Absolute Zircon Ages for Pre-Nectarian Events and a Proposed Age for the Near Side Megabasin

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Introduction: Events in the lunar pre-Nectarian period are of recent interest to several investigators [1, 2]. In this early period the solar system was settling down to its present state and life was starting on Earth [2].

Since the comprehensive presentation on the history of this period was presented by Don Wilhelms [3], several lunar probes have produced new data on topography, gravity, and the distribution of anomalous elements such as thorium. Combining the new data with earlier evidence has led to the proposal of additional early impact features, such as the Near Side Megabasin (NSM) [4, 5, 2], the St. John-Tselius Basin [6] and several other basins [7].

Our best guide to absolute ages for these events is the study of lunar rock samples, based on concentration of nuclei produced by radioactive decay. However, the strength of the early bombardment has been such that most rocks near the surface have been through either a melt phase or impact shock, resetting their clocks.

Several investigators have concentrated on zircon crystals included in thin sections of breccia rock samples returned from the Moon by Apollo missions. These crystals are relatively refractory: they retain their clock settings at relatively high temperatures that melt other components of rock and are also relatively resistant to shock. These crystals form from melts containing elevated amounts of incompatible elements (such minerals that reach the lunar surface were known as KREEP from early multi-spectral observations). Although the principle compound that forms zircon crystals is $ZrSiO_4$, there is a significant component of uranium, which decays to lead.

A method of measurement of the age of zircon crystals was suggested by Compston in 1977 and an age for an Apollo 17 sample (73217) was first reported in detail in 1984 [8, 9]. The measurement is difficult because of the small size of the crystals (typically 10 to 30 microns) and the need to take measurements in even smaller spots in order to avoid the peripheral areas where some of the lead may have escaped. Consequently, it was difficult, in the early measurements, to obtain sufficient statistical evidence for precise aging.

A second-generation measuring instrument [10] and analsysis of zircons from several Apollo samples have provided precise ages for several events that have been strong enough to reset the zircon clocks [11, 12]. This leads to an interesting question: which events have been associated with which ages? This abstract discusses clues associating possible events with specific age measurements.

Samples: The rock samples analyzed in [11, 12] were obtained from Apollo 14, in the ejecta blanket of the Imbrium Basin (Fra Mauro Formation) and from Apollo 17, just inside of the southeast rim of the Serenitatis Basin. In both cases, the samples were thin sections of breccias, rocks that had been formed by impact shock applied to mixtures of smaller rocks from other sources.

Zircon Ages: Measurements of the samples of both Apollo 14 and Apollo 17 showed discrete ages, with the ages of many individual zircon crystals correlated (Fig. 1).

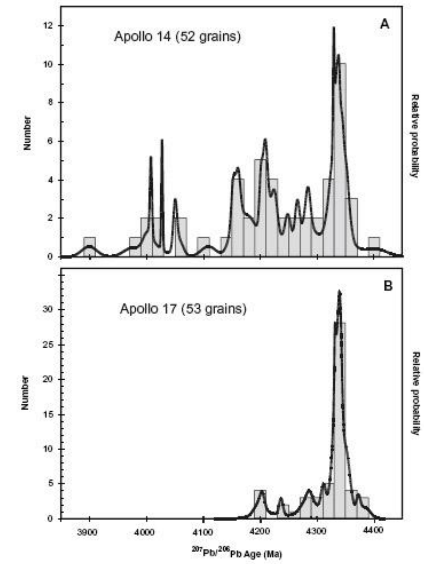

Fig. 1: Ages of individual measurements of zircons from samples taken at three Apollo 14 stations and two Apollo 17 stations (Fig. 10 of [11]). Note that an age of 4.34 Ga was most frequent for each site, but there were several younger ages strongly represented at the Apollo 14 site. Yet all zircon ages except one were older than the 3.9 Ga age of the Imbrium impact as determined from the ages of the other minerals in the sample.

Where did the sampled rocks come from? These rocks were taken from the surface of very different geologic contexts. The material at the surface of the Apollo 17 site would have been brought up by the Serenitatis impact from a great depth. Impacts produce "overturn" whereby the surface of the rim is coated with materials that come from greater depths than the material below the surface or from further out in the ejecta blanket. Surface samples could have come from the younger Imbrium Basin as well but they would not be as common as those from the depths below Serenitatis. If the material at depth was relatively homogeneous, that would explain the relative uniformity of the ages at the Apollo 17 site (Fig. 1).

On the other hand, the rocks taken from Fra Mauro ejecta had been launched from well within the area that became the Imbrium Basin cavity. The Apollo 14 site (3.7 º S, 17.5 º W) is about 38 º (great circle arc) from the center of the Imbrium Basin (34.0 º N, 15.4 º W). The radius of the Imbrium Basin is 17.6 º, so the ejecta fell at about 2.16 radii from the center of Imbrium.

By reference to Fig. 2, the ejecta that was deposited at the Apollo 14 site must have been launched from within Imbrium, at 0.65 of the Imbrium radius from its center. Mare Imbrium now covers this position (about 22 º N, 16 º W) but of course was not there when the Fra Mauro material was ejected. Impact dynamics would have collected the ejecta from a much shallower depth than was the case with the Apollo 17 site. It would have included material from the surface itself, and such material might not have been deeply buried in the chaotic Fra Mauro deposit event.

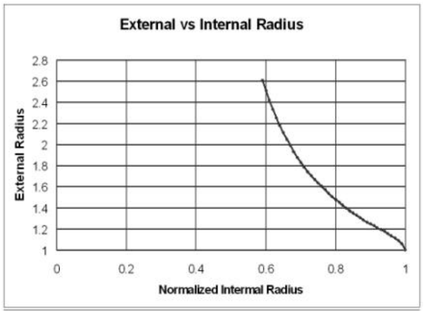

Fig. 2: The radius of a deposit of ejecta is a function of the radius of its launch. The radius of deposit is the sum of the radius of launch plus the ballistic range implied by its velocity, at a typical launch angle of 45 º. The launch velocity as a function of launch radius is derived in [4].

A possible impact event for oldest zircons: The zircons, at age 4.34 Ga are too young to have retained the age of the primitive crust that solidified from the lunar magma ocean [12]. It has been suggested [13] that a subsequent cataclysmic impact or impacts have reset these zircons.

The Near Side Megabasin: It has been previously proposed that there was an early giant impact producing the NSM [4]. This basin, centered at 8.5 º N, 22.5 º E, has a diameter of 6850 km (parameters derived from the Kaguya 1 º Digital Elevation Map), Its cavity covers more than half of the Moon (including nearly all of the near side) and its ejecta covers the far side. Because of the limited area for the ejecta to land, it forms a giant bulge centered at the basin's antipode, 8.5 North and 157 West (within the Korolev Basin).

The NSM accounts for the extraordinary shape of the Moon, both its topography and its estimated crustal thickness. Its shape is quantitatively similar to all the lunar basins and large craters, scaled by the principles of dimensional analysis [14].

Simulations show that an impact this large would create a melt column that would reach far below its cavity. The same can be said of the South Pole-Aitken Basin (SPA). These two giant basins would have undergone nearly complete isostatic compensation, as the re-melted crust beneath them rose to form a level floor, allowing the mantle to rise.

The sites of Apollo 14 and Apollo`17 are each within the area of the level floor of the NSM. The deep source of the Serenitatis ejecta at Apollo 17 would have been from this re-melted crust. The shallow source of the Imbrium ejecta at Apollo 14 must have brought up some of this re-melted crust, mixed with material that had been re-melted (or very strongly shocked) by other, later impacts.

Possible impact sources for younger zircons: The South Pole-Aitken Basin (SPA) was probably as effective as the NSM in bringing up zircons from the incompatible layer and resetting their clocks, but such zircons would have initially stayed within its cavity.Later impacts such as the Apollo Basin would have spread such zircons, but not too far from the SPA. Since the SPA ejecta would be from primative crust, it would not have been rich in zircons. Further, just as Imbrium did not reset the clocks of the great majority of its zircons, one would expect that the same would be true of any zircons ejected from the SPA.

Zircons from the SPA floor, collected near the rims of basins within it, would reveal its age.A smallt gravity anomaly revealed by Kagurya data ssuggests that the that the SPA is younger than the NSM.

To explain the younger peaks of the Apollo 14 graph in Fig. 1, we should look closer to the launch area within Imbrium of the Apollo 14 Fra Mauro deposit. For example, the Insularum Basin, revealed only by peaks of its rim rising above mare, has its northern half actually buried by the rim and cavity of the Imbrium Basin. Zircons within the Insularum melt sheet may well have had their clocks reset. The northern edge of that melt sheet is very close to the launch point for the ejecta deposited at the Apollo 14 site; rocks from the northern edge of Insularum could easily have been thrown onto the Fra Mauro launch site. The Apollo 14 peak at 4.16 Ga might be the age of the Insularum Basin. The 4.2 Ga age also appears at the Apollo 17 site and could be the age of a larger event than Insularum.

Several of such sequences, starting with other basins, could have been the sources of zircon crystals with diverse ages, even within the same breccia rock.

Summary: An early massive event at 4.34 Ga has been inferred [12] from analysis of zircons in samples collected from widely separated sites on the lunar near side. The evidence is consistent in detail with this event being the impact that formed the NSM, a line of evidence that is independent from the previous proposal of that basin.

Further analysis of zircon ages from Apollo samples for other landing sites would be very desirable, as would be new far side samples.

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