NATIONAL ACADEMY OF SCIENCES

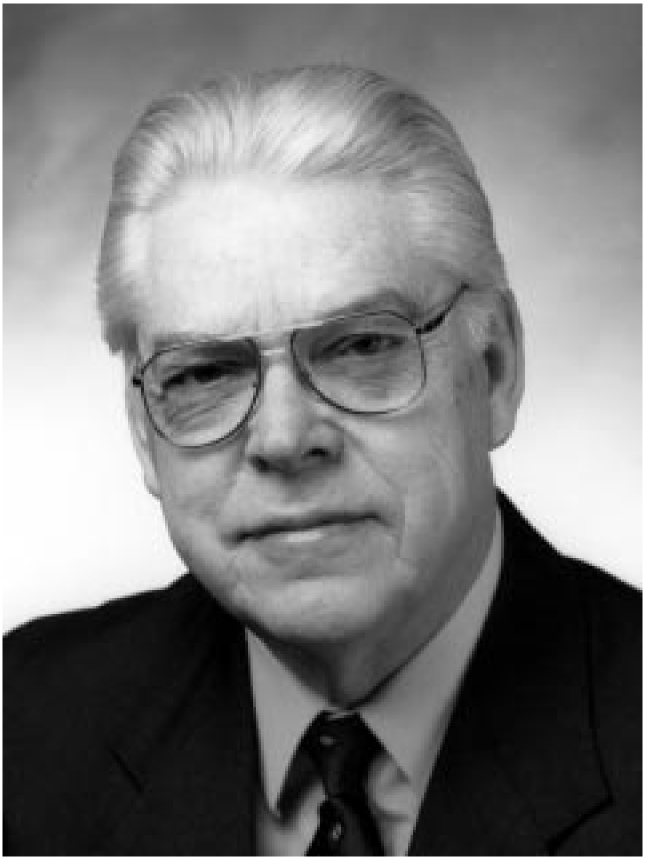
PHILIP F. LOW
1921–1997

A Biographical Memoir by

W.R. GARDNER AND C.B. ROTH

Biographical Memoirs, VOLUME 78

PUBLISHED 2000 BY
THE NATIONAL ACADEMY PRESS
WASHINGTON, D.C.



Philip F. Low

PHILIP F. LOW

October 15, 1921– January 14, 1997

BY W. R. GARDNER AND C. B. ROTH

PHILIP LOW'S UNCOMPROMISING honesty, keen intellect, and ability to lead by example resulted in an influence on science and higher education that ranked him among the top scientists in the country. Whatever endeavor he undertook he addressed with a singleness of purpose that never faltered short of achieving his goal. He devoted his career to advancing our understanding of the physics and chemistry of the absorption of water by the soil's clay mineral fraction, which dominates almost all the physical and chemical properties of soils even though it is less than two microns in size. During much of his career his thinking ran counter to the general scientific consensus, however he invariably fielded his scientific arguments with dignity and fairness.

Philip Low was a pioneer in applying thermodynamics to clay-water systems and in elucidating the nature of phosphate fixation, potassium fixation, aluminum release by exchangeable hydrogen, and osmosis and ion diffusion in these systems. Despite almost universal skepticism, Low challenged the concept that double-layer theory described clay swelling and proceeded to prove that this phenomenon is due to long-range interaction between particle surfaces and the water. Also, he developed general equations that relate both the swelling pressure and the properties of the water to the thickness of the water films on the particle surfaces. He eventually reduced many clay-water properties to a form that permitted them to be calculated from each other using an absolute minimum number of laboratory measurements. Though his work dominated the field of clay-water phenomena, Phil Low was not a one-dimensional individual. He had a thorough grasp of soil physics, plant physiology, and clay mineralogy as well as soil chemistry. His lectures dealt fairly with theories opposing his own. He had a keen interest in his own students and colleagues, and especially in his later years, he gave unstintingly of his time to assist younger scientists and colleagues.

Philip Funk Low was born on a farm near Carmangay, Alberta, Canada, on October 15, 1921, the son of Philip and Pearl Helena Funk Low. Before 1929 the family enjoyed great prosperity but with the market crash and the onset of the Great Depression, their prosperity vanished, and they became well acquainted with dire poverty. This poverty was made even more painful by marital problems between Philip's father and mother, who eventually separated. There were times when there was no food in the house, and the rent could not be paid. To alleviate the situation, Philip's mother took in boarders. Many times she advised her children to wait at the dinner table until the boarders had been served in order to be sure that there was enough food to go around. Hoping for a better life, the family moved to Calgary, Alberta, in about 1933.

Anyone familiar with Phil's dignified demeanor as an adult may find this hard to believe, but young Philip was a very inquisitive and mischievous child. These traits got him into trouble almost every day, and a spanking or a silent sitting on the stairs was the conventional punishment. Despite warnings, one cold winter day temptation got the best of him, and he touched his tongue to an iron gate. It froze fast to the gate. After a few minutes it came loose, but not without leaving some skin behind. On another occasion he tried to emulate the engineer who frequently oiled and greased the big J. I. Case steam engine at threshing time. He took a 5-pound pail of lard from the shelf and greased every door knob and water tap in the house. Later, in a single day, he broke his grandfather's wooden churn, axed his water hose into two pieces, dropped and broke his stove grate, and chased his chickens so they wouldn't lay eggs. These early exploits presaged the imagination and innovation that he displayed later in his scientific career and in an unwillingness to take the unproved for granted.

Philip's mother wanted her children to have a good education in city schools, and despite the continuing poverty, Philip did well there. The twelfth grade in Alberta was so difficult that most students had to spend two years to complete it. At the end of the school year, the government-administered final exams lasted three to four hours and covered all subjects, including mathematics (with beginning calculus), chemistry, English, and French. Most students failed at least one exam the first try and required a second year of study. Philip knew this and he also knew that he could not afford to spend extra time in high school. Consequently, he declined all outside activities to concentrate on his studies. He passed all of his exams the first time, several of them with honors.

While Philip was in the twelfth grade, his sister Gwen enrolled at Brigham Young University in Utah, proving it possible to attend a university on limited finances. Philip and his younger brother Maurice realized that, if they were to find a position with any kind of financial security, they would need a college degree.

Even though Gwen and Philip both worked until the start of BYU's fall quarter, it became obvious that there would not be enough money for both of them to enroll at that institution. Gwen selflessly volunteered to continue to work and help support the family so that her brother would not be denied the education he would so need. Also, an aunt kindly agreed to live with the family and to share expenses. Thus, Philip was able to enroll at BYU, and Gwen's sacrifice was eventually rewarded with a very successful career of her own.

In the meantime Mother Low had decided to move her family permanently to Utah. She shipped her household belongings to Salt Lake City, bought bus tickets for herself and her two sons, and presented herself at the immigration office at the U.S.-Canadian border. The $80.00 in her purse was all the money she had in the world, but Divine Providence had never failed her in times of need, and her faith was unshakable. An unfavorable reception at the U. S. Immigration and Naturalization Service awaited her. After three days, as the money decreased and anxiety increased, a kindly immigration officer took interest in her case. With his help, she and her children were granted U.S. citizenship on July 2, 1940.

Because of the rigor of Canadian high schools, BYU granted Philip college credit for the courses he took in the twelfth grade. This was a mixed blessing. Although it reduced the time he had to spend in college, it put him in his sophomore year without prior college experience and without a major field. As a result, he floundered, and his grades were not good for the first quarter. A roommate suggested that he take a course in soils from T. L. Martin, an inspiring and legendary soil scientist (and father of the internationally known soil scientists William and James Martin). This suggestion changed the course of Phil's life. Martin not only inspired Phil but he also guaranteed him an assistantship at one of the best graduate schools in the nation if he would take the courses he recommended. Martin could guarantee this because his reputation for producing outstanding students was well known nationally (e.g., National Academy of Sciences member C. B. Tanner). Thus, an enthusiastic and dedicated soil scientist was created.

Phil's time at BYU was well spent, and he took time from his studies and work to participate in a range of social activities. Most importantly, he met Mayda Stewart, and they were married on June 11, 1942, after more than a year's courtship. This was the day following her graduation with a B.A. degree; Phil had another year to go before he would complete his degree requirements.

The first year of their marriage was an anxious one for Phil and Mayda. Phil was subject to being drafted into military service. On March 2, 1943, while still at BYU he was notified to report to Fort Douglas, Utah, for induction at about the time that Mayda was expected to deliver their first child. Phil was accepted into a technical program designed to train meteorologists for the U. S. Army Air Corps. Immediately after his induction, he was sent to the University of New Mexico in Albuquerque, and Mayda did not know where he was for several days because of military secrecy. This was obviously an anxious time for both of them, as Mayda was obliged to bear their child alone during this separation.

From New Mexico, Phil and his company were sent to the California Institute of Technology in Pasadena, California, for a year's training in practical and theoretical meteorology, including an excellent training in mathematics and physics. In June 1944 Second Lieutenant Philip F. Low was transferred to Fairbanks, Alaska, for six months and Fort Nelson, British Columbia, for another seven months. Eventually he was assigned to Great Falls, Montana, as an instructor.

Phil had received his B. S. degree from BYU in absentia. With that degree and a M.S. degree granted by Cal Tech (for his training there while in the Army Air Corps), Phil was ready to undertake his Ph.D. training immediately after discharge. But few graduate schools were prepared to offer graduate assistantships or fellowships, and Phil returned to BYU, where he helped Martin for an academic year as a laboratory assistant and studied physical chemistry intensely. At the end of that year, Iowa State and Rutgers universities offered him fellowships almost simultaneously. He accepted the offer from Iowa State and began his graduate study in Ames in the fall of 1946.

This was a good time to be a graduate student in soils at Iowa State. Not only did Iowa State have an outstanding soils faculty but it also had extremely good physics, chemistry, and biology teachers to provide the needed foundation for soil science. Phil was assigned to work on phosphorus fixation under C. A. Black, a highly respected scientist and teacher. With Black's full support, Phil was permitted to depart from the usual curriculum and became the first graduate student in soils at Iowa State University to take graduate courses in chemistry. The courses he took emphasized physical chemistry, and thus it was that he developed an intense interest in this subject, especially in thermodynamics. He graduated in June 1949 with the equivalent of a Ph.D. in chemistry.

The U.S. Department of Agriculture offered Phil a job in a new laboratory that the department was establishing at New Mexico State College in Las Cruces. Given the paucity of positions in soil chemistry, Phil felt fortunate indeed. Within four months he received an offer to be an assistant professor of soil chemistry in the agronomy department at

Purdue University. J. B. Peterson, the new head of that department, had known Phil at Iowa State University and had waited for the opportunity to employ him. Peterson was a man of great vision and believed in giving young scientists the freedom to develop their interests and capitalize on their abilities. He was exceptional in this regard in that many younger faculty members in agriculture at that time were apprenticed to senior faculty members who had definite ideas of the type of applied research that was needed. A farm background was often considered a better guide to success than the course of study followed. As at Iowa State, Phil was fortunate to be surrounded by outstanding colleagues.

Early in his career Phil postulated that clays dissociate into their component ions and have a solubility product constant. Remarkably, this young faculty member was the first to make such a proposal. It then followed, he showed, that soluble phosphates can be “fixed” by forming insoluble compounds with aluminum ions dissociated from the clay and that, as a consequence, the clay decomposes. This work encouraged others to investigate the kinds and stability of phosphates that occur in the soil. Investigation of the solubility products of clays was also stimulated. A new and promising area of soil chemistry had been opened.

Soon afterwards, Low and another team of investigators working independently found that exchangeable hydrogen ions that adsorbed on the surfaces of clay crystals release aluminum ions from these crystals. Hence, the surface charge is partly compensated by the aluminum. A similar finding had been made by others several years earlier, but had not been appreciated. This was not the case with the later work, which caused considerable excitement and resulted in a new concept of soil acidity and in many related investigations.

Thermodynamics was always of special interest to Phil, who applied it to the study of water in clays, phase equilibrium, ionic diffusion, soil swelling and freezing, and to water flow in soils and clays. His thermodynamic treatment of water flow in heterogeneous systems evoked the idea that water flows along a partial molar-free energy gradient and led him to be the first to show that osmosis could occur through thick "membranes" composed of consistent clay gels. He also determined that osmosis occurs by a kind of viscous or laminar flow rather than by diffusion and that the pressure distribution in the membrane was not the primary driving force. However, since the partial molar-free energy of the water was found to decrease continuously in the direction of flow, he concluded that it was the driving force. The relevance of these results to biological membranes is significant.

Phil was a pioneer in elucidating the principles of ion diffusion in clays. He wrote one of the first published papers on this subject. At the time this seminal work was written, it was widely believed that ion diffusion in the soil did not contribute to the nutrition of plants, however in the intervening years there has been a dramatic change in philosophy, and it is now believed that ion diffusion is a major factor in plant nutrition. Interestingly, some of the early papers describing the cloud of ions surrounding the plant roots were groping for this concept. Phil's work helped to clarify and focus the attention of soil scientists on the subject of ion diffusion and contributed to a better understanding of the role of convection, diffusion, and adsorption on ion uptake by plants. In total, he wrote some 15 papers relevant to this subject. His strong training in plant physiology combined with his thorough understanding of physical chemistry gave Phil a distinct advantage in addressing soil-plant relationships.

In 1960 the editor of *Soil Science*, Fireman E. Bear, requested Phil's help in collecting a group of *Soil Science* papers that would express imaginatively and speculatively in one issue the most advanced thinking of Purdue University soil and plant scientists. In his contribution to this issue (1962), Phil postulated that ordered or quasi-crystalline water near clay surfaces should affect the rate processes involved in plant nutrition. Although, as noted below, he had evidence that water near these surfaces was ordered, he had no evidence that it affected plant nutrition or biological activity. Therefore, he initiated experiments to test his postulate. During the course of these experiments, he found that the arrangement of clay particles in clay-water system affects the properties of the adjacent water and, when the particle arrangement is changed by a mechanical disturbance, biological activity in the system changes correspondingly. For example, seed germination, bacterial thermogenesis, and nutrient uptake by corn seedlings were greater in the disturbed clay-water systems than in the undisturbed ones. These findings have never been tested fully in the field, but they deserve further consideration.

When Phil began his professional career, it was widely believed that water next to the surfaces of all solids behaves like normal bulk water and that all colloidal phenomena, including those involving clays, could be described adequately by electrical double-layer theory. This theory had the advantage of being quantitative and intellectually satisfying. One of its most useful applications was in the prediction of the swelling pressure of clays. Therefore, his hypothesis was not readily accepted when Phil hypothesized instead that interaction between the surfaces of clay particles and the inter-particle water lowers the potential energy of the water and thereby contributes to the swelling pressure of the clay. Nevertheless, he decided to test it by investigating the physical and thermodynamic properties of the water in clay-water systems. His idea was that these properties should deviate from those of normal bulk water if the swelling interaction was strong enough to alter the molecular arrangement (hence, the potential energy) of the water. This line of reasoning led to studies of clay-water interaction that consumed most of the remainder of his career.

As is often the case in science, when evidence favoring his hypothesis accumulated, opposition from those who thought otherwise increased. Most of the objections were based on conceptual arguments or indirect inferences. The complexity of the problem discouraged all but the most intrepid experimentalists. Phil and his students designed and carried out over the years the most elegant and difficult experiments in order to resolve the question of the state of water near particle surfaces based on a quantitative physical model. It turned out that Phil was to spend some 35 years obtaining and refining the data required to clarify the issues. The difficulties inherent in the experimental process dictated that progress be slow and tedious. Eventually the data and its analysis showed unequivocally that inter-particle water differs appreciably from normal bulk water in many physical properties. These properties include supercooling, viscosity, heat and entropy of compression, specific volume, specific heat capacity, specific expansibility, specific compressibility, free energy, enthalpy, and entropy. Moreover, it differs in such spectroscopic properties as molar absorptivity, O-H stretching and H-O-H bending. A careful analysis of the data shows, importantly, that the exchangeable cations cannot account for the differences. Therefore, consistent with his hypothesis, Phil concluded that the particle layer surfaces were responsible for the observed effects. These studies established that the bound water in intimate contact with clay and other minerals in the Earth's crust differs from normal bulk water. Moreover, they indicate the nature and extent of the difference. It is noteworthy that Phil's contributions in this regard are well recognized.

In a remarkable synthesis of his studies of clay-water interaction, Phil discovered that all the properties of the inter-particle water and clay-water system are described by two parameters in an exponential function. The first is a common variable in the exponent representing the average thickness of the water film on the particle surface. The second parameter is a constant that is characteristic of the particular property involved. As a consequence, elimination of the single variable between analogous equations for any two water properties yields an equation that allows one property to be calculated from any other when the respective values of the characteristic constants are known. Since these constants are determinable, the calculation of every property of the water in a clay-water system from the measured value of a single property is feasible. Hence, the aforementioned equation had great practical significance. Its theoretical significance was even greater, however. It showed that every property of the inter-particle water was affected similarly by the interaction of the water with the particle surfaces and that this interaction did not depend on the specific nature of these surfaces.

Once the difference between normal bulk water and the water near clay surfaces had been established, Phil resumed his study of clay swelling in a series of remarkable experiments in which X-ray diffraction was used to measure the distance between superimposed, parallel clay layers as a function of the swelling pressure. He found that the swelling pressure of all expanding lattice clays is described by an exponential equation containing two universal constants and a single variable (i.e., either the interlayer distance or the water content). These two variables were found to be proportional to each other. Since the properties of the inter-particle water were also functions of the latter variable, it was evident that these properties and the swelling pressure were related. Double-layer theory does not predict the equation that relates the swelling pressure to the interlayer distance, nor does it predict the relation between this pressure and the properties of the inter-particle water. Thus, Phil showed eventually that electrical double-layer theory effects were overshadowed by the water structure properties and that his initial hypothesis was vindicated.

In an article entitled "The Background to Hydration Forces" published in the proceedings of a conference on hydration forces and molecular aspects of solvation (*Chemica Scripta* 6l[1985]:25) the statement is made that "P. F. Low in the West . . . and Deryaguin in the East carried the flag for advocates of in-depth hydration over the difficult period that such views (were) unpopular and indeed heretical." As is often the case, the heretical became the orthodox.

During the course of his studies on clay swelling, Phil observed that the reduction of octahedral iron in clay crystals reduced the swelling of the crystals by causing their superimposed layers to collapse. Since potassium fixation is due to the entrapment of potassium ions between collapsed clay layers, this observation led to the idea that the reduction of octahedral iron in clays would enhance potassium fixation. When the idea was tested, it was found to be valid. Moreover, it was determined that soil microorganisms could reduce the octahedral iron under the anaerobic conditions in wet soils. Thus, Phil's fundamental research yielded a new and important concept of potassium fixation with many practical ramifications.

One of Phil's last experiments was among the most exciting. He discovered that the frequency of the Si-O stretching vibrations in the clay layers changed with water content over the entire range of swelling. The inevitable conclusion is that the structure of the clay changes correspondingly. Further, the Si-O stretching frequency was found to depend exponentially on a single variable—the water content. Since the equation relating the Si-O stretching frequency to the water content has the same form as the equation relating the H-O-H bending frequency and clay swelling pressure to the water content, it follows that the structure of the clay, the structure of the interlayer water, and the swelling pressure of the clay are interrelated. This interrelationship suggested that the Si-O stretching vibrations in the clay are coupled to the H-O-H bending vibrations in the inter-layer water and that, as these vibrations change with inter-layer distance (water content), the energy of the system changes. This, in turn, affects the swelling pressure of the clay. Thus, a much more comprehensive understanding of the phenomenon of swelling now exists.

Phil and Mayda Low had two sons and four daughters. Son Philip S. followed in Phil's footsteps and became a professor of biochemistry on the Purdue faculty. Mayda, a gifted and well-trained violinist, served as concertmistress of the Lafayette Symphony and trained many students. Her standing in the music world gave Phil's life an additional and valued dimension. There was never any question about Phil Low's priorities. First came his family, second his church, and then his work. His ability to concentrate and budget his time was a substantial asset.

Because of his leadership abilities he was called upon by the Church of Latter Day Saints (Mormon) soon after he arrived in Lafayette, and for many years Phil was the ecclesiastical leader for the church throughout Indiana. This responsibility made it difficult for Phil to take the normal academic sabbatical. However, Phil was an excellent administrator and delegated responsibility wisely, and therefore could take his summers off. Phil and his family used the summer months to visit a large number of different laboratories. Many of these laboratories were in the oil or related industries and gave Phil a much broader view of applied physical chemistry than that of many colleagues in soil science. Phil spent one summer in one author's (W.R.G.) laboratory in Riverside, California. Phil's thoroughness, tenacity, and objectivity soon became apparent. Over the course of the summer we argued in detail every point, every assumption, and every experiment either of us had ever published. It was clear that he was as rigorous a critic of his own work as that of any colleague, despite the belief of some colleagues that he was a difficult man to dissuade from his own point of view. Phil was an outstanding colleague and free in his praise of the work of others. His religious obligations helped make him into an outstanding public speaker, as well as a compassionate friend. He served as president of the Soil Science Society of America, on the Council of the Clay Minerals Society, and on the Highway Research Board. In all his activities Mayda's hospitality, charm, and warmth aided his career greatly as she supported it in unique and important ways.

He received Purdue University's Herbert Newby McCoy Award, the Soil Science Society of America's Research, and Bouyoucos awards. He was a distinguished member of the Clay Mineral Society and a fellow of the Soil Science Society and the Agronomy Society of America.

Phil was a widely sought lecturer and could fill only a fraction of the requests for lectures. He was one of the very first scientists in any discipline to be invited to lecture at length in the People's Republic of China after improvement of diplomatic relations with that country. As a result he was very influential in bringing a better understanding of the United States to the Chinese scientific community and its senior scientific leaders. He and Mayda made four trips to China and hosted a significant number of Chinese scientists, who became fast friends. His influence on science was felt well beyond the 23 Ph.D. and 15 postdoctoral students he supervised directly.

SELECTED BIBLIOGRAPHY

1957

With D. M. Anderson. The partial specific volume of water in bentonite suspensions. *Soil Sci. Soc. Am. Proc.* 22:22-24.

1961

Physical chemistry of clay-water interaction. *Adv. Agron.* 13:269-327.

1962

Effect of quasi-crystalline water on rate processes involved in plant nutrition. *Soil Sci.* 93:6-15.

Influence of absorbed water on exchangeable ion movement. *Clays Clay Miner.* 9:219-28.

1963

With J. D. Oster. Activation energy for ion movement in thin water films on montmorillonite. *Soil Sci. Soc. Am. Proc.* 27:369-73.

With R. J. Miller. Threshold gradient for water flow in clay systems. *Soil Sci. Soc. Am. Proc.* 27:605-609.

1964

With J. D. Oster. Heat capacities of clay and clay-water mixtures. *Soil Sci. Soc. Am. Proc.* 28:605-609.

1967

With D. M. Anderson and E. S. Gafney. Frost phenomena on Mars. *Science* 155:319-22.

1968

With P. F. Hockstra and D. M. Anderson. Some thermodynamic relationships for soils at or below the freezing point. I. Freezing point depression and heat capacity. *Water Resour. Res.* 4:379-94.

With P. Hockstra and D. M. Anderson. Some thermodynamic relationships for soils at or below the freezing point. II. Effects of temperature and pressure on unfrozen soil water. *Water Resour. Res.* 4:541-44.

With B. G. Davey, K. W. Lee, and D. E. Baker. Clay soils versus clay gels: Biological activity compared. *Science* 161:897.

1972

With I. Ravina. Relation between swelling, water properties and ‘b-dimension in montmorillonite water systems. *Clays Clay Miner.* 20:109-23.

With B. D. Kay. Pressure-induced changes in the thermal and electrical properties of clay-water systems. *J. Colloid Interface Sci.* 40:337-43.

1975

With B. D. Kay. Heats of compression of clay-water mixtures. *Clays Clay Miner.* 23:266-71.

1976

Viscosity of interlayer water in montmorillonite. *Soil Sci. Soc. Am. J.* 40:500-505.

With D. M. Clementz. Thermal expansion of interlayer water in clay systems. I. Effect of water content. *J. Colloid Interface Sci.* 3:485-502.

1979

With J. F. Margheim. The swelling of clay. I. Basic concepts and empirical equations. *Soil Sci. Soc. Am. J.* 43:473-481.

Nature and properties of water in montmorillonite water systems. *Soil Sci. Soc. Am. J.* 43:651-58.

1980

The swelling of clay. II. Montmorillonites. *Soil Sci. Soc. Am. J.* 44:667-76.

1981

The swelling of clay. III. Dissociation of exchangeable cations. *Soil Sci. Soc. Am. J.* 45:1074-78.

With B. E. Viani and C. B. Roth. Direct measurement of the relation between interlayer force and interlayer distance in the swelling of montmorillonite. *J. Colloid Interface Sci.* 96:229-44.

With D. J. Mulla and J .H. Cushman. Molecular dynamics and statistical mechanics of water near an uncharged silicate surface. *Water Resour. Res.* 20:619-28.

1986

With Y. Sun and H. Lin. The non-specific interaction of water with the surfaces of clay minerals. *J. Colloid Interface Sci.* 112:556-64.

1990

With Z. Z. Zhang, J. H. Cushman, and C. B. Roth. Adsorption and heat of adsorption of organic compounds on montmorillonite from aqueous solution. *Soil Sci. Soc. Am. J.* 54:59-66.