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21 November 2002

Ms. Antoinette Bigby
Administrative Grants Officer
Office of Naval Research, Atlanta Regional Office
Suite 4R15
100 Alabama Street, S.W.
Atlanta, GA 30303-3104

Dear Ms. Bigby:

Please find enclosed a copy of the Final Technical Report for NASA Grant NAG 5-4077, entitled "Tectonic evolution of the terrestrial planets." The period of the grant extended from 1 April 1997 through 30 September 2001.

If you have any questions regarding this report, please contact me by phone (202/478-8850) or electronic mail (scs@dtm.ciw.edu).

Sincerely,

Sean C. Solomon
Director

cc: Terry L. Stahl, DTM Fiscal Officer
Jeffrey J. Lightfield, CIW Deputy Financial Manager
David G. Senski, NASA Technical Officer
Sandra R. Russo, NASA Grant Negotiator
CASI

FINAL TECHNICAL REPORT

to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM

NASA GRANT NAG 5-4077

"Tectonic Evolution of the Terrestrial Planets"

for the period 1 April 1997 — 30 September 2001

Principal Investigator: Sean C. Solomon
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21 November 2002

Introduction

Grant NAG 5-4077, from the NASA Planetary Geology and Geophysics Program, supported a wide range of work on the geophysical evolution of the terrestrial planets during the period 1 April 1997 — 30 September 2001. We here provide highlights of the research carried out under this grant over the final year of the award, and we include a full listing of publications and scientific meeting presentations supported by this project.

Throughout the grant period, our group consisted of the Principal Investigator and several Postdoctoral Associates, all at the Department of Terrestrial Magnetism (DTM) of the Carnegie Institution of Washington. Postdoctoral scientists who were in the group for a portion of the grant period include Jonathan Aurnou (now on the faculty at U.C.L.A.), Andrew Dombard (now on the research staff at Washington University), Andrew Freed (now on the faculty at Purdue University), Steven Hauck (still at DTM), Catherine Johnson (now on the faculty at the University of California at San Diego), and Patrick McGovern (now on the research staff at the Lunar and Planetary Institute).

Recent Progress

Highlights of the completed work from last year include the following:

• Our group completed a global analysis of gravity/topography admittance on Mars. The analysis makes use of topography and gravity collected by the Mars Global Surveyor spacecraft, the spatio/spectral localization methodology of Mark Simons and others, and the correction for finite-amplitude topography and interface relief of Mark Wieczorek and Roger Phillips. These procedures obviate the need to invoke anomalously dense surface material or buried excess masses in areas of highest admittance (e.g., Tharsis), as others have concluded. In general, the thicknesses of the Martian elastic lithosphere derived from a comparison of observed and forward modeled admittances decrease with the age of the loading feature, consistent with a general decline in mantle heat flux over Martian history.

• Our group also completed a more detailed analysis of the topography, gravity, and tectonics of Alba Patera in an effort to understand the evolution of one of the largest volcanic constructs on Mars. By combining finite-element models of loading with gravity/topography admittance analysis, we showed that sub-lithospheric and intrusive loads in addition to extrusive loads and regional extension played important roles in the evolution of the shape and deformation of the edifice.

• We participated in an analysis of the conditions under which the characteristics of a core in Mercury can be recovered by measurement of the obliquity, the second degree and order gravity field, and the amplitude of the physical libration forced by periodic solar torques. New work included demonstrations that core-mantle coupling by pressure forces on an irregular boundary, gravitational torques between an axially symmetric mantle and an axially asymmetric solid inner core, or magnetic coupling between a fluid metallic outer core and a conducting layer at the base of the mantle do not frustrate the conditions for recovering the state and radius of the outer core.

• Through finite-element models of loading of the lunar lithosphere by mascon maria, we showed that the absence of strike-slip faults around lunar mare basins predicted by many earlier models can be explained by including the effects of surface curvature, more complete fault-style criteria, multi-stage histories of mare flooding, and heterogeneous crustal strength. Specific models for Mare Serenitatis confirm earlier results that the underlying lithosphere was about 25 km thick at the time of local rille formation and had thickened to about 75 km by the time of late stage mare ridge formation, and that superposed global contraction is needed to account for the radial extent of mare ridges and the inferred cessation of rille formation prior to the time of emplacement of youngest mare basalts.

Each of the three postdoctoral scientists in our group during the past year carried out independent research that led to publications or to papers submitted for publication. Among these projects were the following:

• Postdoctoral scientist Andrew Dombard tested an earlier hypothesis that floor-fractured craters on the Moon may be the product of viscoelastic relaxation of topographically-induced stresses. Combining an elastoviscoplastic finite-element model and the ductile flow law of anhydrous diabase determined from recent laboratory measurements, it can be shown that relaxation is insufficient to produce the observed shoaling of floor depths in floor-fractured craters for a wide range of assumptions regarding local heat flux. Alternative hypotheses for the origin of floor fracturing (e.g., igneous intrusions) are therefore favored.

• Postdoctoral scientist Jonathan Aurnou carried out a numerical study of zonal wind generation by thermal convection in rotating spherical shells. He showed that for quasi-geostrophic, high-Rayleigh-number convection, particularly in thin shells with stress-free boundaries, strong zonal winds are predicted to be prograde (eastward) near the equator and westward at higher latitudes. Episodes of strong winds are predicted to alternate with episodes of strong convection. His models support the interpretation that the prograde equatorial jets on Jupiter and Saturn originate from deep convection.

• Postdoctoral scientist Steven Hauck completed a study of parameterized thermal history models for Mars that incorporated melt generation and fractionation of heat-producing elements during melting. Models providing the best matches to the timing of formation and present volume of crust on Mars have chondritic abundances of heat-producing elements, significant fractionation of these elements into the crust, and a mantle water content sufficiently high to lower the creep strength from that at dry conditions.

Publications

During the period 1 April 1997 — 30 September 2001, grant NAG 5-4077 supported the publication of 27 articles, including 24 papers in refereed journals, one book chapter, one encyclopedia article, and one piece in a popular science magazine. In addition, the grant supported 65 published abstracts of presentations made at national and international scientific meetings.

Published Articles Supported by Grant NAG 5-4077
1 April 1997 — 30 September 2001

Aurnou, J. M., and P. L. Olson, Strong zonal winds driven by thermal convection in a rotating spherical shell, *Geophys. Res. Lett.*, *28*, 2557-2559, 2001.

Dombard, A. J., and A. M. Freed, Thermally induced lineations on the asteroid Eros: Evidence of orbit transfer, *Geophys. Res. Lett.*, *29* (16), 10.1029/2002GL015181, 2002.

Dombard, A. J., and J. J. Gillis, Testing the viability of topographic relaxation as a mechanism for the formation of lunar floor-fractured craters, *J. Geophys. Res.*, *106*, 27,901-27,909, 2001.

Dombard, A. J., and W. B. McKinnon, Formation of grooved terrain on Ganymede: Extensional instability mediated by cold, superplastic creep, *Icarus, 154*, 321-336, 2001.

Freed, A. M., H. J. Melosh, and S. C. Solomon, Tectonics of mascon loading: Resolution of the strike-slip faulting paradox, *J. Geophys. Res.*, *106*, 20,603-20,620, 2001.

Hauck, S. A., II, and R. J. Phillips, Thermal and crustal evolution of Mars, *J. Geophys. Res.*, *107* (E7), 10.1029/2001JE001801, 2002.

Johnson, C. L., S. C. Solomon, J. W. Head III, R. J. Phillips, D. E. Smith, and M. T. Zuber, Lithospheric loading by the northern polar cap on Mars, *Icarus*, *144*, 313-328, 2000.

McGovern, P. J., and S. C. Solomon, Filling of flexural moats around large volcanoes on Venus: Implications for volcano structure and global magmatic flux, *J. Geophys. Res.*, *102*, 16,303-16,318, 1997.

McGovern, P. J., and S. C. Solomon, Growth of large volcanoes on Venus: Mechanical models and implications for structural evolution, *J. Geophys. Res.*, *103*, 11,071-11,101, 1998.

McGovern, P. J., S. C. Solomon, J. W. Head III, D. E. Smith, and M. T. Zuber, Extension and uplift at Alba Patera, Mars: Insights from MOLA observations and loading models, *J. Geophys. Res.*, *106*, 23,769-23,809, 2001.

McGovern, P. J., S. C. Solomon, D. E. Smith, M. T. Zuber, M. Simons, M. A. Wieczorek, R. J. Phillips, G. A. Neumann, O. Aharonson, and J. W. Head, Localized gravity/topography admittance and correlation spectra on Mars: Implications for regional and global evolution, *J. Geophys. Res.*, in press, 2002.

Namiki, N., and S. C. Solomon, Volcanic degassing of argon and helium and the history of crustal production on Venus, *J. Geophys. Res.*, *103*, 3655-3677, 1998.

Olson, P. L., I. Sumita, and J. M. Aurnou, Diffusive magnetic images of upwelling patterns in the core, *J. Geophys. Res.*, in press, 2002.

Peale, S. J., R. J. Phillips, S. C. Solomon, D. E. Smith, and M. T. Zuber, A procedure for determining the nature of Mercury's core, *Meteorit. Planet. Sci.*, *37*, 1269-1283, 2002.

Phillips, R. J., C. L. Johnson, S. J. Mackwell, P. Morgan, D. T. Sandwell, and M. T. Zuber, Lithospheric mechanics and dynamics of Venus, in *Venus II*, edited by S. W. Bougher, D. M. Hunten, and R. J. Phillips, pp. 1163-1204, Univ. Arizona Press, Tucson, 1997.

Phillips, R. J., M. T. Zuber, S. C. Solomon, M. P. Golombek, B. M Jakosky, W. B. Banerdt, D. E. Smith, R. M. E. Williams, B. M. Hynek, O. Aharonson, and S. A. Hauck II, Ancient geodynamics and global-scale hydrology on Mars, *Science, 291*, 2587-2591, 2001.

Sandwell, D. T., C. L. Johnson, F. Bilotti, and J. Suppe, Driving forces for limited tectonics on Venus, *Icarus*, *129*, 232-244, 1997.

Simons, M., S. C. Solomon, and B. H. Hager, Localization of gravity and topography: Constraints on the tectonics and mantle dynamics of Venus, *Geophys. J. Int., 131*, 24-44, 1997.

Smith, D. E., M. T. Zuber, H. V. Frey, J. B. Garvin, J. W. Head, D. O. Muhleman, G. H. Pettengill, R. J. Phillips, S. C. Solomon, H. J. Zwally, W. B. Banerdt, and T. C. Duxbury, Topography of the northern hemisphere of Mars from the Mars Orbiter Laser Altimeter, *Science*, *279*, 1686-1692, 1998.

Smith, D. E., M. T. Zuber, S. C. Solomon, R. J. Phillips, J. W. Head, J. B. Garvin, W. B. Banerdt, D. O. Muhleman, G. H. Pettengill, G. A. Neumann, F. G. Lemoine, J. B. Abshire, O. Aharonson, C. D. Brown, S. A. Hauck, A. B. Ivanov, P. J. McGovern, H. J. Zwally, and T. C. Duxbury, The global topography of Mars and implications for surface evolution, *Science*, *284*, 1495-1503, 1999.

Solomon, S. C., Venus: Geology and geophysics, in *Encyclopedia of Planetary Sciences*, edited by J. H. Shirley and R. W. Fairbridge, pp. 895-904, Chapman & Hall, London, 1997.

Solomon, S. C., Return to the iron planet, *New Scientist, 165* (2223), 32-35, 2000.

Solomon, S. C., Planetary science: An older face for Mars, *Nature, 418*, 27-28, 2002.

Solomon, S. C., M. A. Bullock, and D. H. Grinspoon, Climate change as a regulator of tectonics on Venus, *Science*, *286*, 87-90, 1999.

Zuber, M. T., D. E. Smith, R. J. Phillips, S. C. Solomon, W. B. Banerdt, G. A. Neumann, and O. Aharonson, Shape of the northern hemisphere of Mars from the Mars Orbiter Laser Altimeter (MOLA), *Geophys. Res. Lett.*, *25*, 4393-4396, 1998.

Zuber, M. T., D. E. Smith, S. C. Solomon, J. B. Abshire, R. S. Afzal, O. Aharonson, K. Fishbaugh, P. G. Ford, H. V. Frey, J. B. Garvin, J. W. Head, A. B. Ivanov, C. L. Johnson, D. O. Muhleman, G. A. Neumann, G. H. Pettengill, R. J. Phillips, X. Sun, H. J. Zwally, W. B. Banerdt, and T. C. Duxbury, Observations of the north polar region of Mars from the Mars Orbiter Laser Altimeter, *Science*, *282*, 2053-2060, 1998.

Zuber, M. T., S. C. Solomon, R. J. Phillips, D. E. Smith, G. L. Tyler, O. Aharonson, G. Balmino, W. B. Banerdt, J. W. Head, C. L. Johnson, F. G. Lemoine, P. J. McGovern, G. A. Neumann, D. D. Rowlands, and S. Zhong, Internal structure and early thermal evolution of Mars from Mars Global Surveyor topography and gravity, *Science*, *287*, 1788-1793, 2000.

Published Abstracts of Scientific Presentations Supported by NASA Grant NAG 5-4077
1 April 1997 — 30 September 2001

Aharonson, O., M. T. Zuber, and S. C. Solomon, Could Mercury's magnetic field be crustal in light of Runcorn's theorem?, *34th Scientific Assembly of the Committee on Space Research and 53rd International Astronautical Congress of the International Astronautical Federation*, American Institute of Aeronautics and Astronautics, abstract 1204, 2002 (CD-ROM).

Al-Shamali, F. M., M. H. Heimpel, and J. M. Aurnou, Varying the shell geometry in planetary dynamo models, *Eos Trans. Amer. Geophys. Un., 82*, Fall Meeting Suppl., F329, 2001.

Aurnou, J. M., and F. M. Al-Shamali, Applying numerical dynamo models to Mercury, in *Workshop on Mercury: Space Environment, Surface, and Interior*, pp. 2-3, Lunar and Planetary Institute, Houston, Tex., 2001.

Aurnou, J. M., F. M. Al-Shamali, and M. H. Heimpel, Dynamo processes in a thin shell geometry, *Eos Trans. Amer. Geophys. Un., 82*, Fall Meeting Suppl., F329, 2001.

Bullock, M. A., S. C. Solomon, and D. H. Grinspoon, Relationships among volcanic eruptions, climate change, and tectonics on Venus: The effects of medium-sized eruptions, in *Lunar and Planetary Science XXXI*, abstract 2051, Lunar and Planetary Institute, Houston, Tex., 2000 (CD-ROM).

Bulmer, M. H., and P. J. McGovern, The role of mass movements in the evolution of Olympus Mons, in *Lunar and Planetary Science XXIX*, abstract 1947, Lunar and Planetary Institute, Houston, Tex., 1998 (CD-ROM).

Dombard, A. J. and A. M. Freed, Thermal stresses on asteroids: Application to Eros, Eos Trans., *Amer. Geophys. Un., 82*, Spring Meeting suppl., S242, 2001.

Dombard, A. J., S. A. Hauck II, S. C. Solomon, and R. J. Phillips, Potential for long-wavelength folding on Mercury, in *Lunar and Planetary Science XXXII*, abstract 2035, Lunar and Planetary Institute, Houston, Tex., 2001 (CD-ROM).

Dombard, A. J., C. L. Johnson, M. A. Richards, and S. C. Solomon, A transient plume melting model for coronae on Venus, in *Lunar and Planetary Science XXXIII*, abstract 1877, Lunar and Planetary Institute, Houston, Tex., 2002 (CD-ROM).

Dombard, A. J., and W. B. McKinnon, Formation of grooved terrain on Ganymede via extensional instability: Regional constraints on thermal gradients and strain rate, in *Lunar and Planetary Science XXXIII*, abstract 1865, Lunar and Planetary Institute, Houston, Tex., 2002 (CD-ROM).

Dombard, A. J., S. C. Solomon, M. A. Bullock, R. J. Phillips, and D. H. Grinspoon, The formation of wrinkle ridges on Venus via climate change: A thermomechanical finite element analysis, in *Lunar and Planetary Science XXXI*, abstract 1197, Lunar and Planetary Institute, Houston, Tex., 2000 (CD-ROM).

Duxbury, T. C. D. E. Smith, M. T. Zuber, H. V. Frey, J. B. Garvin, J. W. Head, D. O. Muhleman, G. H. Pettengill, R. J. Phillips, S. C. Solomon, H. J. Zwally, and W. B. Banerdt, MOLA: The Future of Mars global cartography, in *Fifth International Conference on Mars*, abstract 6040, Lunar and Planetary Institute, Houston, Tex., 1999 (CD-ROM).

Freed, A. M., H. J. Melosh, and S. C. Solomon, Tectonics of mascon loading: Resolution of the strike-slip fault paradox, in *Lunar and Planetary Science XXX*, abstract 1691, Lunar and Planetary Institute, Houston, Tex., 1999 (CD-ROM).

Hauck, S. A., II, Statistics on Venus: Craters and catastrophes (?), *Interface 2002, Program*, p. 22, Montreal, Canada, 2002.

Hauck, S. A., II, A. J. Dombard, R. J. Phillips, and S. C. Solomon, Thermo-compressional strain evolution of Mercury, *Eos Trans Amer. Geophys. Un., 81*, Spring Meeting suppl., S296, 2000.

Hauck, S. A., II, A. J. Dombard, R. J. Phillips and S. C. Solomon, Mercury's thermal, tectonic, and magmatic evolution, in *Workshop on Mercury: Space Environment, Surface, and Interior*, pp. 40-41, Lunar and Planetary Institute, Houston, Tex., 2001.

Hauck, S. A., II, A. J. Dombard, S. C. Solomon, and J. M Aurnou, Internal structure and mechanisms of core convection on Ganymede, in *Lunar and Planetary Science XXXIII*, abstract 1380, Lunar and Planetary Institute, Houston, Tex., 2002 (CD-ROM).

Head, J. W., and S. C. Solomon, Noachian-aged large impact basins: A comparison, *Abstracts with Programs, 34*, 70, Geol. Soc. Amer., Boulder, Colo., 2002.

Jager, K. M., J. W. Head, III, B. Thomson, P. J. McGovern, and S. C. Solomon, Alba Patera, Mars: Characterization using Mars Orbiter Laser Altimeter (MOLA) data and comparison with other volcanic edifices, in *Lunar and Planetary Science XXX*, abstract 1915, Lunar and Planetary Institute, Houston, Tex., 1999 (CD-ROM).

Johnson, C. L., P. J. McGovern, S. C. Solomon, D. T. Sandwell, and M. Simons, Lithospheric thickness variations on Venus, in *Geodynamics of Venus: Evolution and Current State*, 15, Amer. Geophys. Un., Washington, D.C., 1997.

Johnson, C. L., and M. A. Richards, A conceptual model for the relationship between coronae and large-scale mantle dynamics on Venus, *Lunar and Planetary Science XXXIII*, abstract 1733, Lunar and Planetary Institute, Houston, Tex., 2002 (CD-ROM).

Johnson, C. L., and S. C. Solomon, A global characterization of the gravity signatures of coronae on Venus, in *Lunar and Planetary Science XXXIII*, abstract 1952, Lunar and Planetary Institute, Houston, Tex., 2002 (CD-ROM).

Johnson, C. L., S. C. Solomon, J. W. Head, III, D. E. Smith, and M. T. Zuber, Lithospheric loading by the northern polar cap on Mars, in *Lunar and Planetary Science XXX*, abstract 1345, Lunar and Planetary Institute, Houston, Tex., 1999 (CD-ROM).

Johnson, C. L., S. C. Solomon, D. T. Sandwell, and M. Simons, Global and regional resolution analyses of Magellan gravity data and comparisons with current gravity models, in *Geodynamics of Venus: Evolution and Current State*, 14-15, Amer. Geophys. Un., Washington, D.C., 1997.

McGovern, P. J., C. L. Johnson, S. C. Solomon, J. W. Head, W. B. Banerdt, M. T. Zuber, D. E. Smith, and R. J. Phillips, Lithospheric loading and evolution of large volcanoes on Mars: New insights from MOLA observations, in *Lunar and Planetary Science XXIX*, abstract 1238, Lunar and Planetary Institute, Houston, Tex., 1998 (CD-ROM).

McGovern, P. J., C. L. Johnson, S. C. Solomon, and M. Simons, Estimates of elastic lithosphere thickness beneath large volcanoes and coronae on Venus from spatio-spectral localization of harmonic gravity and topography, in *Geodynamics of Venus: Evolution and Current State*, 15-16, Amer. Geophys. Un., Washington, D.C., 1997.

McGovern, P. J., C. L. Johnson, S. C. Solomon J. W. Head, W. B. Banerdt, M. T. Zuber, D. E. Smith, and R. J. Phillips, Lithospheric loading and evolution of large volcanoes on Mars: Latest insights from MOLA observations, *Eos Trans. Amer. Geophys. Un., 79*, Spring Meeting suppl., S190-S191, 1998.

McGovern, P. J., S. C. Solomon, S. E. Faulkner, D. E. Smith, and M. T. Zuber, Extension and volcanic loading at Alba Patera: Recent insights from MOLA observations, *Eos Trans. Amer. Geophys. Un., 79*, Fall Meeting suppl., F526, 1998.

McGovern, P. J., and S. C. Solomon, Effects of sub- and intra-lithospheric loading on topography and stresses in growing volcanoes: Applications to Galápagos and Canaries, *Eos Trans Amer. Geophys. Un., 81*, Spring Meeting suppl., S411, 2000.

McGovern, P. J., S. C. Solomon, S. E. Faulkner, J. W. Head, III, D. E. Smith, and M. T. Zuber, Extension and volcanic loading at Alba Patera: Insights from MOLA observations and loading models, in *Lunar and Planetary Science XXX*, abstract 1697, Lunar and Planetary Institute, Houston, Tex., 1999 (CD-ROM).

McGovern, P. J., S. C. Solomon, S. E. Faulkner, J. W. Head, D. E. Smith, and M. T. Zuber, The interplay of edifice and regional stress fields at Alba Patera: Insights from MOLA observations and loading models, *Eos Trans. Amer. Geophys. Un., 80*, Spring Meeting suppl., S202-S203, 1999.

McGovern, P. J., S. C. Solomon, D. E. Smith, G. A. Neumann, and J. W. Head, Localized gravity/topography admittances on Mars, in *Lunar and Planetary Science XXXI*, abstract 1792, Lunar and Planetary Institute, Houston, Tex., 2000 (CD-ROM).

McGovern, P. J., S. C. Solomon, D. E. Smith, M. T. Zuber, G. A. Neumann, and J. W. Head, Localized gravity/topography admittances in Tharsis, in *Abstracts, Tharsis Workshop*, Keystone, Colo., October 16-18, 2000.

McGovern, P. J., S. C. Solomon, D. E. Smith, M. T. Zuber, G. A. Neumann, J. W. Head, R. J. Phillips, and M. Simons, Gravity/topography admittances and lithospheric evolution on Mars: The importance of finite-amplitude topography, in *Lunar and Planetary Science XXXII*, abstract 1804, Lunar and Planetary Institute, Houston, Tex., 2001 (CD-ROM).

McKinnon, W. B., P. M. Schenk, and A. J. Dombard, Estimates of Europa's heat flow and ice shell thickness: Convergence at last?, *Abstracts, Astrobiology Science Conference 2002*, p. 50, NASA Ames Research Center, Moffett Field, Calif., 2002.

Peale, S. J., R. J. Phillips, S. C. Solomon, D. E. Smith, and M. T. Zuber, A procedure for determining the nature of Mercury's core, in *Workshop on Mercury: Space Environment, Surface, and Interior*, pp. 73-74, Lunar and Planetary Institute, Houston, Tex., 2001.

Phillips, R. J., R. M. Williams, M. T. Zuber, G. A. Neumann, D. E. Smith, C. L. Johnson, S. C. Solomon, and W. J. Sjogren, Gravity-topography relationships in the northern polar region of Mars, *Eos Trans. Amer. Geophys. Un., 80*, Spring Meeting suppl., S202, 1999.

Smith, D. E., M. T. Zuber, H. V. Frey, J. B. Garvin, J. W. Head, D. O. Muhleman, G. A. Neumann, G. H. Pettengill, R. J. Phillips, S. C. Solomon, H. J. Zwally, W. B. Banerdt, and T. Duxbury, Regional elevations in the southern hemisphere of Mars from the Mars Orbiter Laser Altimeter, *Eos Trans. Amer. Geophys. Un., 80*, Spring Meeting suppl., S202, 1999.

Smith, D. E., M. T. Zuber, S. J. Peale, R. J. Philips, and S. C. Solomon, Estimating the libration of Mercury by remote sensing of gravity and altimetry, in *Workshop on Mercury: Space Environment, Surface, and Interior*, pp. 90-91, Lunar and Planetary Institute, Houston, Tex., 2001.

Smith, D. E., M. T. Zuber, S. C. Solomon, J. W. Head, G. A. Neumann, O. Aharonson, and W. B. Banerdt, The shape of the northern hemisphere of Mars from the Mars Orbital Laser Altimeter, *Eos Trans. Amer. Geophys. Un., 79*, Spring Meeting suppl., S190, 1998.

Smith, D. E., M. T. Zuber, S. C. Solomon, R. J. Phillips, J. W. Head, J. B. Garvin, H. V. Frey, D. O. Muhleman, G. H. Pettengill, H. J. Zwally, B. Banerdt, T. C. Duxbury, G. A. Neumann, and J. B. Abshire, Latest results from the Mars Orbiter Laser Altimeter (MOLA), in *Lunar and Planetary Science XXXI*, abstract 1870, Lunar and Planetary Institute, Houston, Tex., 2000 (CD-ROM).

Solomon, S. C., New insights into the thermal history and crustal evolution of Mars from Mars Global Surveyor, in *Fifth International Conference on Mars*, abstract 6212, Lunar and Planetary Institute, Houston, Tex., 1999 (CD-ROM).

Solomon, S. C., The seven ages of terrestrial planetary science and the pervasive contributions of William Kaula, *Eos Trans. Amer. Geophys. Un., 81*, Fall Meeting suppl., F307, 2000.

Solomon, S. C., The Harold Masursky Lecture: An Earth in Moon's Clothing?, or Mercury as an object lesson on approaches to planetary exploration, in *Lunar and Planetary Science XXXII*, abstract 1345, Lunar and Planetary Institute, Houston, Tex., 2001 (CD-ROM).

Solomon, S. C., The role of water in the internal evolution of the terrestrial planets, *Abstracts with Programs, 33*, A-260, Geol. Soc. Amer., Boulder, Colo., 2001.

Solomon, S. C., Crust and mantle evolution on the terrestrial planets: A geophysical perspective on early differentiation, *Abstracts of the 12th Annual V. M. Goldschmidt Conference, Geochim. Cosmochim. Acta, 66*, Suppl. 1, A727, 2002.

Solomon, S. C., O. Aharonson, J. M. Aurnou, W. B. Banerdt, M. H. Carr, A. J. Dombard, H. V. Frey, M. P. Golombek, S. A. Hauck II, J. W. Head III, W. E. Hutchison, B. M. Jakosky, C. L. Johnson, P. J. McGovern, G. A. Neumann, R. J. Phillips, M. A. Richards, D. E. Smith, and M. T. Zuber, Insights into the earliest history of Mars: A new synthesis, in *Lunar and Planetary Science XXXIII*, abstract 1687, Lunar and Planetary Institute, Houston, Tex., 2002 (CD-ROM).

Solomon, S. C., M. A. Bullock, and D. H. Grinspoon, Climate change as a regulator of global tectonics on Venus, in *Lunar and Planetary Science XXIX*, abstract 1624, Lunar and Planetary Institute, Houston, Tex., 1998 (CD-ROM).

Solomon, S. C., M. A. Bullock, and D. H. Grinspoon, Climate change as a regulator of global tectonics on Venus, *Eos Trans. Amer. Geophys. Un., 79*, Spring Meeting suppl., S197, 1998.

Solomon, S. C., and J. W. Head, The nature and evolution of Tharsis: Global context and new insights from MGS observations, in *Abstracts, Tharsis Workshop*, Keystone, Colo., October 16-18, 2000.

Solomon, S. C., C. L. Johnson, J. W. Head, M. T. Zuber, G. A. Neumann, O. Aharonson, R. J. Phillips, D. E. Smith, H. V. Frey, M. P. Golombek, W. B. Banerdt, M. H. Carr, and B. M. Jakosky, What happened when on Mars?: Some insights into the timing of major events from Mars Global Surveyor data, *Eos Trans Amer. Geophys. Un., 82,* Spring Meeting suppl., S244, 2001.

Solomon, S. C., C. L. Johnson, P. J. McGovern, O. Aharonson, W. B. Banerdt, J. W. Head, R. J. Phillips, D. E. Smith, and M. T. Zuber, An overview of lithospheric flexure on Mars: Implications of initial MOLA observations, in *Lunar and Planetary Science XXIX*, abstract 1389, Lunar and Planetary Institute, Houston, Tex., 1998a (CD-ROM).

Solomon, S. C., C. L. Johnson, P. J. McGovern, O. Aharonson, W. B. Banerdt, J. W. Head, R. J. Phillips, D. E. Smith, and M. T. Zuber, An overview of lithospheric flexure on Mars: Implications of latest MOLA observations, *Eos Trans. Amer. Geophys. Un., 79*, Spring Meeting suppl., S190, 1998.

Solomon, S. C., C. L. Johnson, P. J. McGovern, and M. Simons, An overview of tectonic evolution on Venus, in *Geodynamics of Venus: Evolution and Current State*, 18-19, Amer. Geophys. Un., Washington, D.C., 1997.

Solomon, S. C., and the MESSENGER Team, Mercury: Key to understanding the terrestrial planets, *Eos Trans. Amer. Geophys. Un., 80*, Spring Meeting suppl., S20, 1999.

Solomon, S. C., and the MESSENGER Team, Mercury: Schubert's contributions and MESSENGER's promise, *Eos Trans. Amer. Geophys. Un., 80*, Fall Meeting suppl., F619, 1999.

Solomon, S. C., M. T. Zuber, R. J. Phillips, D. E. Smith, and G. L. Tyler, The nature of Martian crust and mantle from Mars Global Surveyor topography and gravity: Implications for the interpretation of crustal magnetic anomalies, *Eos Trans Amer. Geophys. Un., 81*, Spring Meeting suppl., S171, 2000.

Solomon, S. C., M. T. Zuber, M. T., R. J. Phillips, D. E. Smith, G. L. Tyler, O. Aharonson, G. Balmino, W. B. Banerdt, J. W. Head, C. L. Johnson, F. G. Lemoine, P. J. McGovern, G. A. Neumann, D. D. Rowlands, W. L. Sjogren, and S. Zhong, Lithospheric structure of Mars from Mars Global Surveyor topography and gravity and implications for the early thermal evolution of Mars, in *Lunar and Planetary Science XXXI*, abstract 1808, Lunar and Planetary Institute, Houston, Tex., 2000 (CD-ROM).

Zimmerman, S. B., and C. L. Johnson, Gravity signatures of coronae on Venus: Implications for models of corona formation and evolution, *Eos Trans Amer. Geophys. Un., 81*, Spring Meeting suppl., S300, 2000.

Zuber, M. T., D. E. Smith, J. B. Garvin, D. O. Muhleman, S. C. Solomon, H. J. Zwally, G. A Neumann, O. Aharonson, and A. Ivanov, Geometry of the north polar icecap of Mars from the Mars Orbiter Laser Altimeter, *Eos Trans. Amer. Geophys. Un., 79*, Fall Meeting suppl., F524, 1998.

Zuber, M. T., D. E. Smith, G. L. Tyler, S. C. Solomon, R. J. Phillips, G. A. Neumann, W. L. Sjogren, O. Aharonson, S. Zhong, and P. J. McGovern, The internal structure and early evolution of Mars from Mars Global Surveyor, *Eos Trans. Amer. Geophys. Un., 80*, Fall Meeting suppl., F602, 1999.

Zuber, M. T., S. C. Solomon, R. J. Phillips, and D. E. Smith, The internal structure of Mars from Mars Global Surveyor, *Geophys. Res. Abstracts, 2*, Eur. Geophys. Soc. 25th Gen. Assembly, Planet. Solar Syst. Sci., 73, 2000 (CD-ROM).

Zuber, M. T., S. C. Solomon, R. J. Phillips, D. E. Smith, G. L. Tyler, O. Aharonson, G. Balmino, W. B. Banerdt, J. W. Head, C. L. Johnson, F. G. Lemoine, P. J. McGovern, G. A. Neumann, D. D. Rowlands, W. L. Sjogren, and S. Zhong, Crustal structure of Mars from Mars Global Surveyor topography and gravity, in *Lunar and Planetary Science XXXI*, abstract 1307, Lunar and Planetary Institute, Houston, Tex., 2000 (CD-ROM).

Zuber, M. T., G. L. Tyler, D. E. Smith, G. S. Balmino, C. L. Johnson, F. G. Lemoine, G. A. Neumann, R. J. Philips, W. L. Sjogren, and S. C. Solomon, Preliminary correlations of gravity and topography from Mars Global Surveyor, *Eos Trans. Amer. Geophys. Un., 80*, Spring Meeting suppl., S202, 1999.