

CHRONOLOGY OF LUNAR BASIN FORMATION AND AGES OF LUNAR ANORTHOSITIC ROCKS. O.A. Schaeffer and Liaquat Husain, Dept. of Earth and Space Sciences, State University of New York, Stony Brook, N.Y. 11790.

We report on the  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages for lunar anorthosites 60015 and 60025 as well as two anorthositic coarse fine fragments 72503,8,12 and 78503,7,1. Argon release patterns are shown in Fig.1.

Rock 60015 weighs 5.57kg. According to Sclar et al.(1) it is a coarsely crystalline cataclastic anorthosite consisting of highly strained plagioclase. The plagioclase contains myriads of bubble-like inclusions which appear to be glass. The rock was apparently severely shocked, raised almost to the melting point and is coated with a dark gray vesicular glass. This rock gives a well defined  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  plateau age of  $3.55 \pm .05$  Gy and is the youngest anorthosite to be found on the moon so far.

Rock 60025, 1.8 kg is a cataclastic anorthosite. It shows well developed shock lamellae and linear chains of low-relief isotropic inclusions (along the shock lamellae) that may represent incipient melting (2). This rock is similar to the coarse fine anorthositic fragments which give ages in excess of 4.2Gy (3). Rock 60025 gives a plateau at high temperatures with an age of  $4.18 \pm .06$  Gy. This is the first instance of a large rock giving an age distinctly in excess of 4.0 Gy.

Rock 72503,8,12 is a gray green recrystallized breccia with poikiloblastic texture (4). This rock shows a well defined plateau age of  $3.96 \pm .02$  Gy with some drop off at the highest temperatures.

Rock 78503,7,1 is a gabbroic anorthosite which shows shock features (4). This rock gives a well defined high temperature plateau age of  $4.13 \pm .03$  Gy and is one of the first old rocks to be reported for the Apollo 17 site.

Impact generated breccia and cataclastic rocks such as those dated here were returned by each of the Apollo-missions. In fact, the Apollo 14 and 16 samples are predominantly this rock type. As these materials form a morphological unit which appears to be widespread and contemporaneous, it appears that except for the very friable soil breccias, the impact generated rocks are for the most part related to the major multi-ring impact basins (5). On the near side of the moon there are ten such structures clearly visible. Starting with the youngest, these are Orientale, Imbrium, Crisium, Humorum, Nectaris, Serenitatis, Fecunditatis, Tranquillitatis E, Tranquillitatis W and Nubium. Each of the basins has an extensive ejecta blanket. The moon thus should be covered by a series of layers of ejecta. By observations from terrestrial cratering and lunar ejecta it was possible to estimate the thickness of the ejecta layers at any particular site (6). The striking result is that all the Apollo landing sites Imbrium ejecta predominates in the upper 100 meters. On the other hand, if one considers the radiometric ages for the impact generated breccias at all the Apollo sites, the age  $4.00 \pm .05$  Gy predominates. It appears then reasonable to assign this age to the Imbrium event which means in addition that the rocks in the Imbrium ejecta blanket were reset either by the impact or in the ejecta blanket itself. The ejecta may have been hot enough to reset the radiometric clocks. In fact, Strangway et al.(7) explain the magnetic anomalies at Apollo 16 by breccia flows which cooled in place from above  $770^\circ\text{C}$ , a temperature adequate to reset the radiometric clocks.

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The K-Ar clock is reset by the diffusion of argon. It has been estimated that a temperature of 4000-700°C may be adequate to degas a rock of argon in a geologically short time. Approximately one year at 700°C and  $10^4$  years at 400°C (8). The Rb-Sr ages for the highland rocks is defined by the analysis of a rubidium rich finely crystalline mesostasis often called quintessence. The resetting of the Rb-Sr clock by the homogenization of such a mineral assemblage is quite likely for the pressures and temperatures accompanying the formation of an ejecta layer.

The morphology of the large ring basins indicates a temporal sequence of some extent. Among other observations the rings of the older basins are considerably more eroded than the rings of the younger basins (9). The ejecta from older basins are most likely found at the landing sites where the Imbrium ejecta is expected to be the thinnest, that is the sites farthest removed from Imbrium. These are the Apollo 11, 16 and 17 landing sites. The Apollo 11 site is flooded with Mare basalt which covers all the basin ejecta. At the Apollo 16 site the upper 200 meters of the surface is expected to contain a substantial contribution of Nectaris ejecta with smaller amounts of Crisium and Humorum ejecta. Rock 60025 reported here as well as four rocks reported earlier have ages distinctly older than 4.0 Gy. The oldest of these have radiometric ages near  $4.20 \pm .05$  Gy which may be the time of the Nectaris event. The time of the Crisium and Humorum events should then lie between 4.0 and 4.2 Gy ago. As the Apollo 17 landing site is closer to the Crisium basin than either the Nectaris or Humorum it is possible that 78503,7,1 is a sample of Crisium ejecta. The Crisium event would then be  $4.13 \pm .03$  Gy ago. Rock 66043,2,4, a feldspathic interstitial igneous rock, with an age of  $4.13 \pm .0569$  (3) may also be a sample of Crisium ejecta.

From crater counts and from the observation that Orientale ejecta does not appear on the surface of the Mare basalts, the Orientale event should be older than the surface mare flows. The oldest mare basalts dated radiometrically lie between 3.7 and 3.8 Gy (basalts at Apollo 11 and 17 sites). On the other hand, Orientale is younger than Imbrium. The Orientale event should thus lie between 3.8 and 4.0 Gy ago. There are several samples from Apollo 14 and 16 sites which have radiometric ages of  $3.85 \pm .05$  Gy (3)(10). These rocks may represent Orientale ejecta. These considerations lead to the following ages for the multi-ring basin events:

Orientale	$3.85 \pm .05$
Imbrium	$4.00 \pm .05$
Crisium	$4.13 \pm .05$
Humorum	between 4.13 and 4.20
Nectaris	$4.20 \pm .05$

A given rock is not necessarily a sample from the ejecta of a multi-ring crater event. There are numerous intermediate size craters which contribute a small but not necessarily negligible amount of material to the lunar surface. The rock 60015 reported here with an age of  $3.55 \pm .05$  Gy is probably ejecta from an intermediate size crater. It is interesting to note that this rock releases more than half its argon above 1600°C. It would appear that this rock was severely heated so that it lost not only all its argon but also most of the potassium from the least retentive mineral sites.

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It is concluded that the multi-ring lunar basins were spread over hundreds of millions of years and not a group in a relatively short time near 4.0 Gy ago. The widespread occurrence of the 4.0 Gy age in lunar rocks from the different Apollo sites is thus due to the widespread occurrence of substantial Imbrium ejecta which lies on top and is the most likely to be sampled. It would appear then that after the lunar crust formed there was an era of multi-ring basin formation lasting until about 3.9 Gy ago. This era was followed by an era of basalt flooding of the basins and low lying areas on the lunar surface which lasted until about 3.1 Gy ago. At this time all major activity ceased.

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