CALIFORNIA INSTITUTE OF TECHNOLOGY

DIVISION OF GEOLOGICAL AND PLANETARY SCIENCES 170-25

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Gloria Blanchard
Grants Officer
Procurement Office
NASA
Goddard Space Flight Center
Greenbelt, MD 20771

ATTN: 286.1

SUBJECT: NASA GRANT NO. NAG 5-842, CIT NO. 64672

Enclosed please find the Final Technical Report for NASA Grant NAG 5-842 "Intraplate Deformation, Stress in the Lithosphere and the Drivig Mechanism for Plate Motions," covering the period through December 31, 1991. We apologize for the delay in submitting this report.

Sincerely,

Arden L. Albee
Principal Investigator

cc: B. Hager
Sponsored Research
Federal Accounting

PASADENA, CALIFORNIA 91125 TELEPHONE (818) 356-6123 FAX (818) 568-0935 TELEX 3730923

Results from Crustal Dynamics Project-funded research

A. Main research directions

Bradford Hager has been an active participant in the Crustal Dynamics Project since its inception, with over 25 papers published or in press and over 40 talks at professional meetings supported by my grant. The initial research proposed was to use the predictions of geodynamical models of mantle flow, combined with geodetic observations of intraplate strain and stress, to better constrain mantle convection and the driving mechanism for plate motions and deformation. As discussed in the main body of the proposal, it is only now that geodetic observations of intraplate strain are becoming sufficiently well resolved to make them useful for substantial geodynamical inference to be made. In the interim, Dr. Hager has made substantial progess in geodynamical modeling of flow and stress in the mantle.

My main research accomplishment supported by this grant has been to develop a model of flow in the mantle that explains almost 90% of the variance in the observed longwavelength nonhydrostatic geoid (degree 2-9). In this model, flow is driven by density contrasts inferred from velocity variations imaged using body wave tomography of the lower mantle and surface wave tomography of the upper mantle, as well as density contrasts from a geophysical model of subducting slabs. The flow results in dynamic topography at the Earth's surface, the core-mantle boundary (CMB), and at any interior compositional boundaries that are included in the model (e.g., the D" layer above the CMB, the 670 km discontinuity). This dynamic topography, which is a strong function of the viscosity and compositional structure of the mantle, has an influence on the geoid comparable in amplitude and opposite in sign to that of the driving density contrasts. By a forward modeling procedure, we arrive at the mantle structure that gives a predicted geoid that best matches the observed geoid. Constraints on CMB topography are provided by the interpretation of nutation amplitudes (provided by other researchers supported by the CDP). This model has a low-viscosity asthenosphere, with an increase in viscosity of about a factor of 300 across the transition zone to a moderately high viscosity lower mantle. The implications of this model for postglacial rebound and stress at the base of the plates are discussed in the main body of the proposal.

Another important research direction has been a collaborative effort with Eugene Humphreys to understand the dynamics of the Big Bend region of the San Andreas fault in southern California. This work resulted in a high-resolution tomographic image of a curtain high velocity material beneath the Transverse Ranges. We interpret this to be a convective downwelling that provides dynamic support of the Transverse Ranges.

In an effort to better constrain the kinematics of this region, a multi-institutional group of researchers began a GPS program, sponsored by NSF and NASA CDP. Part of this project involved a footprint in the vicinity of the Santa Paula VLBI site in the Ventura Basin. After several surveys, spanning three years, we have resolved the horizontal velocity field in the vicinity of Santa Paula. The VLBI site is an a region undergoing intense strain and rotation, with strain rates a factor of two higher than those associated with the San Andreas fault.

B. Papers published with CDP Support (abstracts excluded)

Subduction, back-arc spreading and global mantle flow, Bradford H. Hager, Richard J. O'Connell, and Arthur Raefsky, *Tectonophysics, 99,* 165-189, 1983.

Subducted slabs and the geoid: constraints on mantle rheology and flow, Bradford H. Hager, *J. Geophys. Res., 89,* 6003-6015, 1984.

The distribution of earthquakes with depth and stress in subducting slabs, Marios S. Vassiliou, Bradford H. Hager, and Arthur Raefsky, *J. Geodyn., 1,* 11-28, 1984.

Geoid anomalies in a dynamic Earth, Mark A. Richards and Bradford H. Hager, *J. Geophys. Res., 89,* 5987-6002, 1984.

A tomographic image of mantle structure beneath Southern California, Eugene D. Humphreys, Robert W. Clayton and Bradford H. Hager, *Geophys. Res. Lett., 11,* 625-627, 1984.

Lower mantle heterogeneity, dynamic topography and the geoid, B. H. Hager, R. W. Clayton, Mark A. Richards, Robert P. Comer, and Adam M. Dziewonski, *Nature, 313,* 541-545, 1985.

A critical assessment of viscous models of trench topography and corner flow, J. Zhang, B. H. Hager, and A. Raefsky, *Geophys. J., R. astr. Soc., 83,* 451-475, 1985.

Kinematic model of southern California, R. Weldon and E. D. Humphreys, *Tectonics, 5,* 33-48, 1986.

The Earth's geoid and the large-scale structure of mantle convection, Mark A. Richards and Bradford H. Hager, in S. K. Runcorn, ed., *The Physics of Planets*, John Wiley and Sons, Ltd., 247-272, 1988.

An improved method of Nusselt number calculation, Phyllis Ho-Liu, Bradford H. Hager and Arthur Raefsky, *Geophys. J., R. astr. Soc., 88,* 205-215, 1987.

Onset of mantle plumes in the presence of pre-existing convection, Norman H. Sleep, Mark A. Richards and Bradford H. Hager, *J. Geophys. Res., 93,* 7672-7689, 1988.

Constraints on the structure of mantle convection using seismic observations, flow models and the geoid, Bradford H. Hager and Robert W. Clayton, in W. R. Peltier, ed., *Mantle Convection*, Gordon and Breach, 657-763, 1989.

Dynamically supported geoid highs over hotspots: Observation and theory, Mark A. Richards, Bradford H. Hager and Norman H. Sleep, *J. Geophys. Res., 93,* 7690-7708, 1988.

Subduction zone earthquakes and stress in subducted slabs, Mario S. Vassiliou and Bradford H. Hager, *Pure Appl. Geophys., 128,* 547-624, 1988.

Effects of a temperature-dependent rheology on large-scale continental extension, *J. Geophys. Res., 94,* 7603-7619,1989.

Effects of long-wavelength lateral viscosity variations on the geoid, Mark A. Richards and Bradford H. Hager, *J. Geophys. Res., 94,* 10,299-10,313, 1989.

Long-wavelength variations in Earth's geoid: Physical models and dynamical implications, Bradford H. Hager and Mark A. Richards, *Phil. Trans. Roy. Soc. Lond. A., 328,* 309-327, 1989.

A kinematic model for the late Cenozoic development of southern California crust and upper mantle, Eugene D. Humphreys and Bradford H. Hager, *J. Geophys. Res., 95,* 19, 747-19,762, 1990.

The June 1986 Global Positioning System (GPS) experiment in southern California, T. Dixon, D. Agnew, G. Blewitt, B. Hager, P. Kroger, K. Larson, L. Skrumeda, and W. Strange, *EOS, Trans. Amer. Geophy. Union, 71,* 1051-1056, 1990.

Short-term earthquake hazard assessment for the Southern San Andreas Fault, southern California, D. Agnew, C. Allen, R. Bilham, M. Ghilarducci, B. Hager, E. Hauksson, K. Hudnut, D. Jackson, and A. Sylvester, *U.S. Department of the Interior U.S. Geological Survey,* USGS Open-file Report 91-xxx, in press, 1991.

GPS Measurements in central and southern California, Duncan Agnew, Yehuda Bock, Bradford H. Hager, David Jackson, Thomas Jordan, and Robert King, *CSTG Bulletin, 10,* 71-87, 1988.

Long-term dynamics of the solid Earth 2: Implications of precise positioning, J.B. H. Minster, T. H. Jordan, B. H. Hager, D. C. Agnew, and L. Royden, in I. I. Mueller and S. Zerbini, eds., *The Interdisciplinary Role of Space Geodesy*, Springer-Verlag, 43-63, 1989.

Driving forces: slab subduction and mantle convection, B. H. Hager, in *Background Papers for the Workshop on Continental Margins: A Research Initiative for Interdisciplinary Studies of Processes Attending Lithospheric Extension and Convergence,* Ocean Sciences Board, National Research Council, 15-28, 131-144, 1989.

Implications of precise positioning, J-B H. Minster, T. H. Jordan, B. H. Hager, D. C. Agnew, and L. H. Royden, *Geodesy in the Year 2000*, Academic Press, 23-52, 1990.

Toroidal-poloidal partitioning of lithospheric plate motions, R. J. O'Connell, C. W. Gable, and B. H. Hager, in R. Sabadini K. Lambeck, and E. Boschi, eds., *Glacial Isostasy, Sea Level and Mantle Rheology*, Kluwer Academic Publishers, Dordrecht, 535-551, 1991.

Mantle Viscosity: A comparison of models from postglacial rebound and from the geoid, plate driving forces, and advected heat flux, B. H. Hager, in R. Sabadini K. Lambeck, and E. Boschi, eds., *Glacial Isostasy, Sea Level and Mantle Rheology*, Kluwer Academic Publishers, Dordrecht, 493-513, 1991.

Measurement of crustal deformation using GPS, B. H. Hager, R. W. King, and M. H. Murray, *Ann. Rev. Earth Planet. Sci.*, 351-382, 1991.

Strain accumulation in the Santa Barbara channel: 1970-1988, S. C. Larsen, D.C. Agnew, and B. H. Hager, *J. Geophys. Res., 98*, 2119-2134, 1993.

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Rapid North-South shortening of the Ventura Basin, southern California: Evidence for creep on blind thrust faults, A. Donnellan, B. H. Hager, and R. W. King, *Nature,* in revision, 1992.

Topographic core-mantle coupling and fluctuations in the Earth's rotation, R. Hide, R. W. Clayton, B. H. Hager ,M. A. Spieth, and C. V. Voorhies, A. G. U. Monograph (Jeffrey's Symposium), in press, 1992.

Measurement of the velocity field of central and southern California, 1984-1992, K. L. Feigl, D. C. Agnew, Y. Bock, D. Dong, A. Donnellan, B. H. Hager, T. A. Herring, D. D. Jackson, T. H. Jordan, R. W. King, S. Larsen, K. M. Larson, M. H. Murray, Z-K Shen, and F. H. Webb, *J. Geophys. Res.* submitted, 1992.

C. Ph. D. students supported (Caltech)

Eugene Humphreys: Studies of the crust-mantle system beneath southern California, 1985.

Mark A. Richards: Dynamical models for the Earth's geoid, 1986.

Shawn Larsen: Geodetic measurement of deformation in southern California, 1990.

Frank Webb: Geodetic measurement of deformation in the offshore of southern California, 1991.

Andrea Donnellan: Analysis of geodetic data in the Ventura Basin, southern California, 1991.

D. Postdoctoral Fellow (Caltech)

Leslie Sonder, 1986-1988

E. Public service

Hager has been an active contributor to community activities associated with CDP, beginning with service on the original review panel. He was an active participant in both the Airlie House meeting and the Erice workshop. He was a member of the Program Panel for the Coolfont meeting. He is now serving on the Global Fiducial Network subcommittee of the NRC Committee on Geodesy.