COMPREHENSIVE PETROLOGIC MODEL BASED ON TOTAL MELTING OF LOW-VOLATILE ULTRABASIC MOON. J. V. Smith and I. M. Steele, Dept. of the Geophysical Sciences, The University of Chicago, Chicago, Illinois 60637.

Total melting was envisaged to result from disintegrative capture followed by sequential accretion (1) but might result from other origins. The 1970 model of Smith et al. (2) is basically retained, but refined to accommodate partial melting of late cumulates together with impact differentiation. For simplicity, late heterogeneous accretion is assumed to be a trivial perturbation, but may be important especially for basins and ejecta blankets. Earth-bound projectiles should be chemically related to the bulk composition of early accreted material and therefore hard to identify. Sun-bound projectiles may cause significant local changes in the major elements, but it is simplest to ignore this possibility.

This petrologic model checks well with chemical models of Philpotts, Taylor etc., but space forbids detailed references: see final paper.

Assumed bulk composition. Disintegrative capture is assumed to result in loss of Fe, siderophile and chalcophile elements to either earth or solar system plus severe loss of volatiles from the circum-earth plasma. The product is dominated by high-temperature ends of olivine, pyroxene and plagioclase series plus ~5% FeS and small amounts of components destined for Cr-Zr-armalcolite, spinel, apatite, etc.

Initial stage. Fig. 1a shows the Fe-rich liquid core which extracts metal-seeking elements including S and noble metals. Olivine, Fo95, and multiple oxides crystallize from the immiscible silicate liquid forming the inner mantle at solidus temperature. The FeS core is superheated by thermal conduction resulting in low viscosity which favors hydrodynamic generation of a magnetic field over a long time span. The picritic proto-crust disintegrates under impact of both earth- and sun-bound projectiles and is mostly reworked. Crystal-liquid differentiation leads to increasing Fe enrichment of the liquid and precipitate. Mg-rich pyroxene begins to precipitate into the outer mantle. Spinel and pseudobrookite minerals change composition in parallel with the silicates. Substantial loss of volatiles occurs at the surface.

Second stage. Fig. 1b shows the second stage which follows the precipitation of plagioclase. Initially plagioclase may float in the ultrabasic magma, but flotation is not a necessary condition for development of a feldspathic crust. Olivine, pyroxene and multiple oxides sink much more rapidly than plagioclase, and fall beyond the reach of impacting bodies. Plagioclase tends to remain nearer the surface and is reincorporated into the residual liquid which is augmented by impact. Consequently the ferromagnesian minerals precipitating from the liquid become more Fe-rich while plagioclase retains its composition near An97.

Minor Ca-pyroxene begins to crystallize. Significant vapor loss causes loss of Na (resulting in slight increase in Ca content of plagioclase) and reduction (resulting in Cr^2+ entering olivine plus reduction of Fe^2+ into Fe^0). The unusual correlation between olivine and plagioclase compositions results from the overall tendency for Fe to increase as Na
remains near-constant or falls slightly plus local perturbations in closed chambers with the usual positive correlation between Na and Fe. Primary anorthosites and troctolites develop. The plagioclase of the anorthosites contains high Fe, Mg and excess SiO\textsubscript{2} which later exsolves to give silica mineral and Fe-rich mafics (3). Mg/Fe\textsuperscript{2+} ratios of rocks and fragments are consistent with crystallization from magmas with Mg near 0.7 when account is taken of this exsolution. Impacts produce shock metamorphism which tends to produce plagioclase melt before ferromagnesians are melted. Some separation of melt could occur, but the process is not necessary for developing a lunar crust. At this stage, the lunar crust is envisaged as a complex mixture of breccias and igneous and metamorphic bodies dominated by plagioclase and ferromagnesian minerals: it is not anorthosite in the true sense.

Third stage. The final liquid becomes rich in the incompatible elements. It tends to permeate the crust erratically because of its high viscosity. Liquid immiscibility causes further complications, probably resulting in small bodies of Ba-rich "granites". If the moon becomes rotation-locked to the nearby earth when substantial liquid remains, crystal-liquid differentiation proceeds in a steep gravitational potential. The crust might develop asymmetrically with light plagioclase tending to concentrate on the far side. The liquid might tend to concentrate on the near side with a subsidiary maximum at the far side. Tidal and gravitational heating might favor higher temperatures on the near side.

Fourth stage (Fig. 1c). Cooling results in formation of a relatively stable crust which develops distinct basins and craters under late impacts. The moon is gravitationally unstable. Small amounts of Fe,S liquid tend to move towards the center but are impeded by the solid (but hot) mantle. The higher Mg content of ferromagnesians towards the center is also unstable gravitationally but the driving force is too low for significant movement. The major events are partial melting and metamorphism. Basins become partly filled by uprising mantle and flooded by basalts, some very rich in Fe and Ti, formed by the remelting of cumulates rich in pyroxene, ilmenite, etc. Heat is supplied by (a) tidal and impact energy which tend to concentrate at liquid-solid surfaces, and (b) radioactive heating which tends to occur near residual liquids. Impact melting produces various rock types including spinel troctolites with a wide range of Mg/Fe and hybrids such as 14310. KREEP-rich materials are remobilized both by partial melting of feldspathic cumulates and by impact melting; hence KREEP-rich materials tend to be hybrids with complex natures. Reworked crustal materials tend to consist largely of various proportions of plagioclase and Mg,Fe pyroxene often loosely called norites. Green and orange glasses are ascribed to volcanic activity from remelting of cumulates. Gradually non-impact metamorphism becomes the dominant process with impact metamorphism reworking only the outer surface.

Alternative model of melting only of outer part. Cold accretion with development of a hot zone by radioactive heating could produce many scenarios. In order to produce a thick crust, melting should go rather deep
and late liquids might be expected to develop from 500-1000 km depth as primitive material is melted. These late liquids should contain KREEP and associated elements. Fe,S liquid should form a shell outside an unmelted primitive core: a magnetic dynamo is unlikely.


Fig.1a. Initial stage of Moon formation after disintegrative capture and total melting of ultrabasic composition. Note liquid core, Mg-rich lower mantle and possible convection. (Not to scale).

Fig.1b. Second stage of formation with mantle consisting of Mg-rich olivine but more Fe-rich toward surface. Plagioclase dominates in "crust". Liquid core provides magnetic field. Lunar crust consists of complex volcanics, breccia and impact melts. (Not to scale).

Fig.1c. Near surface structure (100 Km). Large basin developed on stable crust is filled with partial melt products (mare basalts). Minor rock types (e.g., granite) permeate crust. Metamorphism, impact melting and partial melting become dominant processes.