ORIGIN OF THE LUNAR MARE BASALT. A.M. Pentecost and J. Arkani-Hamed, Earth and Planetary Sciences, McGill University, Montreal, Quebec, Canada, H3A 2A7. E-mail: alison@eps.mcgill.ca

Summary: The existing models of the origin of mare basalt do not satisfy the observations made by Clementine. In particular, they do not explain the lack of pervasive mare flooding of Aitken basin. We propose a model that explains this observation. On the basis of our dynamic modeling, we show that the mantle convection triggered by the heat impulse of Aitken impact can strip away the lower parts of the crust, and the entire KREEP layer with the high concentration of heat producing elements, from beneath the surroundings of the basin. However, the smaller impacts that created the nearside circular basins are not capable of removing these materials. The high concentration of the radioactive elements of the less perturbed lower crust and the KREEP layer will increase the temperature and result in partial melting as time passes.

Introduction: The origin of the lunar mare basalt has been debated since the Apollo era. Because the floors of mare basins tend to lie on a smooth surface, it was suggested that basaltic melt originated in the deep interior and flooded the basins to an equipotential level [e.g., 1]. The spatial and temporal characteristics of the linear rills and mare ridges of Serenitatis supported the scenario that the lunar interior expanded at around 3.6-3.8 Gyr ago and created tensile stresses which facilitated the transport of molten basalt from the deep interior to the surface [2]. The offset of the center-of-mass of the Moon toward the Earth relative to its center-of-figure was interpreted in terms of a thicker crust in the far side [3] that caused the equipotential surface to lie below the lunar surface [e.g., 4], resulting in the lack of mascon basins in the far side as revealed from Apollo measurements. The Clementine altimetry measurements [5] provide new constraints that are not in accord with this scenario. The floors of many unflooded basins, especially that of Aitken basin, are below the flooded basins. The expansion of the lunar interior should have also helped the melt to flood Aitken basin. Mare Moscoviense, which is a much smaller basin in the far side, has been flooded and has an appreciable mascon. Furthermore, according to this lunar expansion hypothesis, the Moon started cooling and contracting at about 3.4 Gyr ago and produced compressional stresses in the crust [6]. This should have prevented the upward transport of mare basalt in later times, and yet basin flooding continued for approximately another 400 Myr. The petrological studies of the lunar rocks do not provide a strong evidence for a deep source of all mare basalts. They show both shallow and deep origin for the mare basalt [7].

An alternative model of the origin of mare basalt [8,9] considered lateral mass transport from beneath the surrounding highlands into the basin. According to this model, the low thermal conductivity of the ejecta blanket hampered heat loss, resulting in rising temperature and partial melting beneath the highlands. The extensional thermal stresses locally reactivated the fractures that have been produced by the shock wave of the impact beneath the surrounding highlands, causing the molten basalt to laterally move from beneath the surrounding highlands into the basin. This lateral mass transport also gave rise to the mass deficiency observed beneath the surroundings of the basins. The model also explained the delay of about 200 Myr between the basin formation at about 3.9-4.0 Gyr ago [e.g., 10] and the period of extensive flooding, inferred from the age of lunar samples [e.g., 11] and crater counts [e.g., 12]. According to this model, Aitken basin should have the most extensive mare flooding, a direct contradiction to the lack of an extensive flooding of the basin.

We propose that the heat impulse of the large impact that created Aitken basin at the earlier time resulted in a vigorous mantle convection that stripped away the lower parts of the crust and the KREEP layer from beneath the surroundings and prevented the subsequent temperature enhancement and partial melting there. The convection produced by the smaller impacts that occurred at later times and created the nearside basins was not strong enough to remove the KREEP layer efficiently. This allowed temperature enhancement and partial melting beneath the surroundings, which not only supplied parts of mare basalt but also facilitated the transport of deeper melt to the surface.

Model: We investigate the effects of heat impulse introduced by an impactor on the thermal convection in the Moon using an axisymmetric spherical shell model. Starting with a solid lunar interior immediately after differentiation and solidification of the magma ocean, we allow the mantle convection to establish an adiabatic temperature distribution in the interior overlain by a thermal boundary layer. We adopt a temperature-dependent Newtonian viscosity and a depth dependent heat sources that include a KREEP layer at the base of the crust. At a given time we incorporate the heat impulse of an impactor, distributed within a given volume according to the energy and angle of incidence of the impactor [13]. For Aitken, we assume that the impact was oblique and the heated region was ellipsoidal with a radius of 600 km and a depth of 300 km. For others, we assume vertical impacts with hemispheric geometry of the thermally enhanced regions. To investigate the convection triggered by the temperature enhancement, we set the velocity field of the previously convecting mantle to zero immediately after the impact and allow a new mantle circulation to develop in response to the lateral variations of temperature created by the impact heating. Figure 1 shows the temperature distribution inside the Moon at every 30 Myr following the Aitken impact that is assumed to occur at 4.2 Gyr ago, and an Imbrium size impact that occurred at 4.0 Gyr ago. The newly established velocity field shows a vortex located at the boundary of the impact-heated zone.

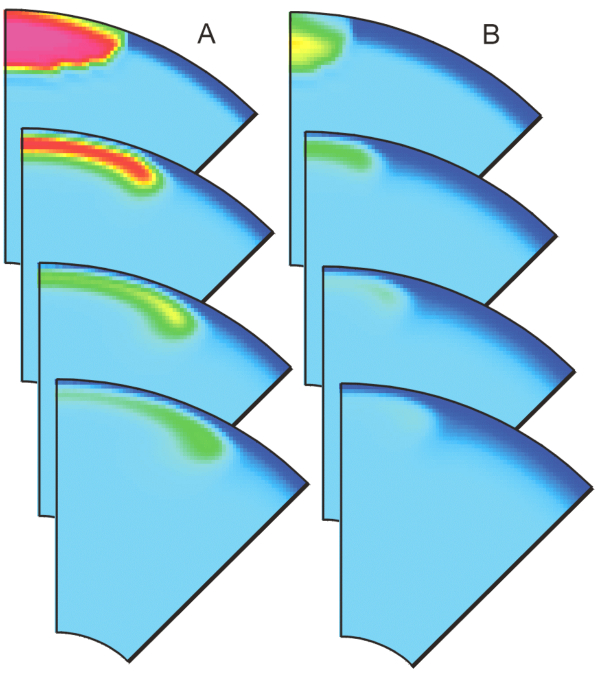

Figure 1. Temperature fields for Aitken (A) and Imbrium (B) at time intervals of 30 Myr.

The colder material from the surroundings moves toward the basin and forces the hotter part to spread laterally. The circulation is much more pervasive and vigorous for the Aitken impact than for the Imbrium impact. Figure 2 shows the locations of the tracers originally put at the crust-mantle boundary, the middle of the KREEP layer. The convection is capable of stripping away the lower crust and the KREEP layer beneath the surroundings of Aitken basin and mixing them with the mantle. However, an Imbrium size impact does not establish such a vigorous convection and thus leaves the lower crust and the KREEP layer less disturbed.

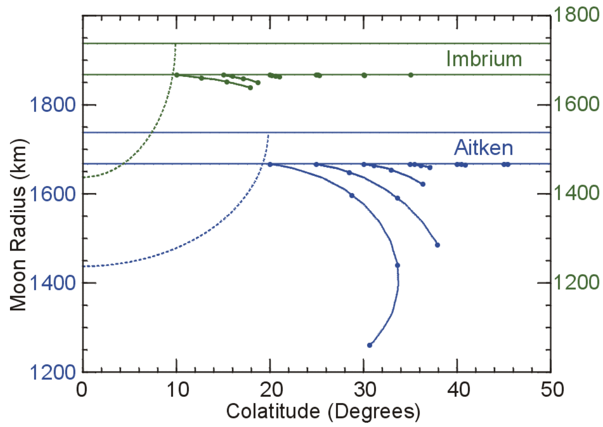

Figure 2. Paths of tracers initially put at the middle of the KREEP layer and at different distances from the basin.

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