CURRICULUM VITAE
Edward W. Bolton

Current Rank: Senior Research Scientist

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Education: 1985, Ph.D. in Geophysics and Space Physics, University of California, Los Angeles
1982, M.S. in Geophysics and Space Physics, University of California, Los Angeles
1980, B.S. in Physics, Pacific Union College
1978, M.A. in Teaching of Physical Science, Pacific Union College
1977, B.S. in Physical Science (magna cum laude), Pacific Union College
1971, High School Diploma, Monterey Bay Academy, Watsonville, CA

Ph.D. Dissertation:

- Problems in Nonlinear Convection in Planar and Spherical Geometries, University of California, Los Angeles, (Advisor: F.H. Busse) 1985

SUMMARY OF PROFESSIONAL CAREER

Professional Experience:

- 2005 - Present: Senior Research Scientist: Department of Geology and Geophysics at Yale University. Numerical solutions of 2D time-dependent evolution of flow and chemical reactions in fractured/porous media (with Danny M. Rye and Jay J. Ague). Modeling kinetically controlled metamorphic reactions in a supercritical H_2O-CO_2 mixture (Andreas Luttge, Danny M. Rye, and Jay J. Ague). Models of trace element exchange between minerals and flowing fluids (with Sumit Chakraborty, Bochum, Germany). Model development for diffusion and exchange of major elements in mantle minerals with applications to thermobarometry (with Alex Andrews and Zhengrong Wang). Modeling of oxygen diffusion and consumption in eroding black shales, including oxidation of ancient organic matter and pyrite, as a control on long-term atmospheric oxygen levels (with Robert A. Berner). A collaboration with Noah Planavsky has started as a continuation the work with Berner. We are preparing codes to deal with redox reactions during Earth periods that had low oxygen levels. Modeling and code development for weathering on early Earth (with Rob Rye) and habitable planets (with the Virtual Planetary Laboratory Team) that includes erosion, mineral and redox reactions, and exchange of volatiles with arbitrary atmospheres. Modeling compositional variation, thermal convection, diffusion, and mixing and

unmixing in hydrocarbon reservoirs with Abbas Firoozabadi (Yale and RERI). With Leo Buss (EEB) modeling, code development, image processing, network analysis, statistical analysis, and pattern formation related to the growth and the muscular and circulation system of the hydrozoan *Podocoryne carnea*. The circulation model for this project is based on an arbitrary network of elastic tubes (solons) with flow driven by polyps (pumps) that has obvious crossover applications to flow in capillary beds, subsurface fractures, and porous networks. Development of 0D, 1D, and 2D models for fluid flow, matrix deformation, and mineral reactions associated with carbon sequestration in mafic and ultramafic rocks and minerals, as well as comparison to geochemical experiments (with the Yale DOE carbon sequestration team: see grant section). Development and testing of grain models and armoring models for reactive transport models. Development of 1D models of geomechanical compaction (viscous or poroelastic solids) coupled with geochemical reactions. Modeling of double diffusive convection and thermobaric effects on vertical heat transport in the oceans, with George Veronis. Development of experiments related to fluid analogies of tectonic wedge environments (with Mark Brandon). Collaboration with J.L. Druhan and C.I. Steefel on the influence of heterogeneous permeability on bulk kinetic rates.

- 2000 -2005: Research Scientist: Department of Geology and Geophysics at Yale University. Numerical solutions of 2D time-dependent evolution of flow and chemical reactions in fractured/porous media (with D.M. Rye and Ague). Modeling kinetically controlled metamorphic reactions in a supercritical H_2O-CO_2 mixture (Luttge, Rye, and Ague). Models of trace element and isotopic exchange between minerals and flowing fluids (with Chakraborty and Rye). Modeling of oxygen diffusion and consumption in eroding black shales, including oxidation of ancient organic matter and pyrite, as a control on long-term atmospheric oxygen levels (with R.A. Berner).
- 1995 - 2000: Associate Research Scientist: Department of Geology and Geophysics at Yale University. Numerical solutions of 2D time-dependent evolution of flow and chemical reactions in fractured/porous media (this and other projects below with A.C. Lasaga and D.M. Rye). Modeling kinetically controlled metamorphic reactions in a supercritical H_2O-CO_2 mixture (also with Luttge). Models of trace element and isotopic exchange between minerals and flowing fluids (also with Chakraborty). Numerical simulation of landform evolution via hydraulic erosion (with F. Kenton Musgrave).
- 1995 - 1996: Lecturer: Department of Mechanical Engineering at Yale University. Taught Computational Fluid Dynamics, and Advanced Ordinary and Partial Differential Equations.
- 1993 - 1995: Associate Research Scientist: Department of Geology and Geophysics, Yale University. Numerical solutions of: entrainment and mixing in high Rayleigh number double diffusive convection, with concentration-dependent viscosity; splat evolution in a shear flow in the lubrication limit; 2D and 3D time-dependent evolution of flow and chemical reactions in fractured/porous media. This work was with Neil Ribe, Lasaga and Rye. Numerical simulation of landform evolution via hydraulic erosion: with Musgrave. Simulation of water/oil/gas flows for water injection secondary recovery with interface motion and induced gravity perturbations. Wavelet analysis of the climate record.
- 1992 - 1993: Lecturer: of Geology and Geophysics, Yale University. Simplified notation for differential vector operations in orthogonal coordinates, complete orthogonal functions for spherical shells that satisfy four boundary conditions, experimental studies of convection in a rotating annulus, pattern formation induced by erosion of land surfaces, wavelet analysis of the climate record.
- 1986 - 1992: Assistant Professor: of Geology and Geophysics, Yale University. Numerical solutions of thermal convection and magnetic field generation in rotating spherical shells, convection in plane layers and spherical shells with temperature-dependent viscosity, experimental studies of convection in a rotating annulus, vortex street generation behind moving bubbles, pattern formation induced by erosion of land surfaces.
- 1985 - 1986: Postdoctoral Research: *Groupe de Physique des Solides, École Normale Supérieure,* Paris, France. Supported by a Joliot-Curie bourse, and then research associate of C.N.R.S.

Application of dynamical systems theory to convective systems and experimental studies of shear flow instabilities in an oscillating fluid plane with Prof. B. Perrin, J. Maurer and S. Fauve.

- 1981 - 1985: Postgraduate Researcher: Institute of Geophysics and Planetary Physics, University of California, Los Angeles. Stability analysis of two-dimensional convection rolls with free-slip and rigid boundaries, experimental investigation of centrifugally induced convection rolls, and numerical solutions of thermal convection in a rotating spherical shell, with Prof. F.H. Busse.
- 1981 - 1981: Postgraduate Researcher: Dept. of Earth & Space Sciences, U.C.L.A., with Prof. D.D. Jackson.
- 1980 - 1980: Teaching Assistantship: Dept. of Earth & Space Sciences, U.C.L.A.
- 1979 - 1980: Computer programmer: Pacific Union College, Angwin, CA. Nutritional studies.
- 1978 - 1979: High School Teacher: in Physics, Chemistry, Science, and Math in Honolulu, HI.
- 1976 - 1978: Laboratory Assistant: in Physics, Astronomy, Biochemistry, and Organic Chemistry; and physics laboratory and demonstration development (320 demos), at Pacific Union College, Angwin, CA.

Areas of Expertice:

- Numerical Modeling and Computational Fluid Dynamics
- Numerical Simulation of Flow, Reactions, and Transport in Heterogeneous Porous Media
- Hydrocarbon reservoir modeling
- Image processing
- Network analysis
- Database creation and statistical analysis
- Finite Difference & Volume, Global-Galerkin, Spectral-Transform, and Particle Tracking Methods
- Experimental Fluid Mechanics: Rotating Convection, Bubble Dynamics, including LABVIEW and Data Acquisition
- Nonlinear Thermal Convection and Stability Analysis
- Wavelet Analysis of Time Series and Climate
- Landform Evolution and Erosion Modeling
- Flow Visualization of Common Fluid Instabilities
- Spherical Shell Basis Functions and Curvilinear Coordinates
- Numerical Modeling of Double Diffusive Convection

Computer Usage Experience:

- UNIX SYSTEMS: DEC Alphas, SUN Ultras, SGI
- VAX SYSTEMS: Microvax user and administrator
- OTHER SYSTEMS: Macs, PCs, Linux
- LANGUAGES: FORTRAN, C, Mathematica, R, Pascal, LABVIEW
- STATISTICAL ANALYSIS: R, Splus, MS Excel
- GRAPHICS: R, Splus, UIS, GL, Matlab, PowerPoint, Photoshop, Illustrator
- TEXT FORMATTING: TEX, LATEX, MS Word
- WEB: html, Drupal

Consulting Experience:

- Synthetic Landform Creation for the U.S. Army and Naval Research Laboratory
- Demonstration Devices and Text Development for The American Museum of Natural History
- Fluid Sculpture Creation
- Educational Video Creation
- Technical Advisor for Tidal Electric, Inc.
- Double Diffusive Processes In Vertical Ocean Heat Transfer for the U.S. Navy

PUBLICATION RECORD:

Articles Submitted:

- Li, Li, Maher, K., Navarre-Sitchler, A., Bao, C., Biesman, J., Bolton, E.W., Brantley, S., Dietrich, B., Druhan, J., Jin, L., Kocar, B., Kumar, M., Lawrence, C., Mayer, U., McIntosh, J., Meile, C., Moore, J., Perdrial, J., Sonnethal, E., Steefel, C.S., Sullivan, P., Thompson, A., Tutulo, B., Valocchi, A., Zachara, J., Barrera, E., Torgerson, T., Lesmes, D., Woodward, N., King, B., a manuscript in preparation summarizing a National Science Foundation sponsored workshop: "Expanding the role of Reactive Transport Modeling (RTM) within the Biogeochemical Sciences", Alexandria, VA, 13-15 April 2014. Submitted to Earth Science Reviews on 13 Dec. 2015.

Published Refereed Articles:

- Van Hise, J.R., D.E. Martz, R.A. Jackson, D.Y. Kunihira and E.W. Bolton (1982) Polonium-218 half-life, Physical Review C, 25. 2802-2804.
- Busse, F.H. and E.W. Bolton (1984) Instabilities of convection rolls with stress-free boundaries near threshold, J. Fluid Mech., 146, 115-125.
- Bolton, E.W. and F.H. Busse (1985) Stability of convection rolls in a layer with stress-free boundaries, J. Fluid Mech., 150, 487-498.
- Azouni, M.A., E.W. Bolton and F.H. Busse (1986) Convection driven by centrifugal buoyancy in a rotating annulus, Geophys. Astroph. Fluid Dyn., 34 301-317.
- Bolton, E.W., F.H. Busse and R.M. Clever (1986) Oscillatory instabilities of convection rolls at intermediate Prandtl numbers, J. Fluid Mech., 164, 469-485.
- Fauve, S., E.W. Bolton and M.E. Brachet (1987) Nonlinear oscillatory convection: A quantitative phase dynamics approach, Physica, 29D, 202-214.
- Bolton, E.W. (1993) A simple notation for differential vector operations in orthogonal curvilinear coordinates, Geophysical Journal International, 115, 654-666.
- Bolton, E.W. and J. Maurer (1994) A new roll-type instability in an oscillating fluid plane, J. Fluid Mech, 268, 293-313.
- Bolton, E.W., K.A. Maasch and J. M. Lilly (1995), A wavelet analysis of Plio-Pleistocene climate indicators: A new view of periodicity evolution, Geophysical Research Letters, 22, 2753-2756.
- Bolton, E.W., A.C. Lasaga and D.M. Rye, (1996) A model for the kinetic control of quartz dissolution and precipitation in porous media flow with spatially variable permeability: Formulation and examples of thermal convection, Journal of Geophysical Research, 101, 22157-22187.
- Bolton, E.W., A.C. Lasaga and D.M. Rye, (1997) Dissolution and precipitation via forced-flux injection in a porous medium with spatially variable permeability: Kinetic control in two dimensions, Journal of Geophysical Research, 102, 12159-12171.
- Bolton, E.W., A.C. Lasaga and D.M. Rye, (1999) Long-term flow/chemistry feedback in a porous medium with heterogeneous permeability: Kinetic control of dissolution and precipitation, American Journal of Science, v. 299, pp. 1-68.
- Luttge, A., E.W. Bolton, and A.C. Lasaga, (1999) An interferometric study of the dissolution kinetics of anorthite: The role of reactive surface area, Invited paper in: Biogeochemical cycles and their evolution over geologic time. D. Canfield (ed) A special triple issue of the American Journal of Science, A tribute to the career of Robert A. Berner, v. 299, pp. 652-678.
- Seilacher, A., M. Meschede, E.W. Bolton, and H. Luginsland, (2000) The Precambrian "fossil" Vermiforma is a tectograph, Geology, v. 28, pp. 235-238.

- Lasaga, A.C., A. Luttge, D.M. Rye, and E.W. Bolton, (2000) Dynamic treatment of invariant and univariant reactions in metamorphic systems, American Journal of Science, v. 300, pp. 173-221.
- Lasaga, A.C., D.M. Rye, A. Luttge, and E.W. Bolton, (2001) Calculation of fluid fluxes in Earth's crust, Geochimica et Cosmochimica Acta, Vol. 65, No. 7, pp. 1161-1185.
- Breeding, C.M., J.J. Ague, M. Brocker, and E.W. Bolton, (2003) Blueschist preservation in a retrograded, high-pressure, low-temperature metamorphic terrane, Tinos, Greece: Implications for fluid flow paths in subduction zones, G-cubed, Vol. 4, No. 1, 22 Jan. 2003.
- Rye, D., E.W. Bolton, A. Luttge (2003) Erratum to Antonio C. Lasaga, Danny M. Rye, Andreas Luttge, and Edward W. Bolton (2001) "Calculation of fluid fluxes in the Earth's crust," Geochimica et Cosmochimica Acta, Vol. 67, No. 9, p. 1755.
- Luttge, A., E.W. Bolton, and D.M. Rye (2004) A kinetic model of metamorphism: An application to siliceous dolomites, Contributions to Mineralogy and Petrology, DOI: 10.1007/s00410-003-0520-8, Vol. 146, No. 5, January 2004, pp. 546 - 565.
- Wildman, R. A., Berner, R. A., Petsch, S. T., Bolton, E. W., Eckert, J.O., Mok, U., and, Evans, J.B., (2004) The weathering of sedimentary organic matter as a control on atmospheric O_2: I. Analysis of a black shale, American Journal of Science, Vol. 304, p. 234-249.
- Bolton, E.W., D.M. Rye, J.J. Ague, and A. Luttge, (2004) Modeling contact metamorphism of siliceous dolomite via kinetic control of overall reactions, Water-Rock Interaction, Vol. 1, R.B. Wanty and R.R. Seal II, eds., Proceedings of the 11th International Symposium on Water-Rock Interaction, 27 June -2 July 2004, Saratoga Springs, NY, USA, pp. 269-272.
- Berner, R.A., E.W. Bolton, R.A. Wildman, and S.T. Petsch, (2004) Organic matter weathering and atmospheric oxygen: A field and modeling study of black shale oxidation, Water-Rock Interaction, Vol. 1, R.B. Wanty and R.R. Seal II, eds., Proceedings of the 11th International Symposium on Water-Rock Interaction, 27 June -2 July 2004, Saratoga Springs, NY, USA, pp. 805-808.
- Bolton, E. W., Berner, R. A., and Petsch, S. T., (2006) The weathering of sedimentary organic matter as a control on atmospheric O_2: II. Theoretical Modeling, American Journal of Science, October, Vol. 306, pp. 575-615.
- Buss L.W., Anderson C., Bolton E.W. (2013) Muscular Anatomy of the *Podocoryna carnea* Hydrorhiza. PLoS ONE 8(8): e72221. doi:10.1371/journal.pone.0072221.
- Bolton, E.W., and A. Firoozabadi, (2014) Numerical modeling of temperature and species distributions in hydrocarbon reservoirs, Journal of Geophysical Research-Solid Earth, Vol. 119, p. 18-31, doi:10.1002/2013JB010043.
- Neogi, S., Bolton, E.W., and Chakraborty, S., (2014) Timescales of disequilibrium melting in the crust: constraints from modeling the distribution of multiple trace elements and a case study from the Lesser Himalayan rocks of Sikkim, Contributions to Mineralogy and Petrology, 168:1020, DOI 10.1007/s00410-014-1020-8.
- Buss, L. W., C. P. Anderson, E. K. Perry, E. D. Buss, and E. W. Bolton (2015) Nutrient distribution and absorption in the colonial hydroid *Podocoryna carnea* is sequentially diffusive and directional. Public Library of Science ONE, PONE-D-15-21037R1.
- Connally, N., Anderson, C.P., Bolton, J.E., Bolton, E.W., Buss, L.W. (2015) The Selective Myosin II Inhibitor Blebbistatin Reversibly Eliminates Gastrovascular Flow and Stolon Tip Pulsations in the Colonial Hydroid *Podocoryna carnea*, Public Library of Science ONE, PONE-D-15-28617R1.

Software Systems Developed:

- KINFLOW: Reactive transport in a 2D, non-isothermal, heterogeneous, dynamic permeability, porous media with mineral reactions under kinetic control and numerous aqueous speciation reactions (see also KINFLOW1D below). The five mineral code was extended to include the 46 minerals, with accompanying thermodynamic and kinetic rate databases.

- META-KINFLOW: Similar to the above model, but with supercritical fluids (H_2O, CO_2) EOS at metamorphic conditions. 8 minerals used for computation of reactions of siliceous dolomites.

- DIG: Diffusion of isotopes and trace elements in grains during recrystallization (a moving boundary problem), exchanging with moving fluids in porous media.

- OMPYR: Weathering of organic matter and pyrite in eroding soils. The formulation and results are described in Bolton, E. W., Berner, R. A., and S. T. Petsch, (2006).

- DIGmajorelem: Diffusion of major elements based on nonequilibrium thermodynamics in a 4 mineral set during rapid uplift of kimberlites with applications to thermobarometry (a collaboration with Alex Andrews and Zhengrong Wang)**.**

- KINFLOW1D: Similar to KINFLOW, but for 1D, with 46 minerals under kinetic control, 27 aqueous phase equilibrium reactions, 64 aqueous species, and 2 gases (O_2, CO_2). A 0D version of this model has been implemented for comparison to the geochemical experiments. This models has recently been linked with a 1D geomechanical compaction model, in collaboration with Zhengyu Cai and David Bercovici. In addition to the viscous solid end-member geomechanical compaction model, a poroelastic solid model has been coded.

- KINFLOWCO2SEQ: Reactive transport in a 2D, non-isothermal, heterogeneous, dynamic permeability, porous media with mineral reactions under kinetic control and numerous aqueous speciation reactions. The code above was extended to 2D and to include liquid and vapor phases, separate EOS for CO_2-brine phases, with applications to subsurface carbon sequestration.

- CVS 5.0, 6.0: Compositional Variation Software for hydrocarbon reservoir evolution in a two-phase fluid based on non-equilibrium thermodynamics. Prepared in collaboration with A. Firoozabadi. Available to members of the Reservoir Engineering Research Institute. Software package included Bolton's modification of the nearly 17,000 lines of code, manuals (1 CVS5 release, 3 CVS6 releases), example input files and case studies with accompanying figures and descriptions, hydrocarbon property databases, instructions for plotting via R and Splus. Bolton implemented dynamic thermal evolution and convection, tilt of the reservoir layers, heterogeneities in tortuosity, separate barycentric reference frames for liquid and vapor phases, multiple injection and extraction wells.

- Diffusion Coefficient Calculations for Hydrocarbon Reservoir Fluids: Created FORTRAN code to implement the diffusion coefficient calculations of Leahy-Dios, Alana and Abbas Firoozabadi, (2007) Unified Model for Nonideal Multicomponent Molecular Diffusion Coefficients, AIChE Journal, November 2007 Vol. 53, No. 11, p. 2932-2939.

- COLONYCODE: Fluid flow and nutrient circulation driven by an arbitrary number of polyps (as pumps) in an arbitrary network of elastic tubes as a model for the circulation system of the hydrozoan *Podocoryne carnea*.

- Double diffusive convection (heat and salt) for the investigation of salt fingering and cabbeling and their contribution to vertical heat and mass transport in the ocean with thermobaric effects. This project is a collaboration with Prof. George Veronis.

Reports of Significance:

- Bolton, E.W. and A. Firoozabadi, (2008) The Addition of Tilt and Charging for Compositional Variation Software, Report for: Reservoir Engineering Research Institute (RERI), Palo Alto, CA, April 21, 2008, available upon request, 130 pages (30 text, 100 figures and captions)
- Li, Li, Maher, K., Navarre-Sitchler, A., Bao, C., Biesman, J., Bolton, E.W., Brantley, S., Dietrich, B., Druhan, J., Jin, L., Kocar, B., Kumar, M., Lawrence, C., Mayer, U., McIntosh, J., Meile, C., Moore, J., Perdrial, J., Sonnethal, E., Steefel, C.S., Sullivan, P., Thompson, A., Tutulo, B., Valocchi, A., Zachara, J., Barrera, E., Torgerson, T., Lesmes, D., Woodward, N., King, B., a report summarizing a National Science Foundation sponsored workshop: "Expanding the role of Reactive Transport Modeling (RTM) within the Biogeochemical Sciences", Alexandria, VA, 13-15 April 2014, has been the National Science Foundation.

Articles in Preparation:

- Bolton, E.W., J. Rimas Vaisnys, and L.W. Buss, A dynamic circulation model for the colonial hydroid *Podocoryne carnea* network.
- Bolton, E.W., Zhengrong Wang, Jay J. Ague, Lin Qiu, Shuang Zhang, David Bercovici, Shun-ichiro Karato, and Michael Oristaglio, Geochemical and kinetic modeling of fluid chemistry during coupled forsterite dissolution and magnesite precipitation.
- Lin Qiu, Zhengrong Wang, Shuang Zhang, Shun-ichiro Karato, Jay J. Ague, Michael L. Oristaglio, Edward W. Bolton, and David Bercovici, Experimental study of the reaction kinetics between CO2-bearing fluid and olivine.
- Bolton, E.W., Druhan, J.L., and Steefel, C.I., "The influence of heterogeneous permeability on bulk kinetic rates".
- Bolton, E.W., A. Luttge, D.M. Rye, and J.J. Ague, Modeling kinetically controlled reactive flows during contact metamorphism, in preparation.

- Papers are also in preparation on topics discussed below.

Book Reviews:

- Bolton, E.W., Review of Buoyancy-induced Flows and Transport, by B. Gebhart, et.al., (Hemisphere, New York, 1988), which appeared in American Scientist, 77, pp. 298-299, 1989.
- Bolton, E.W., Review of Annual Review of Fluid Mechanics, 22, John L. Lumley, et al., editors, published by Annual Reviews, Palo Alto, California 1990, for the Bulletin of the American Meteorological Society, 72, 1399-1400, 1991.

Invited Lecture Series:

- Modeling Reactive Flows in Earth's Crust (August 3-4, 2001; *Institut fuer Geologie, Mineralogie und Geophysik; Ruhr-Universitat* Bochum, Germany)

Other Invited Lectures (see also conference presentations for 5 other Invited presentations):

- Transcending "Effective Stress" in fluid saturated rock-squeezing experiments: The role of buoyancy and grain contact areas (Rheology of the Earth, Colloquium for both Engineering and Earth Sciences, SFB 526; Ruhr-*Universitat* Bochum, Germany; April 24, 2003)
- Modeling reactive flows in saturated rocks (Environmental Engineering Scholars Colloquium, University of Connecticut; May 2, 2003).
- Kinetic models of fluid/rock interaction: From surface weathering to contact metamorphism, (DOE Basic Energy Sciences-Geosciences Workshop: "Integrating numerical models of

reactive flow and transport into fundamental Geosciences research", June 9, 2003, Camel Valley, CA).

- Models of Kinetically Controlled Fluid/Rock Interaction in Earth's Crust (U.S. Department of Energy Geosciences Research Program Symposium on "Flow and Transport Characterization and Modeling from Pore to Reservoir Scales", Gaithersburg, MD; Sept. 24, 2004).
- Computational models of kinetic processes in subsurface reactive flows (U.S. Department of Energy Geosciences Research Program Symposium on "Computational and Numerical Geosciences", Gaithersburg, MD; May 3 and 4, 2007).
- Bolton, E.W. and A. Firoozabadi, "Incorporation of Heterogeneity, Tilt, Filling, and Leakage into Reservoir Compositional Variation Simulations", 19th annual workshop of the Reservoir Engineering Research Institute, May 2008
- Bolton, E.W. and A. Firoozabadi, **"**Numerical modeling of temperature and species distributions in hydrocarbon reservoirs", 20th annual workshop of the Reservoir Engineering Research Institute, May 2009.
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Selected Professional Activities:

- Associate Editor, American Journal of Science, January 2004 – Present.
- Co-Organizer (with Karl Turekian) of the 7, 8 April 2006 Forum at Yale entitled: "Carbon Sequestration: Is It Feasible?" (see http://www.yale.edu/yibs/carbon.html).
- Spearheaded an effort to create an interdisciplinary Center for the Study of Multiphase Interactions, combining research interests of six academic units at Yale. Created mission and goals, sought support from industry and foundations (August 2005 - January 2007). Petroleum companies expressed great interest in the carbon sequestration aspect of this proposed center. Although this endeavor did not succeed, research funding for carbon sequestration was eventually successful.
- Planned and hosted a 12 September 2007 Yale visit from Sally Benson, Executive Director of Stanford University's Global Climate and Energy project, with presentations given by Geology and Geophysics, Chemical and Mechanical Engineering, School of Forestry and Environmental Studies, and the Center for Green Chemistry and Green Engineering.
- Made site visit to the National Energy Technology Laboratory (DOE) in Pittsburgh, PA, to assess potential support for carbon sequestration research at Yale (21 February 2008). NETL members expressed interest in the reactive-transport carbon-sequestration modeling improvements planned by Bolton.
- Participation in the effort to create a Climate Institute at Yale (Spring 2008).
- Organized a series of lunch-time discussions on the topic of carbon sequestration and storage for members of the Yale community in economics, law, management, policy, forestry, environmental studies, chemical engineering, chemistry, geology, geophysics, and sustainability.
- Managing Principal Investigator for Dept. of Energy grant "Integrated Experimental and Modeling Studies of Mineral Carbonation as a Mechanism for Permanent Carbon Sequestration in Mafic/Ultramafic Rocks", a collaborative 3 year project among 9 PIs at Yale Univeristy, University of Maryland, and University of Hawaii.

Service in Departmental Committees: Yale University, Dept. of Geology and Geophysics

- Faculty Search Committee (Solid Earth Geophysics): 1987 - 1990
- Computer Committee: 1986 - 1993
- Graduate Admissions Committee: 1987 - 1988
- Secretary for Departmental Faculty Meetings: 1988 - 1991
- Program Review and Examination Committee: 1990 - 1992

- Brochure Committee: 1989 - 1991

Grants and Gifts:

- National Science Foundation, EAR-8721027, "A Geodynamo Model: Time Dependence and Response to Lateral Temperature Variations", (1 May 1988 - 31 October 1990), $69,036, Principal Investigator: Edward Bolton.
- National Science Foundation, EAR-8916241, "Studies of 3D Convection with Temperature Dependent Viscosity", (1 May 1990 - 31 October 1992), $65,000, Principal Investigators: Neil Ribe and Edward Bolton.
- National Science Foundation, EAR-9018215, "Modeling Rough and Anisotropic Upper Mantle Structure using Long-period Seismograms", Bolton was a co-PI with Jeff Park and Neil Ribe, (1 March 1991 - 31 August 1992), $52,264, (with another $62,471 for 1 March 1992 - 31 August 1993), Principal Investigators: Jeffrey Park, Neil Ribe and Edward Bolton.
- National Science Foundation, EAR-9018442, "Upgrading the Seismology/ Geodynamic Computing Facilities at Yale", (1 February 1991 - 31 July 1993), $38,209 equipment grant, Principal Investigators: Jeffrey Park, Neil Ribe, Jonathan Lees, and Edward Bolton.
- Schlumberger-Doll Research, (1995), $25,000 gift to Yale to support Bolton's research.
- Department of Energy, "Reactive Fluid Flow Models and Applications to Diagenesis, Mineral Deposits and Crustal Rocks", $709,116. (9/1/98-8/31/01) Principal Investigators: A.C. Lasaga, D.M. Rye, and E.W. Bolton.
- Department of Energy, "Integrated Studies of Coupled Flow, Reaction, and Diffusion in Earth's Crust", $1,109,560, (09/01/01-10/31/06), Principal Investigators: J.J Ague, D.M. Rye, E.W. Bolton.
- NASA, subcontract on "Developing Model-Based Temperature Constraints for the Archean", $403,047, (9/15/05 – 9/14/08), Principal Investigator: R. Rye (University of Southern California), Co-Investigator: E.W. Bolton.
- NASA, subcontract on "Astronomical Detection of Biosignatures from Extrasolar Planets", $65,556, (1/26/06 – 12/25/06). Principal Investigator: Victoria Meadows, JPL/Caltech.
- Department of Energy, DE-FG02-07ER15838: "Code and Documentation Release for Fluid-Rock Interaction Models", $77,148, (11/01/06-12/31/07), Principal Investigator: E.W. Bolton.
- Schlumberger-Doll Research, (2007), $20,000 gift to Yale to support Bolton's research on carbon sequestration.
- Reservoir Engineering Research Institute, (9/1/07-Feb. 2008) $45,206. gift to support Bolton's research on compositional variation in hydrocarbon reservoirs for ExxonMobil.
- Reservoir Engineering Research Institute, (start Sept., 2008) $33,495 + some additional support, gift to support Bolton's research on compositional variation in hydrocarbon reservoirs for ExxonMobil. This funding was secured by a proposal written by Bolton and Firoozabadi to ExxonMobil entitled "Proposal for improvements to CVS 5.0: 1) Thermal evolution and generalized charging/leakage, 2) Runtime improvements.", and was approved on 26 Sept. 2008.
- NASA, NAI CAN-Cycle 4, "The Virtual Planetary Laboratory: Exploring the Habitability and Biosignatures of Extrasolar Terrestrial Planets". Expected Yale portion: ($26,000 for the period 11/1/08-10/31/09; $62,000 for the period 11/1/09-10/31/10; $62,000 for the period 11/1/10-10/31/11; $62,000 for the period 11/1/11-10/31/12). Bolton is one of 30 Co-Investigators. Principal Investigator: Victoria Meadows, U. Washington.
- Yale Climate and Energy Institute, Interdisciplinary Grant in Climate and Energy Studies, seed grant: Principal Investigator: Zhengrong Wang. Co-Investigators: Jay Ague, Rob Bailis, David Bercovici, Edward Bolton, Shun-ichiro Karato, Collaborative Study of CO2 Storage in Ultramafic Rocks: An Experimental and Economic Investigation
- Department of Energy, National Energy Technology Laboratory, $2,441,180, "Integrated Experimental and Modeling Studies of Mineral Carbonation as a Mechanism for Permanent

Carbon Sequestration in Mafic/Ultramafic Rocks", Principal Investigator: Zhengrong Wang. Co-Investigators: Jay Ague, David Bercovici, Edward Bolton (managing PI), Shun-ichiro Karato, Michael Oristaglio, Kevin Johnson, Wen-lu Zhu, (10/1/2010-9/30/2013), DE-FE0004375.

- Reservoir Engineering Research Institute, (6/15/12), An additional gift of $4,961 paid on June 15, 2012 to aid in finishing work on a reservoir simulation paper. This was an additional $1,500 added to the final 10% of the project.
- NASA, NAI (NASA Astrobiology Institute): CAN-Cycle 6, "The Virtual Planetary Laboratory". Yale portion: ($40,000 per year subcontract for the 5 period 11/1/12-10/31/17). Bolton is one of ~30 Co-Investigators. Principal Investigator: Victoria Meadows, U. Washington, funded with a Jan. 2013 start date.

Grants Pending:

- NASA, NAI Director's Discretionary Fund entitled: "Coupling reactive transport modeling efforts between Alternative Earths and Virtual Planetary Laboratory NAI teams", by Edward Bolton, Noah Planavsky, and Christopher Reinhard, ($40,000 for the 5 period 1/1/16-12/31/16), submitted 29 Oct., 2015.

Service on Panels and Special Workshops:

- Department of Energy, Environmental Management Science Program Review, Merit Review Panel, June 1999, Research Related to Subsurface Contamination/Vadose Zone Issues.
- Department of Energy, Environmental Management Science Program Review, Merit Review Panel, May 2002.
- Department of Energy, Basic Energy Sciences-Geosciences Workshop: "Integrating numerical models of reactive flow and transport into fundamental Geosciences research", Camel Valley, CA, June 2003.
- Department of Energy Office of Advanced Scientific Computing Research in collaboration with the Offices of Fossil Energy, Environmental Management, and Civilian Radioactive Waste Management, Computational Subsurface Sciences, Carbon sequestration panel, compose Priority Research Directions for "Improved computation of coupled multi-scale process models for carbon sequestration", January 2007.
- U.S. Department of Energy (DOE) Geothermal Technologies Program Peer Review, May 2010.
- National Science Foundation sponsored workshop: "Expanding the role of Reactive Transport Modeling (RTM) within the Biogeochemical Sciences", Alexandria, VA, 13-15 April 2014.

Conference Presentations: Mostly With Published Abstracts:

- Bolton, E.W., F.H. Busse and R.M. Clever, An antisymmetric oscillatory instability of convection rolls (Am. Phys. Soc., fluid dynamics meeting at Houston, Texas, Nov. 1983), Bull. Am. Phys. Soc., 28 (9), 1399, Abstract FD3, 1983.
- Busse, F.H., and E.W. Bolton, Instabilities of convection rolls with stress-free boundaries, (Am. Phys. Soc., Fluid Dynamics Meeting at Houston, Texas, Nov. 1983), Bull. Am. Phys. Soc., 28 (9), 1398, Abstract FD2, 1983.
- Azouni, M.A., E.W. Bolton and F.H. Busse, Convection columns driven by centrifugal buoyancy, (Am. Phys. Soc., Fluid Dynamics Meeting at Houston, Texas, Nov. 1983), Bull. Am. Phys. Soc. 28 (9), 1373, Abstract CD1, 1983.
- Bolton, E.W., M.A. Azouni, and F.H. Busse, Drifting convection columns in a rotating annulus, XVth International Congress of Theoretical and Applied Mechanics, August 1984, Lyngby, Denmark, Poster 624P, Section fB-#10.

- Quintanar, I.A., E.W. Bolton, F.H. Busse and M.A. Azouni, Experimental measurements of drifting convection columns in a rotating annulus, paper presented on 6 Dec. 85 at the Fall Meeting of the Am. Geoph. Union, San Francisco, CA, EOS, Trans. Am. Geoph. Union, 65, No. 45, p. 871, 1984.
- Azouni, M.A., E.W. Bolton, F.H. Busse and I.A. Quintanar, *Etude experimentale de la structure convective dans un anneau vertical en rotation*, paper presented on 10 Sept. 85 at the *Congres National of the Societe Francaise de Physique*, Nice, France, 1985.
- Bolton, E.W., and F.H. Busse, Nonlinear thermal convection in rotating spherical shells, paper presented on 4 Aug. 87 at the Nonlinear Dynamics of Rotating Magnetic Systems Conference at University of California, Los Angeles, 1987.
- Bolton, E.W., and F.H. Busse, Nonlinear thermal convection in rotating spherical shells, paper GA1.3-7 presented on 19 Aug. 87 at the International Union of Geodesy and Geophysics (IUGG) at Vancouver, Canada, 1987.
- Bolton, E.W., and J. Maurer, A new roll-type instability in an oscillating fluid plane, paper IB-4 presented on 24 Nov. 87 at the Division of Fluid Dynamics Meeting of The American Physical Society at Eugene, Oregon, Bulletin of the American Physical Society, 32, No. 10, p. 2097, 1987.
- Bolton, E.W., and H.F. Bolton, Vortex street generation and bubble motion in inclined fluid planes, presented at the Division of Fluid Dynamics Meeting of The American Physical Society at Buffalo, NY, Bulletin of the American Physical Society, 33, No. 10, p. 2253, 1988.
- Bolton, E.W., and N.M. Ribe, Square-cell convection in a fluid with temperature dependent viscosity, EOS, Trans of Am. Geoph. Union, 70, p. 1333, 1989.
- Bolton, E.W., and B. Sayler, Karman vortex feedback and chaotic bubble motion in a rotating annulus, presented at the Division of Fluid Dynamics Meeting of The American Physical Society at Palo Alto, CA, Bulletin of the American Physical Society, 34, No. 10, p. 2331, 1989.
- Bolton, E.W., and B. Sayler, The influence of lateral variations of thermal boundary conditions on core convection: Numerical and laboratory experiments, presented at Santa Fe, Studies of the Earth's Deep Interior (SEDI) symposium, August, 1990.
- Bolton, E.W., and J. Park, The development of anisotropy in a convecting mantle, EOS, Trans of Am. Geoph. Union, 72, p. 508 of Fall 1991 AGU Meeting Supplement, 1991.
- Bolton, E.W.,, Radial functions for spectral/Galerkin modeling of spherical-shell convection, EOS, Trans of Am. Geoph. Union, 73, p. 575 of Fall 1992 AGU Meeting Supplement, 1992.
- Bolton, E.W.,, K.A. Maasch and J. M. Lilly, A Wavelet Analysis of Plio-Pleistocene Climate Indicators: A New View of Periodicity Evolution, EOS, Trans of Am. Geoph. Union, 74, #43, p. 366, 1993.
- Maasch, K.A., T.K. Dupont and E.W. Bolton, Climate transition in the mid-Pleistocene: Was the onset of the 100-kyr cycle gradual or abrupt?, EOS, Trans of Am. Geoph. Union, 75, #16, p. 56, 1994.
- Faux, R.J., E.W. Bolton and A.C. Lasaga, Cellular automata modeling of growth of 1:1 ordered compound in a binary system and applications to low temperature dolomite formation, EOS, Trans of Am. Geoph. Union, 75, #16, p. 189, 1994.
- Bolton, E.W.,, A.C. Lasaga and D.M. Rye, Kinetically controlled quartz dissolution and precipitation in porous media flow with spatial and temporal variations in permeability, EOS, Trans of Am. Geoph. Union, 75, #44, supplement p. 293, 1994.
- Bolton, E.W.,, A.C. Lasaga and D.M. Rye, Oscillatory quartz precipitation in porous media flow, V.M. Goldschmidt Conference programs and abstracts, p. 32, 24 May 1995 (at Penn State).
- Bolton, E.W.,, A.C. Lasaga and D.M. Rye, Kinetic Effects and Fully-Coupled Long-Term Evolution of Quartz Dissolution and Precipitation in Heterogeneous Porous Media Thermal Convection, EOS, Trans of Am. Geoph. Union, 77, #17, supplement p. S97, 1996.

- Bolton, E.W., A.C. Lasaga, D.M. Rye, and S. Chakraborty, Kinetics isotope effects: The competition of diffusion and recrystallization, Geologic Society of America, Abstracts with Programs, vol. 29, no. 6, p. A-25, 1997.
- Luttge, A., E.W. Bolton, D.M. Rye, and A.C. Lasaga, Kinetics control of metamorphic isograds, Geologic Society of America, Abstracts with Programs, vol. 29, no. 6, p. A-94, 1997.
- Chakraborty, S., A.C. Lasaga, and E.W. Bolton, Diffusion controlled fractionation of trace elements in magmatic systems, EOS, Trans of Am. Geoph. Union, vol. 78, no. 46, supplement, p. F833, V52A-1, 1997.
- Bolton, E.W., A. Luttge, D.M. Rye, and A.C. Lasaga, A 2D model of kinetic metamorphic ``isograds" for the system CaO-SiO_2-MgO-H_2O-CO_2, EOS, Trans of Am. Geoph. Union, vol. 78, no. 46, supplement, p. F835, V52A-19, 1997.
- Luttge, A., U. Winkler, E.W. Bolton, and A.C. Lasaga, The dynamics of dissolution as observed by near atomic scale scanning white light interferometry, Geologic Society of America, Abstracts with Programs, vol. 30, no. 7, p. A-187, 1998.
- Bolton, E.W., A. Luttge, D.M. Rye, and A.C. Lasaga, Kinetic control of contact metamorphism, Geologic Society of America, Abstracts with Programs, vol. 30, no. 7, p. A-280, 1998.
- Lees, J.M., and E.W. Bolton, Pressure cookers as volcano analogues, (**INVITED** poster) EOS, Trans of Am. Geoph. Union, vol. 79, no. 45, supplement, p. F620, S22C-10, 1998.
- Bolton, E.W., D.M. Rye, and A.C. Lasaga, A Model for Isotopic Changes During Metamorphism, EOS, Trans of Am. Geoph. Union, vol. 80, no. 46, supplement, p. F1157, V32D-04, 1999.
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- Bolton, E.W., On the use of effective stress in granular media, Am. Geoph. Union, Fall Meeting, San Francisco, H71B-0816, 2002.
- Bolton, E.W.; Wildman, R.A., Jr.; Berner, R.A.; Eckert, J.O., Jr.; Petsch, S.T.; Mok, U.; and Evans, B., Black shale weathering: An integrated field and numerical modeling study, EGS-AGU-EUG Joint Assembly, Nice, France, Geophysical Research Abstracts, No. EAE03-A-04423, Vol. 5, April 2003.
- Chakraborty, S., S. Neogi, and E.W. Bolton, Formation and Segregation of Melts in the Continental Crust: Time Scales From Trace Element Modeling of Rocks From the Sikkim Himalaya, India, EOS, Trans of Am. Geoph. Union, supplement, V42F-06, **INVITED**, Fall, 2003.
- Bolton, E.W., A. Luttge, D.M. Rye, and J.J. Ague, Unexpected Temperature-Fluid Composition Paths in Kinetic Models of Contact Metamorphism of Siliceous Dolomites, EOS, Trans of Am. Geoph. Union, V42G-05, Fall, 2003.
- Bolton, E.W., D.M. Rye, J.J. Ague, and A. Luttge, Modeling contact metamorphism of siliceous dolomite via kinetic control of overall reactions, Water-Rock Interaction, Vol. 1, R.B. Wanty and R.R. Seal II, eds., Proceedings of the 11th International Symposium on Water-Rock Interaction, Saratoga Springs, NY, USA, pp. 269-272, 27 June -2 July 2004.
- Berner, R.A., E.W. Bolton, R.A. Wildman, and S.T. Petsch, Organic matter weathering and atmospheric oxygen: A field and modeling study of black shale oxidation, Water-Rock Interaction, Vol. 1, R.B. Wanty and R.R. Seal II, eds., Proceedings of the 11th International Symposium on Water-Rock Interaction, Saratoga Springs, NY, USA, pp. 805-808, 27 June -2 July 2004.
- Bolton, E.W., and R.A. Berner, Oxygen diffusion and consumption in eroding black shales: A control on long-term atmospheric oxygen, **INVITED**, 15th annual V.M. Goldschmidt Conference, Moscow, ID, May 2005, Geochimica et Cosmochimica Acta, v. 69, (10), Suppl. 1, p. 173.
- Bolton, E.W., Fluid-Rock Interaction Models: Code Release and Results, EOS, Trans. of Am. Geophys. Union, Supplement, V31B-0592, Fall Meeting, 2006.

- Bolton, E.W., Rob Rye, (2007) Reactive transport modeling of weathering, with applications to paleosols, Geological Society of America meeting, Abstracts With Programs, Vol. 39, No. 6. Session: 2. Hydrogeology 28 October 2007, Denver CO.
- Rye, Rob, and Bolton, E.W. (2007) Reconstructing Archean climate with hard and modified KINFLOW, Geological Society of America meeting, Abstracts With Programs, Vol. 39, No. 6. Session: 121. Precambrian Geology, 30 October 2007, Denver CO.
- Bolton, E.W., D.M. Rye, J.J. Ague, and A. Luttge, (2007) Modeling metamorphism: Current results and future directions, **INVITED**, Geological Society of America meeting, Abstracts With Programs, Vol. 39, No. 6. Session: 127. Numerical Modeling Of Hydrothermal Fluids, 30 October 2007.
- Bolton, Edward W., Jay Ague, Rob Bailis, David Bercovici, Shun-Ichiro Karato|, Zhengrong Wang (lead PI), Experimental Studies of Thermodynamics, Kinetics and Mechanics of Ultramafic Rocks for CO2 Storage, Talk given by Bolton for Yale Climate and Energy Institute Student Congress, Spring Symposium, 27 March, 2010.
- Zhengrong Wang, Jay Ague, David Bercovici, Edward W. Bolton, Shun-Ichiro Karato|, Rob Bailis, Experimental Studies of Thermodynamics, Kinetics and Mechanics of Ultramafic Rocks for CO2 Storage, Poster Paper presented by Bolton for Yale Climate and Energy Institute, 1st Annual Conference, 2010, Clean Energy Innovation: Overcoming Barriers to A New Energy System, 23 & 24 April, 2010.
- Zhengrong Wang, Edward Bolton, Shun-ichiro Karato, Jay Ague, David Bercovici, Michael Oristaglio, Wen-lu Zhu, Kevin Johnson, "Integrated experimental and modeling studies of mineral carbonation", Poster paper presented by Oristaglio for CCS Oman 2011.
- Zhengrong Wang, Edward Bolton, Shun-ichiro Karato, Jay Ague, David Bercovici, Michael Oristaglio, Wen-lu Zhu, Kevin Johnson, "Integrated experimental and modeling studies of mineral carbonation", Poster paper presented by Bolton for the Yale Climate & Energy Institute 2nd Annual Conference, Technological Innovations for a Secure Energy Future, April 9, 2011, Yale University.
- Andrews, A.L., Z. Wang, E.W. Bolton, and J.O. Eckert Jr., The Effect of Diffusion on P-T Conditions Inferred by Cation-Exchange Thermobarometry, Goldschmidt Conference in Prague, Czech Republic, August 14-19, 2011.
- Bolton, E.W., "Subsurface Carbon Dynamics: Sequestration in Basalts and Petroleum Reservoir Unmixing", 19th Hubbert Quorum 2011, USGS, Palo Alto, CA, 4 December 2011.
- Lin Qiu, Zhengrong Wang, Shun-Ichiro Karato, Jay J. Ague, Michael Oristaglio, Edward Bolton, and David Bercovici, "Experimental study of mineral sequestration of CO_2 in mafic/ultramafic rocks", Poster presentation for the American Geophysical Union Fall 2011 Meeting, in San Francisco, CA.
- Lin Qiu, Zhengrong Wang, Shun-Ichiro Karato, Jay J. Ague, Michael Oristaglio, Edward Bolton, and David Bercovici, "Experimental study of the kinetics of CO_2-sequestration by olivines and Hawaiian picrites", Presentation for Goldschmidt 2012, in Montreal, Canada, June 24-29.
- Shuang Zhang; Lin Qiu; Zhengrong Wang; Shun-ichiro Karato; Kevin T. Johnson; Jay Ague; Michael L. Oristaglio; Edward W. Bolton; David Bercovici, Experimental Study of the Kinetics of CO2-Sequestration by Hawaiian Picrites, Poster presentation for the American Geophysical Union Fall 2012 Meeting, in San Francisco, CA, B33D-0546.
- Bolton, Edward W., Zhengrong Wang; Jay Ague; David Bercovici; Zhengyu Cai; Shun-ichiro Karato; Michael L. Oristaglio; Lin Qiu: Constraining kinetic rates of mineral reactions using reactive transport models, Poster presentation for the American Geophysical Union Fall 2012 Meeting, in San Francisco, CA, B33D-0552.
- Lin Qiu, Zhengrong Wang, Shuang Zhang, Shun-Ichiro Karato, Jay J. Ague, Michael Oristaglio, Edward Bolton, and David Bercovici, "Experimental study of reaction kinetics between CO_2-bearing solution and olivine", Goldschmidt 2013, in Florence, Italy, August 25-30.
- Bolton, Edward W., Zhengrong Wang, Jay Ague, David Bercovici, Zhengyu Cai, Shun-ichiro Karato, Michael Oristaglio, Lin Qiu and Shuang Zhang: Comparing Modeling to Experiments:

Kinetic Rates of Mineral Reactions Related to Carbonation of Olivines, Poster presentation for the Yale Energy Sciences Institute 2013 Spring Symposium, 26 April.

- Zhang, Shuang, Zhengrong Wang, Lin Qiu, Shun-ichiro Karato, Kevin Johnson, Jay Ague, Michael Oristaglio, Edward Bolton, and David Bercovici, Experimental study of the reaction kinetics between CO2-bearing solution and picrite cubes, Presentation for the American Geophysical Union Fall 2013 Meeting in San Francisco, CA, 11 Dec., Poster MR33B-2337.

Professional Honors or Recognition: Fellowships and Awards:

- Joliot-Curie Bourse, 1985, at *École Normale Supérieure*, Paris, France, administered by the Commissariat a l'Energie Atomique, France.
- Lilly Teaching Fellowship, 1987-1988, The Lilly Endowment, Inc., $5,000.
- Moore Fund, Construction of Fluid Dynamic Displays, $3,000.

STATEMENT REGARDING TEACHING:

University Courses Taught: Yale University

- Geophysical Fluid Dynamics, (G&G 421/521), 1986-1993, yearly
- Physical Oceanography, (G&G 335/535), 1987-1992, yearly
- Theoretical Fluid Dynamics, (Mech. Eng. 463/704) with B.T. Chu, 1988
- Applied Mathematics Senior Seminar, 1990
- Pattern Formation in Biological and Physical Systems, (G&G 768a) with Adolf Seilacher, 1990
- Computational Fluid Dynamics, Yale Dept. of Mechanical Engineering, Fall, 1995.
- Advanced Differential and Partial Differential Equations, Yale Dept. of Mechanical Engineering, Spring, 1996.

Senior Thesis Advising: Yale University

- Bentley Sayler, Karman vortex feedback on bubble motion in a rotating annulus, (Geology and Geophysics), 1990.
- Brian G. Jamieson, Thermal convection in a rotating annulus, (Physics Dept.), 1991.
- Alexandra Andrews, The effect of diffusion on P-T conditions inferred by cation-exchange thermobarometry, Bolton was secondary reader and advisor. Primary Advisor: Zhengrong Wang. (Geology and Geophysics), 2011.

Masters Thesis Advising: Yale University, Dept. of Geology and Geophysics

- Bentley Sayler, M.S., A laboratory experiment in rotating thermal convection, 1991.
- Wenjie Zhao, M. Phil., Numerical simulation and instability of eroding landforms, 1992.

Ph.D. Dissertation Advising: Yale University, Dept. of Geology and Geophysics

- Randolph J. Faux, Ph. D., Cellular automata simulation of structure formation in low-temperature dolomite, co-advisor with Antonio C. Lasaga, 1996.

Service on Dissertation Committees [chairman indicated]:

Yale University, Students from Dept. of Geology and Geophysics, Computer Science and Mechanical Engineering

- Bewley, Gregory P., (Mechanical Engineering), Using frozen hydrogen particles to observe rotating and quantized flows in liquid helium, [Sreenivasan], 2006.
- Countryman, Jim, Nonlinear leewaves, [Smith].
- Davis, Mark, Influence of water and thermal history on nucleation kinetics and viscosity in alkali silicate melt [Ihinger and Lasaga].
- Grubisic, Vanda, Influence of the critical layers on the 3D flow over irregular terrain, [Smith].
- Hu, Haijun, topic to be chosen, [Saltzman].
- Koch, Dorothy, Gravity anomalies and the viscosity structure of the mantle, [Ribe].
- Kyle, David (Mechanical Engineering), The instability and breakdown of a round variable-density jet, [Sreenivasan], 1991.
- Lee, Jae Hak, The determination of velocities and diffusion coefficients from tracer distributions, [Veronis].
- Matteucci, Gianni, The role of stochastic noise on the abrupt climatic transitions of the Pleistocene, [Saltzman].
- Musgrave, Kenton (Computer Science), Methods for realistic landscape imaging, [Galernter, Mandelbrot].
- Stottlemyer, Thomas R. (Mechanical Engineering), An experimental study of the acoustic emissions from collapsing cavities in liquids, [Apfel].
- Sun, Jielun, Tropopause fold investigations: secondary circulation, water vapor and Ozone analyses, [Smith].
- Zhang, Taiping, Modeling and parameterization of the land surface processes: Towards the incorporation of an interactive biosphere with the general circulation models, [Saltzman].
- Zubair, Lareef (Mechanical Engineering), Studies in turbulence using wavelet transforms for data compression and scale separation, [Sreenivasan], 1993.

Additional Teaching Experience:

- 1980 - 1980: Teaching Assistantship in Applied Geophysics: Dept. of Earth & Space Sciences, U.C.L.A.
- 1978 - 1979: High School Teacher: in Physics, Chemistry, Science and Math in Honolulu, HI.
- 1976 - 1978: Laboratory Assistant and Instruction: in Physics, Astronomy, Biochemistry and Organic Chemistry, and physics laboratory and demonstration development (320 demos), at Pacific Union College, Angwin, CA.

Topics of Current Research:

The bulk of Bolton's recent effort has been in development and extensions of numerical models for flow and reactions in porous media: reactive transport modeling of mineral dissolution and precipitation in subsurface environments. Bolton also developed research linking isotope and trace element diffusion in grains with other already developed flow and reaction codes that simulate mineral dissolution and precipitation in one and two dimensions. Particular focus on fracture/matrix interaction and more modest heterogeneous permeability fields will provide constraints on time scales and fluid velocities when compared to field data. Modeling applications include carbon sequestration, surface weathering (along with estimates of volatile fluxes), hydrothermal systems, contact metamorphism, and exploration of trace element composition of mid-ocean ridge basalts.

Bolton has finished a project funded by the Department of Energy to release to the public a number of numerical codes he has developed over the last several years. Final code release was delayed by copyright issues (related to two matrix inversion routines). The release will give free access to Fortran source code, documentation about how to use the codes, their theoretical and numerical basis, and example input files and results. The first two models are for flow and mineral reactions in a two-dimensional domain (horizontal and depth). KINFLOW is a weathering and hydrothermal model that

simulates flow and reaction in a heterogeneous, non-isothermal porous medium. Mineral reactions are kinetically controlled and speciation reactions in the aqueous solution are in equilibrium. Although this code only includes five minerals, he has extended this to dozens of minerals in another project mentioned below. The META-KINFLOW model simulates flow and reaction during metamorphism (contact or regional) of siliceous dolomites where the fluid is a supercritical mixture of CO_2 and H_2O. During heating of an initial quartz-dolomite system, decarbonation reactions releasing CO_2 compete with thermal buoyancy to establish the flow regime. Many surprises have come out of the simulations that are based on laboratory measurements of mineral kinetics. Univariant curves can be overstepped and each location has a unique P-T-composition history. The resulting mineralogy for contact metamorphic conditions yields "isograds" similar to field observations, but the thermal and compositional history of the domain cannot be simply predicted by observed minerals due to unique and unexpected reaction paths that differ from those expected on the basis of equilibrium pathways. New simulations examined the thermal overstep of reactions at various heating rates and fluid injection rates. This has significant implications on what has been described as a discrepancy between rates of reaction from the field and the lab. Proper understanding of these oversteps resolves this so-called discrepancy. This will be the final result needed for submission of a manuscript with Ague, Rye, and Luttge. I've had to temporarily delay this paper in order to focus on more current projects, but this topic related to the lab-field connection is still important to publish. Another code in the release is DIG: diffusion in grains during recrystallization. The aim is to understand the kinetic isotope effect in more detail and to understand kinetic corrections to trace element models for fractional crystallization and melting. OMPYR is the last code in the release, which solves for diffusion of oxygen into shales rich in ancient organic matter (OM), where oxidation of OM and pyrite lead to reactive fronts in soils derived from black shales. This model has implications for calculations of the long-term evolution of oxygen in Earth's atmosphere.

Bolton worked with Abbas Firoozabadi (Yale Dept. of Chemical & Environmental Engineering) on modeling the evolution of petroleum fluid composition in the subsurface. To an existing two-dimensional simulation package Bolton added the injection of fluids to simulate reservoir filling ("charging"), thermal convection, and the possibility that the reservoir is tilted with respect to true vertical. The model is based on non-equilibrium thermodynamics, taking into account diffusion due to gradients in pressure, temperature, and composition via the phenomenological coefficients. Flow is calculated via Darcy's law and the pressure equation is solved by an implicit method (IMPES). The goal is to understand the compositional variation of petroleum fluids in subsurface reservoirs and to assess the influence of convection, permeability barriers, and reservoir filling effects. ExxonMobil has funded extensions of this project. Recent work has focused on implementation of separate barycentric velocity frames for the liquid and vapor phases. Simulations show interesting mixing and unmixing dynamics allowed by nonequilibrium multicomponent systems with diffusion driven by a combination of compositional, thermal, and pressure gradients. Additional funding was provided on 15 June 2012. A paper on this topic appeared in 2014.

Bolton has worked on two related projects with NASA support. Both aim to extend our understanding of weathering of planetary surfaces under vastly different climatic conditions than exist currently on Earth. A collaborative project with Rob Rye (USC) aimed to understand paleosol development in the Archean. They will compare model results with paleosol profiles under various hypothesized atmospheric compositions and temperatures. For this project, Bolton has extended a weathering code (KINFLOW) to include surface erosion, 48 minerals, 68 aqueous species, 29 aqueous phase reactions (including redox reactions), gas exchange between air and aqueous fluids (8 gaseous species), and coupling to an atmosphere of specified composition (Bolton and Rye, 2007, abstract.; Rye and Bolton, 2007, abst.). The most recent work on this project is on improving the stability of the code for cases with dominant redox reactions.

For several years Bolton has been part of a group called the Virtual Planetary Laboratory (VPL). Victoria Meadows (now at U. Washington, formerly JPL and Caltech) is the lead PI on this multi-institution NASA project that aims to identify features of planetary atmospheres that may be indicative of the presence of life on other planets. This project will provide the basis for the design of future satellite detectors. Bolton has two months of funding per year through 2017. VPL has modules to calculate radiative properties of planetary atmospheres, climate dynamics, land-atmosphere gas exchange via surface weathering and volcanism, planetary chemical evolution, and formation. The weathering and gas exchange module is the focus of his contribution to this project and is a natural extension of the work he has done with Rob Rye. Bolton recently made code extensions to include more minerals and gases, as well as developing both liquid and vapor phase dynamics to include vadose zone processes. Simulations for weathering of igneous rocks under various atmospheric compositions and temperatures are in progress. The focus of the first paper on this project is the influence of temperature, CO_2 levels, and infiltration rates on the drawdown of CO_2 by basalt weathering in reactive soil boundary layers.

Bolton has continued research on the profound influence of heterogeneous permeability on the spatial distribution of mineral reaction rates. The deviation from equilibrium of aqueous species with respect to a given mineral has large spatial variations that are not clearly correlated with the inverse of fluid residence times in the pores. This research may help to resolve causes of the so-called "lab-field kinetic rate discrepancy". Paper in preparation: Bolton, E.W., Druhan, J.L., and Steefel, C.I., "The influence of heterogeneous permeability on bulk kinetic rates". Bolton is also working on simple analytical models to capture the first-order effects of heterogeneities in permeability at the sub-grid scale, and on developing a subgrid-scale pore model.

Bolton has collaborated on modeling of trace element diffusion in mineral grains during recrystallization. This work is related to the DIG code described above (Neogi, Bolton, and Chakraborty, 2014). The DIG model is expected to have important applications to improve our understanding of the time scales of fluid / rock interaction in crustal and mantle systems. Multiple trace elements can be modeled. A version of the code also has been prepared for isotope exchange during recrystallization. Bolton hopes to couple codes he has developed for diffusion of isotopes and trace elements in grains that communicate with pore-scale fluids into the two-dimensional flow and reaction codes. Such a coupled code would have broad applications to environments where isotopes and trace elements are used to infer the hydrogeological history (ore fields, sedimentary basins, and mantle geochemistry). An extension of the DIG model to major elements was formulated, based on the framework of non-equilibrium thermodynamic, in Spring and Summer of 2011, and served as the basis of part of the senior thesis work of Alexandra Andrews, which was presented at the Goldschmidt conference in 2011 (Andrews, Wang, Bolton, and Eckert, 2011). Work has started with Sumit Chakraborty on the publication of the trace-element diffusion code in a journal such as Computers & Geosciences.

Bolton is keenly interested in simulating carbon sequestration in subsurface environments. It is critical for the future of our nation and humanity that carbon storage in the subsurface be implemented, as long as fossil fuel burning continues to add greenhouse gases into the atmosphere. CO_2 has long been pumped into the subsurface as part of secondary oil recovery, but significantly larger operations are planned by the Department of Energy and affiliates with the aim of mitigating the problem of global warming. Bolton collaborated with others at Yale to get a YCEI seed grant for the study of carbon sequestration. He collaborated with 5 others in G&G, and PIs in Maryland and Hawaii to help successfully get a 3-year grant to study carbon sequestration in mafic and ultramafic rocks. Bolton was the Managing PI (Zhengrong Wang was the lead PI). This project involves experiments in geochemistry and geomechanics, which will be linked by models Bolton, Cai, and Bercovici are developing. Mineral dissolution verses pore-scale clogging would occur differently in different target rock types. The codes Bolton is developing for kinetically controlled mineral reactions

and dynamic permeability will be of great use in the study of these problems. Although his past codes can deal with supercritical CO_2-H_2O mixtures *or* aqueous solutions, in a major code upgrade he has extended the flow system to include multiphase fluids, and upgraded his codes to include equations of state for brines and CO_2-H_2O mixtures at sequestration conditions. This will allow modeling of mineralogic changes during carbon sequestration in order to better identify optimal target sites. Specialized codes for 0, 1, and 2D have been developed. Major progress was made in an implementation of an implicit method for dealing with "stiff" reaction terms and an adaptive time step that allowed an efficiency increase of many orders of magnitude (smaller CPU time). Current focus is on comparison of forward models of olivine (forsterite) dissolution with magnesite formation to compare to geochemical kinetic experiments. Simulations with various mineral phases suppressed have been done, and analysis of these simulations is being prepared for publication. Bolton also collaborated with Zhengyu Cai and David Bercovici on the creation of a coupled poroelastic deformation (compaction) and mineral reaction 1D code. Simulations of forsterite dissolution and magnesite precipitation have been performed for a wide range of simulation parameters. Reaction rates are strongly coupled, and the presence or absence of other secondary mineral reactions, as well as armoring is profound.

Bolton has been collaborating with Leo Buss (Yale Dept. of Ecology & Evolutionary Biology) to develop a circulation model for a marine hydrozoan that lives on the back of hermit crabs. This animal can be studied in detail in the lab as it grows as two-dimensional networks on microscope slides. We aim to quantitatively capture dynamics of flow and deformation in the stolon (elastic tubes) network and to relate such dynamics to our newly developed numerical model (with flow driven by the polyps as pumps). Several manuscripts will result from this research. We are also developing tools to quantitatively track the growth statistics and development of the hydroid colonies, and relate this to classic papers on pattern formation and energy use. The papers planned relate separately to the topics: 1. Observation and simulation of fluid flow and nutrient absorption in colony networks (L.W. Buss, Anderson, Perry, E.D. Buss, & Bolton, 2015, accepted 20 Aug. 2015), 2. Processing techniques for the extraction of developing complex networks from images, 3. Pattern formation during ontogeny of marine hydroids and the influence of variable feeding patterns, 4. A dynamic circulation model for the colonial hydroid *Podocoryne carnea* network, as mentioned above. 5. *Podocoryne carnea* stolon tip growth and regulation (N. Connally, C.P Anderson, J.E. Bolton, E.W. Bolton, L.W. Buss, The Selective Myosin II Inhibitor Blebbistatin Reversibly Eliminates Gastrovascular Flow and Stolon Tip Pulsations in the Colonial Hydroid *Podocoryna carnea*, Public Library of Science ONE, Accepted, 12 Nov. 2015). A paper in hydroid musculature has appeared (Buss, Anderson, and Bolton; 2013).