rock, Rb was depleted by ~65%, whereas Sr was depleted by only ~9%. Sr-isotopic equlibration appears to have been incomplete because the Plag(r) and WR(r) data are displaced from an isochron through the remaining data. The isochron age is 3.84±0.10 Ga ($\lambda(^{87}Rb) = 1.402\ Ga^{-1}$ [9]).

Discussion: Several Apollo 16 impact melt rocks have been dated by the Rb-Sr method ([10,11,12,13], but this investigation reports the first determination of a Sm-Nd isochron for this rock type. Such rocks are composed of mixtures of two or more lithic components, and isochron methods are subject to ambiguity because of possibly incomplete isotopic equilibration among components during a brief melting episode. This uncertainty is circumvented if two isochron methods are applied and age concordancy achieved.

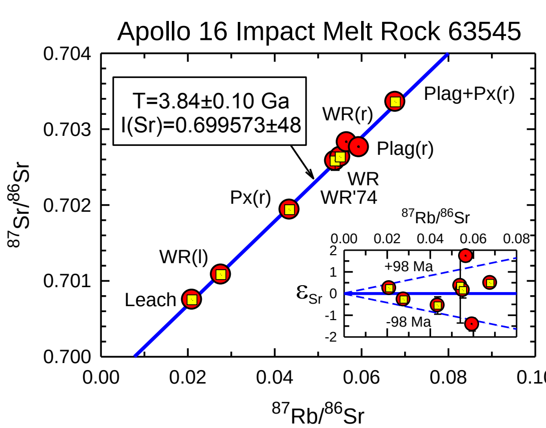

Fig. 3. Rb-Sr isochron for 63545. An age of 3.84±0.10 Ga is defined by data highlighted by internal yellow squares. ($\lambda(^{87}Rb) = 1.402\ Ga^{-1}$ [9]).

Reimold et al. [10] analysed the more coarsely-crystalline 67747 obtaining an age of 3.91±0.04 Ga adjusted to $\lambda(^{87}Rb) = 1.402\ Ga^{-1}$, and initial $^{87}Sr/^{86}Sr$ I_{Sr} = 0.69952±0.00010 in agreement with the present results for 63545. Fig. 4 shows Rb-Sr data for VHA rock 60335 (also group 2M [7]) combined with those for 63545. The combined data yield an isochron age of 3.90±0.07 Ga and I_{Sr} = 0.699547±0.000052 refining the (T, I_{Sr}) parameters for VHA melt rocks first reported by [14] from a whole rock isochron.

Conclusions: The weighted average Rb-Sr ages of of VHA melt rocks 67747 and 63543 of 3.90±0.04 Ga agrees with the Rb-Sr ages of Apollo 15 KREEP basalts (*e.g.*, 3.88±0.04 for 15434,73 [15]) as well as that of Apollo 16 KREEP-rich impact melt rock 65015 (3.89±0.01, adjusted, [12]) and also the Sm-Nd age of 63545. Furthermore, VHA rocks bear the characteristic REE pattern of KREEP (Fig. 1). Thus, we tentatively identify the age of this sample group with the *Imbrium* basin. That this ~3.90 Ga exceeds the widely accepted age of 3.85±0.02 Ga [16] by ~1.3% may be explainable by a necessary revision of the age of the Mmhb-1 monitor by 1.4-1.8% [6].

References: [1] Lofgren G. (1972) in *Lunar Sample Inf. Cat..- Apollo 16*, p. 197. [2] *Apollo 16 Prelim. Sci. Reprt.* [3] Hubbard N. J. et al. (1973) *PLSC 4th*, 1297-1312. [4] Delano J. W. (1977) *PLSC 8th*, 2097-2123. [5] Norman M. D. et al. (2006) *GCA 70*, 6032-6049. [6] Norman M. D. et al. (2010) *GCA 74*, 763-783. [7] Korotev R. L. (1994) *GCA 58*, 3931-3969. [8] Stöffler D. et al. (1985) *PLPSC 15th*, 90, C449-C506. [9] Begemann F. et al. (2001) (2010) *GCA 65*, 111-121. [10] Reimold W. U. et al. (1985) *PLPSC 15th*, 90, C431-C448. [11] Deutsch A. and Stöffler D. (1987) *GCA 51*, 1951-1964. [12] Papanastassiou D. A. and Wasserburg G. J. (1972a) *EPSL* 16, 289-298. [13] Papanastassiou D. A. and Wasserburg G. J. (1972b) *EPSL* 17, 52-63. [14] Nyquist L. E. et al. *PLSC 4th*, 1823-1846. [15] Nyquist L. E. et al. (1974) *PLSC 5th*, 1515-1539. [16] Stöffler D. and Ryder G. (2001) *Space Sci. Rev.* 96, 9-54.

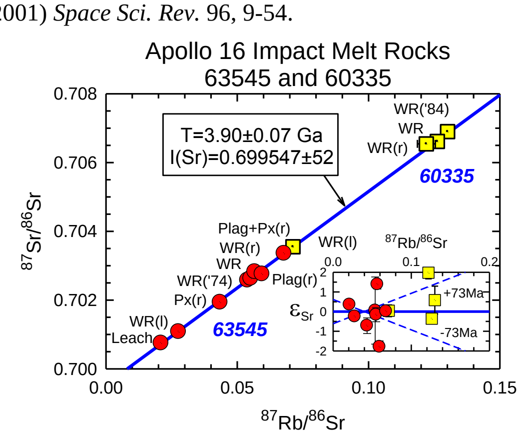

Fig. 4. Combined Rb-Sr data for 63545 and 60335.