BIOGRAPHICAL BACKGROUND

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Professional Interests: Mineral chemistry and physics. Clay mineralogy/environmental mineralogy. Clays as materials. Current interests involve the understanding of the relationship of atomic structure (bulk and surface) and chemistry to layer silicate stability and properties.

Education

Degrees

Ph.D., University of Wisconsin-Madison, Wisconsin: 1976 (Geology), S.W. Bailey, advisor

M.S., S.U.N.Y. at Stony Brook, L.I., New York: 1972 (Geology), J.J. Papike, advisor

B.S., Marietta College, Marietta, Ohio: 1970 (Geology)

Thesis Titles

Ph.D., Cation Ordering in Subgroup Symmetry in the Micas
M.S., X-ray Diffraction Study of Heat-treated Lunar Pigeonites

Awards/honors

Foreign Member, Accademia Nazionale dei Lincei (Italian Academy of Sciences and Humanities), elected 2007

AIPEA Medal for Research Excellence for 2005-09 presented by the Association Internationale Pour L'Etude des Argiles (International Association for the Study of Clays).

Editor-in-Chief, *Clays and Clay Minerals*, Journal of The Clay Minerals Society, Oct., 1998-Jan., 2001

President, **Clay Minerals Society of America**, 1996-7

Recipient, **UIC Teaching Recognition Award**, UIC Council for Excellence in Teaching and Learning (1997)

Marion L. and Chrystie M. Jackson Mid-Career Clay Science Award for 1994 presented by the Clay Minerals Society of America for research excellence in clay science.

Fellow: Mineralogical Society of America, elected Nov., 1989

Hawley Medal of the Mineralogical Association of Canada for the best paper of 1986 published in the Canadian Mineralogist (see listing below for "Structural modulations in iron-rich and magnesium-rich minnesotaite"), with R.A. Eggleton.

Keynote speaker, 10th International Clay Conference, Adelaide, Australia, 20 July 1993; 12th International Clay Conference, 22-28 July 2001, Bahia Blanca, Argentina; EuroClay Conference, Modena, Italy, 23 June, 2003.

Experience

Sept., 1988 - Present	Professor, Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, IL
Aug., 1990 - July, 1991	Visiting Fellow, Department of Geology, Australian National University, Canberra, A.C.T., Australia
Sept., 1982 - Aug.,1988	Associate Professor, Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, IL
Aug., 1983 - Aug., 1984	Visiting Fellow, Department of Geology, Australian National University, Canberra, A.C.T., Australia
Sept., 1976 - Aug., 1982	Assistant Professor, Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, IL

Consultant:

March, 1980 - June, 1983	Consultation for government: City of West Chicago subcontracting through Radiation Safety Services, Inc., Evanston, IL. Geological appraisal of proposed plans by Kerr-McGee Chemical Division to dispose of thorium contaminated buildings from a 27 acre site in West Chicago.
1980 - 1999	Mineralogical studies: Several x-ray studies for engineering or consulting companies or through subcontracting agreements have been done over the past several years. (Companies have included Rockwell International, Harza Engineering,Illinois Institute of Technology Research Institute, Oil Dri Corporation, SDS Consultants, and others.)
2000 - present	Expert witness: 2000 - 2003 Expert witness testimony has been provided to the law firm of Foley and Lardner (Washington, D.C. office). The lawsuit involved patent infringement of key automotive parts that use clay minerals in their construction. 2005 - present: Expert witness is being provided to law firm of Smart & Bigger (Toronto, Canada office). The lawsuit involves the use of synthetic smectite and patent infringement in the papermaking process.

RESEARCH EXPERIENCE

Overview of research objectives, previous and current research

I define research problems that are of special significance in mineralogy and materials science. Generally, these problems relate to the understanding of phyllosilicate (clay mineral) stability by understanding atomic structure. In addition, I "re-invent" myself every 7 to 8 years, so that I work on new topics that allow a greater understanding and appreciation of phyllosilicates in general. Thus, instead of one or two research areas involving special techniques or research with two or three minerals, I have had five major directions of research over the last twenty-five years involving many techniques (e.g., XRD and high-temperature and high-pressure powder and single-crystal XRD, HR TEM, high-pressure DTA, optical harmonics, computer simulations of crystal structures, etc) and all the phyllosilicate mineral groups. My major projects include:

1. *Clay-hydrate intercalates*. Methane hydrates are ubiquitous on the ocean floor and represent a vast reservoir of methane, a greenhouse gas. A low-temperature, elevated- pressure powder X-ray diffraction

environmental chamber was developed to study hydrate formation intercalated in the clay structure. Initial studies indicate that methane hydrates do indeed intercalate in swelling clays, suggesting an additional reservoir for methane that may have important implications for climate change, for energy-resource development, for understanding geologic hazards on the ocean floor, and for energy-exploration strategies. There are also important implications for clays on Mars, where methane and carbon dioxide may be candidates for clay intercalates located at the Martian poles. Studies are now involving variations in interlayer compositions (Na, K, Ca) for specific smectite minerals (montmorillonite, nontronite) that may be common on the ocean floor. Future investigations involving a new chamber capable of examining phases in sea water will study the effect of different salt solutions and various gases (such as ethane, CO_2 and others).

2. *Organo-clay interactions*. Interactions between organic molecules and clays represent an important part of the field of "environmental mineralogy". Understanding these interactions is critical in developing new materials for remediation of polluted ground water and soil. Organic molecule interstratifications in vermiculite are being studied by single crystal X-ray methods. Previous workers did not have a systematic approach to investigate the atomic structure of the organic molecule in the clay they studied. In contrast, I have been studying both the atomic structure of the organic molecule and the clay and how organic-molecule complexity affects the overall structure of the clay. Thus, individual studies of tetramethylammonium (TMA-) and tetramethylphosphonium(TMP)-exchanged vermiculites have showed the effects of organic-molecule size on the structure, and monomethylammonium and dimethylammonium-exchanged vermiculite along with TMA-exchanged vermiculite showed the effects of increasing the complexity of the organic molecule on the structure. By transmission electron microscopy (TEM), I showed that structural defects play an important role in how organic molecules interact in certain clays. I am also considering how organo-clay interactions can self-assemble organic molecules perhaps as a prelude to the origin of life. More recently, along with a former student, I am developing clays as universal nucleants for the crystallization of protein structures.

3. *Dehydration and dehydroxylation reactions*. The role of water (H_2O, OH) in reactions involving phyllosilicates is fundamental in sedimentary, metamorphic, and diagenetic processes, as well as in many industrial and engineering applications. My research combines high-temperature, X-ray diffraction techniques with high-pressure DTA to propose atomistic models for these reactions, in addition to the description of the thermodynamic properties. Studies have included a wide range of interlayer cation-exchanged smectite minerals to understand the dehydration and dehydroxylation of these minerals. During the same period, high-temperature studies of the atomic structure of muscovite (for dioctahedral micas), phlogopite (for trioctahedral micas), lizardite (for serpentines), and chlorite were made to understand how phyllosilicate atomic structures respond to temperature increases. The muscovite structure paper was seminal in the use of Pauling's rules to develop an atomistic dehydroxylation model. I was quite pleased that this approach was used later by Drits and co-workers to develop models for the dehydroxylation of *cis*-vacant micas.

4. *Modulated phyllosilicates*. The characterization of modulated layer silicates is important in the understanding of topological limits and possible chemical variations of common layer silicates. This work emphasizes the use of high-resolution transmission electron microscopy (HR TEM) and electron diffraction to determine the complex crystal structures of the modulated phyllosilicates. Structural models were developed that allowed the prediction of which structures of some phyllosilicates should be considered candidates for structural modulations. In addition, a general classification scheme was developed for the modulated phyllosilicates. Much of the TEM work on developing structural models was done in the 1980s, long before most workers (at least in the West) recognized that structures could be obtained from intensity data.

5. *Structure studies of phyllosilicates*. Understanding the crystal structures of layer silicates is fundamental in predicting the physical and chemical properties of these materials. Current work involves X-ray structural studies at high temperatures (see dehydration and dehydroxylation studies

below), in addition to examining phyllosilicates of unusual chemistries. My earlier studies, in collaboration with my doctoral advisor, S.W. Bailey, developed models of cation ordering in subgroup symmetries, in particular, for mica minerals such as margarite, lepidolite, and zinnwaldite. The idea that ordering effects could only be recognized by considering subgroup symmetries of the space groups was novel, and we were the first to develop techniques where subgroups could be tested.

Publications

Guggenheim, S. and Bailey, S.W. (1975) Refinement of the margarite structure in subgroup symmetry. American Mineralogist, 60, 1023-1029.

Hall, S.H., Guggenheim, S., Moore, P. and Bailey, S.W. (1976) The structure of Unst-type 6-layer serpentines. Canadian Mineralogist, 14, 314-321.

Guidotti, C.V., Cheney, J.T. and Guggenheim, S. (1977) Distribution of titanium between coexisting muscovite and biotite in pelitic schists from northwestern Maine. American Mineralogist, 62, 438-448.

Guggenheim, S. and Bailey, S.W. (1977) The refinement of zinnwaldite-l*M* in subgroup symmetry. American Mineralogist, 62, 1158-1167.

Guggenheim, S. and Bailey, S.W. (1978) Refinement of the margarite structure in subgroup symmetry: Correction, further refinement, and comments. American Mineralogist, 63, 186-88.

Guggenheim, S. (1978) Polytype transformations in experimentally deformed wollastonite. American Mineralogist, 63, 1260-1263.

Guggenheim, S. and Schreckeis, J. (1980) Mechanical aids for the alignment of four-circle single-crystal diffractometers. Review of Scientific Instruments, 51 (8), 1138-1139.

Lee, J. and Guggenheim, S. (1981) Single crystal X-ray refinement of pyrophyllite-1Tc. American Mineralogist, 66, 350-357.

Guggenheim, S. (1981) Cation ordering in lepidolite. American Mineralogist, 66, 1221-32.

Baur, W.H., Guggenheim, S. and Lin, J.-C. (1982) Rutile-type compounds. VI. Refinement of VF_2 and computer simulation of V:MgF_2. Acta Crystallographica, B38, 351-5.

Guggenheim, S., Bailey, S.W., Eggleton, R.A. and Wilkes, Peter (1982) Structural aspects of greenalite and related minerals. Canadian Mineralogist, 20, 1-18.

Cramer, W.E., Guggenheim, S. and Port, E. (1982) A fail safe design for X-ray safety shutters. Journal of Applied Crystallography, 15, 138-9.

Guggenheim, S. and Bailey, S.W. (1982) The superlattice of minnesotaite. Canadian Mineralogist, 20, 579-84.

Lin, J.-C. and Guggenheim, S. (1983) The crystal structure of a Li,Be-rich brittle mica: A dioctahedral-trioctahedral intermediate. American Mineralogist, 68, 130-142.

Guggenheim, S., Schulze, W.A., Harris, G.A. and Lin, J.-C. (1983) Noncentric layer silicates: An optical second harmonic generation, chemical, and X-ray study. Clays and Clay Minerals, 31, 251-260.

Koster van Groos, A. F. and Guggenheim, S. (1984) The effect of pressure on the dehydration reaction of interlayer water in Na montmorillonite (SWy-1). American Mineralogist, 69, 872-879.

Guggenheim, S. and Kato, T. (1984) Kinoshitalite and Mn phlogopites: Trial refinements in subgroup symmetry and further refinement in ideal symmetry. Mineralogical Journal, 12, 1-5.

Yeskis, D., Koster van Groos, A. F. and Guggenheim, S. (1985) The dehydroxylation of kaolinite. American Mineralogist, 70, 159-164.

Koster van Groos, A.F. and Guggenheim, S. (1986) The dehydration of K-exchanged montmorillonite at elevated temperatures and pressures. Clays and Clay Minerals, 34, 281-286.

Vaughan, M.T. and Guggenheim, S. (1986) Elasticity of muscovite and its relationship to crystal structure. Journal of Geophysical Research, 91, 4657-4665.

Eggleton, R.A. and Guggenheim, S. (1986) A re-examination of the structure of ganophyllite. Mineralogical Magazine, 50, 307-318.

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Koster van Groos, A.F. and Guggenheim, S. (1987) Dehydration of a Ca- and a Mg-exchanged montmorillonite (SWy-1) at elevated pressures. American Mineralogist, 72, 292-298.

Guggenheim, S., Chang, Y.-H. and Koster van Groos, A.F. (1987) Muscovite dehydroxylation: High temperature studies. American Mineralogist, 72, 537-550.

Guggenheim, S. and Eggleton, R.A. (1987) Modulated 2:1 Layer Silicates: Review, Systematics and Predictions. American Mineralogist, 72, 726-740.

Koster van Groos, A.F. and Guggenheim, S. (1987) High pressure differential thermal analysis (HP-DTA) of the dehydroxylation of Na-rich montmorillonite and K-exchanged montmorillonite. American Mineralogist 72, 1170-1175.

Komarneni, S. and Guggenheim, S. (1988) Comparison of cation exchange in ganophyllite and [Na + Al]-substituted tobermorite: Crystal chemical implications. Mineralogical Magazine 52, 371-375.

Guggenheim, S. and Bailey, S.W. (1989) An occurrence of a modulated serpentine related to the greenalite-caryopilite series. American Mineralogist 74, 637-641.

Koster van Groos, A.F. and Guggenheim, S. (1989) Dehydroxylation of Ca- and Mg-exchanged montmorillonite. American Mineralogist 74, 627-636.

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Guggenheim, S. and Bailey, S.W. (1990) Baumite discredited. American Mineralogist 75, 705.

Guggenheim, S. (1990) The dynamics of thermal decomposition in aluminous dioctahedral 2:1 layer silicates: A crystal chemical model. Sciences Geologiques v. II, 99-107.

Miller, A.K., Guggenheim, S., and Koster van Groos, A.F. (1991) Bond energy of adsorbed and interlayer water: Kerolite dehydration at elevated pressures. Clays and Clay Minerals 39, 127-130.

Miller, A.K., Guggenheim, S., and Koster van Groos, A.F. (1991) The incorporation of "water" in a high-pressure 2:1 layer silicate: a high-pressure differential thermal analysis of the "10A phase". American Mineralogist 76, 106-112.

Tyrna, P.L. and Guggenheim, S. (1991) The crystal structure of norrishite, $KLiMn^{3+}_2Si_4O_{12}$: an oxygen based mica. American Mineralogist 76, 266-271.

Martin, R.T., Bailey, S.W., Eberl, D.D., Fanning, D.S., Guggenheim, S., Kodama, H., Pevear, D.R., Srodon, J., and Wicks, F.J. (1991) Revised classification of clay materials: Report of the Clay Minerals Society Nomenclature Committee for 1986-1988. Clays and Clay Minerals 39, 333-334.

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Guggenheim, S. and Koster van Groos, A.F. (1992) High-pressure differential thermal analysis (HP-DTA): II. Dehydroxylation reactions at elevated pressures in phyllosilicates. Journal of Thermal Analysis 38, 2529-2548.

Bai, T.-B., Guggenheim, S., Wang, S.-J., Rancourt, D.G., and Koster van Groos, A.F. (1993) Metastable phase relations in the chlorite-H_2O system. American Mineralogist 78, 1208-1216.

Nelson, D.O. and Guggenheim, S. (1993) Inferred limitations to the oxidation of iron in chlorite: A single-crystal high-temperature X-ray study. American Mineralogist 78, 1197-1207.

Heinrich, A.R., Eggleton, R.A., and Guggenheim, S. (1994) Structure and polytypism of bementite, a modulated layer silicate. American Mineralogist, 79, 91-106.

Eggleton, R.A. and Guggenheim, S. (1994) The use of electron optical methods to determine the crystal structure of a modulated phyllosilicate: Parsettensite. American Mineralogist 79, 426-437.

Guggenheim, S. and Eggleton, R.A. (1994) A comparison of the structures and geometric stabilities of parsettensite and stilpnomelane: A Distance Least-Squares (DLS) study. American Mineralogist 79, 438-442.

Bai, T.B., Koster van Groos, A.F., and Guggenheim, S. (1994) Phase transition, dehydration, and melting relationships of portlandite. American Mineralogist 79, 1223-1226.

Guggenheim, S. and Martin, R. T. (1995) Definition of clay and clay mineral: Joint report of the AIPEA Nomenclature and CMS Nomenclature Committees. Clays and Clay Minerals, 43, 255-6, and Clay Minerals, 30, 257-259.

Guggenheim, S. (1995) Structural studies and recent trends in the research of phyllosilicates. Clays Controlling the Environment, Proceedings of the 10th International Clay Conference, Adelaide, Australia, Churchman, G.J., Fitzpatrick, R.W., and Eggleton, R.A., eds, 24-29.

Guggenheim, S. (1995) Oxidation and thermal decomposition of chlorite. Clays Controlling the Environment, Proceedings of the 10th International Clay Conference, Adelaide, Australia, Churchman, G.J., Fitzpatrick, R.W., and Eggleton, R.A., eds, 213-218.

Zhan, W. and Guggenheim, S. (1996) The dehydroxylation of chlorite and the formation of topotactic product phases. Clays and Clay Minerals, 43, 622-629.

Wang, S., Koster van Groos, A.F., and Guggenheim, S. (1996) The effect of $CaCl_2$-H_2O fluids on the dehydration of Ca-exchanged montmorillonite (SWy-1) at elevated temperatures and pressures: The significance of brines in sedimentary basins. Geochimica Cosmochimica Acta, 60, 2167-2172.

Guggenheim, S. and Martin, R. T. (1996) Reply to comment by D.M. Moore on "Definition of clay and clay mineral: Joint report of the AIPEA Nomenclature and CMS Nomenclature Committees". Clays and Clay Minerals, 44, 713-715. Also published in Clay Minerals.

Wu, T-c., Bassett, W.A., Huang, W-L., Guggenheim, S., and Koster van Groos, A.F. (1997) Montmorillonite under high H_2O pressures: stability of hydrate phases, rehydration hysteresis, and the effect of interlayer cations. American Mineralogist, 82, 69-78.

Guggenheim, S., Alietti, A., Drits, V., Formoso, M., Galan, E., Paquet, H., Watanabe, T., Bain, D., and Hudnall, W. (1997) Report of the Association Internationale pour L'etude des Argiles (AIPEA) Nomenclature Committee for 1996. Clays and Clay Minerals, 45, 298-300, and Clay Minerals 32, 493-495.

Vahedi-Faridi, A. and Guggenheim, S. (1997) Crystal structure of tetramethylammonium (TMA)-exchanged vermiculite. Clays and Clay Minerals, 45, 859-866.

Guggenheim, S. and Eggleton, R.A. (1998) The crystal structures of greenalite and caryopilite: A system with long-range, in-plane structural disorder in the tetrahedral sheet. Canadian Mineralogist, 36, 163-179.

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