

CHIN-FU TSANG

Earth Sciences Division
Ernest Orlando Lawrence Berkeley National Laboratory
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EDUCATION

Ph.D., Physics, 1969, University of California at Berkeley, USA
B.Sc. (First Class Honours), Physics, 1964, University of Manchester, England.
Higgenbottom Exhibition Award (top of class), 1962, University of Manchester, England.

PROFESSIONAL POSITIONS

Visiting Professor of Hydrogeology, Department of Earth Science and Engineering,
Imperial College London, UK, September 2008 – September 2010.

Visiting Professor of Hydrology, Department of Earth Sciences, Uppsala University,
Sweden, July 2008 – February 2011.

Senior Scientist Emeritus, Lawrence Berkeley National Laboratory, July 2005 – present.

Senior Scientist (highest level in Earth Sciences Division), Lawrence Berkeley National
Laboratory, May 1981 – June 2005.

Head, Department of Hydrogeology and Reservoir Dynamics, Earth Sciences Division,
Lawrence Berkeley National Laboratory, June 1998 – May 2002.

Director, LBL Russian-American Center for Contaminant Transport Studies, Lawrence
Berkeley National Laboratory, June 1993 – 1998.

Head, Department of Environmental Remediation Technology, Lawrence Berkeley
National Laboratory, 1993 – 1996.

Group Leader, Reservoir Engineering and Hydrogeology Group, Lawrence Berkeley
Laboratory, April 1991 – September 1993.

Deputy Group Leader, Reservoir Engineering and Hydrogeology Group, Lawrence
Berkeley Laboratory, October 1982 – November 1987.

Deputy Group Leader, Geophysics and Reservoir Engineering Group, Lawrence
Berkeley Laboratory, May 1979 – October 1982.

Scientist and Staff Scientist, Lawrence Berkeley Laboratory, July 1969 – May 1981.

RESEARCH INTERESTS

Coupled hydro-mechanical and thermo-hydro-mechanical processes in fractured rocks
Fluid flow and solute transport in fractured media and heterogeneous porous media
Flow channeling in geologic media
Advanced well tests analysis and borehole testing methods
Non-isothermal reservoir dynamics
Site characterization and performance assessment for site evaluation
Injection of liquids and CO₂ into deep underground formations

PROJECTS AND CONTRIBUTIONS

Dr. Tsang is principal investigator and project manager for a large number of projects over the years. These include projects on groundwater contaminant transport; underground thermal energy storage; geothermal reservoir modeling; deep injection disposal of hazardous wastes; basic study of reservoir dynamics; and technical issues in geologic disposal of nuclear wastes. He initiated a number of new research areas for the Berkeley Laboratory, such as underground thermal energy storage, flowing borehole fluid logging methods, and coupled thermo-hydro-mechanical processes in fractured rocks.

He initiated, organized and served as the Director of the Russian-American Center for Contaminant Transport Studies at the Berkeley Laboratory, 1993-1998, and led the first joint Russian-American field test at the radioactively contaminated Mayak site at Chelyabinsk, Southern Urals, Russia in 1994.

He was one of the leading scientists that opened the field of coupled thermo-hydro-mechanical processes in geological systems, and served as the Chair of the Steering Committee of the international DECOVALEX project, a research collaboration among over 10 countries on this subject (managed by SKI, Sweden and with Secretariat based at Royal Institute of Technology, Stockholm), from 1992 to 2008..

He is a leading researcher in the field of fracture hydrology and a recognized expert in hydrogeology and tracer transport related to the problem of nuclear waste geological repositories. He serves as an expert reviewer for Swedish and Finnish government agencies to evaluate the site characterization and safety assessment work related to nuclear waste repository development in the two countries respectively.

HONORS AND PROFESSIONAL ACTIVITIES OVER PAST 10 YEARS

(SOME HIGHLIGHTS)

2006-2009

Keynote Lecture and General Rapporteur, EU conference on THERESA and TIMODAZ multiple-year and multi-organization research programme, Luxembourg, September 30 – October 2, 2009

2009 Applied Rock Mechanics Award, American Rock Mechanics Association. For contributions in fractured rock hydrogeomechanics with applications ranging from pressure testing, tracer transport to CO₂ injection-storage.

Keynote Lecture, Rock Mechanics Analysis Workshop, Mont Terri Project, Nagra, Unterageri, Switzerland, June 3-5, 2009

Invited Speaker at Science Colloquium for celebration of 50th Anniversary of the Federal Institute for Geosciences and Natural Resources (BGR). Lecture title: Thermo-Hydro-Mechanics of Geological Systems: Advances, Challenges, and Limits. Hannover, Germany, November 25, 2008.

Visiting Professor of Hydrogeology, Department of Earth Science and Engineering, Imperial College London, UK, September 2008 – September 2010.

Visiting Professor of Hydrology, Department of Earth Sciences, Uppsala University, Sweden, July 2008 – February 2011

Invited to be member of Expert Consultant Group to advise Finnish Government authority, STUK, on Posiva's work in the development of Finnish nuclear waste repository, December, 2007 – December 2009.

Expert member of INSITE Core Group to advise the Swedish government authority, Swedish Nuclear Power Inspectorate (SKI) on Swedish site investigation program for siting nuclear waste repository in Sweden being conducted by Swedish Nuclear Fuel and Waste Management Company (SKB), 2002 – present

Expert member of International Review Team to advise Finnish Government authority, STUK, in their review of TKS2006, "Posiva's Research Programme for 2007-2009", January-May, 2007.

Keynote Lecture, *Coupled Hydromechanical Processes in Crystalline Rock and in Plastic and Indurated Clays – a Comparative Discussion*. The Second International Conference on Coupled Thermo-Hydro-Mechanical-Chemical Processes in Geosystems, GeoProc2006, Nanjing, China, May 22-24, 2006.

2006 Rock Mechanics Case History Award, American Rock Mechanics Association. Awarded for contributions to the field of rock mechanics as a co-investigator in coupled thermo-hydrological-mechanical analysis of the Yucca Mountain Drift Scale Heater Test, which was the largest heater test in geological formation to-date with four-year heating period followed by an equal period of cooling. 2006.

Co-organizer of the International Symposium on Site Characterization for CO₂ Geological Storage, held at Berkeley, California, March 20-22, 2006

Chairman of Steering Committee, *DECOVALEX-THMC Project*, a ten-nation international cooperative research program on Coupled Thermo-Hydro-Mechanical-Chemical (THMC) Process Model Development and Validation against Experiments, managed by Swedish Nuclear Power Inspectorate, with Secretariat at Royal Institute of Technology, Stockholm, Sweden, 2004-2007.

2000-2005

Opening Keynote Speaker, *Studies in Fractured Rock Hydromechanics: from Borehole Testing, Solute Transport, to CO₂ Storage*. Euro-Conference 2005 on Rock Physics and Geomechanics, Saint-Pierre d'Oléron, France, 18-22 September, 2005.

Invited Speaker, International Workshop on: "Practical Experience and Results of Research for Deep Well Injection", Dimitrovgrad, Yliankov Region, Russia Federation, August 23-25, 2005.

Issue Paper: *Is Current Hydrogeologic Research Addressing Long-Term Predictions?* Journal of *Ground Water*, 43, No. 3: 296–300, June, 2005.

2005 Applied Rock Mechanics Award, American Rock Mechanics Association. Awarded for seminal contributions in the field of rock mechanics by conducting a comparative evaluation of geohydromechanical processes in the excavation damaged zone in crystalline rock, rock salt, and indurated and plastic clays – in the context of radioactive waste disposal, 2005.

Chairman of Steering Committee, *DECOVALEX-THMC Project*, a ten-nation international cooperative research program on Coupled Thermo-Hydro-Mechanical-Chemical (THMC) Process Model Development and Validation against Experiments,

managed by Swedish Nuclear Power Inspectorate, with Secretariat at Royal Institute of Technology, Stockholm, Sweden, 2004-2007.

Expert member of INSITE Core Group to advice the Swedish government regulatory agency, Swedish Nuclear Power Inspectorate (SKI) on Swedish site investigation program for siting nuclear waste repository in Sweden, being conducted by Swedish Nuclear Fuel and Waste Management Company (SKB), 2002 - present

Chairman of Steering Committee, *DECOVALEX Project*, a ten-nation international cooperative research program on Coupled Thermo-Hydro-Mechanical (THM) Process Model Development and Validation against Experiments, managed by Swedish Nuclear Power Inspectorate, with Secretariat at Royal Institute of Technology, Stockholm, Sweden, Phase I, 1992–1995; Phase II, 1995–1999; Phase III, 2000–2003.

Expert member of International Expert Review Group of the Radiation and Nuclear Safety Authority of Finland (STUK) to review Finnish programme TKS2003 for research, development and technical design for 2004–2006, being conducted by Finnish nuclear waste management company, POSIVA, September 2004.

General Rapporteur, European Commission CLUSTER Conference on *Impact of the Excavation Disturbed or Damaged Zone (EDZ) on the Performance of Radioactive Waste Geological Repositories*, Luxembourg, 3–5 November 2003

Keynote Speaker, International Conference on Coupled THMC Processes in Geosystems: GeoProc2003, organized by Royal Institute of Technology, Stockholm, Sweden, October, 2003

Invited Expert Speaker, Underground Injection and Control Technology for Waste Disposal Workshop, organized by Chinese Society of Environmental Sciences and Du Pont Chemical Company, Beijing, China, 20-22 August 2003

Foreign Member of Review Committee to evaluate and promote a candidate to full professorship at the Swedish Agricultural University, Uppsala, Sweden, 2003

Organizer of Second International Symposium on Underground Injection Science and Technology, Lawrence Berkeley National Laboratory, Berkeley, California, October 2003.

Scientific Advisory Committee, International Association of Hydrogeologists (IAH) Conference on “GROUNDWATER IN FRACTURED ROCKS”. Prague, Czech Republic, September 2003.

Reviewer and Collaborator on International Science and Technology Centre (ISTC) project on mining waste disposal, with VNINIPT, Ministry of Atomic Energy, Moscow, 2000 to 2004

Reviewer for Finnish Center for Radiation and Nuclear Safety, STUK, to evaluate hydrogeology aspect of Posiva’s site characterization program of the Finnish potential radioactive waste repository site, 2002

Invited Paper, “*Near-field THM processes in Bentonite-Rock System*”, at the EBS Workshop, organized by Swedish Nuclear Power Inspectorate (SKI), Kraggard, Sweden, Nov., 2002

After-Dinner Speech: “*Nuclear Waste Issues in the 1950s*” at at the EBS Workshop, organized by Swedish Nuclear Power Inspectorate (SKI), Kraggard, Sweden, Nov., 2002

Keynote Paper, *“Issues and Strategies in Hydrogeology Research”*, International Symposium on Hydrogeology Research in the 21st Century, organized by National Natural Science Foundation of China, Wuhan, China, November 2002.

Co-chair of Organization Committee, IAHR Symposium on Groundwater: Bridging the Gap between Measurements and Modeling in Heterogeneous Media, Berkeley, California, March 25–29, 2002.

Invited Speaker, International Conference on Fractured Rocks 2001, organized by the U.S. Department of Energy, U.S. Environmental Protection Agency, and Smithville Phase IV Program, Canada, March 26–28, 2001, Toronto, Canada. Invited paper title: *“Flow Channeling in Fractured Rock and Tracer Breakthrough Analysis”*, published in Proceedings of Fractured Rock 2001.

Adjunct Professor, China University of Geosciences, Wuhan, China, 2000 – 2004.

Keynote Speaker, International Association of Hydrogeologists (IAH) XXX Congress 2000 in Cape Town, South Africa, 26 November – 1 December, 2000. Keynote paper title: *“Modeling Groundwater Flow and Mass Transport in Heterogeneous Media – Issues and Challenges,”* (LBNL-45640), published in Proceedings of the International Association of Hydrogeologists XXX Congress 2000, Cape Town, South Africa, A.A. Balkema Publishers, Rotterdam, Netherlands, 2000.

Keynote Speaker, International Conference on Hydrogeology and the Environment, organized by the China University of Geosciences, Wuhan, China, October 17–20, 2000. Keynote paper title: *“Overview of Coupled THM Processes Affecting Flow and Transport in Fractured Rock”*, published in Conference Proceedings.

THESES DIRECTED

Dr. Tsang served on the thesis committees of a number of Ph.D. and M.S. students in Geological Engineering in the Department of Materials Science and Mining Engineering of the University of California at Berkeley. He also directed Ph.D. students on two-month to one-year visits to the Berkeley Laboratory from Royal Institute of Technology, Stockholm, Sweden, Aachen University of Technology, Aachen, Germany, and Chalmers University, Goteborg, Sweden.

In 1991 and 1995, he was invited to be the Foreign Examiner for a Ph.D. thesis in Hydrology in the Aligarh Muslim University, India, and also for a Ph.D. thesis in Civil Engineering, Kerala University, India, respectively

In 1997, he was invited to be Foreign Examiner for Ph.D. thesis entitled, *“Hydrogeological Evaluation of Proposed Landfill Sites in the Greater Auckland Area (N.Z.): Mt. Wellington and Peach Hill Valley”*, by Parviz Namjou, Department of Geology, University of Auckland, New Zealand.

In 1998, he was invited to be the Faculty Opponent for a Ph.D. thesis entitled, *“The Underground as a Storage Facility: Modeling of Nuclear Waste Repositories and Aquifers Thermal Energy Stores”*, by Thomas Probert, Department of Mathematical Physics, Lund Institute of Technology, Lund University, Sweden.

In 1999, he was invited to be Foreign Examiner for a Ph.D. thesis entitled, *“Aquifer System and Groundwater Resource Potential of Patiyali Sub-Division in Pars of Ganga-*

Kali Sub-Basin, District ETAH, U.P.", by Asad Umar, Department of Geology, Aligarh Muslim University, Aligarh, India.

In 2000, he was invited to be Foreign Examiner for Ph.D. thesis entitled, "Optimisation Techniques for Groundwater Management", by Noel Merrick, National Center for Groundwater Management, Faculty of Science, University of Technology, Sydney, Australia.

In 2001, he was invited to be External Examiner for Ph.D. thesis entitled, "Three-dimensional Flow and Solute Transport in Rough-walled Fractures," by David Brush, Department of Civil and Environmental Engineering, University of Waterloo, Canada.

In 2005, he was invited to be Faculty Opponent of Ph.D. thesis on "Flow and transport in fractured rocks", by Hua Cheng, Department of Land and Water Resources Engineering, Royal Institute of Technology (KTH), Stockholm, Sweden.

In 2007, he was invited to be Faculty Opponent of Ph.D. thesis on "Modelling long-term redox processes and oxygen scavenging in fractured crystalline rocks", by Magnus Sidborn, School of Chemical Science and Engineering, Royal Institute of Technology (KTH), Stockholm, Sweden.

PATENTS AND COPYRIGHT

Patent on Thermal Well Test Method, approved December 24, 1985.
Patent Number 4,559,818, U.S. Patent Office.

Copyright on Computer Code "BOREXT," a borehole fluid logging analysis procedure, 1995 (updated to BOREII code, 2000).

PUBLICATIONS

Dr. Chin-Fu Tsang has over 390 research reports, papers, book chapters, and invited or keynote presentations, including 160 papers in refereed scientific journals. In addition, he is the co-author and co-editor of thirteen books or special issues of scientific journals. Details may be found in his Publication List.

EXAMPLE PAPERS (about one or two from each of the last 10 years)

Stefan Wessling, Ralf Junker, Jonny Rutqvist, Dmitriy Silin, Hans Sulzbacher, Torsten Tischner, Chin-Fu Tsang. Pressure analysis of the hydromechanical fracture behaviour in stimulated tight sedimentary geothermal reservoirs, *Geothermics* 38, 211–226, 2009.

Quanlin Zhou, Jens T. Birkholzer and Chin-Fu Tsang, A semi-analytical solution for large-scale Injection-induced pressure perturbation and leakage In a laterally bounded aquifer–aquitard system, *Transp Porous Med* 78:127–148, DOI 10.1007/s11242-008-9290-0, 2009.

Tsang, C., C. Doughty, and M. Uchida. Simple model representations of transport in a complex fracture and their effects on long-term predictions, *Water Resour. Res.*, Vol. 44, W08445, doi:10.1029/2007WR006632, 2008.

Odén, M.; Niemi, A., Tsang C.F. and Öhman J, Regional Channelized Transport in Fractured Media with Matrix Diffusion and Linear Sorption. *Water Resources Research*, Vol. 44, W02421, doi:10.1029/2006WR005632, 2008.

Doughty, C., C.-F. Tsang, K. Hatanaka, S. Yabuuchi, and H. Kurikami. Application of direct-fitting, mass integral, and multirate methods to analysis of flowing fluid electric conductivity logs from Horonobe, Japan, *Water Resour. Res.*, Vol. 44, W08403, doi:10.1029/2007WR006441, 2008.

Tsang C.-F., Birkholzer J., and Rutqvist J. A Comparative Review of Hydrologic Issues Involved in Geologic Storage of CO₂ and Injection Disposal of Liquid Waste. *Journal of Environmental Geology* (Online: October 2007; Volume 54, No. 8, 2008).

Tsang C.-F., Rutqvist J., and Min K.B. Fractured Rock Hydromechanics: from Borehole Testing, Solute Transport, to CO₂ Storage, In: *Rock Physics and Geomechanics in the Study of Reservoirs and Repositories*, David, C. and Le Ravalec-Dupin, M. Editors. Geological Society of London Special Publication 284, pp. 15-34, 2007.

Cappa F., Guglielmi Y., Rutqvist J., Tsang C.-F., and Thoraval A. Hydromechanical modeling of pulse tests that measure both fluid pressure and fracture-normal displacement at the Coaraze Laboratory site, France. *International Journal of Rock Mechanics and Mining Sciences*, 43, 1062-1082, 2006.

C. F. Tsang. Is Current Hydrogeologic Research Addressing Long-Term Predictions? *Ground Water*, 43, No. 3: 296–300. 2005.

Chin-Fu Tsang, F. Bernier and C. Davies. Geohydromechanical processes in the Excavation Damaged Zone in crystalline rock, rock salt, and indurated and plastic clays—in the context of radioactive waste disposal. *International Journal of Rock Mechanics and Mining Sciences*, Volume 42, No. 1, Pages 109-125, January 2005.

Pozdniakov, S. and C. F. Tsang, A self-consistent approach for calculating the effective hydraulic conductivity of a binary, heterogeneous medium, *Water Resources Research*, 40, W05105, (10.1029/2003WR002617), 2004.

Min K.B, Rutqvist J., Tsang C.-F., and Jing L. Stress-dependent permeability of fracture rock masses: a numerical study. *Int. J. Rock mech. & Min. Sci.*, 41, 1191-1210, 2004.

Tsang, C. F. and C. Doughty (2003). A Particle Tracking Approach to Transport in a Complex Fracture, *Water Resources Research*, Vol. 39, No. 7, 1174-1178 (10.1029/2002WR001614). LBNL-50537, July, 2003

Tsang, C. F. and C. Doughty, Multirate flowing fluid electric conductivity logging method, *Water Resources Research*, 39, 12, 1354-1362 (10.1029/2003WR002308), 2003.

Peter Starzec and Chin-Fu Tsang, Use of Fracture Intersection Density for Predicting the Volume of Unstable Blocks in Underground Openings, *International Journal of Rock Mechanics and Mining Sciences* 39, 807-813, 2002.

D.B. Silin and C.-F. Tsang, Estimation of formation hydraulic properties accounting for pre-test injection or production operations. *Journal of Hydrology*, 2002, 265, 1-14, 2002.

Y.W. Tsang and C.F. Tsang, A Particle-Tracking Method for Advective Transport in Fractures with Diffusion into Finite Matrix Blocks, *Water Resources Research*, 37(3): 831-835, 2001.

Chin-Fu Tsang, Luis Moreno, Yvonne W. Tsang, and Jens Birkhölzer, Dynamic Channeling of Flow and Transport in Saturated and Unsaturated Heterogeneous Media, (LBNL-45474). *AGU Monograph on Flow and Transport through Unsaturated Fractured Rock*, Dan Evans, Tom Nicholson and Todd C. Rasmuson, editors, pp 33-44, August, 2001.

C.F. Tsang, O. Stephansson and J. Hudson, A discussion of THM processes associated with nuclear waste repositories, *International Journal of Rock Mechanics and Mining Sciences* 37(1-2): 397-402, 2000.

Pozdniakov, S. P. and C.F. Tsang, A Semianalytical Approach to Spatial Averaging of Hydraulic Conductivity in Heterogeneous Aquifers, *Journal of Hydrology*, 216: 78-98, 1999.

Tsang, C.F., Linking Thermal, Hydrological and Mechanical Processes in Fractured Rocks, *Annual Review of Earth and Planetary Sciences*, Volume 27, pp. 359-384, 1999.

Tsang, C.F. and I. Neretnieks, Flow Channeling in Heterogeneous Fractured Rocks. *Reviews of Geophysics*, Vol. 36, No. 2, 275-298, 1998.

Birkholzer, J. and C. F. Tsang, Solute Channeling in Unsaturated Heterogeneous Porous Media, *Water Resources Research*, Vol. 33, No. 10, pp. 2221-2238, 1997.

E. G. Drozhko, Y. U. Glagolenko, Y. G. Mokrov, I. A. Ivanov, G. A. Postovalova, L. M. Samsonova, A. V. Glagolev, S. A. Ter-Saakian, M. L. Glinsky, N. A. Vasil'kova, A. V. Skokov, H. A. Wollenberg, C.-F. Tsang, W. Frangos, R. D. Solbau, K. A. Stevenson, W. M. Lowder, and M. G. Foley, Joint Russian-American Hydrogeological-Geochemical Studies on the Karachai-Mishelyak System, South Urals, Russia. *Journal of Environmental Geology*, Vol. 29, No. 3/4, pp. 216-227, 1997.

BOOKS AND JOURNAL SPECIAL ISSUES (13)

Groundwater Transport, by I. Javandel, C. Doughty and C. F. Tsang; Water Resources Monograph 10, American Geophysical Union, 1984. (5 printings)

Coupled Processes Associated with Nuclear Waste Repositories, C. F. Tsang, Editor, Academic Press, 1987.

First Eight Years of Seasonal Thermal Energy Storage Bulletin, C. F. Tsang, editor. Published by International Council for Thermal Energy Storage, Public Works of Canada, Ottawa, Canada, 1987.

Flow and Contaminant Transport in Fractured Rocks, Jacob Bear, C. F. Tsang, and Ghislain de Marsily, editors. Academic Press, 1993.

Fractured and Jointed Rock Masses, L. R. Myer, C.-F. Tsang, N.G.W. Cook, and R.E. Goodman, editors. A.A. Balkema Publishers, Rotterdam, Netherlands, 1995.

Scientific and Engineering Aspects of Deep Injection Disposal of Hazardous and Industrial Wastes, J. A. Apps and C. F. Tsang, editors. Academic Press, March 1996.

Coupled Thermo-Hydro-Mechanical Processes in Fractured Media: Mathematical and Experimental Studies, Ove Stephansson, Lanru Jing, and Chin-Fu Tsang, editors. Developments in Geotechnical Engineering, Volume 79, Elsevier Science Publishers, December, 1996.

Journal of Hydrological Science and Technology, Special Issue, C. F. Tsang and J. A. Apps, Guest Editors. American Institute of Hydrology, Volumes 15–16, Number 1–4, 1999.

International Journal of Rock Mechanics and Mining Sciences, Neville Cook Special Issue, C.F. Tsang and L. Myer, Guest Editors. Pergamon Publishers, Volume 37, Number 1–2, January/February 2000.

Journal of Environmental Geology, Special Issue, guest edited by C. F. Tsang and V. Shestakov, Guest Editors. Springer Verlag, Volume 42, No. 1-2, June, 2002.

Underground Injection Science and Technology, C.F. Tsang and J. Apps, editors. Elsevier Science Publishers, Developments in Water Science, Volume 52 (December 2005).

Journal of Environmental Geology, Special Issue on Site Characterization for CO₂ Storage”, Jens Birkholzer and C. F. Tsang, Guest Editors. Springer Verlag, Germany (2008).

Journal of Environmental Geology, Special Issue on Coupled THMC Processes, Chin-Fu Tsang, Guest Editor, Springer Verlag, Germany, 2009