FINAL REPORT

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EXPERIMENTAL STUDY OF LUNAR AND SNC MAGMAS

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PROJECT SUMMARY

1. General The research described in this progress report involved the study of petrological, geochemical, and volcanic processes that occur on the Moon and the SNC meteorite parent body, generally accepted to be Mars. The link between these studies is that they focus on two terrestrial-type parent bodies somewhat smaller than earth, and the fact that they focus on the types of magmas (magma compositions) present, the role of volatiles in magmatic processes, and on processes of magma evolution on these planets. We are also interested in how these processes and magma types varied over time. The research activities of the P.I., four graduate students, and two undergraduates have been supported at various levels during the tenure of the grant.

The work on the lunar volcanic glasses has resulted in some exciting new discoveries over the years of this grant. In earlier work on the A15 green and A17 orange lunar glasses, we discovered a variety of metal blebs. Some of these Fe-Ni metal blebs occur in the glass; others (in A17) were found in olivine phenocrysts that we find make up about 2 vol % of the orange glass magma. The importance of these metal spheres is that they fix the oxidation state of the parent magma during the eruption, and also indicate changes during the eruption (Weitz et al., 1997; 1999). They also yield important information about the composition of the gas phase present, the gas that drove the lunar fire-fountaining. During the tenureof this grant, we have continued to work on the remaining questions regarding the origin and evolution of the gas phase in lunar basaltic magmas, what they indicate about the lunar interior, and how the gas affects volcanic eruptions. (Rutherord an Papale, 2003; Nicholis and Rutherford, 2004).

Work on Martian magmas petrogenesis questions during the tenure of this grant has resulted in advances in our methods of evaluating magmatic oxidation state variations in Mars (Mccanta et al., 2004a, b), and some new insights into the compositional variations that existed in the SNC magmas over time (Calvin and Rutherford, 2004). Additionally, Minitti has continued to work on the problem of possible shock effects on the abundance and distribution of water in Mars minerals.

2. Results on specific projects

a) Picritic Lunar Glasses, Volcanism, Volatiles, and Lunar Oxidation State

The first lunar project where new results were obtained during the tenure of this grant was the modeling of the physics of lunar fire-fountain eruptions of primitive mare basalt based on the new oxidation state and gas composition data we have obtained (Rutherford and Papale, 2003; ms in revision). Using the new estimate for the depth of carbon oxidation in the A17 orange glass, and our new data estimating the amount of sulfur that subsequently was lost to this gas phase, we have modeled the bubble content and magma rise velocity as a function of

magma position above the site of the first C-O gas production. We also determined that the magma would not fragment until it exited from the vent at the surface because the viscosity we calculated was so low. The second project where interesting new data were obtained is a project in which Mike Nicholis is experimentally calibrating the position of the graphite + C-O gas equilibrium (Nicholis and Rutherford, 2004). We have determined that this equilibrium is significantly offset from the position calculated using available thermodynamic data,. The new results significantly increase the depth estimates of where graphite would experience oxidation to form CO-rich gas as it is carried toward the surface in magmas of small terrestrial-like planets such as the earth's moon. These results are being expanded to include analyses of the effects of metal impurities, and the abundance of sulfur in these melts and the associated gas phase.

b. SNC "Mars" Meteorite Studies

The SNC meteorites, including the compositions of SNC basaltic melts, and the role of volatiles in SNC magmatic processes is another set of problems we studied during the tenure of this grant. To review, the SNC meteorites are the only samples we have from Mars, some are basaltic, but many are cumulate rocks, and all have been heavily shocked by the impacts that released them from Mars. All of the Mars samples found among the terrestrial meteorite collections so far (> 30 samples) have chemical characteristics indicating they are part of the low-Al, high-Fe SNC group. Since almost all of these SNC samples are totally crystallized as well as shocked, it has been difficult to determine precisely what melt compositions existed during his phase of magmatic activity on Mars. It has also been difficult to determine the precise conditions, pressure, temperature, wate abundance and oxidation state. During the tenure of this grant, recent PhD., Molly McCanta and the P.I. have completed two projects, one calibrating the distribution of rare earth elements between pyroxenes and basaltic melt as a function of oxygen fugacity. This result is particularly important in attempting to access the oxygen fugacity at depth in Mars (McCanta et al., 2004a). In the other project we worked on the developing new methods for determining iron oxidation states in basaltic liquids (McCanta et al., 2004b). In our third Mars research project, we (Calvin and Rutherford, 2004) have developed and used techniques to experimentally rehomogenize interstitial and inclusion (within phenocrysts) melts to determine their composition, and depth of equilibration.

3. PUBLICATIONS AND THESES

Published papers:

1. Minitti, M.E., and Rutherford, M.J.(2000) Genesis of the Pathfinder "sulfur-free" rock from SNC parental liquids. GCA, 64, 2535-2547.
2. Minitti, M.E., Mustard, J.F., and Rutherford, M.J., (2002) The effects of Glass content and Oxidation on the spectra of SNC-like basalts: Applications to Mars

Remote Sensing. JGR,, 107, E5, 6-1 to 6-14.
3. McCanta M.C., Dyar M.D., Rutherford M.J., and Delaney J.S. (2004a, in press) Iron partitioning between basalt and clinopyroxene as a function of oxygen fugacity. *Amer. Mineral.*
4. McCanta M.C., Rutherford M.J., and Jones J.H. (2004b) An experimental study of rare earth element partitioning between a shergottite melt and pigeonite: implications for the oxygen fugacity of the Martian interior. *Geochim. Cosmochim. Acta. V 68, 1943-1952.*
5. Rutherford, MJ and Papale, P. (in prep) Pre-eruption conditions and Eruption mechanisms of the Lunar A17 orange Glass eruption.

Recent Abstracts of Talks presented at National & International Science meetings:

McCanta, M.C., and Rutherford, M.J. (2001) SNC oxygen fugacity as recorded in Pyroxenes: an experimental study. LPSC 32, #1938.

McCanta, MC, Rutherford, MJ, and Jones, JH, 2002. An experimental study of Eu/Gd partitioning between a shergottite melt and pigeonite: Implications for the fO2 of the Martian interior. LPSC XXXIII, #1942.

Rutherford, M.J., and Paolo Papale (2003) Eruption conditions and mechanism of the A17 Orange Glass magma eruption: Petrology and Modeling Data. LPSC XXXIV, #1322.

Calvin, C and Rutherford, M.J. (2004). Rehomogenizing melt intestitial and inclusion melts in Lherzolitic Shergotite Alh 77005: Petrologic Significance. LPSC XXXV, 1371.

McCanta M.C., Rutherford M.J., Dyar M.D., and Delaney J.S. (2004) The relationship between clinopyroxene Fe^{3+} content and oxygen fugacity. In *Lunar and Planetary Science XXXV,* Abstract 1165 (CD-ROM).

McCanta M.C., Rutherford M.J., Dyar M.D., and Delaney J.S. (2003) $Fe^{3+}/\sum Fe$ ratios in pigeonite as a function of fO2: a preliminary investigation. In *Lunar and Planetary Science XXXIV,* Abstract 1361 (CD-ROM)).

Nicholis, M.G., and Rutherford, M.J., (2004) Oxidation-reduction processes on the Moon: Experimental verification of graphite oxidation in the Apollo 17 orange glass. (Invited). Oxygen in the Terrestrial Planets; LPI Workshop, Santa Fe, New Mexico, July 20-23, 2004.

Rutherford, M.J. (2004) Magmatic Volatiles: Speciation and the role of Oxidation State. (Invited) Oxygen in the Terrestrial Planets; LPI Workshop, Santa Fe, New Mexico, July 20-23, 2004.

Theses Completed:

PhD.

1. Michelle Minitti. PhD in 2000. Thesis topic: Role of Water in SNC magma evolution and possible effects of Shock pressures on observed water abundances. Michelle is now a research associate at Arizona State University.
2. Molly McCanta. Phd in 2004. Thesis topic: The effect of Oxygen Fugacity and volatile Content on Martian and terrestrial basalt evolution. McCanta is now the Urey post-doc at the LPI.

Supported and still in Progress:

3. Mike Nicholis. Experimental calibration of the Graphite-C-O equilibrium and evaluation of associated oxidation-Reduction reactions in lunar magmas.
4. Christine Calvin. Investigation of SNC melt compositions by rehomogenization of interstitial and inclusion melts in SNC meteorites.

Undergraduate

Nora Sullivan. In progress. Experimental investigation of melt composition in the EETA 79001 SNC meteorite.