An interview with Paul Witherspoon, distinguished hydrogeologist from the USA

R. Allan Freeze · Iraj Javandel

Keywords Profiles · Interview · USA · Sweden

Introduction

On 30 October 2007, Paul Witherspoon was interviewed by Allan Freeze as part of the Hydrogeologist Time Capsule program (http://timecapsule.iah.org). The interview was organized by Iraj Javandel of the Lawrence Berkeley National Laboratory (LBNL), USA and sponsored in part by LBNL. Filming was carried out on the campus of the University of California at Berkeley by UCB Media Services. This short biographical profile is intended to accompany the videotaped interview posted on the Time Capsule website. It is based (in many cases, word for word) on autobiographical material provided to the authors by Paul Witherspoon, in preparation for the interview.

Paul Witherspoon has been an influential research leader in hydrogeology for over 50 years. He has made significant contributions to the understanding of the flow of fluids in fractured and porous rock formations, and has applied his findings to a diverse set of societally important issues, including the development of geothermal energy, the use of underground gas storage, and the siting and design of nuclear waste disposal facilities. He has been an inspirational mentor over many years to a large number of well-known researchers in the hydrogeological community.

Early years

Paul Witherspoon was born on 9 February 1919, in Dormont, Pennsylvania, a suburb of Pittsburgh, USA. During his early childhood, his family lived on an 8-acre tract in a truck-farming community, and Paul earned his spending money by raising chickens and selling eggs. Paul's father was a civil engineer who worked for a time for the Carnegie Coal Company. As a young child, Paul took his first trips underground into the Carnegie coal mines with his father, where he was fascinated by the mining methods and special surveying procedures used in the underground operations. While Paul was still quite young, his father left the coal company, bought an old cable-tool drilling rig, and formed a small business to drill for natural gas. During high school, Paul's father hired him to work on the rigs as a tool dresser, a job that involved hard physical labor and considerable danger when pockets of gas were encountered. These early experiences in the budding natural gas industry with his father had a direct and lasting influence on Paul's choice of career. After graduating from Dormont High School, Paul entered the University of Pittsburgh in 1937 and graduated with a Bachelor of Science degree in Petroleum Engineering in June 1941.

Early career as a petroleum engineer

From 1941 to 1949 Paul worked in various capacities for the Phillips Petroleum Company in Oklahoma City, Oklahoma; Bartlesville, Oklahoma; Borger, Texas; and Eureka, Kansas. His work in Borger was in support of a Department of Defense contract that was sufficiently important to the Second World War effort that Paul was exempted from military service. The Japanese attack on Pearl Harbor had disrupted the flow of rubber to the United States, and Paul's work at Borger was as a chemical process engineer at a plant designed to convert butane (which Phillips had in abundance) to butadiene, which can be co-polymerized with styrene to produce synthetic rubber.

In 1946 Paul met and married Elizabeth Talbot. Their son was born in 1948, and two daughters followed. On 26 October 2006, Paul and Elizabeth celebrated their 60th wedding anniversary.

Graduate education

In the fall of 1949 at the age of 30, Paul felt the need to improve his background in mathematics, engineering, and geology. He decided to leave Phillips and enroll as a

Received: 22 January 2008 / Accepted: 9 April 2008
Published online: 17 May 2008

R. A. Freeze (✉)
3755 Nico Wynd Drive, Surrey, BC V4P1J1, Canada
e-mail: freezer3@telus.net

I. Javandel
Lawrence Berkeley National Laboratory,
Building 50E, Berkeley, CA 94720, USA
e-mail: IJavandel@lbl.gov

DOI 10.1007/s10040-008-0308-z

Master's candidate in the Department of Petroleum Engineering at the University of Kansas in Lawrence, Kansas. Paul and Elizabeth made ends meet on a $1,100 teaching assistantship and a little money that Elizabeth could bring in. In January 1951, Paul completed a Master of Science degree in petroleum engineering physics.

With several years experience in the oil industry under his belt, and his Master's degree in hand, Paul applied for the position of Head of the Petroleum Engineering Division of the Illinois State Geological Survey in Champaign, Illinois. He got the job and took up his duties in early 1951 (Fig. 1). The offices of the State Survey were on the campus of the University of Illinois, and for the next five years, while working full-time for the Survey, Paul pursued a Ph.D. in the Department of Geology at the University. He made an arrangement with the Survey to work Saturdays to make up for the time he spent attending classes during the week.

At Illinois, Paul was strongly influenced by the eminent clay mineralogist, Ralph Grim, not only by his scholarly expertise, but also by the kind and gentle manner he exhibited in his dealings with students and colleagues. Under Grim's direction, Paul set about investigating the role of clay minerals and colloidal particles on the movement of oil and water through reservoir rocks. He used an ultracentrifuge in the Department of Chemistry to carry out his studies on fluid samples collected from three Illinois oil fields. His Ph.D. thesis *Studies on Petroleum with the Ultracentrifuge* was completed in 1957.

Underground gas storage

While working at the Illinois Survey, Paul became involved in a project to store natural gas in an aquifer near Herscher, Illinois. Depleted gas fields had been safely converted to storage operations for many years, but this represented the first attempt to use an aquifer that was not a proven trap for oil and gas. The project was carried out in the Galesville sandstone at a depth of 1,750 ft (530 m), with a potential gas storage volume on the order of 10^{11} ft^3 (2.8×10^9 m^3). The project was not without problems, and the early operations had to be curtailed because of the many indications that the caprock overlying the aquifer was leaking. Eventually, the project sponsors were able to develop a protocol that allowed them to store gas in the Galesville sandstone without producing unacceptable impacts elsewhere in the subsurface environment. It was this experience in Illinois that led Paul to begin his research career investigating improved methodologies for assessing caprock integrity.

Fig. 1 1956, Paul Witherspoon as the head of the petroleum department at Illinois geological survey

Fig. 2 1989, Paul Witherspoon with a group of his former students in front of the Hearst Memorial Mining Building at University of California

 DOI 10.1007/s10040-008-0308-z

University of California at Berkeley

Paul joined the faculty in the Department of Mineral Technology at Berkeley in 1957 as a Professor of Petroleum Engineering (Fig. 2). He continued his work assessing the tightness of caprocks, and successfully applied these techniques at several aquifer gas storage projects in Illinois. He began to gain considerable experience in the various kinds of geological and engineering problems one encounters when working with groundwater systems. In the early 1960s, he obtained a large research grant from the American Gas Association to look at the pumping-test methodologies commonly used by groundwater hydrologists, and try to adapt them to the needs of aquifer gas storage projects. This study, coupled with the declining enrolments in petroleum engineering at this time, prodded Paul toward fulltime research on hydrogeological topics. He arranged to have his position retitled as Professor of Geological Engineering.

Aquitards and groundwater flow systems

Paul's work on gas storage caprocks led directly to his early recognition of the importance of aquitards in hydrogeological systems. He was well ahead of his time in realizing that a hydrological understanding of rock mass properties was going to be needed for purposes other than just withdrawing fluids from aquifers. His emphasis on the role of aquitards was a precursor of the issues that would soon arise in connection with contaminant transport problems, geothermal energy production, land subsidence, and nuclear waste isolation. He organized a seminal conference at Monterey, California, in 1971, which was the first to bring attention to the role of aquitards in groundwater flow systems (Witherspoon and Freeze 1972).

This was also the period that saw the emergence of the digital computer as a research tool. Paul was quick to recognize the potential of mathematical modeling in hydrogeology and cajoled all his students to take a mathematics minor and to become familiar with the powerful capabilities of the new computer systems. His first three graduate students in the geological engineering program all benefited from Paul's vision: Allan Freeze in his numerical simulations of natural groundwater flow systems (Freeze and Witherspoon 1966), Shlomo Neuman in his development of improved pump-testing methodologies for complex aquifer/aquitard systems (Neuman and Witherspoon 1968, 1969, 1972), and Iraj Javandel who introduced the finite-element method to the group (Javandel and Witherspoon 1968, 1969).

Advisor and mentor

Working with Paul Witherspoon was a life-altering experience for his many graduate students and colleagues. He was supportive, available, optimistic, and fun. We all benefited from his ebullient life view, and the role model he provided in fostering a research environment that featured such a wonderful spirit of cooperation and camaraderie. For those of us who went on to academia ourselves, the goal was always to create a learning experience that was as similar as we could make it to the one that Paul had given us.

Paul's students and close colleagues came from all over the world: Jane Long and Charles Wilson from the USA, Allan Freeze and John Gale from Canada, Shlomo Neuman from Israel, Iraj Javandel and Jahandar Noorishad from Iran, T.N. (Nari) Narasimhan from India, Tor Brekke from Norway, Alain Gringarten from France, Neville Cook from South Africa, Marcelo Lippmann from Argentina, Karsten Pruess from Germany, Kenzi Karasaki from Japan, G.S. (Bo) Bodvarsson from Iceland, Yvonne and Chin-Fu Tsang from China, and Boris Faybishenko from Ukraine. Paul always revelled in his international coterie. He knows fewer words in more languages than anyone you will ever meet. He also developed close ties with scientists and organizations in Russia, France, Sweden, and many other countries, and travelled widely to give talks and courses.

The strong feeling of Paul's students and colleagues for his influence on their lives gave rise to three memorable research conferences at LBNL on the occasions of Paul's 60th, 70th, and 80th birthdays. Each one provided a wonderful opportunity to catch up with former friends and coworkers, but also turned into important venues for scientific exchange. The proceedings from the 1979 and 1999 events were published by the Geological Society of America as a Special Paper (Narasimhan 1982) and the American Geophysical Union as a Geophysical Monograph (Faybishenko et al. 2000), respectively.

Geothermal energy

In the 1970s and 1980s, there was considerable national interest in investigating alternative energy sources other than coal and petroleum. Paul heeded this call, setting up several projects to assess the potential contributions of geothermal energy, under the sponsorship of the Energy and Environment Program at LBNL. The work included reservoir engineering, production engineering, geochemical and geophysical studies, and land subsidence investigations (Gringarten et al. 1975; Narasimhan and Witherspoon 1979; Pruess et al. 1982).

Lawrence Berkeley National Laboratory

In 1977, Paul was asked to move "up on the hill" permanently to become the first Director of the new Earth Sciences Division at LBNL. He maintained a dual appointment with the University and continued teaching there until 1989. On the hill, he held the Director's position for five years, and then spent another six years as Leader of the Reservoir Engineering and Hydrogeology Group. Many of Paul's former students and colleagues

 DOI 10.1007/s10040-008-0308-z

followed him from UCB to LBNL, and he has watched the Earth Sciences Division take its place as one of the world's leading research institutes in the applied earth sciences under the leadership of this next generation of Berkeley-trained scientists and engineers.

Nuclear waste isolation, the Stripa project, and fractured-rock hydrogeology

In the late 1970s, a burgeoning worldwide increase in nuclear power generation was marching forward without any meaningful solution to the question of nuclear waste disposal. National programs sprang up in several countries around the world, including the United States, to assess this issue. The Earth Sciences Division at LBNL was well-placed to participate in this effort and Paul began to search out a role for himself and his staff.

In a serendipitous coincidence, Paul had been asked by the US Energy Research and Development Agency (ERDA) to organize a workshop on low-permeability rocks in Austin, Texas, and this workshop was attended by a representative of the Swedish Nulear Fuel Safety Program, who told Paul about their plans to carry out an underground testing program in an abandoned iron ore mine near Stripa, Sweden. The upshot was a cooperative research program between Sweden and the US with LBNL taking the lead American role. At Stripa, the joint teams developed new methods of fractured-rock characterization, and applied them to the hydrogeologic assessment of alternative waste-emplacement strategies. The Stripa studies set the standard for the investigation of nuclear waste repositories, and were among the first comprehensive studies of flow and transport in fractured rocks at depth (Witherspoon et al. 1981; Witherspoon 2000, 2006)

Back home, Paul and his LBNL team offered their expertise to the US Department of Energy (DOE) in their assessment of rock conditions at the proposed nuclear waste site at Yucca Mountain, Nevada, an endeavor that is still ongoing. In 1996, Paul chaired a peer review of the thermohydrologic modeling and testing programs at Yucca Mountain, highlighting the many coupled interactions that can occur between fluid flow, heat flow, the stress/strain field, geochemical reactions, and radionuclide transport in fractured unsaturated rocks (Witherspoon et al. 1996). Since 1991, Paul has been the prime mover in producing a series of comprehensive reviews of the developing technology in nuclear waste isolation. The latest version, *Geological Challenges in Radioactive Waste Isolation, Fourth Worldwide Review*, was published in 2006 (Witherspoon and Bodvarsson 2006).

In all this work, an overarching theme has been the physics of flow through fractured rock, and the integrated assessment of the thermohydrologic and hydromechanical couplings between the flow field, the stress field, and the heat field in subsurface environments (Wang et al. 1981; Tsang and Witherspoon 1981; Long and Witherspoon 1985). For a summary, see Witherspoon (2000).

Paul Witherspoon's legacy

Paul has been widely honored for his work. He and Shlomo Neuman were awarded both the Horton Award from the Hydrology Section of the American Geophysical Union and the Meinzer Award from the Hydrogeology Division of the Geological Society of America for their work on aquifer/aquitard systems. In 1989, he was elected to the National Academy of Engineering for "pioneering work in geothermal energy, underground storage, hydrogeology, and the flow of fluids in fractured and porous rocks." In 1990, he received the Horton Medal from the American Geophysical Union (AGU), and in 1996, the Distinguished Service Award from the Geological Society of America (GSA).

Paul has left us with several messages: that aquitards are at least as important as aquifers in assessing subsurface-flow phenomena; that it is critical to get underground and carry out large-scale in-situ testing of hydrogeological conditions; and that the complete hydrogeological engineer must understand and integrate both field-measurement technology and mathematical-modeling expertise. Perhaps Paul's greatest legacy is his stu-

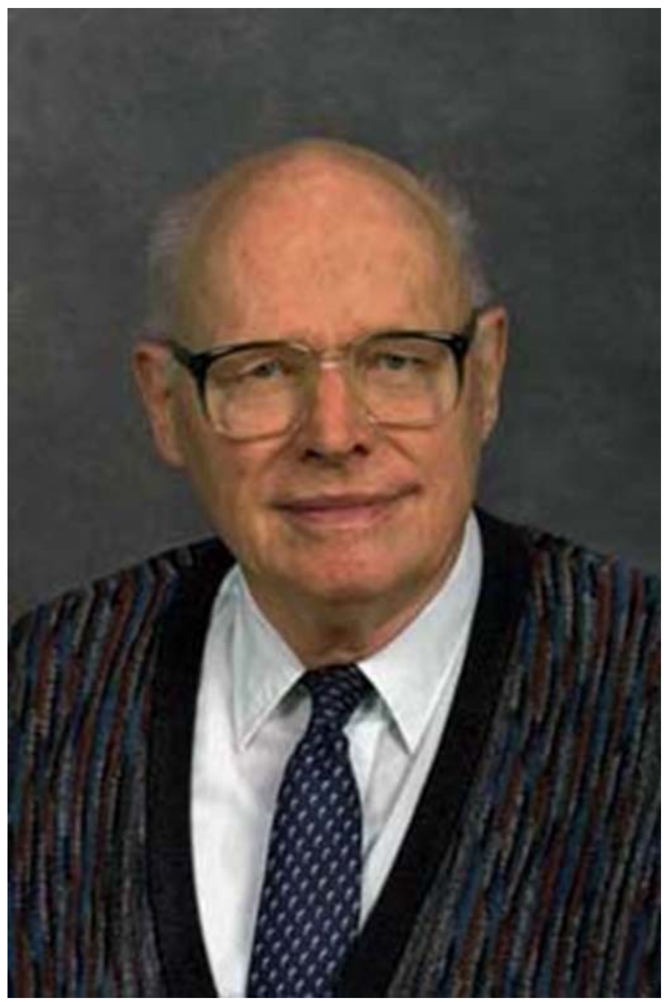

Fig. 3 A more recent photo of Paul Witherspoon

 DOI 10.1007/s10040-008-0308-z

dents and colleagues, who benefited from his generous mentorship, and a lifelong friendship of inestimable value (Fig. 3).

References

Faybishenko B, Witherspoon PA, Benson SM (eds) (2000) Dynamics of fluids in fractured rock. Geophysical Monograph 122, American Geophysical Union, Washington DC, 400 pp

Freeze RA, Witherspoon PA (1966) Theoretical analysis of regional groundwater flow, 1. Analytical and numerical solutions to the mathematical model. Water Resour Res 2:641–656

Gringarten AC, Witherspoon PA, Ohnishi PA (1975) Theory of heat extraction from fractured hot dry rock. J Geophys Res 80:1120–1124

Javandel I, Witherspoon PA (1968) Application of finite element method to transient flow in porous media. Soc Pet Eng J 8:241–252

Javandel I, Witherspoon PA (1969) A method of analyzing transient fluid flow in multi-layered aquifers. Water Resour Res 5:856–869

Long JCS, Witherspoon PA (1985) The relationship of the degree of interconnections to permeability in fracture networks. J Geophys Res 90(B4):3087–3098

Narasimhan TN, Witherspoon PA (1979) Geothermal well testing. J Hydrol 43:537–553

Narasimhan TN (1982) Recent trends in hydrogeology. Geol Soc Am Spec Pap 189:1–448

Neuman SP, Witherspoon PA (1968) Theory of flow in aquicludes adjacent to slightly leaky aquifers. Water Resour Res 4:103–112

Neuman SP, Witherspoon PA (1969) Applicability of current theories of flow in leaky aquifers. Water Resour Res 5:817–829

Neuman SP, Witherspoon PA (1972) Field determination of the hydraulic properties of leaky multiple aquifer systems. Water Resour Res 8:1224–1298

Preuss K, Bodvarsson GS, Schroeder RC, Witherspoon PA (1982) Model studies of the depletion of two-phase geothermal reservoirs. Soc Pet Eng J 22:280–290

Tsang YW, Witherspoon PA (1981) Hydromechanical behavior of a deformable rock fracture subject to normal stress. J Geophys Res 18(B10):9287–9298

Wang JSY, Tsang CF, Cook NGW, Witherspoon PA (1981) A study of regional temperature and thermohydrologic effects of an underground repository for nuclear wastes in hard rock. J Geophys Res 86(B5):3759–3770

Witherspoon PA (2000) Investigations at Berkeley on fracture flow: from the parallel plate model to chaotic systems. In: Dynamics of fluids in fractured rock, vol 122. Geophysical Monograph, American Geophysical Union, Washington, DC, pp 1–72

Witherspoon PA (2000) The Stripa Project. Int J Rock Mech Min Sci 37 (1):385–396

Witherspoon PA, Bodvarsson GS (eds) (2006) Geological challenges in radioactive waste isolation: fourth worldwide review, Report 59808, Lawrence Berkeley National Laboratory, Berkeley, CA, 283 pp

Witherspoon PA, Cook NGW, Gale JE (1981) Geologic storage of radioactive waste: field studies in Sweden. Science 211 (4485):894–900

Witherspoon PA, Freeze RA (1972) Penrose conference: the role of aquitards in multiple-aquifer systems. Geotimes 17(4):22–24

Witherspoon PA, Freeze RA, Kulacki FA, Moore JN, Schwartz FW, Yortsos YC (1996) Peer review report on thermohydrologic modeling and testing program. Yucca Mountain site Characterization Project, Department of Energy Office of Civilian Radioactive Waste Management, Washington, DC, 117 pp

 DOI 10.1007/s10040-008-0308-z