THE BEGINNING AND END OF MARE VOLCANISM ON THE MOON.

P.H. Schultz, Lunar and Planetary Inst., 3303 NASA Road 1, Houston, TX 77058; P.D. Spudis, Dept. of Geology, Arizona State University, Tempe, AZ 85287.

The emplacement of the lunar maria is generally regarded as a relatively short lived epoch of basaltic volcanism between 3.9 and 3.0 AE (1, 2). Growing photogeologic, geochemical, and spectral evidence, however, indicates that widespread mare volcanism began at significantly earlier times but has largely been masked by veneers of impact-derived debris (3, 4, 5). Although past crater statistical data revealed that such volcanism continued locally to times as recent as 1.7 AE - 2.0 AE (6), we present new data that indicate the emplacement of significant Copernicus-age mare units. Consequently we propose that lunar mare volcanism occurred continuously from prior to 4.1 AE to as recently as 1.0 AE.

Sample studies reveal that mare basalt fragments occur as clasts in breccias that were assembled prior to 3.9 AE (7, 8), thereby indicating mare volcanism was at least contemporary with the formation of the last major impact basins. The global extent of such an early epoch is believed to be indicated by dark-haloed impact craters (3) that have excavated units having geochemically (3, 4) and spectrally (5) mafic signatures. The distribution of these buried mare units suggests that their areal extent exceeds 12% of the post-Imbrium maria, the principal concentrations occurring in or around very old basins. Several basins (Smythii, Crisium) have undergone two distinct stages of mare volcanism: the earliest maria (Nectaran-age basalts now covered by a light-colored veneer) occur between the outer rings; the latest maria (Imbrian, Eratosthenian, and Copernican age) are confined to within the interior ring. We interpret the concentration of later mare volcanism to the basin interior as an epoch of resurgence following a very early stage of widespread volcanism that once extended to the outer rings.

At the other end of the lunar time scale, current interpretations date the last stages of widespread lava flooding at about 2.5 ± 0.5 AE (6) with the youngest eruptions occurring around 1.7 - 2.0 AE (9), about twice the estimated age of Copernicus. However, earth-based telescopic studies suggested that mare units overlap the bright rays of the crater Lichtenberg (10). This observation is confirmed in Lunar Orbiter photography where embayment of Lichtenberg ejecta deposits by mare basalt flows is clearly shown (11). From (12), the rays of a crater the size of Lichtenberg (20 km diameter) should have disappeared if it were older than Copernicus (96 km diameter), i.e. about 1.0 AE (13). Separate calibration is provided by the cumulative number of craters per unit area (N_c) larger than 0.5 km in diameter on the mare surface. This lower size limit is small enough to provide meaningful statistics but large enough to avoid irregularities in statistics at small sizes (14). Calibrating N_c with lunar sample ages from Apollo 12 and Apollo 15 (15) and with the inferred absolute ages of Copernicus (13) and Tycho (16), we determined an absolute age for the post-Lichtenburg unit as 0.9 ± 0.3 AE. The same technique was applied to selected mare units and produced statistical ages consistent with results from other workers. Five potentially young mare units, however, proved to exhibit ages between 0.9 AE and 1.2 AE (Figure 1) in contrast with previous estimates of about 2.0 AE (6). Although seemingly in conflict, the disparate results reflect differences in techniques: other studies combined units of various ages and included large craters from older horizons, thereby producing an average age older than the last erupted unit. The combined area covered by these very young thin units exceeds 10^4 km^2. They generally correspond to the dark blue high Ti basalts of western Oceanus Procellarum (17) that typically have fine-scale (25 m) flow features preserved (18) and include: interior of the Flamsteed

MARE VOLCANISM

Schultz, P. H. and Spudis, P. D.

Ring; a unit within Letronne; mare near Gruithuisen; and southwest of Maestlin. In addition, a comparable young age has been determined for mare within Smythii.

We conclude that lunar volcanism was relatively continuous on a global scale beginning as early as 4.3 AE and gradually terminating around 1.0 AE. On a local or regional scale, however, certain basins ceased volcanic activity along the outer rings prior to 3.9 AE but underwent resurgent activity within the inner rings after 3.9 AE. The significance of such a scenario for lunar geochemistry is considered elsewhere (19).

REFERENCES

1. Head, J.W. Rev. Geophys. Space Sci. 14, 265-300 (1976). 2. Taylor, S.R. Lunar Science, Pergamon, 327p. (1975). 3. Schultz, P.H. and Spudis, P.D., Proc. Lunar Planet. Sci. Conf. 10th, 2899-2918 (1979). 4. Hawke, B.R. and Spudis, P.D. Proc. Conf. Lunar Highlands Crust, 467-481 (1980). 5. Hawke, B.R. and Bell, J.F. Proc. Lunar Planet. Sci. 12B, p. 665-678 (1981). 6. Boyce, J.M. and Johnson, D.A. Proc. Lunar Planet. Sci. Conf. 9th, 3275-3283 (1978). 7. Ryder, G. and Taylor, G.J. Proc. Lunar Sci. Conf. 7th, 1741-1755 (1976). 8. Ryder, G. and Spudis, P.D. Proc. Conf. Lunar Highlands Crust, 353-375 (1980). 9. Young, R.A. Proc. Lunar Sci. Conf. 8th, 3457-3473 (1977). 10. Moore, H.J. U.S. Geol. Survey Inv. Map I-527, (1967). 11. Schultz, P.H. Moon Morphology, p. 424, (1976). 12. Neukum, G. and Koning, B. Proc. Lunar Sci. Conf. 7th, 2867-2881 (1976). 13. Silver, L.T., EOS (Trans. Amer. Geophys. Union), 52, p. 534. 14. Schultz, P.H., Greeley, R., and Gault, D.E. Proc. Lunar Sci. Conf. 7th, 985-1003 (1976). 15. Hartmann, W.K., et al., Bas. Volc. on the Terr. Planets, 1049-1127, Pergamon (1981). 16. Arvidson, R., et al., Proc. Lunar Sci. Conf. 7th, p. 2817-2832 (1976). 17. Pieters, C.M. Proc. Lunar Planet. Sci. Conf. 9th, 2825-2849 (1978). 18. Schultz, P.H., Greeley, R., Gault, D.E. Proc. Lunar Sci. Conf. 8th, 3539-3563 (1977). 19. Spudis, P.D. and Schultz, P.H. (1983), Lunar and Planetary Science 14 (this volume).

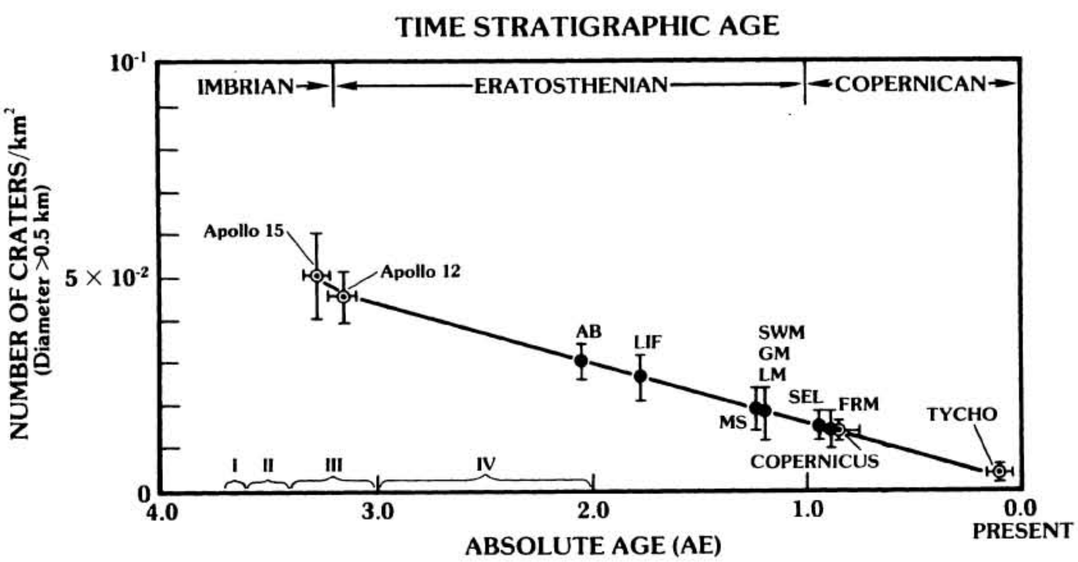

Figure 1. Number density of craters larger than 0.5 km on selected units. Absolute ages are calibrated by Apollo 12 and 15 samples and inferred ages for Copernicus and Tycho. Age groupings (I, II, III, IV) at bottom are from (6); approximate time stratigraphic boundaries are shown at top. Abbreviations are as follows: AB (region in Oceanus Procellarum 8°.5N, 58°.5W); LIF (late Imbrium flows); SWM (southwest of Maestlin); LM (Letronne mare); GM (Gruithuisen mare); FRM (Flamsteed Ring mare); SEL (southeast of Lichtenberg).