MODERN TRENDS IN ENGINEERING GEOLOGY

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Keywords: Geology, principles, applied, engineering geology, resource, development, natural processes, hazard, risk, material properties, characterization, regulation, litigation.

Contents

Summary

Future challenges and opportunities for engineering geologists will be dominated by digital data collection, utilization, and display. Engineering geologists will be challenged by the task of quantifying variability and uncertainties in observations and interpretations. Interpreting and communicating the relevance and distribution of earth materials and identifying and quantifying hazardous natural processes takes on increasing importance for sustainable developments. Impressive tools are emerging for virtual geologic mapping using three-dimensional laser scanning and terrestrial photogrammetry. Geographic Information System technology, routine for even small-scale projects, is being applied in the field with pen-based computers equipped with

Global Positioning System satellite receivers and wireless communication for seamless data management. Traditional geologic maps will be replaced by interactive, digital three-dimensional models attributed with geotechnical data. Many engineering geology service companies compete in regulated, litigious environments, resulting in engineering geology becoming a cost-driven commodity with little opportunity for professional judgment. Some engineering geology services remain highly specialized and valued. Many undergraduate engineering geology programs have small enrollments and are being eliminated or combined with other programs.

1. Introduction

The science of geology applied to relevant aspects of engineering practice is *engineering geology*, in a general sense. Association of Environmental and Engineering Geologists states that it is the discipline of applying geologic data, techniques, and principles to the study of rock and soil materials, surface and subsurface fluids, and interactions of introduced materials and processes with the environment so that geologic factors are adequately recognized, interpreted, and presented for use in engineering and related practice. The International Association for Engineering Geology and the Environment states that is the science devoted to investigating and solving problems caused by geological hazards and other interactions between geology and human works and activities.

The intent of this article is to describe some aspects of modern engineering geology in a way that might be of interest to policy makers and forecasters of science and technology trends. Relevant principles of the broad science of geology provide context for approaches and methodologies that may aid in future actions leading to and supporting sustainable world development. The importance of population growth is a dramatic underscore for intelligent application of the principles of geology in health, safety, and welfare of the societies of the world.

Geology is involved in a variety of project phases, depending on the extent to which the project contacts the earth. A mountain highway tunnel involves geology to a greater extent than a conventional, level-terrain highway. The practice of geology is influenced by governmental regulations and business pressures. Characterizing material properties, site conditions, and potentially hazardous processes are important tasks undertaken by engineering geologists. The results of these geology tasks are vitally important to engineers, governmental officials, and members of the general public.

The nature of engineering geology practice promotes relationships with civil engineers. Average individuals typically interact with governmental officials and possibly with engineers; however, few average individuals deal directly with geologists. Consequently, the importance of geology in society tends to be disregarded until a natural process causes disruption to daily life and/or damage to valuable infrastructure, at which point ‘geologic hazards’ and resulting ‘engineering failures’ are recognized.

1.1. Science and Engineering

Science seeks to explain and predict (i.e., forecast), whereas *Engineering* seeks to plan, design, construct, maintain, and decommission safe, economical, and environmentally sound facilities. The science of geology is the study of the earth in a broad context. Geologists use earth history to explain what they observe. Rocks and sediments record the earth's processes, but observable rocks may not contain complete records. Some processes are not recorded uniformly; important features are eroded or buried; subsequent processes obscure earlier processes.

A major volcanic eruption could deposit a uniform blanket of ash over a large area. Erosion, plant growth, burrowing animals, and soil-forming processes remove volcanic ash from some areas, transporting and concentrating it in thicker deposits in other areas, and generally mixing it with non-volcanic materials. These subsequent processes obscure the character of the initial deposit, increasing the challenge for recognition and interpretation.

Engineers optimize facility design so that construction and operation costs are minimized while the facility remains functioning as intended for a specific period of time (*design life*). Engineers use basic science (physics, chemistry, and mathematics) and applied science (mechanics of materials, structural statics and dynamics, and hydraulics), along with experience, to determine internal and external loads and forces to which the facility is likely to be subjected and the magnitude of deflections that the facility is likely to undergo in its response to those loads and forces.

The desired facility performance is expressed in terms of design objectives that incorporate appropriate factors of safety. The engineer's understanding of facility performance is based on precedent or experience with facilities that were built years, decades, or even centuries ago. Engineers use *factors of safety* to compensate for uncertainties in loads and forces, as well as variability in material properties and minor defects in construction.

The design life of a conventional building might be 50 to 100 years, whereas the design life for a critical facility might be 10 to 25 time longer. Incomplete understanding of and variability in potentially hazardous processes contribute to uncertainties that could be included in estimates of external loads and forces needed for design.

Many potentially hazardous processes are considered to be random in time; like the toss of a coin, the next event is independent of the time since the last event (i.e., Poisson distribution). Statistical inferences can be used to express long design periods as *exceedance probabilities* during an understandable period of time, such as 50 years. The average recurrence interval can be expressed in terms of exposure time and exceedance probability:

$$\frac{1}{RI} = AF = \frac{-\ln(1-p)}{t}; \qquad p = 1 - e^{-(t \cdot AF)} = 1 - e^{-\left(\frac{t}{RI}\right)} \tag{1}$$

where RI is average recurrence interval, AF is annual frequency, $\ln$ is the natural logarithm of the expression inside the parentheses, p is exceedance probability, t is exposure time, and e is the base of natural logarithms (Euler's constant). Thus, random processes with recurrence intervals of 50 years would have exceedance probabilities of 63.2% in 50-year exposure periods. Some building codes specify design based on loads associated with exceedance probabilities of 10% in 50-year periods, resulting in recurrence intervals of 474.6 years. Modern *building codes* specify design based on loads associated with exceedance probabilities of 2% in 50 years, resulting in 2,474.9-year recurrence intervals.

Engineering geologists use recent earth history to forecast processes and conditions for engineers to use in designing facilities. Engineering geologists understand and apply the principles of geology in characterizing site conditions, and pay attention to evidence of potentially hazardous processes. The processes that are important for engineering design tend to be those that have occurred repeatedly during the past approximately 10,000 *radiocarbon years* (11,600 calibrated years before present).

This period of earth history is called the *Holocene Epoch*, and is considered to be short enough that hazardous processes that occurred during this interval should be considered in design of future facilities, and long enough for reasonably active process events to have occurred at least once.

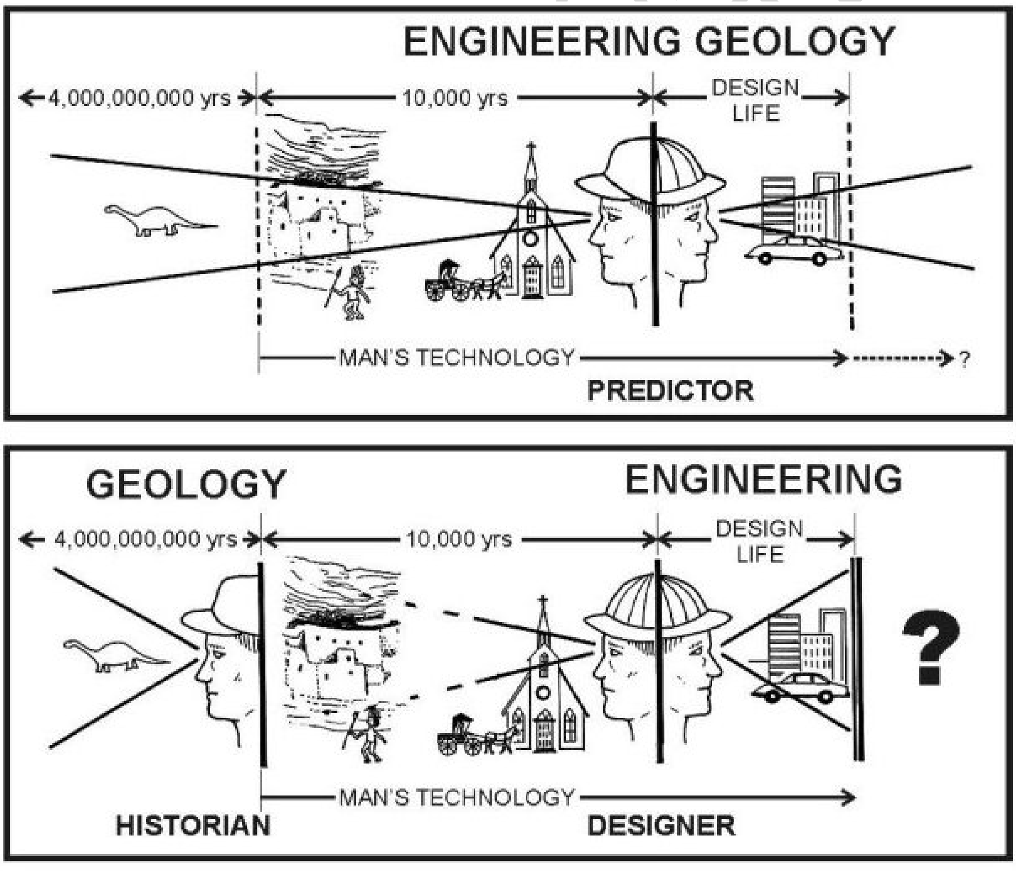

Figure 1. Views and perspectives of geology, engineering, and engineering geology.Modified from illustration provided by Christopher C. Mathewson, Texas A&M University.

The relationship among geology, engineering geology, and civil engineering can be illustrated with a timeline that begins in early earth history and extends into the future past the engineering design life (Figure 1). The geologist, as a *historian*, looks back to the beginning of earth history. The engineering geologist, as a *predictor*, looks back into earth history focusing on the most recent 10,000 years for some applications, and looks into the future to a time beyond the design life of proposed facilities. The civil engineer, as a *designer*, looks back to the beginning of construction, and into the future as far as the design life of the proposed facility.

Inductive and deductive procedures are used to arrive at scientific explanation. The inductive method begins with observations and experiences represented as unordered facts. These facts are grouped, classified, measured, and analyzed into ordered facts about which generalizations are made. Generalizations lead to *scientific explanation* known as theories or laws. The inductive method depends completely on observations and experiences collected as part of the procedure, and on grouping and classification schemes.

The deductive method begins with some level of observation and experience used to form an image of the world or a part of the world which is formalized into a model. Hypotheses formulated to test model validity are evaluated with experiments designed to group, classify, measure, and analyze observational data. Statistical tests are applied which leads to revised or enhanced models. Scientific explanation is achieved through positive feedback leading ultimately to theories and laws.

The deductive method applied to even routine engineering geology assignments in many parts of the world begins with a general understanding of the regional and local geologic setting. This geologic setting is an image of the world that serves as the initial model. The borings and test pits at the site serve to test the hypothesis that the model is accurate or provide a basis for modifying or refining the model.

Borings and test pits are placed at two types of locations: 1) where the engineer needs samples for laboratory testing, and 2) where the geologist needs data to test the geologic model. In a deductive procedure, the borings and test pits are focused elements of field investigation, rather than purely exploratory elements. Engineers who do not understand the deductive method tend to believe that geology is a random variable.

1.2. Principles of Geology and Engineering Geology Corollary

Five primary principles (uniformitarianism, original horizontality, superposition, crosscutting relationships, and concordant junctions) and two cycles (rock cycle and hydrological cycle) govern understanding of rocks and processes in geology.

These principles and cycles are described in other articles in the UNESCO Encyclopedia of Life Support Systems. The principle of uniformitarianism provides the basis for a corollary that is vitally important to engineering geology.

Uniformitarianism has been described in plain English as meaning that *the present is the key to the past*. Process types and intensities operating today have operated throughout earth history in similar fashions. *Actualism* was the term developed in the

20th Century to express the understanding that earth processes acting today have acted in the same general way throughout earth history, although at varying rates and intensities.

The *engineering geology corollary* to uniformitarianism or actualism is *the recent past is the key to the near future*. This corollary means that geologic processes which have been active in the past few thousand years of earth history are expected to remain active for the next few thousand years.

Most definitions of natural hazards are based on this corollary. For example, an active fault is one that is considered likely to generate earthquakes in the future, but the likelihood of a future earthquake event is defined on the basis of the age of the most recent displacement along the fault.

Regulations for conventional facilities in California define active faults as those which have ruptured in the last 11,000 years. Other guidelines have been developed for defining active faults, recognizing that degrees of activity are likely to exist.

For example, the Western States Seismic Policy Council (http://www.wsspc.org/PublicPolicy/PolicyRecs/policy02-3.html) recommends the following definitions for use in the Basin and Range Province of the western United States:

Holocene active fault - a fault that has moved within the last 10,000 years.
Late Quaternary active fault - a fault that has moved in the last 130,000 years.
Quaternary active fault - a fault that has moved in the last 1,600,000 years.

A ‘disaster cycle’ has evolved in engineering geology (Figure 2). People initially settle in a region because of natural resources or transportation routes without realizing that hazardous processes (e.g., earthquake or hurricane) occur relatively infrequently.

A hazardous process strikes, causing some damage which might not be perceived as a disaster if damage is limited or residents simply deal with such adversity by cleaning up the debris and returning quickly to functioning condition.

The community grows and essential infrastructure is developed (e.g., water supply, waste disposal, transportation). A hazardous process, such as a flood, may cause minor damage and raise awareness about the natural setting of the community.

The community may have developed to the point that relocating the community is viewed by some as inappropriate so flood-protection infrastructure (e.g., levees and flood-control dams) is constructed instead.

Thus, the susceptibility to large-scale damage grows as the community develops. A period of time goes by without significant damage; long-time residents become complacent, new residents are unaware of the damage history, and development continues. Disaster strikes, producing sudden awareness, and the cycle begins again.

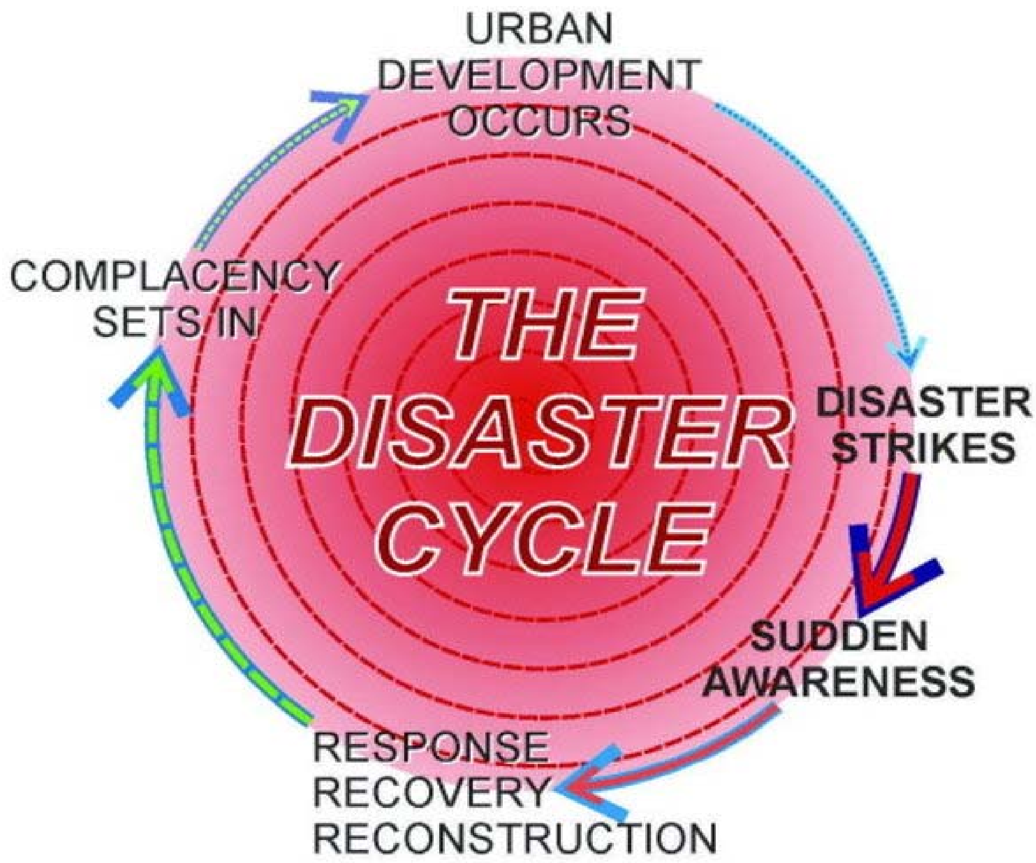

Figure 2. The disaster cycle. Adapted from a concept by Christopher C. Mathewson, Texas A&M University

2. Importance of Population Growth

The human population of the world exceeded 6.56 billion in February 2007 (world population calculator on EOLSS website; www.eolss.net). The human impact on the earth is dramatic, and has been described in a number of publications since "The Tragedy of the Commons" (Hardin, 1968) nearly 40 years ago when the population was <3.9 billion. Societal needs, resource consumption, waste disposal, and marginal-area development are important factors driven by population growth.

2.1. Societal Needs

Society needs many things for safe and comfortable existence. Many of the world's urban places have concentrations of non-self-sufficient people, people who consume items and services that they do not produce. They also produce items or services that they do not consume, which leads to a setting that requires large-scale infrastructure.

This *infrastructure* includes transportation for bringing in raw materials and exporting finished products, communication to allow materials to be ordered and products to be sold, housing for workers and service providers, and shops and community facilities to support the workers and their families, who also need government agencies, education, medical, recreation, electric power, potable water, and waste disposal facilities.

Engineering geology plays a major role in society. Engineering geologists assist urban planners and civil engineers with developing and maintaining infrastructure by characterizing subsurface conditions and hazardous natural processes. Resources usually developed locally are water and common construction materials (sand and gravel).

Past disposal of solid and liquid waste in many locations has resulted in contamination of soil and water resources. Cleanup of contamination caused by waste disposal at inadequate or poorly engineered sites and characterization of suitable sites, constitute important contemporary practice areas for engineering geologists.

2.2. Resource Consumption and Waste Disposal

Resources consumed by typical communities range widely from energy (electricity, natural gas, oil, gasoline, coal, uranium) to water to construction materials (sand, gravel, cement, clay, wood, steel). Imported electricity typically is transmitted along high-tension power lines that are supported by steel lattice towers that touch the ground at isolated locations.

Electrical substations are needed within communities to reduce voltages for consumers. Pipelines transmit natural gas and refined products (gasoline, diesel fuel) from refineries to large communities. Natural gas or refined products might be delivered by tanker trucks operating on highways and local streets.

Engineering geologists participate in a variety of projects by characterizing alignments and sites for facilities that extract, produce, transport, store, distribute, and recycle all types of resources.

Waste is generated as a part of community existence and resource consumption. Solid waste tends to be placed in pits or piles, whereas liquid waste, particularly sanitary waste, tends to be treated to at least some degree before being discharged into rivers, lakes, or oceans. In some areas, treated water may be used for landscape irrigation.

Radioactive and other hazardous waste materials tend to be handled specially. Engineering geologists contribute to waste disposal projects by participating in site selection studies that lead to identification of suitable sites. Ranking of sites allows a preferred site to be selected for more detailed characterization.

Engineering geologists also contribute to waste disposal projects by participating in studies to characterize the extent and nature of contamination of soil and groundwater and monitoring progress during mitigation.

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Biographical Sketch

Jeffrey R. Keaton was born in Pittsburgh, Pennsylvania, USA; he obtained his B.S. in Geological Engineering (1971) at the University of Arizona (USA), M.S. in Engineering (soil mechanics) (1972) at the University of California Los Angeles (USA), and Ph.D. in Geology (1988) at Texas A&M University (USA). He has been employed as a consulting engineering geologist since 1970 at Dames & Moore, AMEC, and MACTEC. He has worked internationally on energy, water-supply, transportation, and mining projects in Iran, Ethiopia, and Peru. He held adjunct professor appointments in Civil and Environmental Engineering at Utah State University and in Geography at University of Utah. Dr. Keaton has been active in professional societies, serving as president of the Association of Environmental & Engineering Geologists, chair of the Engineering Geology Division of the Geological Society of America, chair of the Section on Geology and Properties of Earth Materials of the Transportation Research Board, and chair of Commission No 1 on Engineering Geological Characterization and Visualization of the International Association for Engineering Geology and the Environment. He was the Richard H. Jahns Distinguished Lecturer in Engineering Geology in 2004.