ENGINEERING GEOLOGY, ENVIRONMENTAL GEOLOGY, AND MINERAL ECONOMICS

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Contents

Summary

The article presents an overview of the applied branches of geology, namely, engineering and environmental geology, and their importance in our life. It also includes a discussion of some of the newer sub-specialties or new applications of geoscience, such as medical geology, forensic geology, use of underground space for human occupancy, and geoindicators.

It then presents an historical review of the evolution of engineering geology, leading to the introduction of degree programs offered at American universities, and the current prospects and employment trends of geoscience graduates in the United States and other countries. The difference between engineering geology and geological engineering is explained. The controversy relating to inclusion of environmental geology within the engineering geology specialty is discussed at length and it is concluded that, despite some overlaps, environmental geology is different from engineering geology and should be treated as such.

Readers are introduced to the newly emerging field of medical geology and its relevance in human health and well-being. It seems likely that geological factors will emerge as one of several factors responsible for the occurrence of diseases such cancer, heart ailments, and other sicknesses that may be related to the excess or deficiency of certain trace elements whose occurrence and distribution are controlled by geological processes. The suggestion is made for inclusion of the relationship between geologic factors and diseases in health education curricula.

The chronic shortage of land in large population centers all over the world has been

posing a serious challenge to land use planners and city administrators. Using the example of Kansas City—the city ranked number one in human use and occupancy of underground space—the article demonstrates that cities confronting space problems should take a close look at their geology and attempt to create and locate structures and facilities in the subsurface. That it entails a significant saving in energy cost, insurance, construction, and leasing and maintenance costs, should be an added incentive for going underground.

1. Introduction

Long before geology came to be recognized as a branch of physical science in 1786, humans had been attempting to gain an understanding of how the planet earth—our home—was formed, how it has evolved through time, why are there mountains at one place and valleys and rivers at another, where to find useful minerals and fuel materials, and why the earth "gets angry" and brings misery to us in the form of floods, earthquakes, and volcanic eruptions. For a long time in the early history of human civilization, these hazardous processes were linked with supernatural forces that were respected, revered, and even worshipped.

About 800,000 years ago when our ancestors learned the use of fire, and much later when the practice of agriculture started around 7,000 B.C. (Keller, 2000), we initiated a process of long-term exploitation of the earth to meet our need of metals, non-metals, and fuels. The onset of the Industrial Revolution around 1760 gave us an unprecedented ability and power to excavate and move earth materials at a much faster pace than we had ever done before. This new capability helped us to explore many uncharted territories and enabled us to harness the energy available from flowing water by building large dams and, since the early twentieth century, power plants. The second half of the twentieth century witnessed a tremendous increase in industrialization and urbanization and we began to realize, for the first time, the danger and harm associated with careless use and exploitation of the earth and its resources. Finally, the last four decades have brought to the fore the threat to the earth and its environment, leading to an awakening followed by a conscientious effort toward environmental preservation.

The overall content of this theme relates to what may be considered "non-traditional geoscience," in that it focuses on topics that, until the past few decades, had been either non-existent in conventional geoscience textbooks or curricula, or were covered in a cursory manner. While some of the topics, such as environmental geology, have been around for thirty to thirty-five years, and engineering geology for several decades, forensic geology, geoindicators, and medical geology are "newcomers" to the geoscience discipline. The various applications of geoscience have become important to our daily lives and play a critical role in the maintenance and preservation of human health and environmental quality.

Engineering and environmental geology are applied branches of geology. Engineering and environmental geologists, unlike traditional practitioners, bear a greater responsibility for their professional work and may be held liable for any mistake they make. In recent years geoscientists specializing in environmental geology, waste management, groundwater pollution, and hazard mitigation have been receiving a great deal of public and media exposure. While this new "visibility" is desirable and was long overdue, it has also imposed a serious challenge: that of maintaining the highest level of professionalism. The latter aspect has received considerable attention from geoscientists, especially in Western countries, who have seen to it that legislation calling for the registration and licensing of geologists is enacted and enforced. This has resulted in strict scrutiny and geologists are subjected to the same rigors of professional evaluation and licensing as engineers, doctors, and other experts.

Like all other newly evolving specialties, environmental geology and medical geology have also experienced "growing pains." Despite the fact that some of the first papers dealing with what is now included in environmental geology were published in the late 1960s, it took another eight or ten years before it came to be recognized as a separate specialty within geosciences, and was no longer viewed as a part of engineering geology. Similarly, for the past two decades a sizable volume of new findings and research results in medical geology have accumulated to the point that it is now recognized as a new sub-specialty within geoscience.

The growing concern about global climate change has led to intense research in geosciences to study the past climatic variations in earth's history and to build upon this understanding to predict future climatic changes. The traditional geological approach provides answers on a long-term basis, on a scale of tens of thousands to millions of years, which is not very helpful in assessing environmental changes on a short-term basis. The need has thus been felt to develop new methodology and tools to predict changes that occur in years, decades, or a century.

A group of geoscientists in Canada, led by Antony Berger, developed a technique that utilizes a set of geologic features or events to predict short-term environmental changes. Using geological indicators—such as coral chemistry and its growth pattern to determine changes in surface water temperature and salinity, or glacier fluctuations for assessing changes in precipitation, insolation, melt water runoff, and the like—geoscientists can now address short-term environmental changes. These common indicators, called geoindicators are defined as: magnitudes, frequencies, rates, or trends of geological processes and phenomena that occur at or near earth's surface and that are significant for assessing environmental change over periods of 100 years or less. Included are both rapid-onset (i.e. catastrophic) and more pervasive, slow-onset events that are generally evident within a human lifespan, whereas important but slower earth processes such as plate tectonics, basin subsidence, and diagenesis are excluded.
(Berger, 1998)

One of the articles under this theme in EOLSS on-line (2002) carries a full discussion of geoindicators.

2. Engineering Geology

Engineering geology is applied geology and deals with the application of geologic principles and concepts to engineering construction projects such as dams and reservoirs, tunnels and other subsurface structures, highways and airport runways, power plants, waste disposal facilities, and engineered construction to mitigate effects of hazardous earth processes, such as flooding, landslides, earthquakes, and coastal erosion. The American Geological Institute defines engineering geology as "geology applied to engineering practice, especially mining and civil engineering" (Bates and Jackson, 1987). However, when environmental concerns became paramount and attracted worldwide attention, many well-known professional engineering geology societies re-defined engineering geology to include environmental and hydrological work within the scope of application of engineering geology. For example, the Association of Engineering Geologists (AEG) in the United States, by far the largest organization serving the needs of engineering geologists with a current membership of about 2,700 (Mathewson, 2001), now uses the following definition for engineering geology:

"Engineering Geology" is defined by the Association of Engineering Geologists as the discipline of applying geologic data, techniques, and principles to the study both of a) naturally occurring soils and rock materials, and surface and subsurface fluids, and b) the interaction of introduced materials and processes with the geologic environment, so that geologic factors affecting, the planning, design, construction, operation, and maintenance of engineering structures (fixed works) and the development, production, and remediation of ground-water resources, are adequately recognized, interpreted, and presented for use in engineering and related practice. (AEG, 2001)

This change is also reflected in the association's well-respected publication, *Bulletin of the Association of Engineering Geology*, first published in January 1964, and renamed *Engineering & Environmental Geoscience* in 1995. Whereas the earlier issues were solely devoted to traditional engineering geology topics (site geology, design considerations, grouting, aggregate availability, and the like), latter issues include papers from the environmental geology area (groundwater contamination and remediation, waste disposal, hazard mitigation, and related topics). Similarly, the International Association for Engineering Geology (IAEG) underwent a name change and adopted the new name: International Association for Engineering Geology and the Environment in 1990.

These changes were prompted by heightened interest in the newly emerging specialty of environmental geology and aimed to ensure that the role of engineering geologists in the environmental field is not diminished. This shift in scope of engineering geology seems appropriate because it was the engineering geologists, more than other geoscientists—petrologists, mineralogists, economic geologists, or geomorphologists—who were best prepared, academically and professionally, to adapt themselves to take up the new challenge of environmental restoration and protection. A survey of employment trend of students graduating with a bachelor's degree in geoscience from American colleges and universities and Master's degree in other countries, conducted by the American Association of Petroleum Geologists (1997), showed that the largest employment was in the environmental sector (see Plate 12.2–1).

Plate 12.2–1. Employment trend of geology graduates: (a) N. America (b) other countries.

Although geologic principles and concepts were used in site selection and design of engineering structures even before geology came to be recognized as a separate discipline, the foundations of modern engineering geology were laid toward the end of the nineteenth century (Kiersch, 1991). Geologists such as Theodore B. Comstock in 1875 and 1876 at Cornell University, William O. Crosby in 1893 at the Massachusetts Institute of Technology, R. S. Tarr in 1894 and Heinrich Ries in 1898 at Cornell University, and John C. Branner in 1898 at Stanford University, offered a series of lectures and coursework in engineering applications of geology and thus paved the way for the new discipline that ultimately came to be known as engineering geology.

During the first four decades of the twentieth century, more and more educational institutions, both in the United States and Europe, continued to develop specialized coursework in the application of geology to engineering practice. This trend was reflected in the publication of the classic work, *Application of Geology to Engineering Practice* (Paige, 1950), popularly referred to as the *Berkey Volume*. This is a collection of papers that deal with the role and importance of geology in the construction of dams and reservoirs, highways and tunnels, and with landslide mitigation, aggregate characterization, and topics relevant to civil engineering. After the Second World War, the need for formal training of engineering geologists became apparent and about twenty universities in the United States and Canada introduced degree programs in engineering geology during the 1950s and 1960s. Many other countries followed suit.

More or less in parallel with the growth of engineering geology degree programs, another program in geological engineering became available at selected universities in the United States. This trend first began at the former mining schools at Golden, Colorado (Colorado School of Mines), Houghton, Michigan (Michigan Technological University), and at Rolla, Missouri (University of Missouri-Rolla). The introduction of new geological engineering degree programs created some misunderstanding and conflict between the two disciplines. However, the confusion was cleared up when it was realized that the *geological engineering* program is actually a specialty within the engineering field, requiring an academic preparation that includes coursework in conventional engineering subjects such as strength of materials and engineering design and concepts along with some *geology* courses. On the other hand, the *engineering geology* program is a geoscience-oriented program that emphasizes coursework in geosciences and geology with some *engineering* courses.

Today, degree programs in engineering geology at the bachelor's, master's, and doctoral levels are offered at a large number of colleges and universities all over the world. While its importance has somewhat decreased in North America and other developed countries, it is still a much sought-after area of study by students in developing countries.

Engineering geology is a dynamic field and new research findings are being added to the body of scientific knowledge all the time. The results of research in engineering geology are published in many journals in nearly all major languages of the world. Well-known journals published in the English language include: *Engineering and Environmental Geoscience* (formerly the *Bulletin of the Association of Engineering Geologists*, first published in January 1964; USA); *Engineering Geology* (Journal of the Elsevier Publishing Co., the Netherlands, first published in August 1965 (Kiersch, 1992)); *Bulletin of the International Association for Engineering Geology and the*

Environment (France); and the *Canadian Geotechnical Journal*, Toronto, Canada.

The Association of Engineering Geologists (AEG), in collaboration with the Geological Society of America, publishes the *Engineering and Environmental Geoscience* journal. AEG also maintains a website (www.aegweb.org) that provides useful information on the scope and area of application of engineering geology, professional practice guidelines, and policy statements on various issues of interest to the association membership.

Many electronic databases store, index, and disseminate engineering geology literature in their databases. Some of the major sources are: GeoRef, GEOBASE, ISI Web of Science and other. These databases are extremely valuable for researchers in geology and engineering geology.

3. Environmental Geology

Yet another applied branch of geology, environmental geology, became popular during the last three decades of the twentieth century. The American Geological Institute defines environmental geology as: [the] application of geologic principles and knowledge to problems created by man's occupancy and exploitation of the physical environment. It involves problems concerned with construction of buildings and transportation facilities, safe disposal of solid and liquid wastes, management of water resources, evaluation and mapping of rocks and mineral resources, and long-range physical planning and development of the most efficient and beneficial use of the land. (Bates and Jackson, 1987)

The definition has essentially remained unchanged but, as already stated, its practice emphasizes hazard mitigation and environmental restoration.

In terms of its scope and application, environmental geology involves studies related to the identification and mitigation of natural hazards, waste disposal, pollution abatement, health and environment, resource conservation, recycling, and landscape evaluation. The aim of environmental geology can be summarized in a simple phrase: *hazard minimization and resource maximization*.

It was in the late 1960s that some geologists in the United States began to apply geologic concepts and principles in land use planning and resource management (Turner and Coffman, 1973; Wayne, 1968). Initial efforts were mainly directed toward preparation of derivative maps from the original geologic maps to depict flooding, landslide, and other natural hazards along with resource availability in the area of interest. The aim was to provide geologic information to land use planners to enable them to make sound land use decisions. In fact, in the initial stage of its evolution, environmental geology was almost entirely devoted to land use planning and resource management. The first textbook on environmental geology by Peter Flawn (1970) was appropriately titled *Environmental Geology: Conservation, Land-use Planning, and Resource Management*.

It did not take very long before the evolving specialty of environmental geology caught everyone's attention and began to experience unprecedented popularity in the United States and other industrialized countries. By the early 1970s it achieved academic recognition when the Beliot College at Beliot in Wisconsin started a Bachelor of Science (B.Sc.) degree program in environmental geology. In the same year, the Western Washington University at Bellingham in Washington, also introduced a bachelor's degree program in environmental geology. These two academic institutions have the distinction of being the first to envision the importance and growth potential of the new specialty of environmental geology and introduce degree programs in this field. Boston University in Massachusetts was the next to offer a B.Sc. degree in this field. Yet, despite the fact that courses in environmental geology were added in existing geosciences offerings at a large number of geoscience departments all across the United States, formal degree programs in this field were slow to come during the later half of the decade of 1970, with one notable exception: The University of Missouri-Kansas City in 1979 introduced a master's degree program in Urban Environmental Geology, achieving the distinction of being the first educational institution in North America and probably in the entire world, to offer a postgraduate degree in environmental geology, a distinction that has not been repeated by any other university during the past twenty-two years.

A study by Hasan (1996) indicated that in 1993 there were only eight colleges and universities in the United States that offered a bachelor's degree in environmental geology and only one that offered a master's degree (Table 1). By 1996 the number had increased by 233 percent! At the same time, many colleges and universities added an environmental geology component in their B.Sc. degree programs in environmental science.

Institution & location (USA)	**Program began**	**Enrollment**	**No. of faculty**	**Degree offered**
Beliot College, Beliot, Wis.	1973	2-4	4	B.Sc.
Western Washington University, Bellingham, Wash.	1973	15–20	5	B.Sc.
Boston University, Boston, Mass.	1975	2–3	3	B.Sc.
University of Missouri-Kansas City	1979	5–6	7	M.Sc. (Urban Environmental Geology)
Colby College, Waterville, Maine	1980	3	4	B.A.
Boston College, Boston, Mass.	1984	8–10	9	B.Sc. (Environ mental Geoscience)
Allegheny College, Meadville, Pa.	1990	10	4	B.Sc.
Northeastern University, Boston, Mass.	1990	10–12	6	B.A. and B.Sc.
Southern Methodist University, Dallas, Tex.	1991	10–15	7-8	B.Sc.

Source: modified from Hasan (1996).

Table 1. Degree programs in environmental geology at US universities

Is environmental geology the same as engineering geology? In its early years when environmental geology had just been recognized as a new specialty within the geosciences discipline, many scholars and practitioners of engineering geology argued that environmental geology is the same as engineering geology. Ever since the middle 1960s, when terms such as geoecology, urban geology, envirogeology, and environmental geology, were being proposed for the emerging specialty in the geologic literature, debate continued on the identity of the new specialty.

George Kiersch, a reputed professor and practitioner of engineering geology, in 1974 and again in 1993 argued that there is no difference between engineering geology and environmental geology. John Ivey, in an article published in 1975 expressed the same view and argued that the two specialties are the same. Jeff Keaton and Greg Hempen (1993) also argued in favor of treating the two specialties the same. Hasan (1993), however, took a different stand and argued that despite some overlap in the scope and application of engineering and environmental geology, the two are not the same. Using a basic definition to clarify the difference in the scope and application of engineering and environmental geology, Hasan pointed out that engineering geology emphasizes the application of geology in civil engineering projects and groundwater resource development only, whereas environmental geology, besides involving hydrogeology, engineering geology, process geology, and so on, also deals with waste disposal, land use planning, environmental health, pollution prevention, and environmental law.

Hasan presented a comparison of the contents of textbooks in both engineering and environmental geology to prove that topics such as hazard evaluation and mitigation, waste management, pollution control, environmental health, land use planning, and environmental laws are either totally excluded or covered in a very cursory manner in popular works on engineering geology but constitute the bulk of the discussion in environmental geology textbooks.

Another argument put forth by Hasan relates to the interaction of engineering and environmental geologists with other experts: whereas engineering geologists traditionally had to deal with civil engineers only, environmental geologists interact with a large number of experts including civil engineers, land use planners, public policy officials and administrators, chemists, biologists, toxicologists, health care professionals, and others. He concluded that environmental geology is not the same as engineering geology and should be recognized as such. Since the mid-1990s not much has been written on the issue, and it appears that the debate has now died and it has been accepted that engineering and environmental geology are two separate specialties.

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Biographical Sketch

Syed E. Hasan is Professor and Director of the Center for Applied Environmental Research, Department of Geosciences, University of Missouri, Kansas City, USA. He was born in India where he received his education to the Master's degree level. He served as a geologist with the Geological Survey of India from 1965 to 1973 and was involved in regional geological mapping, mineral exploration, and engineering geologic investigations for a number of projects in the Himalayas.

He came to the United States in 1973 to join the Purdue University for his doctoral studies, and received his Ph.D. in geology with environmental geology concentration in 1978. He joined the faculty of the University of Missouri at Kansas City (UMKC) in 1979. He is a professor of geology and director of the Center for Applied Environmental Research in the Department of Geosciences at UMKC. Dr Hasan's teaching and research specialties are in the area of engineering and environmental geology. He has published his research results in professional journals and presented his research findings at numerous national and international conferences.

His textbook *Geology and Hazardous Waste Management*, received the Association of Engineering Geologists' Claire P. Holdredge Award. He also received the Educator's Environmental Excellence Award from the US Environmental Protection Agency.

Dr Hasan is a Fellow of the Geological Society of America, Life Fellow of the Geological Society of India, and a Member of several professional societies. He comments on environmental issues in the media.