N92-10794

THE PROBABLE CONTINUUM BETWEEN EMPLACEMENT OF PLUTONS AND MARE VOLCANISM IN LUNAR CRUSTAL EVOLUTION

Carle M. Pieters, Brown University, Providence RI 02912

Facts and generally accepted information

- Ages of basaltic surface units sampled by the Apollo and Luna missions have been measured directly in the laboratory and range from around 3.2 to 3.9 Ga [1]. Crater degradation analyses indicate ages of unsampled basalt units can extend to about 2.0 Ga [2]. Superposition arguments for the Lichtenberg region suggest limited deposits with even younger ages [3].
- A great diversity of mare basalt types exist within the lunar sample collections [4]. Remote sensing studies show that only about 1/3 of basalts that exist as extensive surface units on the nearside have been directly sampled [5].
- "Pristine" samples of the original lunar crust that somehow escaped the brecciation transformation suffered by most highland materials continue to be identified [e.g. 6]. These pristine samples form two distinct suites with different chemical trends [7]: the ferroan anorthosites (hypothesized to be remnants from a magma ocean scale differentiation) and the Mg-rich suite (hypothesized to represent intrusions or plutons emplaced within the plagioclase-rich crust). Although compositional trends observed for the two suites of pristine materials are similar to those observed for materials found at the Stillwater, a classic layered mafic intrusion, these two lunar suites are not believed to be directly related based on other geochemical and isotopic properties [7, 8].
- As components of the original lunar crust, the pristine lunar samples are naturally old, clustering near 4.3 Ga, but with the oldest almost 4.5 Ga. There is no clear age relation between the Ferroan and the Mg-rich suites, although it is assumed the Mg-rich suite must be later [1, 7].

Additional new information.

- Fragments of mare basalts have been found in the sample collection with ages as old as 4.2 Ga [9]. The existence of ancient volcanism partially covered by subsequent lighter deposits has been argued on the basis of orbital chemistry, albedo, and reflectance spectroscopy [3, 10].
- A variety of surface compositions ranging from what is almost certain to be anorthosite to compositions consistent with several Mg-suite/KREEP rock types have been identified for areally extensive highland regions overflown by the Apollo gamma ray experiment [11]. This variety is particularly important information about the farside highland crust, which is presumed to be thicker than the nearside and to contain only minor amounts of mare-like volcanism.
- A diversity of rock types reminiscent of layered mafic plutons have been identified at higher spatial resolution using large nearside craters as probes to the interior [12]. The classic example is at Copernicus, where the dunite-troctolite central mountains range about factor of three in olivine abundance [13]. Additional examples of deep-seated rock types distinct from the noritic anorthosite breccias that apparently dominate the nearside highland megaregolith [12] include the clinopyroxene-rich gabbro pervasive at Tycho [14, 12], the clinopyroxene-rich gabbro and troctolite mixtures at Aristarchus [12], and the variety of gabbros overlying crystalline norite at Bullialdus [16]. The age of these large craters is Eratosthenian or Copernican [17].

Hypothesis

Any one of these additional fragments of information can be viewed as unusual or simply interesting, but taken together they suggest there is no gap in magmatic evolution of the Moon. Only the form varies with time and random events as the crust evolves. The scale and variety of highland materials observed with remote observations is inconsistent with a compositionally homogeneous crust to 25 - 60 km depth. The association of frequent "unusual" compositions at 5-10 km depth for nearside crustal areas excavated by late large impact events suggests extensive plutonism occurred in the nearside highland crust roughly contemporaneous with the mare basalts. Although our current data about the Moon are seriously incomplete and we are in desperate need of regional and global information, the following scenario appears to be consistent with these data and the leading hypothesis of formation of the Moon and is worthy of discussion and testing:

Ga b. p.	Event(s)
4.6 - 4.5	Proto-Earth forms, differentiates, and meets other large proto-planetary body in disruptive event creating a large mass of material in near-earth orbit.
4.5 - 4.45	Moon accretes and forms refractory An-rich crust [and mantle and core (?)]. Concentration of KREEP-rich zones must occur during the later stages.
<-->	Continued heavy bombardment
4.4 -->	Initiation of internal magmatism. Several (Mg-suite) plutons must have formed and cooled by 4.3.
4.3 - 3.8	Basin forming period (with rigid crust). These events mixed and delivered much of the highland material eventually to be sampled. They also fractured the crust to depths providing easier conduits for low density melts.
3.9 - 3.2	Major outflow of mare basalts on the nearside Plutonic activity continued within the highland crust.
3.2 - 2.0	Continued basaltic volcanism until conduits closed. Plutonic activity within crust paralleled mare volcanism.
2.0 - present	Random local activity (degassing, minor melt, etc.)

Conclusion

Although the volume of mare basalts is estimated to be only 0.1% of the lunar total [1], this value should not be taken to represent the amount of partial melt produced within the lunar interior nor should the mare basalts be viewed to represent the only products of internal heating. The actual amount of magmatic activity is certain to be substantially larger, but cannot be estimated without a global assessment of lunar highland heterogeneity and the character, scale, and abundance of lunar plutons.

References:

[1] S. R. Taylor (1982) *Planetary Science: A Lunar Perspective*, pp. 481.
[2] J. M. Boyce et al. (1974), *Proc. Lunar and Planet. Sci. Conf.5th*, pp. 11-23.
[3] P. H. Schultz and P. Spudis (1983), *Nature*, 302, 233-236.
[4] J. J. Papike et al. (1976), *Rev. Geophys. Space Physics*, Vol. 14, No. 4, pp. 475-540.
[5] C.M. Pieters (1978), *Proc. Lunar and Planet. Sci. Conf.9th*, pp. 2825-2849.
[6] J. W. Shervais (1988), *Moon in Transition*, pp. 82-91.
[7] P. H. Warren (1985), *An. Revs. Earth Planet. Sci., 13*, 201-240.
[8] L.D. Raedeke and I.S. McCallum (1980), *Proc Conf. Lunar Highland Crust*, pp. 133-153.
[9] L.A. Taylor, L.E. Nyquist, and J.C. Laul (1983), *Earth Planet. Sci. Lett. 66*, pp. 33-47.
[10] B.R. Hawke and J.F. Bell (1981), *Proc. Lunar and Planet. Sci. Conf. 12B*, pp. 655-678.
[11] P.A. Davis and P.D. Spudis (1985), *Proc. Lunar and Planet. Sci. Conf. 16, J. Geophys. Res.*, D61-D74.
[12] C.M. Pieters (1986), *Revs. Geophys., Vol 24*, No. 3. pp. 577-578.
[13] C. M. Pieters (1990), *Lunar and Planetary Science XXI*, pp. 962-963.
[14] B. R. Hawke et al. (1986), *Lunar and Planetary Science XVII*, pp. 999-1000.
[15] P. Lucey et al. (1986), *Proc. Lunar Planet. Sci. Conf 16th, J. Geophys. Res.*, D344-D354.
[16] C.M. Pieters (1989) *Lunar and Planetary Science XX*, pp. 848-849.;
------ (1990) *Remote Geochemical Analysis*, LPI and Cambridge Univ. Press, in press.
[17] D.E. Wilhelms (1987) *The Geologic History of the Moon*, USGS-PP #1348, pp. 302.