SOME GEOCHEMICAL AND GEOPHYSICAL IMPLICATIONS OF VERY OLD AND VERY YOUNG LUNAR MARE VOLCANISM. Paul D. Spudis[1] and Peter H. Schultz[2]. 1. Dept. of Geology, Ariz. State Univ., Tempe, AZ 85287. 2. Lunar and Planetary Inst., 3303 NASA Rd. 1, Houston, TX 77058.

Introduction. The duration of lunar mare volcanism is commonly accepted (e.g., 1) to have been about one billion years: from just prior to the Imbrium impact (3.85 AE; 2) extending to about 3.1 AE, the age of the Apollo 12 basalts (3). Although many investigators acknowledge that mare volcanism may have extended slightly beyond these times, it is considered to have been of minor extent and importance (1). It has recently been suggested that mare volcanism was extensive in pre-Imbrian time (4,5) and may have continued well into the Copernican Period (< 1.0 AE; 4). Here, we examine selected implication of long-duration mare volcanism.

Ancient Mare Volcanism. Photogeologic (6), remote sensing (5,7) and lunar sample data support the presence of pre-3.9 AE mare volcanism (8,9,10); however, the relative importance of this process remains in question (1). The Moon displays both the well-known nearside/farside maria dichotomy, and a geochemical dichotomy in the lunar farside (mostly highlands). The geochemical dichotomy is indicated by three observations. First, the average highlands between 90° E and 180° display consistently higher Fe values (11) than does the terra between 180° and 90° W. Second, numerous farside basins with no recognizable dark mare fill display mafic geochemical signatures within their interiors (4,12). Third, the lunar quadrant between 90° E and 180° contains the largest concentration of light plains with dark-halo craters (4,6), many of which are in old impact basins. We conclude that large regions of the lunar farside were flooded by mare basalts, but the surficial record of these episodes has been obliterated by the high cratering rates of the pre-Nectarian and Nectarian Periods.

One objection commonly advanced against extensive pre-Imbrian volcanism is that the geochemistry of the highland crust is too aluminous (feldspathic) for extensive pre-Imbrian mare volcanism (1). Most preserved remnants of ancient farside crust appear to be very localized and are mostly pure anorthosite (12,13). Even if the volumes of mare extrusion in the pre-Imbrian were a factor of ten higher than the post-Imbrium rates (from 14), mare basalt would comprise up to 10 percent of the volume of the pre-Imbrian highland crust. If the mafic component were mixed with an anorthositic megaregolith of several km depth (15) by impact cratering, the total Al_2O_3 of highlands soils would still average greater than 30 weight percent. This value exceeds the observed value (∿ 28 percent; 1); therefore, there are no data from remote-sensing geochemistry that rule out extensive pre-Imbrian mare volcanism. The low mare content of the Apollo 16 samples (1) is also cited as evidence against extensive pre-Imbrian volcanism; however, there are preserved remnants of unmodified ancient crust elsewhere on the Moon (2,12). The assesment of which regions have undergone mare resurfacing must be based on the regional context provided by the orbital geochemical data.

The only valid constraint on the time of the beginning of mare activity is that the source regions of the mare basalts became isotopically closed at 4.3 AE (16,17). We suggest that basaltic volcanism began immediately after solidification of the source regions, both by convective heat transfer that produced local zones of partial melting and by heterogeneous concentrations of heat-producing isotopes. Such magamas could be expected to be compositionally diverse, and the high temperatures in the early Moon would exacerbate the processes of magma mixing and assimilation. Asymmetric lithospheric thicknesses; controlled the extrusion of these basalts; thus, the widespread occurrence of ancient basin-fill basalts (4) would be expected.

Recent Mare Volcanism. We have described elsewhere (4) that numerous unsampled mare regions have relatively low crater density; some flows even embay rayed craters. These young mare flows display a wide diversity of chemistry, from low to very high Ti varieties (19) to high KREEP content for the late Imbrium flows (20,21). Moreover, this late phase of mare volcanism is not strictly confined to the Procellarum region, but may be moonwide, as demonstrated by young, penecontemporaneous flows in Procellarum and Mare Smythii (4).

Lunar thermal models (22) suggest that the Moon underwent gradual cooling. Such a thermal history implies that mare volcanism would not "shut down" at 3.0 AE; rather it suggests decreasing volumes of magma production with time. The question of importance is whether these magmas could reach the lunar surface (23). Models of the growth of the lunar lithosphere are predicated on the assumption that mare volcanism was essentially complete at about 3.0 AE (24). We suggest this assumption is ill founded and that there apparently were pathways for mare extrusion as recently as 900 m.y. ago. This implies that what is observed for one mare basin is not necessarily applicable to the Moon as a whole. We are in agreement with (24) that these last phases of mare activity were of low volume, but their existence strongly argues for a reassessment of the role of lithospheric thickness and asymmetry on mare basalt emplacement.

Conclusions. We propose that lunar mare volcanism has been a more or less continuous process on the Moon from 4.3 AE to less than 1.0 AE. The overlap of volcanism with the high flux rate in early lunar history produced an extremely complex, heterogeneous highlands crust to which basaltic compositions are an important contributor. Evidence from remote-sensing data indicates that mare volcanism is compositionally diverse, and that KREEP and widely-variable mare lava extrusion overlapped in time. Although the vast majority of visible (dark) maria is of Imbrian age, mare extrusions outside this time period were not insignificant. The limited returned lunar sample should not constrain physical models, since the Moon remains at best, poorly sampled. The wide spectrum of basalt types seen in the limited sample that we do have suggests that lunar volcanism is extremely complex (cf. 3).

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