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Colloquium Paper

This paper is the introduction to the following papers, which were presented at the National Academy of Sciences colloquium "Geology, Mineralogy, and Human Welfare," held November 8–9, 1998 at the Arnold and Mabel Beckman Center in Irvine, CA.

Geology, mineralogy, and human welfare

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The complex sciences of geology and mineralogy couple the focused sciences of physics, chemistry, and biology to the "diffuse" disciplines of ecology and the environment. For this colloquium, 18 papers have been selected on matters related to human welfare, particularly health and both physical and mental wellbeing, to demonstrate the importance of new research plans and new instrumentation.

Agricultural Mineralogy, Soils, and Surfaces. Emerging "chemical microscopes" using neutrons, synchrotron x-rays, and electrons allow physicochemical characterization of mineral surfaces and adsorbed molecules and ions in soils (1). Plant growth depends on subtle interactions between mineral surfaces, saline fluids, and microbes. Incorporation of "good" trace elements into food depends on the interaction of organic and inorganic components, as does that of toxic ones. One-quarter of the wheat and rice crops are lost to Mn-oxidizing bacteria. Soils become contaminated with mobile toxic elements, including Pb, Cd, Se, and As, which can affect plant growth and food safety (2–4).

Aerosols and Climate. Mineral dust blown from drying geological basins pervades the atmosphere, and falls to earth with both good results—loess soil in central Europe, China, and North America was important for early agriculture, and still supports large populations—and bad ones—air pollution causes lung problems (5). Chemical microscopes provide physicochemical analysis of tiny particles, particularly useful for distinguishing the natural and industrial components (6).

Oceans. Minerals in the oceans range from several dozen types in bioorganisms to various zeolites grown from volcanic ash, sulfides in hot smokers in volcanic ridges, and precipitates in Mn-rich nodules (7). The reactions with sea-water depend on temperature and composition and ultimately can be related to climate and plate-tectonic processes. Highly touted as a major energy source for the future are the methane-water clathrate beds on cold ocean beds; however, current evidence is not promising for successful commercialization (8).

Biomineralogy. Chemical microscopes coupled with biochemical techniques are opening up a rapidly expanding field of studies on microbes. Before these tools were developed, mineralogists could only speculate on how microbes concentrated useful elements (including uranium!) into ore bodies, how microbes interact with atmospheric gases to modify the climate, how deep-seated ones relate to the spatial distribution and chemical signatures of natural gas and oil in the continents, and so on. Microbes can make organic acids that accelerate mineral weathering to make soil minerals (good), and eat away outdoor statues (bad) (9).

Honeycombed surfaces of weathered feldspars may have been the first home of primitive cells where they were protected from destruction by solar ultraviolet radiation. The internal hydrophobic silica-rich surface in nanometer-wide channels of a zeolite mineral formed from abundant volcanic ash (e.g., *mutinaite* = synthetic *silicalite-ZSM-5*) might have scavenged organic species from the proverbial water-rich "soup" and catalyzed assembly into primitive polymers that extruded like spaghetti to become tangled up to form the nucleus of a proto-cell (10).

Radwaste, Mining, and Environmental Issues. Perhaps a billion people, including some in developed countries, currently ingest harmful amounts of toxic elements. A prime aim of this colloquium was careful evaluation of selected problems, and establishment of an international plan for coupling scientific and administrative skills for mitigation (11–14).

Pure and Applied Mineralogy. Improvements in the chemistry of electric storage batteries are related to mineralogy (e.g., long-life Pb; high-energy Li, etc). Over 400 minerals contain Mn; we selected Mn-oxides for presentation because of advances in understanding their chemistry using the new chemical microscopes (15).

Perhaps the most spectacular advances have been in the petroleum industries, to the great benefit of the consumer. Three-dimensional-seismic imaging, slant drilling, and other engineering advances are tripling the recovery of petroleum from geologic reservoirs and actually advancing the provable reserves (although most prognostications assert that supply will not meet demand some time before 2030). The value of mineral geochemistry was illustrated by use of subtle argon-age dating of clay minerals across a potential basin to predict its yield of oil (16).

An even broader success story has been the invention of zeolite/molecular sieve adsorbent/catalysts and industrial development of myriad applications (17). Almost unknown to all but the zeolite chemists and engineers are everyday applications: the 3-fold increase in yield of gasoline from petroleum from tailored zeolite catalysts, also higher octane number and lower pollutants in automobile exhausts; clearer multi-pane windows from zeolite adsorbing dirty vapors; safer brakes in trucks and trains from pressure-swing zeolite adsorbent; longer life of refrigerators; and selective adsorbents in nuclear waste. Just moving forward into major use are natural zeolites whose low cost and high exchange capacity are leading to bulk applications in agriculture, gardening, and waste management (18).

Geoscientists now have the "chemical microscopes" and other tools to study the scientific characteristics of toxic materials, and we can now study at the atomic level those interactions between the inorganic and organic worlds that have positive aspects for human welfare. However, the available funds are far too small to properly service the growing community of environmental geoscientists. Hence, the colloquium concluded with presentations on a concept for establishment of a new efficient program for instrumentation in the environmental sciences costing only $100 million to be complemented by a similar one for research, teaching, and public

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outreach over the initial five years at universities, colleges, and experimental stations. An additional $100 million is needed to bring together research professionals and students around the world to quantify the dangers to human health of toxic elements, including As, Se, and Pb; to devise plans for dissemination of information; and to evaluate ideas for remediation in the context of diplomatic, social science, and economic planning procedures.

To conclude, particularly important for this colloquium is that the boundaries between subdisciplines are falling; that humans are now moving as much material on the Earth's surface as geological processes; that natural climatic changes are being modified willy-nilly by human activities; and that the recent increase in population and use of energy is beginning to slow down as fundamental limits are approached, but they may not slow down fast enough. Doubling of the population might be sustainable, but quadrupling almost certainly would lead to serious problems and possible catastrophes. Biological evolution, as seen in the context of geologic time, indicates that fortune goes with increasingly skilful use of resources of many types, not the maximum use of resources.

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