GRANITE GENESIS IN A PLANETARY CONTEXT: PROCESSES AND IMPORTANT VARIABLES FOR MARS, M.J. Rutherford and P.C. Hess, Dept. of Geological Sciences, Brown University, Providence, RI 02912

INTRODUCTION - Granitic rocks are extremely important components of the earth's crust and are also an important although much less abundant constituent of the lunar crust (1,2,3). Recently it has also been suggested (4) that some of the lava flows and dome-like structures in the Acadia Planitia region of Mars are granitic in composition based on their morphology. The purpose of this paper is to examine and evaluate the factors involved in granitic magma genesis based on investigations of the earth and lunar examples. New experimental data has been obtained regarding the effects of volatiles on the formations of granitic magmas and this is added to the existing literature on the subject. This synthesis and evaluation considered along with what is known about the composition, thermal histories, etc. should enable us to predict something of the nature and importance of granitic materials on other terrestrial planets such as Mars.

The problem that will be examined here is that of generating granitic compositions from a basaltic parent. On the earth there has certainly been production of granites by partial melting of metamorphosed sediments such as arkosic sandstones and shales and earlier generations of granitic rocks. Given the fact that the other terrestrial planets show no evidence of plate tectonics and large scale erosion and sedimentation, the main focus for the earth examples will be on the generation of granitic magmas in the basaltic oceanic crust. There is ample photogeologic and geophysical data to suggest that basaltic magmatism was a major process on planets such as Mars.

PROCESSES OF GRANITE GENESIS - The available theoretical, experimental and observational evidence indicates that there are essentially three different processes that can produce a granitic magma in a region of basaltic crust and basalt magmatic activity. These processes are listed below. (a) Extreme fractional crystallization involving continuous SiO_2 enrichment of the residual melt from the initial basalt through andesite to dacite and rhyolite. (b) Fractional crystallization of basalt involving extreme FeO enrichment followed by immiscibility. This process definitely has been important on the moon (1,5) but it also appears to have occurred on the earth (6,7). (c) Partial melting of a hydrated basalt. It is generally accepted that all of these processes have occurred on the earth, but the relative importance of each process is certainly not known. In addition, it has been argued (5) that the most important mode of basalt fractionation on the moon is that of extreme FeO enrichment, although there may have been cases where granites were produced by a continuous SiO_2 enrichment process (8,9). An intriging problem is that of determining which process, if any, would be most likely on a planet such as Mars?

EXPERIMENTS AND IMPORTANT VARIABLES - Recently completed experiments on the crystallization and partial melting of basalts now provide a better understanding of the factors important in each of the above processes. Experiments at low pressure(5,10) show that a wide range of basalt compositions fractionate along an FeO-enrichment trend providing no H_2O is present and the fo_2 is low. The same experiments have not been completed at high pressure, but data on simple chemical systems (11) holds at high pressures as well. The fractionation of a basalt along a strong SiO_2 enrichment trend is dependent on relatively early crystallization of a mineral assemblage with low total SiO_2 compared to the basalt. Of the minerals likely to crystallize, those with low SiO_2 relative to a basaltic parent are amphibole, the Fe-oxides and Fe-sul-

fide. The variables which will be important in determining whether these minerals crystallize early or late (or at all) in a fractionating basalt are f_{H_2O}, f_{HF}, f_{S_2}, and f_{O_2} in addition to the basalt composition. Previous work (12, 13) has shown that amphibole could appear early enough to produce SiO_2 enriched differentiates but only at pressures greater that 2.5 kb and only with relatively high fugacities of H_2O and/or HF. These data were obtained at relatively high f_{O_2}'s (NNO buffer). We have done experiments at low f_{O_2}'s (wustite field) which are possibly more appropriate to the interiors of the terrestrial planets (14). Our data show that the lowering of f_{O_2}'s does not affect the amphibole crystallization temperature (other variables remaining constant), but it does appear to reduce the amount of amphibole which forms. The tentative conclusion is that the effectiveness of amphibole as a basalt fractionating agent may be limited in reduced systems.

More important however, the same set of low f_{O_2}, hydrothermal experiments when compared to otherwise identical anhydrous experiments show that f_{H_2O} (.6 P_{fluid} where $P_{fluid} = P_{total}$) caused Fe-Ti oxides to appear relatively earlier (50% crystallization vs 75%) in the crystallization sequence of a fractionating basalt. As a result, the residual melt after 60% crystallization in a hydrothermal experiment at 1 kb contained 60 wt% SiO_2, while the same degree of crystallization in an anhydrous experiment produced a residual melt with only 52 wt% SiO_2. This is especially important because it means that basalts can follow a SiO_2 enrichment trend during fractionation at high as well as low levels in a planetary crust as long as the f_{O_2} is low and H_2O is present in the melt. Above 2.5 kb amphibole and then Fe-Ti are the fractionating low SiO_2 phases; only Fe-Ti oxides are involved in the 0.5-2.5 kb range, but they are effective (14). Thus an abundance of H_2O appears to be one of the critical factors in determining the nature of the basalt fractionation path.

Fractionation of Fe-metal or FeS, important processes in the early history of some terrestrial planets, could also occur in basalts under certain conditions and would favor an SiO_2 enrichment fractionation path. This has been demonstrated in anhydrous low pressure experiments on a somewhat evolved (MgO/FeO = 7/14) basalt which was pre-reduced so that Fe-metal formed during the experiment. The resulting melt contained 60 wt% SiO_2 after 50-75% crystallization of silicates + Fe-metal. SiO_2 enrichments have also been produced by crystallizing the same basalt at sulfur fugacities sufficiently high to form an immiscible FeS phase (15).

The process of partial melting of hydrated basalt to produce granitic magmas (process (c)) has also been demonstrated by our near equilibrium experiments (14). The main requirements for such a process are a source of H_2O, a mechamism for emplacing the water to some depth in the crust and a heat source. On the earth, it is now well established that water is emplaced to at least 2 km depth and probably deeper at fracture zones and by convection cells set up around hot intrusions. Later intrusions of anhydrous basalt magma are 300°C above the temperature required to produce granitic melts from a hydrated basalt (at 1 kb) and could serve as a heat source.

DISCUSSION-Is it likely that granitic magmas were produced on Mars? In what quantities? By what process? A number of observations concerning the planet are important in attempting to answer these questions. (a) Basaltic volcanism has been an important processes on Mars over a long period of time (16); thus there has been the source material and the time necessary for these basalts to fractionate (b) The bulk composition of Mars in terms of the non-volatiles is considered similar to, but somewhat Fe-enriched com-

pared to the earth (17). This would appear to favor SiO_2 enrichment-type basalt fractionation processes because it would enhance early formation of Fe, Fe oxides and/or FeS. (c) The question of whether there was sufficient volatiles, particularly water, on Mars to facilitate the production of granitic melts is not well resolved. However, there is a growing body of evidence to suggest that H_2O occurs in the polar caps, probably as a layer of ground ice (18) in the atmosphere (19), even though the planet may be somewhat volatile poor (20). If the abundances of chlorine and sulfur are high in the crust as suggested by the soil analyses (21) the net result would be similar to an increase in f_{H_2O}.

CONCLUSIONS - In conclusion, it seems appropriate to think of granitic magma genesis on Mars in the context of what we now know about the earth and the moon. Numerous factors all suggest that granitic rocks should be more abundant on Mars than they are on the moon. The prolonged igneous history, the Fe-enriched composition and the presence of some H_2O as well as S and Cl all favor the production of granitic melts via the continuous SiO_2 enrichment process. The identification of table mountains on Mars indicates volcanism after the formation of glaciers on the planet. This would indicate there was opportunity for volatiles to be incorporated into the crust and then be available for involvement in a basalt melting process. Finally, we have the new experimental data which shows that in a reduced planet fractionation along a SiO_2 enrichment trend is facilitated by early crystallization of Fe-Ti oxides if there is some H_2O present. All of these points suggest that granitic rocks should be fairly common in the Mars crust. In terms of the amount of rock-types present it may be appropriate to think of Mars somewhere between the moon as our extreme and Iceland (10% exposed granites) on the other.

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