ON THE ORIGIN OF THE APOLLO-16 DIMICT BRECCIAS. O. Eugster[1], O.B. James[2], and Ch. Thalmann[1], [1] Physikalisches Institut, University of Bern, 3012 Bern, Switzerland; [2] 959 National Center, US Geological Survey, Reston, VA 22092.

Introduction: We are currently participating in a consortium study of Apollo 16 dimict breccias. Dimict breccias are a unique type of lunar breccia virtually restricted to the Apollo 16 site. These rocks consist dominantly of granulated ferroan anorthosite and impact-melt rock of a distinctive, very-high-alumina bulk composition; they are commonly coated by impact-generated glass. The Apollo 16 dimict breccias are thought to have formed by injection of impact melt into anorthosite in the walls and floor of a growing impact-crater cavity [1, 2]; this impact took place between 3.78 and 3.92 Ga and was probably closer to 3.92 Ga [2-4]. The glass coatings formed in the later, smaller impact(s) that emplaced the breccias onto the lunar surface.

One of our consortium goals is to determine the crater in which the dimict breccias formed. Therefore, we must understand the geologic occurrence of these rocks. Previous studies showed that many of the large dimict breccia samples were ejected from South Ray Crater [2, 5], a crater that was formed 2.0±0.1 Ma ago [6] on the plains of the Cayley formation southwest of the site. In this and a previous preliminary study [7], we have determined cosmic-ray exposure ages of five dimict breccias (60215, 61015, 65035, 64425, 61016), to evaluate whether or not these rocks also are South Ray ejecta. The exposure ages represent the time when the rocks were excavated by an impact from a depth below the lunar surface of more than about 3 m; thus they are surface residence times.

Sample occurrence: The surface characteristics and distribution of most Apollo 16 dimict breccias are consistent with ejection from South Ray Crater. The stations from which these rocks were collected lie within the South Ray ejecta blanket, and most of the samples were found perched atop the regolith, suggesting recent emplacement on the lunar surface.

Samples 61015, 61016 and 65035, all found atop the regolith, have sample surface characteristics suggesting that virtually all of their exposure took place in a single orientation and the duration of this exposure was only a few million years [8-11]; these characteristics are consistent with ejection from South Ray Crater. When collected, sample 61015 was still in the position in which the exposure took place, but samples 65035 and 61016 appear to have been flipped over very recently [10-12]. Sample 60215, also found atop the regolith, has surface characteristics suggesting exposure in only a single orientation, but the duration of the exposure is indeterminate.

The occurrence of 64425 suggests it was not South Ray ejecta. This small sample (14.6 g) was found at the bottom of a trench dug by the astronauts in the floor of a crater at Station 4; other studies have shown that the soil in that area does not contain any significant South Ray ejecta [13], so the soil that was lying over the rock cannot be part of a debris blanket ejected from South Ray.

Previous work, rationale for this study: For two of the samples, previous exposure age studies yielded inconsistent results. For 61015, ages of 5.4 and 34 Ma were reported for two different splits [4], and the higher age was attributed to the presence of inherited spallogenic ^{38}Ar in the glass coat; our ^{38}Ar exposure age for this rock is 2.65 Ma [7]. Breccia 61016 was studied by several authors and ages of 1.2 Ma (from surface microcraters [14]), 1.5 Ma (charged particle track data [15]), and 1.7 and 3.7 Ma (solar cosmic-ray ^{38}Ar and galactic cosmic-ray ^{38}Ar data, respectively [16]) were reported.

In our preliminary study [7], we obtained ^{38}Ar exposure ages ranging from 2.26 to 2.65 Ma for dimict breccias 60215, 61015, 64425, and 65035. In this study, we have applied the ^{81}Kr-Kr method, which yields the most reliable exposure ages (insensitive to production rate determinations), to two samples, 61016 and 64425. We analyzed 61016 because of the inconsistency of the earlier results and 64425 because its occurrence suggests that it might not be South Ray ejecta.

Results: The results of our work are summarized in Table 1. Cosmic-ray exposure ages were derived based on the concentrations of stable ^{38}Ar and cosmogenic ^{126}Xe, using appropriate production rates, and on ^{81}Kr-Kr dating. Within experimental errors the different methods yield consistent results. Our data suggest that all five breccias studied were ejected from South Ray Crater.

Geologic implications: Our results indicate that 64425 is indeed South Ray ejecta, despite the fact it was collected from the bottom of a trench. Perhaps this small rock was buried by relatively

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System

recent local slumping of soil from the wall of the crater in which the trench was dug, or perhaps it fell into the trench during excavation. Our data support the interpretation that all samples ≥10 g of Apollo 16 dimict breccias are South Ray ejecta. South Ray Crater was excavated in Cayley formation, which is thought to consist of secondary ejecta from the Imbrium basin-forming impact [2]; the dimict breccias probably form a large block or mass within this formation in the South Ray area.

Current understanding of the nature of ejecta deposits serves to limit the possible sources of the dimict breccias. At the distance of the Apollo 16 site from Imbrium, very little of the Cayley deposit should be primary Imbrium ejecta; most should consist of locally derived material that was transported by Imbrium-related secondary impacts [17]. This material should mostly be Nectarian and pre-Nectarian in age and derived from deposits of Nectaris primary and secondary ejecta.

The compositions of the lithologies in the dimict breccias also suggest a local origin. The unusually aluminous composition of the melt rock, as well as the presence of anorthosite as a dominant lithology, suggest a source area that was unusually aluminous. These characteristics point to a source in the Apollo 16 region, which is relatively aluminous overall [18].

There are several possibilities for the crater in which the dimict breccias formed. Perhaps the most likely is that they formed in a pre-Nectarian intermediate-sized crater (50-150 m) located within a few hundred km of the Apollo 16 site. Masses of breccia formed in such a crater could have been laterally transported by secondary cratering related to the Nectaris and Imbrium impacts.

The restricted distribution of dimict breccia at the site raises the possibility that this breccia formed in one of the two large pre-Nectarian craters that underlie the site, unnamed A and B [19]. South Ray is near the central peak of unnamed A and near the rim of the later, smaller unnamed B. Because both A and B underlie the Nectaris debris deposit, no large amount of material from either crater should be near the surface at the site. However, a small mass of material from one or both of these craters could have been incorporated in the Nectaris deposit by secondary cratering.

The 3.92-Ga age of dimict-breccia formation, roughly contemporaneous with the time of the Nectaris impact [2], raises the possibility that the source crater is the Nectaris basin. Although analogies with terrestrial impact craters suggest that a Nectaris source is unlikely, this source cannot be ruled out. Dimict breccias are analogous to terrestrial dike breccias, which are rarely ejected from the craters in which they form; the Apollo 16 site is well outside the rim of the Nectaris basin, about four-tenths the crater radius [20]. It is possible, however, that in lunar basin-forming impacts more melt was produced and this melt was ejected to greater distances than would be predicted by extrapolation of the data for terrestrial craters. Thus, a Nectaris source remains possible.

Determination of which of these sources is most likely will depend upon further study of the entire suite of Apollo 16 rocks. Consortium studies now in progress of the siderophile elements in Apollo 16 melt rocks will, hopefully, help identify the dimict-breccia source crater.

Acknowledgements: Work supported by the Swiss NSF.

References: [1] Stöffler et al., 1979, PLPSC10, 639; [2] James, 1981, PLPSC12, 209; [3] Jessberger et al., 1977, LSC VIII, 511; [4] Marvin et al., 1987, PLPSC17, E471; [5] Norman and Nagle, 1981, LPI Tech. Rep. 81-01, 98; [6] Drozd et al., 1974, GCA38, 1625; [7] Eugster, 1992, LPSC XXIII, 341; [8] James et al., 1984, PLPSC15, C63; [9] James and Lindstrom, 1991a, LPSC XXII, 635; [10] Ryder and Norman, 1980, Catalog of Apollo 16 Rocks, JSC 16904; [11] Prelim. Exam. Team, 1972, Lunar Sample Information Catalog, Apollo 16, MSC 03210; [12] Sutton, 1981, in USGS Prof. Paper 1048, 231; [13] McKay and Heiken, 1974, PLSC4, 41; [14] Bhandari et al., 1975, PLSC6, 1913; [15] Battacharya and Bhandari, 1975, PLSC6, 1901; [16] Rao et al., 1979, PLPSC10, 1547; [17] Morrison and Oberbeck, 1975, PLSC6, 2503; [18] Andre and El-Baz, 1981, LPI Tech. Rep. 81-01, 33; [19] Head, 1974, Moon 11, 77; [20] Wilhelms, 1987, USGS Prof. Paper 1348.

Table 1. Cosmic-ray exposure ages (Ma)

	T_{38}	T_{81}	T_{126}	$T_{adopted}$
60215,2	2.26 ± 0.50	--	--	2.26 ±0.50
61015,178	2.65 ± 0.90	--	--	2.65 ± 0.90
61016,4	--	1.4 ± 0.4	0.9 ± 0.2	1.4 ± 0.4
64425,17	2.36 ± 0.70	1.9 ± 0.9	1.2 ± 0.7	1.9 ± 0.7
64425,22	2.59 ± 0.60	--	--	
65035,94	2.30 ± 0.50	--	--	2.30 ± 0.50

© Lunar and Planetary Institute • Provided by the NASA Astrophysics Data System