American Mineralogist, Volume 92, pages 708–710, 2007

Memorial of Werner Schreyer, 1930–2006

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Werner Schreyer, mineralogist and petrologist, passed away peacefully on February 12, 2006, after a short struggle with cancer. A Roebling medalist and Fellow of the Mineralogical Society of America, he was in the midst of a prolific second career as Professor Emeritus at the Institut für Geologie, Mineralogie und Geophysik, Ruhr-Universität Bochum, Germany.

Werner was born on November 14, 1930, in Nuernberg, Bavaria. He studied geology and petrology at the Universities of Erlangen and then Munich, where he received his doctoral degree in 1957 with a thesis on the petrography of high-grade metamorphic rocks in the Bavarian Forest under the guidance of Georg Fischer. Dissatisfied with the mainly descriptive approach of such studies, he joined the Geophysical Laboratory as a post-doc from 1958 to 1962, where he was introduced to the more quantitative concepts of experimental petrology by scientists like Hatten S. Yoder, Jr. and Frank Schairer. Those years in Washington, D.C., were decisive for his career, both scientifically as well as personally, and Werner gave a vivid account of the importance of this period in his acceptance speech for the 2002 Roebling Medal of the Mineralogical Society of America. In 1962 he returned to Germany and joined the Department of Mineralogy at the University of Kiel, where he had to endure the Habilitation procedure (an initiation rite for professorship in the German academic system), and found the entire atmosphere there to be in stark contrast to the freedom that he had enjoyed so much at the Geophysical Laboratory. However, rescue arrived shortly, because he was appointed Full Professor of Mineralogy and Petrology at the then newly founded Ruhr-Universität Bochum in 1966. This gave him the opportunity and the resources to establish a research group and a department according to his own ideas, which then became the leading institution for high-pressure mineralogical research, at least within Germany. Despite attractive offers from other renowned universities, Werner remained professor at Bochum University until his retirement in the year 1996. He retained his official affiliation there as an emeritus as well, and continued to be scientifically productive, further contributing to the Earth sciences through publications and lectures until shortly before his death.

Many of Werner Schreyer's more than 250 publications opened windows on new research areas, and their seminal nature for the development of the geosciences can often be recognized only in retrospect. Werner successfully combined a two-pronged approach that characterized his style of work: detailed conscientious observation in the field, flanked by carefully planned and well-constrained experiments, as well as intuition in the application of this "simple-systems" approach to the complex relations and processes in natural rocks on the one hand, and the ability to span the entire range of dimensions from the crystal chemistry and structure of minerals to the implications of petrology for global dynamics on the other, thus avoiding the fallacies of both the narrow-minded specialist and the superficial generalist.

The starting point for his studies at the Geophysical Laboratory was the mineral cordierite, which he had encountered in high-grade metamorphic rocks in the study area of his thesis. As it happened, Hatten S. Yoder, Jr. then also had an interest in this mineral as a petrogenetic indicator, and Frank Schairer was keen to elucidate the stability, phase compatibilities, and solid solubility of a phase that is central to the MgO-Al_2O_3-SiO_2 system. At least two results pointed far into the future. These studies on the interaction of the zeolite-like channels in the cordierite structure with fluids (water in the beginning, later on also argon, CO_2 and even low-charge cations) were far ahead of (applied) zeolite research at that time. Furthermore, the observation that,

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0003-004X/07/0004–708$05.00/DOI: 10.2138/am.2007.491

even at moderate temperature, Mg-cordierite first crystallizes in the hexagonal high-temperature form (so-called indialite) and then slowly transforms by Al,Si ordering in the tetrahedral framework to the orthorhombic low-temperature form represents one of the first kinetic studies of mineral transformation through ordering. Werner recognized early on that this process has the potential of a geospeedometer, which is petrologically and in terms of geodynamics as important as the equilibrium aspect of mineral stability.

The mineral cordierite in the system $MgO-Al_2O_3-SiO_2-H_2O$, and, later on, expansion of this system by additional components or to minerals commonly coexisting with or replacing cordierite remained *tema con variazioni* for Werner and his students for quite some time. As in music, variations on an established theme may lead to surprises and new insights. Many minerals or end-member phases were synthesized for the first time (e.g., yoderite, Mg-staurolite, boron-free kornerupine, Mg-Mg-Al-pumpellyite—later renamed Mg-sursassite, Mg-carpholite), and their stability and compatibility relations clarified. Quite a few of them were only later found in nature, because Werner's studies had predicted that they should exist stably. Others, such as osumilite or sapphirine, had been known as rare minerals before, but now gained petrological relevance and were in fact soon found to be widespread in high-grade metamorphic rocks. The wealth of phases in these systems and the many discontinuous reactions between these compounds offered—at least in those days before the advent of internally consistent thermodynamic databases—much better chances of defining metamorphic conditions than the sliding reactions typical of basaltic systems. Even within the groups of common and well-studied minerals such as amphiboles, garnets or micas he made important contributions to stability, miscibility and crystal chemistry. Werner's observations of natural assemblages and reaction textures on the one hand, and their combination with experimentally or theoretically derived metamorphic reactions and crystal-chemical deductions on the other, led to a cross-fertilization of field-related and laboratory studies, quantification of petrological processes in nature and ground-truthing of new concepts of petrogenesis.

In this way, several key mineral assemblages such as muscovite + talc were found that appeared to be of high-pressure nature. A key accelerator for Werner's early studies in high-pressure metamorphism, and—in retrospect—for metamorphic petrology as a whole, materialized when the late Holger Kulke returned from a trip to Afghanistan in 1972 and brought with him samples from the Sar e Sang lapis-lazuli deposit in Badakshan. These consisted of greenish-blue kyanite crystals several centimeters long set in a matrix of talc. This was exactly the hydrous breakdown assemblage of cordierite that Werner had predicted from his experiments to occur near 10 kbar water pressure (later corrected to some 6 kbar). Even more exciting, however, was that the whole-rock chemistry came very close to the model $MgO-Al_2O_3-SiO_2-H_2O$ system, clearly indicating a crustal origin for these rocks. So these whiteschists, as Werner called them, must represent crustal material transported to nearly mantle depths at particularly low geothermal gradients and then brought back up again (and even this exhumation process is documented in these samples by thin retrograde reaction rims of cordierite + corundum enveloping the kyanites). These papers opened up the entire field of ultrahigh-pressure metamorphism, a process still in full vigour today and central to our perception of subduction and exhumation. Werner himself further explored and expanded the *P/T*-ranges of these processes, and the next big leap forward was represented by his studies with Christian Chopin on the coesite inclusions in pyrope at Dora Maira in the Western Alps. In the meantime, ultrahigh-pressure metamorphism has come to be known from many orogenic belts world-wide, and the culmination so far has been the finding of microdiamonds in gneisses that, although otherwise inconspicuous, are clearly of crustal origin.

In parallel with these high-pressure studies, Werner developed a keen interest in boron minerals. Due to analytical problems with the electron microprobe, the role of this element had long been neglected despite the fact that it may be incorporated—as an essential structural component or as a substituent for Al, Si, etc.—into many rock-forming minerals. Its dual role in the form of planar BO_3 groups or BO_4 tetrahedra often leads to complex, pressure-dependent crystal-chemical behavior. This is best demonstrated by Werner's discovery that tourmaline may, contrary to common wisdom, contain both species side by side. Again, Werner proceeded from the simple to the complex, and he successfully predicted the occurrence in nature of these newly synthesized compounds.

The success of all these efforts may be tracked to his ability to filter the wealth of information contained in the textures of a thin section or in the nearly infinite number of reactions in a multicomponent multiphase system, and to focus on the significant questions, with a persistent quest for insight and, *horribile dictu*, curiosity-driven research.

With his contagious enthusiasm for science, his encycopledic knowledge of petrology and mineralogy, and his skills as a speaker, Werner was also an inspiring and highly successful academic teacher, advising dozens of Ph.D. theses. Leading his students on a long leash, he often gave them just subtle suggestions to put their work back on track or to show them a particularly promising direction. The renown enjoyed by the "Bochum School of Petrology" attracted both postdocs and also senior scientists on their sabbaticals to Bochum from around the world. They all gained from his willingness to share—not only his knowledge, but, even more important, his spirit.

Werner was active in scientific and professional national and international organizations, for instance as chairman of the German Mineralogical Society (1971– 1973), member of the senate of the Leopoldina Academy (1999–2002), in the Deutsche Forschungsgemeinschaft (DFG), the Alexander-von-Humboldt Foundation, the Alfred-Wegener-Stiftung (President, 1982–1983), the International Union of Geosciences (Chairman of the Commission on Experimental Petrology at High Pressures, 1971–1992), and the International Mineralogical Association (Councilor, 1994–2006). He was a key promoter of a number of cooperative efforts such as the DEKORP program, the German Continental Deep Drilling programme (KTB), and the DFG-funded research group on "High-pressure metamorphism in nature and experiment" at Bochum University (1991–1996). As a member of a committee that was supposed to propose cuts for Earth Sciences in Bavaria, he enthusiastically and successfully pledged to establish a brand new research facility in the field of experimental geochemistry and geophysics, which was then founded in 1986 as the Bayerisches Geoinstitut in Bayreuth. The *modus operandi* of this institute still largely reflects Werner's ideas of freedom of research in a group of cooperating scientists.

For his scientific achievements and his leadership Werner Schreyer received many high distinctions, of which he considered the Roebling Medal of the Mineralogical Society of America (2002) to be the most eminent. He was also awarded honorary doctorate degrees by the University of Hannover, Germany, in 1991 and the University of Liege, Belgium, in 1995. He was made Honorary Member of the Mineralogical Society of Great Britain and Ireland in 1989, and, in the same year, received the highest distinction of the Austrian Mineralogical Society, the Friedrich-Becke Medal. The German Mineralogical Society awarded him the Abraham-Gottlob-Werner Medal in 1991 and made him an honorary member in 1999. Werner was a member of a number of scientific academies: Nordrhein-Westfälische Akademie der Wissenschaften (Düsseldorf, appointed 1973), Deutsche Akademie der Naturforscher Leopoldina (Halle, 1983), Österreichische Akademie der Wissenschaften (Vienna, 1985), Academia Nazionale dei Lincei (Rome, 1987), Academia Europea (London, 1990), and Academie Royale de Belgique (Bruxelles, 1995). The mineral schreyerite, a polymorph of $V_2Ti_3O_9$, has been named after him.

Werner is survived by his wife Marianne and his two sons, Andreas and Christoph. We will all miss his contagious youthful enthusiasm and his eagerness to learn. Mineralogy has lost one of its most prestigious post-war scientists.

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