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FINAL REPORT

Early Differentiation of the Moon: Experimental and Modeling Studies

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SUMMARY

NASA grant NAGW-175 (John Longhi, P.I.) was in effect from 2/1/81 to 1/31/86, the last year being a no-cost extension. During this period the P.I. gave 10 talks at professional meetings, had 9 abstracts published, edited 1 LPI workshop report, and submitted 7 manuscripts for publication in refereed journals - all of which pertained to tasks listed in his proposals. A list of these activities is given at the end of this report along with copies of all the abstracts.

The major accomplishments of this research effort have been: 1) the mapping out of liquidus boundaries of lunar and meteoritic basalts at low-pressure; 2) the refinement of computer models that simulate low-pressure fractional crystallization; 3) the development of a computer model to calculate high-pressure partial melting of the lunar and martian interiors; and 4) the proposal of a new hypothesis of early lunar differentiation based upon terrestrial analogs.

1) Since the beginning of this century petrologists tried to understand the crystallization behavior of basaltic magmas by determining simple 2-, 3-, and occasionally 4-component liquidus diagrams. These diagrams have proved to be extremely useful, but have always fallen short of describing the full complexity of the natural system. The experimental data gathered by the P.I. and their graphical presentation [17, 18] go a long way toward bridging the gap between simple laboratory melt systems and natural magmas.

2) Many natural magmatic processes, such as fractional crystallization, accumulation, and assimilation, cannot be investigated directly with laboratory experiments. These processes can be effectively simulated, however, once the liquidus equilibria (liquidus boundaries and crystal-liquid partition coefficients) are quantified. Incorporation of new experimental data into existing computer models of magmatic crystallization originally developed by the P.I. has been an on-going effort. Applications of the refined models were made in simulations of mineral composition trends observed in pristine lunar highland rocks [13] and the role of assimilation in the petrogenesis of magmas parental to the Stillwater Complex [14], an intrusive body often referred to as an analog for magmatic processes in the early lunar crust. [13] showed that the pattern of mineral compositions observed in lunar anorthosites and thought to be "anomalous" was in fact normal for lunar compositions. [14] showed that the compositions of ultramafic magmas that intrude the Earth's crust to form large layered intrusions may be significantly altered by assimilation.

3) Although the experimental data base for high-pressure liquidus equilibria is much less extensive than that at low pressure, it is nonetheless possible to develop reasonably accurate quantitative models for high-pressure partial melting. [12] showed that the magmas parental to the suite of lunar pristine high-Mg cumulate rocks could not have been direct melts of a chondritic lunar interior as had been widely believed given their antiquity. [16] constrained the range of composition in the martian interior that could have melted to produce the lava

flows now degraded to soil.

4) Two opposing models of early lunar evolution exist. One postulates a global magma ocean and the formation of lunar anorthosites as a floating crust. The other (serial magmatism) postulates numerous relatively small intrusions of magma near the surface of the moon and the formation of anorthosites within these intrusions. The former model does not agree with slow accretion models and the crystallization dynamics of a magma ocean are not understood well enough to actually predict anorthosites; the latter model does not explain the absence of rocks comagmatic with the anorthosites. [15] bridges the gap between the two models by appealing to multiple intrusions of partially molten anorthositic diapirs in a manner analogous to that proposed for the largest masses of terrestrial anorthosites.

Talks at Professional Meetings and Workshops

"Modeling Equilibrium Partial Melting: Implications for Early Lunar Differentiation" - Twelfth Lunar and Planetary Science Conference, March, 1981.

"Multicomponent Phase Diagrams and the Phase Equilibria of Basalts" - Workshop on Magmatic Processes of Early Planetary Crusts, August, 1981.

"Modeling High Pressure Partial Melting of the Martian Mantle" - Thirteenth Lunar and Planetary Science Conference, March, 1982.

"A Brief Survey of Early Lunar Igneous History" - Workshop on Pristine Highlands Rocks and the Early History of the Moon, October, 1982.

"High-K Komatiite Dikes from the Beartooth Mts." - Fourteenth Lunar and Planetary Science Conference, March, 1983.

"Empirical Modeling of High-Pressure Partial Melting: The Alkali Effect" - American Geophysical Union Spring Meeting, May, 1983.

"Geochemical and Petrological Constraints on Planetary Volcanism" - Geological Society of America Annual Meeting, October, 1983.

"A Two-stage Model for Lunar Anorthosites: An Alternative to the Magma Ocean Hypothesis" - Fifteenth Lunar and Planetary Science Conference, March, 1984.

"Geochemical Constraints on the Origin of the Moon" - Conference on the Origin of the Moon, November, 1984.

Short Abstracts

[1] Longhi, J., Empirical modeling of high-pressure partial melting: The alkali effect (abstract), EOS, 64, p. 349, 1983.

[2] Longhi, J., Geochemical and petrological constraints on planetary volcanism, Abstracts with Programs, 1983, Geological Society of America, p. 630-631, 1983.

Extended Abstracts

[3] Longhi, J., Modeling equilibrium partial melting: Implications for early lunar differentiation (abstract). Lunar and Planetary Science XII, p. 625-627. The Lunar and Planetary Institute, Houston, 1981.

[4] Longhi, J., Multicomponent phase diagrams and the phase equilibria of basalts, in Workshop on Magmatic Processes of Early Planetary Crusts, pp. 92-94. The Lunar and Planetary Institute, Houston, 1982.

[5] Longhi, J., Mineral composition trends and cumulate processes, in Lunar and Planetary Science XIII, p. 443-444. The Lunar and Planetary Institute, Houtson, 1982.

[6] Longhi, J., Modeling high pressure partial melting of the Martian mantle, in Lunar and Planetary Science XIII, p. 445-446. The Lunar and Planetary Institute, Houston, 1982.

[7] Longhi, J., Early lunar igneous history, in Workshop on Pristine Highlands Rocks and the Early History of the Moon, p. 58-61. Lunar and Planetary Institute, Houston, 1983.

[8] Longhi, J. and J. L. Wooden, High-K komatiite dikes from the Beartooth Mts., in _Lunar and Planetary Science XIV_, p. 444-445. The Lunar and Planetary Institute, Houston, 1983.

[9] Longhi, J. and L. D. Ashwal, A two-stage model for lunar anorthosites: An alternative to the magma ocean hypothesis, in _Lunar and Planetary Science XV_, p. 491-492. The Lunar and Planetary Institute, Houston, 1984.

[10] Longhi, J., Ultramafic parent magmas for mare basalts? in _Workshop on the Geology and Petrology of the Apollo 15 Landing Site_, Lunar and Planetary Institute, p. 35-38, 1985.

Workshop Reports

[11] Longhi, J. and G. Ryder (eds.) _Workshop on Pristine Highlands Rocks and the Early History of the Moon_, LPI Tech. Rpt. 83-02, Lunar and Planetary Institute, Houston, 92 pp., 1983.

Journal Articles

[12] Longhi, J., Preliminary modeling of high pressure partial melting: Implications for early lunar differentiation, _Proc. Lunar Planet. Sci. Conf. 12_, p. 1001-1018, 1981.

[13] Longhi, J., Effects of fractional crystallization and cumulus processes on mineral composition trends of some lunar and terrestrial rock series, _J. Geophys. Res._, _87_, _Suppl._, A54-A64, 1982.

[14] Longhi, J., Wooden, J. L., and K. D. Coppinger, The petrology of high-Mg dikes from the Beartooth Mountains, Montana: A search for the parent magma of the Stillwater Complex, J. Geophys. Res., 88, Suppl., B53-B69, 1983.

[15] Longhi, J. and L. D. Ashwal, Two-stage models for lunar and terrestrial anorthosites: Petrogenesis without a magma ocean, J. Geophys. Res., 90, Suppl., C571-C584, 1985.

[16] Longhi, J., Some constraints on weathering and magmatism on Mars, Icarus, in revision.

[17] Longhi, J., Liquidus equilibria and solid solution in the system Anorthite-Forsterite-Wollastonite-Silica at low pressure, Am. J. Sci., in revision.

[18] Longhi, J. and V. Pan, A reconnaissance study of phase boundaries in low-alkali basaltic liquids, J. Petrol., in revision.