APPLICABILITY OF P-T DIAGRAMS TO MARE BASALT GENESIS. Eric Dowty, Department of Geological and Geophysical Sciences, Princeton University, Princeton, N. J. 08540.

It is commonly presumed that inferences about the depth of origin and source materials of lunar mare basalts can be directly drawn from the phase equilibria of these basalts, which are usually summarized in the form of P-T diagrams. However, the fundamental assumptions which underly the applicability of these experimental results have seldom been seriously examined. The abundant data on major and minor element compositions of mare basalts can and should be used as tests of the assumptions. The principal assumptions of the use of P-T diagrams are (a) that equilibrium was strictly maintained between magma and the source region (or residua thereof); (b) that the magmas were unmodified by differentiation, mixing or assimilation on their ascent; and (c) in the "multiple saturation" approach, that the residua in the source region necessarily consisted of more than one phase. Two simple models for basalt genesis by equilibrium partial melting will be examined first: origin from undifferentiated, primitive pyroxenitic material (1); and origin from a series of mafic cumulates, the product of original differentiation of the outer part of the moon (2). Later, models involving mixing, assimilation, etc., will be examined to see whether they can surmount the problems encountered by the simple models.

Minor elements. The general abundance pattern of trace elements in mare basalts is inconsistent with equilibrium partial melting of any source containing high-calcium pyroxene (3); for example, the rare-earth patterns of such partial melts should have a negative slope whereas the actual pattern is near level or has a positive slope. The overall patterns actually resemble the solid portion of a liquid-solid equilibrium assemblage rather than the liquid portion (3). The patterns expected from equilibrium melting of cumulates vary, ranging from that of a differentiated liquid (this depends on when the cumulates were originally separated) at very low degrees of partial melting, to that of the solid cumulate phases at high degrees of partial melting. However, use of the multiple-saturation principle assumes that the degree of partial melting was rather low.

Isotopes. The Rb-Sr(4), Nd-Sm(5) and U-Th-Pb(6) systematics of mare basalts record extensive fractionation at 4.4-4.6 AE, and limited subsequent refractionation, which is not suggestive of extensive equilibrium partial melting at 3.3-3.7 AE, especially if the source region is presumed to contain high calcium pyroxene.

Major elements and other petrologic aspects. If it is permissible to infer any compositional relationships at all among known mare basalts, these relationships are usually accounted for by olivine alone (7), not by pyroxene alone or by both minerals, as would be expected in the two simple models. Several other aspects of the composition of the basalts are not congenial to the multiple-saturation hypothesis, such as the facts that the Apollo 12 and 15 quartz-normative lavas have pyroxene on the liquidus at low pressure, and
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that all lavas from a given site tend to be either Ti-rich or Ti-poor, although very different depths of origin may be indicated by multiple saturation. Also, the Apollo 11 and 17 lavas are disturbingly close to being co-saturated with as many as five phases at low pressure (8).

Correlation of major and trace elements: hybridization models.

Ringwood (9) and later Hubbard and Minear (10) pointed out that the relations among certain elements are inconsistent with simple models such as those mentioned above. Especially, the Mg/Mg+Fe ratio and the Cr content are not well correlated with the overall content of incompatible elements or the eucrite anomaly. In order to explain this particular aspect of the data, it seems necessary to postulate mixing of "primitive" and "differentiated" material (7, 10, 11, 12). It should be obvious that when the process proposed is magma mixing or assimilation, the composition of the liquid is changed and P-T diagrams are not applicable. In the sinking-blob model of Ringwood and Kesson (12), the late-cumulate blobs are postulated to come to equilibrium with the primitive undifferentiated material into which they sink. There are many reasons why this model is highly speculative, and far from being the only possible type of mixing model. Furthermore, such a complete re-equilibration is physically unlikely.

Summary. There are many aspects of the data on lunar mare basalts which appear to be inconsistent with the hypothesis that these basalts were derived by a process of equilibrium partial melting. One might argue that there are loopholes in the above arguments, and that the hypothesis of equilibrium partial melting should not be irrevocably rejected. On the other hand, scientific hypotheses are only "accepted" if they are useful in explaining data above and beyond the data which were used in their formulation. The equilibrium melting hypothesis is of essentially no use in explaining the principal aspects of the data on mare basalts; the processes which provide the critical explanations are a previous lunar differentiation and formation of cumulates, and subsequent mixing of these with more primitive material. Thus, there are no grounds for "accepting" the equilibrium partial melting hypothesis: in practical terms, this means that interpretations from P-T diagrams cannot be used as tests or limits on models for mare basalt generation which are in accordance with the actual compositional and geophysical data.

Mare basalts must have been derived by melting of the lunar interior, but processes other than equilibrium partial melting, such as whole-rock bulk melting (3), and incremental "surface equilibrium" partial melting (4, 13) must also be considered. For whole-rock melting, absolutely no information about the depth of origin is given by P-T diagrams. It is conceivable, and in fact quite likely, that the actual process of melting did not correspond exactly to any of these end-member processes, and some assimilation, differentiation and even separation of immiscible liquids may have been involved also. In principle, any or all of these processes can
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be modelled mathematically, given certain basic data, and some attempts have been made (14). However, realistic modelling of this sort requires several types of information not supplied by P-T diagrams. Experimental petrology studies must be broadened to provide such additional information. For example, the process of "surface equilibrium" melting seems not to have been investigated directly, although it has often been proposed for basalt genesis.