MARIA BASALTS AND COMPOSITION OF LUNAR INTERIOR
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The compositions of maria basalts were determined principally by partial melting processes in their source regions followed by fractional crystallization near the surface. Detailed studies of Apollo 12 and 15 basalts showed that a limited degree of near-surface fractionation had occurred, controlled mainly by the separation and accumulation of olivine. The high abundances of Cr and V (which are rapidly depleted by near-surface crystallization) also demonstrated the limited role of near-surface crystallization. Basalts which were erupted at the lunar surface as primary liquids and which had suffered little or no fractionation en route from their source regions may be recognised by the application of chemical and petrological criteria combined with demonstrations that the cores of the earliest formed crystals are isochemical with the liquidus phases of the whole rock as determined experimentally (1).

The compositions of such basalts place constraints upon the compositions of their source regions which can be established by determining experimentally the nature and compositions of near-liquidus phases over a wide range of P and T conditions (1,2,3,4). These experiments demonstrate that the Mg/Mg+Fe ratio of the source region of maria basalts ranges between 0.75 and 0.80. A notable feature is that plagioclase does not occur near the liquidus of the vast majority of returned basalt macrospecimens (exceptions are 12038, Lunar 16 and some of the Apollo 11 ophitic basalts). The marked undersaturation of plagioclase in most basalts, particularly those which can be demonstrated to have erupted as liquids, proves that the source material from which they formed by partial melting did not contain plagioclase.

Measurements of the compositions of near-liquidus phases from Apollo 11,12,15 and 17 basalts demonstrate that they were formed by varying degrees of partial melting of a source composed dominantly of subcalcic pyroxenes with some olivine, at pressures between 10 and 20 kb (1,2,3,4,8). Apollo 12 parental basalts appear to have segregated at 10-12 kb, 1320-1370°C whilst Apollo 15 parental basalts (including Green Glass) segregated at 15-17 kb, 1400-1450°C. Compositions of liquidus pyroxenes observed at 10-20 kb on Apollo 11,12,15 and 17 basalts imply that the source region contained 4-5 percent of CaO and Al_2O_3, ie. about twice the chondritic abundances of these components. It is suggested that a wide range of other highly involatile oxyphile elements, eg. U,Th,Ba,Sr,REE,Zr,Sc also occurred in the source region at approximately twice chondritic levels.

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Abundances of incompatible elements (eg. U,Ba,La,Nb,Zr) in maria basalts range more or less continuously from 10X chondritic to 100X chondritic. Assuming that these elements are almost completely partitioned into the melt, then their abundances are inversely proportional to the degrees of partial melting. Apollo 15 Green Glass has a bulk composition closely related to maria basalts and contains incompatible elements at about 5X chondritic levels. Experimental studies show that Green Glass can be formed by 40-60 percent of partial melting of the same source region inferred from other maria basalts (4). This again implies a source region containing about twice the chondritic abundances of involatile elements.

A self consistent model of maria basalt genesis has been constructed on the basis of experimental petrology investigations. The source material (Mg/Mg+Fe = 0.75 - 0.80, $CaO, Al_2O_3 = 4 - 5\%$) consists of subcalcic pyroxenes plus some olivine. Apollo 11 and 17 basalts represent 2 to 5 percent partial melts of this source, whilst Apollo 12 basalts represent 10 to 15 percent partial melts. Residual phases are clinopyroxene, orthopyroxene ± olivine. Apollo 15 olivine basalts represent 10 to 20 percent partial melts. With increasing degree of partial melting, residual clinopyroxene melts incongruently to orthopyroxene plus liquid. Green Glass represents 40 to 60 percent partial melting at 10-20 kb, ~1450°C, leaving residual orthopyroxene and olivine.

The source composition derived for the maria basalts is believed to have been originally representative of the entire moon, which accreted homogeneously from material of this composition. An earlier inference (5) that the moon may have accreted inhomogeneously is abandoned. Formation of the lunar highlands requires a thorough differentiation of the outermost 300-400 km of the moon, about 50 percent of its volume. The heating required for this differentiation was probably supplied by gravitational energy of accretion (6,7) which implies an accretion time scale smaller than 1000 years. Such a short time scale can be achieved only for accretion from material in earth orbit - eg. coagulation of a sediment ring. Accretion as an independent planet from sun-orbiting material would be much too slow to cause heating of the exterior.

Generation of maria basalts between 3 and 4 b.y. ago is believed to be caused by heating from U and Th in the deep interior (below 400 km) which was not affected by the early lunar differentiation. The heating led to convective instability and upward rise of diapirs of primitive source material, accompanied by partial melting. The diapirs rose to within 200-400 km of the surface before magma segregation occurred.

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Differentiation affected the entire lunar interior below 400 km
leading to extraction of U,Th and K via the generation of basalt-
ic magmas which were intruded upwards into the outer 400 km.
Redistribution of radioactive heat sources in this manner could
be responsible for the apparent cessation of volcanism about 3 b.y
ago. Only a small proportion of the magmas reached the surface.
Most crystallized at depth, often to form dense eclogite bodies.
Sinking of some of these eclogite bodies might be connected with
current seismic activity.

Temperatures in the source regions of basalt magmas between
3.2 and 3.8 b.y. ago would have been in the vicinity of 1250°C
(Apollo 11,17) to 1450°C (Apollo 15). Allowing for radioactive
heating in the source regions caused by 2X chondritic abundances
of U,Th, and K/U of 2000, the temperature in the deep interior of
the moon soon after its formation 4.6 b.y. ago was about 900-
1000°C. Since accretional heating does not make an important
contribution in the very deep regions of the lunar interior, it
is concluded that the ambient temperatures in the earth's
vicinity during accretion of the moon must have been high and
probably in the region of 900-1000°C. This is consistent with
the depletion of volatile elements in the lunar interior.

Thermodynamic calculations show that silicates containing
the FeO/FeO+MgO ratios inferred for the deep lunar interior
cannot condense directly from the solar nebula in this tempera-
ture range. The temperatures required would be below 300°C which
is much too low. It appears that the material of the lunar
interior originally condensed (or equilibrated) with a gas phase
depleted in H_2 relative to H_2O by one or two orders of magnitude,
as compared to the solar nebula. Such an environment could have
been provided by a primitive atmosphere "blown off" from the
earth (6).

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