

# **Engineering Geology – Definitions and Historical Development Applications in Life Support Systems**

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<b>Introduction</b>	<b>2</b>
<b>Definitions</b>	<b>3</b>
<b>Application of Geology in Life Support Systems</b>	
<b>5000 B.C. to 1900</b>	<b>4</b>
<b>1900 to 1960</b>	<b>9</b>
<b>1960 to 1980</b>	<b>13</b>
<b>1980 to Present</b>	<b>18</b>
<b>Education</b>	<b>23</b>
<b>Certification, Codification, Registration and Standards</b>	<b>24</b>
<b>Summary and Future</b>	<b>26</b>
<b>Bibliography</b>	<b>27</b>

## Introduction

Engineering geology in the context of this historical review can be defined as the interaction of geology with natural resources for the benefit of Life Support Systems. Definitions also stress public health, safety and welfare with the interaction of engineering geology and engineering works. Given that the theme of this review is *Life Support Systems*, the historical beginning best fits with the development of the first civilization. This theme follows throughout the presentation. Several references are made to Diamond (2004) whose work entitled *Collapse* described several reasons for the successes and failures of civilizations. The neglect of a civilization's natural resources is of particular interest to Life Support Systems as a cause of failure. Those civilizations that cared for their natural resources lasted longer.

The beginning of what is today known as engineering geology extends far back into antiquity. Great works of old civilizations still in existence rest on foundations that demonstrate the best of any site characterizations made by geologists and engineers. Ancient Greeks developed a fundamental understanding of springs and the hydrologic cycle as related to water supply sources. Two thousand years ago, the Romans were constructing large aqueducts and water handling systems to supply water for the Roman public. Those Roman engineering and geology feats would rival modern water resources infrastructure developments.

With the decline of the Roman civilization, metropolitan-scale road and water supply systems ceased to exist for centuries. A return to planned and built public works began in the 1790s when William Smith, an English civil engineer, undertook the design and construction of transportation routes (Kiersch, p. 14, 1955). Smith recognized that earthen materials could be consistently identified in a manner that would aid civil engineering works. Although Smith is noted for the use of several geologic principles and practices as we know them today, it was James Hutton who provided geology with a dynamic scheme: “a *theory in the original sense of something seen in the mind*” (McIntyre in Albritton, 1963)...

Early transportation needs also existed in the United States. Canals, railroads and roads, initially mere trails, rapidly expanded into effective transport networks. Following the Civil War, geologists worked with engineers in selecting transportation routes and subsequent construction. This partnership continued for several decades until economic incentives in mining and the universities became more attractive for geologists. With that shift, geologists lost interest in construction, engineering and public related works. The general absence of geological contributions to construction projects was accompanied by major disasters as dam failures where engineers did not recognize the geological risks.

The rapid economic expansions of the post World War II years were the catalyst for engineering geology to become a cohesive profession. This was the period when “engineering geology” usage became more frequent although “applied geology” remains in use. “Environmental geology”, “hydrogeology” and “urban geology” were soon to follow as professional descriptive sub disciplines. The explosive growth also led to changes in some university curricula. A few developed geological engineering in schools of engineering as a degreed program. Professional organizations began to promote registration or some form of certification for geologists, it was only the U.S. that registration developed along with certification. Other countries preferred various ways of certification or academic training combined with work experience to establish qualification criteria. These trends caused profound changes for geologists, many directly and some indirectly.

Several detailed chronologies of engineering geology history are readily available in the literature. These have many specific dates and examples, but do not include direct references to life support system effects. George A. Kiersch provides an excellent summary of events dating back several thousand years (Kiersch, Table 1, pp. 37-39, 1955). He later authored a more detailed review of the first hundred years of engineering geology (Kiersch, 1991). Kiersch and Hatheway provide a detailed history of the Engineering Geology Division of the Geological Society of America (Kiersch and Hatheway, 1991). Hatheway and others have summarized the annual status of engineering geology on an international perspective for many years (Hatheway, 2003-2004). A detailed historical record of engineering geology beginning with William Smith has been prepared by Galster (2004). This publication also includes extensive references and historical accounts of early histories of several professional organizations. Krishnaswamy (1982) presents the history and development of engineering geology and geotechnology in India

### **Definitions**

This review of life support systems and engineering geology begins long before geology was defined as a highly skilled craft much less a science. “Science” as a word itself is relatively new being first used in 1840 (Whewell in Vickery). Regardless of a formal geology science recognition, those civilizations that prospered did so using various forms of basic governmental structures and many life support systems including geology and engineering geology concepts.

The usage of *engineering geology*, *environmental geology*, *hydrogeology*, *urban geology* and *geological engineering* are not precise having interfingering relationships. Some geologists also consider such fragmentation of what was considered all inclusive as engineering geology is unnecessary. However, except for *urban geologist*, all are prominent as professional work titles in the literature, and in academic training especially since the 1980-present period. Some of these sub disciplines also are defined according to legal standards where states in the U. S. have registration laws. In other states and countries, the definitions are less rigorous, may not exist, or may be as a part of various forms of certification. In this review of definitions and life support systems, “geology” and “applied geology” are used as descriptive terms until “engineering geology” came into common use. From that point on, engineering geology is used to include the other sub disciplines of engineering geology or geology. This is not to negate equality, rather aid in ease of presentation.

The American Geological Institute (1984) defines engineering geology as the “Application of the geological sciences to engineering practice to assure that the geologic factors affecting the location, design, and construction of engineering works are recognized and adequately provided for”. The Glossary notes that the geological engineer is a synonym. However, the differences are so distinct that many would quarrel with this opinion. In Europe engineering geology is described as belonging to the profession of Ground Engineering (Norbury).

Environmental geology for the most part developed from engineering geology but as an equal geology sub discipline. The Glossary defines the environmental geology as “The application of geologic principles and knowledge of problems created by man’s occupancy and exploitation of the physical environment”. Many would consider this definition to be limited however. Environmental geology is practiced as much or more in the sense of identifying geologic conditions beforehand which could or would affect a proposed development and do so without the implications of the word “exploitation”. The fixing of problems and exploitation is an inadequate definition of the total environmental geology role.

Hydrogeology is defined by the Glossary as “The science that deals with subsurface waters and with related geologic aspects of surface water. It is commonly used interchangeably with geohydrology”. Many geologists of today involved with water resources use either of these two sub discipline identities. However, for years geologists specializing in water resources used “ground water geologist” to describe their work title. Later, some engineering geologists began to include ground water investigations within their sphere of interests. And some geologists involved with water resource, including ground water investigations use no sub discipline title.

Urban geology, less commonly used than the other related practices, is defined by the Glossary as “The application of geologic knowledge and principles to the planning and management of cities and their surroundings”. It includes geologic studies for physical planning, waste disposal, land use, and water resource management, and extraction of usable raw materials. The Glossary also references “environmental geology” which seems appropriate. Unfortunately this holistic approach of urban geology in land use planning is seldom applied. There are however classic books about urban geology including “*Cities and Geology* (Legget, 1973) but the intent was not to develop a separate title definition. Legget was a generalist rather than one who would develop new work definitions.

The Glossary does not define geological engineering. This field is primarily one of engineering by virtue of the Accreditation Board of Engineering Technology (ABET) accredited course curriculum required for the degree. This is not true for engineering geology, environmental geology, hydrogeology or urban geology emphasized education in the general degree of geology. Even for those few universities in the U. S. that have engineering geology specifically defined as a course of study, the degree of engineering geologist lacks the accreditation status available to the graduating engineer, including geological engineers. Academically and professionally, there are issues of disagreement between the professions of engineering geologist, geological engineer, and geotechnical engineer. In some school curricula, the geotechnical engineer has little to no course work in geology but is considered adequately educated in both professions. For the geological engineer, some schools require only a limited education relative to geology. Other schools with geological engineer graduates provide a more even balance of training in geology and engineering. Consequently, the degree awarded may not correctly represent the education received (Williams, 1984).

The academic differences may be primarily a U. S. problem of academic confusion. For example, as early as 1980 a number of universities in India were offering a specialized curriculum in engineering/applied geology. One such university also had a special post graduate course in engineering geology (Krishnaswamy).

I use applied geology prior to these sub disciplines and to recognize the early interrelationships with engineering, Leonardo de Vinci, 1452-1519, the example. Considering the early works of the Sumerians, these interrelationships of the professions dealing with earthen materials existed then and continue today.

### **Application of Geology in Life Support Systems 5000 BC to 1900**

Life Support Systems include the dependence on others to obtain food, water and the protection of the Systems, This dependence began when individuals changed from nomadic hunter traditions and formed the ancient beginnings of cities. There has been no greater cultural change in human existence than this transition. Those most successful in making these changes constructed dwellings on firm ground, or figured out how to stabilize foundations, develop stable roadways, and the means to successfully obtain and convey water via the first public water supply systems. With this transition also

came the need to protect or desire to conquer. Warfare requires among other things materials to make weapons. The most successful warriors were aided also by their abilities to apply geologic concepts in locating suitable terrain for the movement of armies.

The earliest civilization, the Sumerian, by 3500 B.C. had created many life support systems for the first time in the world. The recognition and appropriate use of the rich and well watered agricultural soils of the Tigris and Euphrates delta (Kerisel 1978) and supplemented by irrigation (Severly) were some of several vital reasons for the civilization success. They developed a stable agriculture for a dependable source of food, a transportation network, and built the first city, Erudi. Kerisel indicates that city building was initially a slow process as the cut building stones settled until consolidation began to stabilize the subsoil foundations. As time passed, innovative Sumerian builders learned to use horizontally placed reeds cabled together with plant tissues and vines into mats that were then placed sequentially between building stone layers. They apparently realized the need to spread loads over a wider foundation area. The Sumerian civilization lasted some 3000 years. It did not fail by misuse of their natural resources or life support systems but rather by war.

Broad concepts of geology have been known and used for thousands of years. Kiersch (p. 2, 1991) includes evidence of tunneling, stone paving, and irrigation. These concepts indicate knowledge of earthen materials that enabled civilizations to be successful. Kiersch also notes transportation routes have origins as old as 2,800 B.C. with evidence of wheeled traffic in Mesopotamia/Persia. Later, 750 B.C., there is evidence of an ancient Persian highway system. I found a stable Roman road of precisely placed and even laid stones during the 1950s in a remote portion of northern Libya. It was an all weather road as if built by today's engineers with geologist advice concerning the road bed's physical properties. The nearest "modern" roads were desert trails and passable at best by four wheel vehicles. In the western hemisphere, remains of the Aztec civilization, 200 B.C.-1521 A.D., indicates they understood the principles of groundwater origin and soil stabilization which enabled the successful building of cities on soft ground (Kiersch, p. 3, 1991). The Spaniards, who destroyed the Aztec cities and ultimately ruining many of their life support systems, were ignorant of soil stabilization. They tried unsuccessfully to build on top of the cities they had destroyed. Kiersch also reports that the Hohokam Indians in Arizona, 100 A.D., constructed tunnels to transport water.

The Pyramids of the Egyptians were built on firm ground. Given the sophistication of the work, including the copper smelting capabilities to develop cutting tools for the building materials, there can be no doubt that the Egyptians understood the essence of engineering geology and geology. Proper site selections and the finding and exploitation of the mineral resources needed for these massive structures must have differed little from work done today by engineering and economic geologists.

Greek elegance and Roman solidity seemed to have one thing in common: stable foundations. By 75 B.C., the Romans were building large public works including roads and aqueducts (Kiersch, p., 1955). Some remain today. I observed a striking example during October of 1958 when the Rhone River, flowing south through eastern France, was in extreme flood stage, most bridges across the Rhone were closed. A remarkable exception remaining open for traffic was the second tier of a three-tiered Roman Aqueduct. Bridge piers were secure and the three tiers were high above the flood level. This well-planned, 2000 year- old-structure was still in use!

The Dark Ages, 500 to 1000 BC and followed by centuries of political and religious bickering, wars, famine, and long periods of coldness caused collapse of overall life support systems and put European civilization on the brink of disaster. Large structures, castles, churches and monuments failed or partially failed. Sustainable needs of people such as public water supplies and other life support

systems including the geologic components were ignored. The Leaning Tower of Pisa built 1173-1370 on soft soils was one of many such failure and partial failure examples. The polluted drinking waters of Dijon, France, (Sharp and Simmons) were another of life support failure example. The multiple contributory causes of civilization difficulties and failures as described by Diamond (2005) came together during this long period of a thousand and more years. The evidence of life support system failures was profound.

By way of contrast with Europe, the Chinese were well on their way to construction based on uniform and well established procedures. Their codification in 1103 may be the first set of building codes that had official government authority to require implementation. These Chinese codes also addressed soil preparations necessary for proper building techniques. Stellar individuals of Greek and Roman times outlined building and soil investigation and preparation procedures. The Chinese also did something unique and generally missing today, integrating building codes and ground preparation. This is in stark contrast to procedures in the United States where applied or engineering geology standards have been removed leaving the U.S. at a more high risk of building code inadequacies than the Chinese of the 12<sup>th</sup> century. As is not uncommon, life support systems retrogress as well as progress in the protection of the public's health, safety and welfare. This same although catastrophically more extreme retrogression occurred in Europe where the life support systems developed by the Greeks and Romans were lost as the result of failed governments.

India also in sharp contrast to the thousand year European decline was busily using the principles of applied geology. The Taj Mahal, 1632-1650, was constructed on a soil stabilized foundation that transferred loads to piles constructed as cylindrical wells. This massive world renowned structure remains today, some 400 years later, stable and sound in its presence (Krishnaswamy).

Fortunately, even during the several centuries of stagnation, famine, wars and decline in Europe, some of the most notable people of that time were able to make significant applied geology contributions. The one most recognized by all is Leonardo de Vinci, 1452-1519, the first practitioner of "applied geology" for engineering works (Kiersch, p 6, 1991). Another first later included rudimentary geologic maps of England and France, followed by a more detailed map of France as made by Guettrad in 1751 (in Kiersch, p. 9, 1991). This is important because of the necessity for such maps in the planning of life support systems such as roads. Nicolaus Steno was another bright light in a period dominated those who built massive structures coupled with many partial failures. Among his many contributions, Steno proposed superposition, original horizontality, and lateral continuity. He also developed meaningful concepts about fossils 1667-1669 (Cutler in Abbott, pp. 8-9, 2003). During this same period, the term "geology" for earth science study was first coined by Jean Andre De Luc in 1778 (p 16, in Kiersch 1991).

No single person did more for life support systems than Henry Darcy. As stated by Darcy that the public had the right to clean water in the translation of *Les Fontaines Publiques de la Villa Dijon* by Patricia Bobeck (Sharp and Simmons): "A city that cares for the interest of the poor class should not limit their water, just as daytime and light are not limited". Darcy's law that is fundamental to the understanding of groundwater flow represents only a fraction of his contributions during his lifetime of 1803 to his early death in 1858. He designed central water systems, drainage systems and canals. A tunnel whose construction he supervised as a part of his overall contributions to transportation systems is still in use today for high speed trains. Sharp and Simmons in their summary of Bobeck's translation available from the Kendall/Hunt Publishing Company, Dubuque, Iowa note that Darcy's law is fundamental to hydrogeology, geology, and several other science and engineering disciplines of today. They further pointed out that Darcy made use of the early geologic studies such as William Smith's

terminology for geologic formations. Sharp and Simmons also comment this focus on geology, such as in water resource planning, is perhaps something we should return to today. The compartmentalizing of these disciplines that is prevalent today is a step backward from the Darcy integration approach as well as other life support system stalwarts of the early and mid 1900s.

By this time in human history, many civilizations had risen and many had collapsed (Diamond, 2005). Diamond lists eight reasons that civilizations undermined themselves, one of the eight being failure of proper water management. Lowdermilk (1953), in an agriculture review of various parts of the world focused on water resource and soil losses as failure reasons as well. He also stressed a reason not addressed by Diamond. Lowdermilk considered associated culture changes with the physical losses are as profound as to make a return to self sufficiency almost impossible. Legget, (1973, pp 549-550) addresses the destruction of the Cedars of Lebanon by Solomon's laborers and selling the logs to the Egyptians. Today, this is being repeated with the selling of logs from huge expanses of tropical forests to nations as Japan. All three authors, Diamond, Legget and Lowdermilk, expressed great concerns about deforestation especially from the perspective of permanent damages to soil and water resources. Life support systems essentially are lost with these everlasting damages.

Lowdermilk and Diamond both agree that some cultures are unable even without warring conditions to properly manage their environment. They had limited abilities to produce food or develop and care for essential natural resources. Other cultures and civilizations however have endured severe hardships of centuries. Leadership with the effectiveness to assure forests, soils and water resources were properly utilized and protected as necessary aided in long term survival. However, there was little consistency in this process until science and engineering along with health and other critical life support needs were better developed. This awaited the 17<sup>th</sup> and 18<sup>th</sup> centuries. There is plentiful evidence that geology in its early form of an applied science contributed much too major culture and civilization stabilization and successes.

The actual science of geology was created by James Hutton in the fifty years between 1775 and 1825 (McIntyre in Albritton). While Aldrovandi (Vai and Caldwell) is credited with the formal name of "geology" in 1603, Hutton is credited with recognizing geology as a science must be one encompassing all parts of the earth. Geology today is a science that includes disciplines ranging from astrogeology to zoogeology. Engineering geology and specialties as environmental geology fit comfortably within the science of geology as envisioned by Hutton. Hutton's concept of geology allowed for branches and disciplines of geology not imagined 200 years ago.

The first geological concepts of stratigraphic correlation of layered sequences of bedrock relative to construction began with the work of William Smith during the late 1700- to early 1800-period (Kirsch, 1955). Also in the 18<sup>th</sup> Century, geologic contributions aided in canal building in India (Krishnaswamy). These examples, mostly associated with road, railroad, tunnel and canal building, began a long world wide period of applied geology being utilized. However, as time progressed with no established identity of applied or engineering geology, it was difficult for engineers or the public to identify geologists who would be qualified for construction or other related tasks of geological investigations. Persons with interests in geology also were those less interested in applying their talents to works of engineering design and construction. Fortunately, a number of engineers also possessed or searched for geological information to assist in their design and construction procedures. The complex foundation investigations by Eiffel in the building of the Eiffel Tower, 1889, was an example of an engineer, perhaps with no known geologist available, successfully applying detailed geologic investigations to determine structural foundation safety (Kerisel, 1987).

During the prolific 1800s of outstanding works, one must include a ten-year project beginning in 1863 by Eduardo Suess, a pioneer of applied geology relative to public works (in Kiersch, G. A., p. 10, 1991). The success of his work included the classification of soils and bedrock in and around Vienna to aid in city planning. His work and recommendations also addressing water supply resources has endured for 150 years and may continue for many more. In this same time frame, Bernard von Cota, a French geologist, made an early foray into what is today medical and environmental geology. His geological investigations were focused on the environmental affects of geology and public health (p. 10, in Kiersch, 1991).

The 19<sup>th</sup> Century saw the beginnings of several national geological surveys. Great Britain (1835) was soon to be followed by the Geological Survey of Canada in 1841. The U. S. Geological Survey (USGS) was created somewhat later by the U. S. Congress in 1879. A national geological survey contributes to the overall recognition of both economic geology as well as geology applied for public use concerning issues such as water resources and other related basic public needs. .

During the early 1800s, in contrast to the slowness of the federal government, some states began to establish State Geological Surveys. Beginning with North Carolina in 1823, state legislators created 15 more state geological surveys in the next two decades (Socolow, A.A., 1988). All of these state surveys had basically the same charges: mineral and water resources. Records of these surveys, including some of the first geologic maps made in the United States, are still available. Many more state surveys were established during the latter portion of the 1800s. Today, practicing engineering geologists use the past records, especially geologic maps, along with current data, that these early surveys have developed during their existence. An early text foray into engineering geology was prepared by Joseph Raymond Thomassy (1860) on practical geology and engineering problems in North America (p 17, in Kiersch 1991). The state surveys concentrated on economic resources of highest priorities, for example mineral resources and water supplies, and then produced an abundance of early reports for public uses. Some state surveys have kept these as primary charges since the formative years; others have become more research oriented.

The engineering works of the late 18<sup>th</sup> Century where the observance of geologic properties for specific works as canals and roads proved to be effective contributions are cited by many as the beginning of engineering geology. However, with the advent of the Civil War in the U. S. and especially during and following wartime from 1860 through the next 30 to 40 years little was accomplished and much destruction occurred to life support systems. Some state geological surveys either ceased to exist entirely or were there in name only. The United States Geological Survey beginnings were off to a slow start. Higher education suffered. All combined to again illustrate how geological sciences and other life support systems are tied to economic and governmental stability regardless of the nation or area effected.

Once recovery did resume, applied geologist employment increased with roads, especially railroads, and canal construction works (Kiersch and Hathaway, 1991). During this period with rapid frontier movements, the development of state geological surveys and the U. S. Geological Survey, geologists in government also had major public roles (Champlin, 1999). Their contributions exist yet today. The biggest canal public role project of all in North America featured engineering geologic work. Pre construction investigations were completed in 1898 by French geologists (Kirsch, p. 21, 1955). They identified slide-prone areas and numerous other features that could affect construction. Unfortunately the geologists findings were overlooked by engineers and numerous failures followed. Subsequently, a staff geologist was attached to the engineering staff; the first management established geologist and engineer relationship known to have been formally designated.

The role of geologists in applied geology concerning public related works declined in the U. S. during the late 1800s and continued for about forty years. During this period, changes of economic importance especially the development of vast mineral resource developments, attracted many geologists. These offered financial rewards as well as professional opportunities. Increasing needs for advanced research coupled with education opportunities for geologists also brought many geologists into career education positions. The teaching interests were focused almost entirely on economic geology. However, there were some exceptions with eminent earth scientists concentrating on the importance of geology in public works. Those scientists focused on major projects affecting public safety and well being. In so doing they can be credited with starting engineering geology on the path that has led to world-wide high esteem of the profession.

### **Application of Geology in Life Support Systems 1900-1960**

The 20<sup>th</sup> Century opened with the geologic map of London identifying 16 subsoil units, one of which the London Clay, as affecting living and future construction decisions. This map, after Woodward in 1906 follows his memoir 1897 addressing public building sites as described in Culshaw (2004). Culshaw considers these works to be the first attempts in the United Kingdom to explain the geotechnical, hydrogeological and geo-environmental influences of geology on the building and construction in urban areas.

Economic priorities, whether locally, nationally or internationally, exercise basic controls on geologists training and employment opportunities. Vast mining development in the late 1800s and into the early 1900s were followed shortly thereafter by a similar explosion of interest in oil reserve and production development. Employment opportunities for economic and petroleum geologists accounted for much of the geologist work force for decades. By contrast, those practicing geology geared to public infrastructure needs were less well rewarded. During the halcyon years of metallic mineral and oil exploration, the many large profitable mines and major oil fields that were located and developed were all aided significantly by geological investigations and recommendations. In the aftermath some sixty years later, the absence of geologists with knowledge about potential surface and subsurface after-effects of mineral and oil extraction proved costly.

From Galster (2004) *“Two totally unrelated events in the 1920s pushed engineering geology ahead more quickly. In 1925 the U.S. Congress passed the Rivers and Harbors Act”*. His other example, one of many major dam failures was caused totally or in part because engineers failed to recognize or modify construction relative to geologic conditions. The St. Francois Dam failure, Galster’s specific second-event example in California in 1928, was a tragedy resulting because engineers either ignored or did not understand possible geologic affects on the structure they are building. Government intervention to avoid further failures began to increase. Engineers began to search for geologists who had the abilities and desire to participate as geologists providing necessary geological information for use in exploration, design and construction. As a community of geologists however, the response was poor (Kiersch p. 32, 1991). One could also speculate that if the geological community had been more active politically and professionally during the earlier period of dam failures, at least a few engineers might well have sought the advice of geologists. Partial responsibility for some of these failures could well rest on the inabilities or lack of desire by geologists to participate in public works.

Enthusiasm with economic geology employment commonly lasts for a few decades at the most, and sometimes for a much shorter duration. The causes usually are oversupply and private sector economics. Normally, these difficulties are limited to geologists and other mining employees.

However, the world-wide depression of the late 1920's and much of the 1930's decades affected millions of people in many nations. It was not to last forever. The rebound from the depression began slowly but recovery increased rapidly with the swiftly approaching World War II global catastrophe. Economic geologists again became much in demand early in the 1940s especially with the emphasis on strategic minerals and oil. This time, the rebound also heralded an increased return of the applied geologists who had knowledge and experience with water resources, earthen materials and a variety of geologic conditions affecting military operations such as airfields and roads.

Negative examples of construction failures common throughout the first half of the 20<sup>th</sup> century alone would never lead to success in the professional world. Fortunately, during this period of multiple failures and public concerns, some distinguished geologists had the vision to see and understand how essential applied geology is to public protection. These geologists were outstanding scientists, not afraid to make decisions even at a time when exploration procedures and data-gathering techniques were far less well developed than some forty to sixty years later. Engineering geologists today owe much to those founders of their profession as it is currently practiced. Their application of geologic knowledge seventy and eighty years ago to site characterization, for example large dams, the integration of geology into highway engineering, and the development of water-resource supplies created the practicing fundamentals of today's engineering geology. They also provided a foundation of knowledge and procedural experiences that aided wartime geologists of WW II where such background information sources greatly aided emergency construction and other military requirements.

William Otis Crosby is considered by Kiersch (p. 16, 1991) to be the "Father of Engineering Geology". He introduced geologic concepts in the planning of public works in Boston as early as 1893. Another geologist of great repute, Charles Peter Berkey first began his work as a geologist in the public sector with the construction of the Catskill Aqueduct (Paige, p. xi, 1949). His academic career was as a professor of geology at Columbia University with strong emphasis on the application of geology to public works. His association with the United States Bureau of Reclamation began in 1928. His appointment by President Coolidge to the Colorado River Commission was true recognition of Charles Berkey's abilities. Hoover Dam was one of many examples where Berkey's knowledge of the geological environment was critical to the success of various engineering projects of great importance to the U. S. Kirk Bryan, a widely respected field geologist for the thoroughness of his field work, also was an stalwart in the early days of major water developments by the Bureau of Reclamation. The Geological Society of America annual Kirk Bryan Award is in recognition of his work. The GSA Kirk Bryan Award does much to emphasize that field work is critical to success of projects and in a longer view to sustain life support systems for the benefit of subsequent generations.

Others having an early influence on engineering geology include Edward Burwell, Jr., the first Corps of Engineers Chief Geologist, Fred O. Jones (Armstrong, 1985), and George D. Roberts. Jones, with Bureau of Reclamation and Corps of Engineers experience in the 1940-50 also directed the U. S. Geological Survey's Northwest Branch. Roberts, at one time in the 1930s was the District Geologist of the former Little Rock Corps of Engineers District. Roberts had a long-lasting influential role in engineering geology in that District including the Missouri Geological Survey. One of many examples was his determination of the causes for severe construction and operation problems with two U.S. Corps of Engineers dams in Missouri. The sites for these two dams were selected by COE engineers as locations that were topographically the most suitable. However, the geological conditions were not considered in the site selection. After the Roberts reviews and recommendations, subsequent COE dam sites in Missouri and Arkansas were located based on Roberts' recommendations. In large part those recommendations included a geomorphic area study followed by more specific site examinations. Providing surface evidence appeared favorable, subsurface work then proceeded.

Subsequent dam sites chosen using geologic criteria experienced no unforeseen problems or difficulties during construction and later operation.

Roberts geological experience, gained in Arkansas and Missouri, also proved of value to many field geologists especially in the recognition of geomorphologic conditions as clues to subsurface conditions in karst areas. His accomplishments were of particular assistance in the formative years of the engineering geology section of the Missouri State Geological Survey. Some of his recommendations have been used for the last 40 years in the site characterization of proposed dams, or dams with problems, as well as geologic conditions affecting waste disposal site characteristics.

There is a tendency to write histories of geological accomplishments as if having no negative sides. This is far from true as indicated by Kiersch (p. 34, 1991). He cites in his historical review the wordy professor example ready to speak on any issue regardless of subject knowledge. For professional differences, regardless of the matter, this is more of a matter between individuals. However, where public works and public issues exist, as in engineering geology, it becomes a much more critical matter. The historical example Kiersch used concerned a well investigated and data substantiated Golden Gate pier foundation. Bailey Willis, who for whatever reason chose to disagree late in the completion of the work with construction deadlines pending, entered in claiming various determinations by others were wrong. He was not able to convince changes be made, lacked data, but managed to achieve costly delays. White (2003) writing in *Governing Magazine* observes that city managers have their shortest employment tenures in university towns due to continued expression of opinions in public meetings on most any subject by professors.

The success and failure of geologist participation in engineering works remained somewhat sporadic even with the examples set by eminent geologists such as Berkey. In contrast with such sporadic geologist activities in civil works during this sixty year hiatus in the United States, individual State Geological Surveys maintained a consistent and reasonable balance between applied and economic geology as well as engineering works affecting the public. Some surveys, for example the Missouri State Geological Survey, were engaged in water resources, dam site evaluations and water well drilling procedures to protect the public health beginning in the early 1900s.

The active and direct involvement of several State Geologists starting highway geology programs and serving as Highway Commission members in essence is a continuation of the William Smith's transportation focus some 130 years prior. E. F. Bean, State Geologist of Wisconsin, in the Berkey Volume, (Paige, pp.181-182) gives specific recognition to six State Geologists who were actively engaged in state highway department works. Several were members of highway commissions. All contributed one way or another to developing long-lasting applied geology programs and knowledge of geologic applications to the building of highways. Bean takes particular note of H. A. Buehler, Missouri State Geological Survey, having been an ex officio member of the Missouri Highway Commission for some twenty years until his death. Ironically, Buehler's death occurred at a Commission meeting he was attending against his doctor's orders because of a heart ailment. During this same 1920 decade, the Illinois State Geological Survey in 1927 became the first state survey to formally establish an Engineering Geology Division (Kiersch, p 33, 1955).

Karl Terzaghi of MIT, Andrew Casagrande of Harvard and Ralph Peck of University of Illinois exerted positive influences on applied geology. Terzaghi known as the Father of Soil Mechanics developed systematic analytical procedures to measure soil properties that would affect construction. He then developed equations and other measurement interpretative procedures that determine soil strength, stress and loading interpretations, and other properties. For the first time, builders could

proceed with far greater confidence when building on soils regardless of soil conditions. Terzaghi had words of caution for soil mechanics engineers that apply equally well to engineering geologists. In Terzaghi and Peck (p. v, 1948), we read *“On the overwhelming majority of jobs no more than an appropriate forecast is needed, and if such a forecast cannot be made by simple means it cannot be made at all”*. Terzaghi’s formulas and philosophy were of world-wide influence (Legget, R.1977). In that same report by Legget, the Terzaghi bibliographic references include *“The Influence of Geologic Factors on the Engineering Properties of Sediments”*. Throughout his career, Terzaghi was a strong proponent of including geology in engineering works. He considered such knowledge and recommendations concerning geologic interpretations an essential part of the project exploration and recommendation process. Later, Terzaghi expressed disappointment that, in general, engineers did not share his views about the importance of geology in site characterization and subsequent analysis including construction reviews. This disinterest in geology that concerned Terzaghi appears to be worsening nationally and also locally in some states. It is not a uniform trend however as some states report good rapport with soils or geotechnical engineers. Such rapport is essential in professions so vital for life support systems. Legget, (p. 384, 1977) admonishes the engineer with this thought: *“we can never successfully divorce our thinking from the overwhelming influence of geology on our works”*.

Peck, another world-recognized soils mechanics engineer had views similar to Terzaghi concerning the importance of geology relative to foundation investigations. In a presentation concerning the failure of the Teton Dam in southeastern Idaho in 1976, Peck commented that no structure can be considered safe where geology is a factor unless there is a geologic back up if something fails or is overlooked in the design and subsequent construction.

The onset of World War II caused abrupt employment changes in all sectors, including geology. Military geology was an active profession in Germany for pre-war planning. The heavy armored equipment the Germans were developing spurred the need for terrain analysis. However, the Germans were far from being the first to consider military geology. That distinction belongs to Karl August Raumer who developed information on the terrain of Silesia (Kiersch, p. 33, 1991).

Wartime geologists were soon working for the military directly as members of the United States forces or as consultants to the government. Both economic and applied geologic interests were involved. Knowledge about strategic minerals and oil reserves were of critical importance. The war also stimulated the need for geologists having experience in water resource exploration and geologists and engineers concerning the physical properties of soils. An example of great importance was the wartime development of the Atterberg Limits and the Unified Soil Classification System by Arthur Casagrande. He successfully devised a testing process that described the physical properties of soils and provided general strength information relative to airfield and other construction where time was of essence. His procedures established a standardized soil classification and testing procedures that remain in wide use today by engineering geologists and geotechnical engineers. Even with the obvious needs for military geology, and demonstrated successes such as the Casagrande example, the United States military as a general rule was slow to consider geology in military planning. That came decades later when more complex problems such as detection of North Korean tunnels at the Demarcation border.

Engineering geology in the 1950s began to emerge with a more specifically defined role compared with the generalist concept of applied geology that had lasted for a century or more. Engineering geologists soon began to develop that role even more specifically by work and in the literature. With these actions, engineering geology became a rapidly expanding profession with population expansion and waste disposal investigations...

To close out the 1900-1960 decade, period, several events of geological importance can be cited. The construction of the Alaskan Highway certainly imposed geological extremes on the builders. As it was a wartime endeavor, brute force construction skills were used to overcome geologic constraints. However, even brute force can fail without the basics of geologic knowledge where physical conditions are extremely treacherous. A second achievement, this time by a single geologist, led to the development of what has now become one of the largest military installations in the United States: Fort Leonard Wood, Missouri. This facility was a pre-war army training establishment originally scheduled for a different location where both water resources and terrain were unsuitable. The Missouri State Geologist, Henry A. Buehler, learned of a Congressional Search Committee in the process of selecting a site in the Midwest. He managed to secure the location in the Missouri Ozarks where terrain and water resources were excellent for the military training needs (DGLS files; Dan Kennedy comm. 1999). Kennedy also noted that Buehler told the Committee that he could begin the boundary surveys the day after returning home. Kennedy, later the supervisor of the USGS Mid Continent Mapping Center, was placed in charge of that survey. Almost eighty years later, Fort Leonard Wood, one of the largest military training facilities in the U. S., exhibits the benefits of combined professional interrelationships, this instance, surveying and geology.

### **Application of Engineering Geology in Life Support Systems 1960-1980**

*What's Past is Prologue* (Legget, 1977) provides a review of significant past events having applied geology implications. He cites (p. 1) Vitruvius in city relocation and harbor building. In considering urban geology in "Cities and Geology" authored by Legget (1973), one could without much stretch of the imagination visualize Vitruvius, some 2000 or more years ago, in a similar setting as that existing with the City of Boston, the bays and transportation complexes. It also does not take much more of an imagination stretch to realize one seldom creates without some historical knowledge for that creation. We have the responsibility to make it better given the resources we have that did not exist in past centuries.

The decades, 1960-80, were a period of rapid urbanization, commercial, and transportation expansion commensurate with immense increases in the use of natural resources such as water and the land. By this time, engineering geology was becoming a widely used sub discipline of geology, hence the notation of that transition beginning in the 1960 decade. These pressures and the increasing risks to life support systems caused many nations to address these risks at national as well as local levels of government. Because many of these government initiatives were specifically directed to environmental safety, some engineering geologists began to specialize in *environmental geology*. Also, with water-resource issues increasing as well, *hydrogeology* became another specialty. A third specialty, *urban geology*, made an appearance, but more often as titles of articles than as work identification titles by individual geologists.

The practicing engineering geologist viewed the newly developing field of engineering geology as one having many rewarding opportunities. At the same time, the level of employment of economic geologists began a slow downturn that was later to worsen severely in all but a few states. This was not true for those who were mine and oil exploration geologists in other parts of the world such as Australia. By way of contrast, the practicing engineering geologist and the environmental geologist now coming on the scene were not included in many of these foreign mine and oil developments. Also, some mine and oil development and operation companies had little desire and saw no need to consider environmental effects of their operations, especially in the poorer nations of the world or in remote locations. Diamond (2005) gives several examples of those companies who recognized environmental

consideration needs and others who chose to ignore such needs. He also outlines some of the consequences, positive and negative, of such actions.

The economic geologist in the United States faced other problems besides the diminishing mining employment opportunities. Some, perhaps many, were not inclined to move into a practice such as engineering or environmental geology, where the public directly or indirectly, and sometimes the government were participants. Also, for many, this was late in their careers which further hampered employment changes. Rumors of possible geologist registration or other credential requirements were additional irritants. Those who could relocate to Canada, South America and elsewhere found employment opportunities.

The year 1960 did not start well for the United States Atomic Energy Commission in Missouri. Past groundwater pollution experiences which had been identified by the U. S. Geological Survey as a wartime investigation at the St. Louis ordinance plant were ignored. In 1960, the Missouri State Geologist issued similar warnings. This attitude by the federal government subsequently changed and illustrates how exemplary cooperative exploration and remediation can be accomplished in the public interest. This process however has been more difficult such as for large abandoned mining operations. Regardless of location or causes, all included large numbers of engineering geologists in the remediation work...

It is important to recognize that the Illinois Geological Survey was the leader by many years in establishing the first engineering geology section in 1927. Subsequently, but generally following WW II, many state geological surveys began focusing on research pertaining to engineering geology. The Missouri Geological Survey began engineering geology type work in the 1920s but did not establish a formal engineering geology section until 1960. The work focused on direct public responses along with regulatory interactions with other agencies and the private sector rather than research. However, a notable research exception for the Missouri Geological Survey in cooperation with the U. S. Geological Survey was an early application of thermal imagery in karst terrane hydrologic studies (U. S. Geological Survey (1977)). The purpose was to determine use of thermal imagery over large watershed areas to aid in land use planning. The results were successful. Currently, an Ozark wide determination of large spring karst recharge areas, Big Spring as an example, is nearing completion and soon to be published.

The engineering geology profession experienced accelerated growth beginning in the early 1970s. That acceleration was propelled by several causes. In the more populated countries, especially in the U. S., populations spread from the cities to outlying areas having ready access for new homes. This expansion continued at an ever increasing rate. Suitable terrain for development was soon occupied leaving less suitable, and in many areas, unstable terrain as the only option for continued expansion. Construction difficulties, landslides in California for example, increased. It was in these more difficult areas for building that the engineering geologist became the professional person who could best determine site conditions, recommend exploration procedures, and help evaluate the exploration data. In addition, serious long term environmental problems had been created by the mishandling of large volumes of waste products by both the private sector and government. Military bases and support facilities dominated the government's pollution problems. .

Increasing resource needs and environmental concerns by the general public gave strong support in the 1970s to government actions ranging from increased investigations to the formation of regulatory agencies and related legislative actions. Examples in the U. S. federal government include the Environmental Protection Agency, the Superfund Act, The Resource Conservation and Recovery Act,

the Formerly Utilized Sites Remedial Action Program (low level radioactive wastes), Coal Gasification Plants clean-up recognition needs and a host of others. An umbrella act, the National Environmental Protection Act, required that any development subject to a federal agency action include an environmental impact statement. Potentially hazardous and low level radioactive waste sites were ranked according to risk posed such as nearby population density, public water uses and other criteria. Those meeting an established risk level were placed on the National Priorities List. To accomplish the work engendered by this legislation, and additional legislation at the state level, government agencies added numerous employees including engineering geologists to their staffs. Concurrent with these happenings, the affected industries and consulting firms also increased staffs of engineers and engineering geologists.

Population and industrial expansion put new stresses on water resources especially in the traditional water short-areas. Water needs created a changing work emphasis for some engineering geologists to the point that many were calling themselves *hydrogeologists*. A greater need for land use planning was evolving as well. Some nations, Czechoslovakia as an example, by virtue of widespread public related works had well staffed and experienced engineering geologists having a broad array of sub disciplines ranging from water resources to those who were constructing detailed engineering geology maps for use in land planning. Large areas such as portions of Africa were less fortunate. Portions of North Africa and the Middle East beset by ancient and recent wars and having a culture modified even more by internal strife are ill equipped for infrastructure resurrection (Lowdermilk, 1953). There is little history to record what is today known as engineering or urban geology in these areas since the time of Roman Empire city and road building even in the extremes of the North African physical environment.

Afghanistan, a nation created partly by some disputed borders, has long been a region noted for its tribal wars and primitive life systems. Gradual changes began in the early 1900s with more rapid changes in the 1950-60 decades including the beginnings also of land use planning. Transportation routes were being pushed into remote regions even though unwanted by those living in such regions. The government planning intentions were to entice at least some of the inhabitants to participate in the beginnings of a more cohesive national government. Other national planning activities included water resource and agriculture development especially supplemented by irrigation. They had the beginnings of life support systems development. This process was described by Dupree (1963) along with an extensive demographic, archeological, water resources and government structure coverage of the country. Tragically, essentially all of the water resource and other life support systems were destroyed during the Russian occupation and subsequent internal strife. Current events in Afghanistan dramatize how difficult it is to reinstate sustainable life support systems after such destruction and subsequent adverse cultural changes. Lowdermilk (1953) with his field observations made prior to WW II provides a clear warning yet today for those who destroy life support systems. He and Diamond (2005) describe a bleak outlook for the future for those living in such areas. The fragility of life support systems cannot be overemphasized.

New U. S. federal life support systems laws were tested early in the 1970s. Early in that decade, my testimony as representing the Department of Justice, the Environmental Protection Agency and the Missouri State Geological Survey provided the evidence that resulted in the first *Superfund* trial decision reached in a federal court. The court found in favor of this testimony and ruled that the Environmental Protection Agency was entitled to its claims for damages. This decision had two important features, both geologic in nature. It was the first *Superfund* damage claim and precedent setting by virtue of the federal court decision finding in favor of the EPA. It also set the precedent that engineering geology would be a well supported part by the EPA. From that point on, such work involved close coordination between the state and federal geologists generally nationwide.

The 1970s also were the decade when construction of major transportation systems began in earnest. Engineering geologists were quickly rewarded with challenging work. Soon, symposia including field illustrations of highway planning and building were offered to assist those specializing in highway engineering geology. In the United States, the Interstate Highway System created a major demand for route determinations and geologic decisions to determine best route locations and geologic factors affecting construction. For example, a lengthy segment of an almost finalized Interstate Route segment in Missouri was changed to avoid karst terrain deemed hazardous by Missouri Geological Survey engineering geologists. Mountainous regions posed extreme geologic conditions requiring extensive studies by engineering geologists. Major metro systems also came into being. Examples include Toronto, Washington D. C. and the San Francisco Bay Area Rapid Transit (BART). Engineering geologists have had life time careers working in some of the most complex conditions imaginable with these metro systems and associated feeder passenger rail lines as in the northeast and Chicago areas.

Transportation in Europe is a more balanced mix of rail and road as compared with the U. S. However, the geologic difficulties are essentially the same regardless of where highways and railroads are constructed. High speed roads as the German Autobahn as well as high speed rail as in Japan require special care in all aspects of building including detailed assessment of geology conditions that affect construction and operation. In the United States, rail transportation is primarily for freight. Road bed conditions including geologic properties are less critical for low speed and less intense rail use. Where there once were numerous engineering geologists employed to assist in the geologic aspects of railroad work, few remain. Search for and evaluation of aggregate sources for rail bed ballast does remain as a geologic activity.

In the early 1930s the U. S. initiated some major river transportation improvements. The Congressional enabling legislation of 1925, the Rivers and Harbor Act, coupled with the Pick-Sloan Act of 1945 for the Missouri River made it possible to construct and improve the river navigation infrastructure on many of the nation's major waterways. Five large Missouri River dams built for flood control, hydropower, river navigation and other purposes were completed during a 20 year period. The sixth dam was constructed much earlier, in the 1930s, on the upstream portion of the Missouri. The construction of such large dams in areas noted for slides and other complex physical problems involved considerable geological work. Lessons learned here helped the profession of engineering grow in numbers and more importantly in professional expertise. Such work in a sense was the close of the big construction era of the 1920-1960 decades extending from the Midwest to the west coast. Many engineering geologists and a multitude of other professionals were employed for long periods of time, especially in the building of large dams. Only a few large water related structures have been built since. One example is a Mississippi River lock and dam on the Mississippi River near St. Louis, Missouri.

The potential remains for engineering geologist employment for transportation needs are significant in the U.S. However, these large areas having such needs also have low density population and inadequate financial support for road construction or to support public transportation such as passenger rail service. The U. S. also is lagging in river transportation infrastructure construction, improvements and maintenance. Here many engineering geologists were once employed, but few are today. Countries as Argentina with needs for bulk transport as by water are prioritizing navigation structures to serve water transport needs. .

The St. Lawrence Seaway construction included investigations of highly complex geological conditions. Physical properties of glacial materials, especially the very dense till, made for difficult

interpretations relative to construction. Sensitive clays further challenged geologists, engineers and contractors. The Seaway, although completed by 1959, was such a massive transportation undertaking that it compares with many other world-scale large transportation networks whose development or resumed development began in the 1960s. Another Canadian project in full swing during the 1970s was hydropower development, for example Hydro Quebec. The multiple large dams and the world's largest underground power station at Churchill Falls in Labrador were major engineering and engineering geologist achievements.

Massive water management developments, including many sizeable water supply reservoirs and lengthy canals in California were and continue to be integrated water complexes to support the large populations of central and southern California together with its water dependent agricultural economy. These water storage and conveyance systems included the building of very large dams in complex geologic settings where suitable dam building materials were difficult to locate. Canals and large pipelines cross active faults as well. In nearby Nevada, water-short areas of the south are looking to more water-plentiful locations to the north, not unlike conditions in California. Large numbers of engineering geologists and hydrogeologists were and are employed for such water-network developments

Coastal erosion, always a public-risk concern, has progressively worsened on both the east and west coasts of the U. S. As with many other consequences of expanding population growth and movement, normal erosion actions are magnified by where and how people build and use the land. People are crowding closer to the coast lines, and moving off shore materials around for harbor improvements or aggregates. Engineering geologists will be working on increasingly difficult problems with these land use changes.

Nationwide by the 1960s with large undertakings as water resource needs being met, expanding suburbs and waste site proposals, maps showing engineering geological conditions were in various stages of development. The Missouri Geological Survey, one of many working on such maps and classifications, was endeavoring to describe and display meaningful concepts of bedrock and overburden materials as a combined entity. This was described in a paper titled "*Missouri's approach to Engineering Geology in Urban Areas*" (Lutzen and Williams, 1968). Krueskopf, in Leggett (p. 1436, 1967) refers to the combined soil and overburden as "...parts of one geological body..." Lutzen and Williams built on that concept and included the physical relationship of the "body" with the underlying bedrock in defining engineering geology mapping units. Certain units identified as having slope failure risks were subsequently designated by planning agencies in the greater St. Louis, Missouri area to be investigated in more detail before building permits would be issued. Although Lutzen and Williams included "*Urban*" as a part of the report title, it was not with the intent to designate a specialty within engineering geology. Somewhat later in the 1970s and subsequent years, the Illinois State Geological Survey published numerous reports specifically directed at geology in planning for use by counties that were experiencing a combination of urbanization and geologically sensitive conditions.

Robert F. Leggett (1967), in his address as retiring president of the Geological Society of America, pointed out the importance of soil as defined in the engineering sense. Leggett urged geologists to recognize that a large part of the earth is a mixture of soil and bedrock, a mixture that has much to do with the application of geology in public works. Leggett urged that geologists to recognize the importance of engineering properties that are intermingled with geologic properties of weathered bedrock and overlying soil. Engineering geology was building fast in the 1960s as a profession encompassing many disciplines and founded on a broad geosciences education. Leggett, a leading

geological scientist and a generalist advocate, emphasized in his GSA address that the role of geology in public works.

Robert Ruhe, working as a Pleistocene geologist, geomorphologist, and soil scientist at Iowa State University (1969) emphasized the integration of these disciplines. His geomorphic concepts of relative landscape ages and geomorphic surfaces, when combined with the Roberts concepts of geomorphology relative to weathered landscape forms, were used in the early development of engineering geology work and site classification systems at the Missouri State Geological Survey. The combined geomorphic surface relationships and landscape surfaces combined with such factors as bedrock, overburden physical properties, and near-surface groundwater hydrology, were used in making site recommendations and surficial material maps.

The acceleration of engineering geology work especially in geologically complex and high risk areas attracted many geologists and certainly engineering geologists. The late 1950 and 1960 decades saw the formation of several professional organizations for purposes of improved communications between geologists and also the beginning footsteps into registration and certification. In California, the first professional organization of engineering geologists, the Association of Engineering Geologists (AEG), was formally organized in 1963. A geological organization, the American Institute of Professional Geologists, with certification as a part of the membership requirements, was formed about the same time. This organization includes all geologists regardless of work or discipline preference. Both organizations have international members.

The International Association of Engineering Geologists (IAEG) was first organized at the International Congress (IGC) meeting in New Delhi in 1964 upon the recommendation of V.S. Krishnaswamy, an engineering geologist from India. The next IAEG meeting was held in conjunction with the International Geological Congress 1968 meeting at Prague. However, the proceedings, including those of the IAEG, (Savtos, 1968) as well as all of the Congress were interrupted by the USSR invasion of Czechoslovakia. Papers as prepared for the Engineering Geology in County Planning Session (Malkovsky and Zaruba, 1968) were chosen to emphasize the importance of initial geological, geomorphological and structural conditions that might affect various developments. The engineering geology maps made by Czech geologists combined soil and bedrock properties, slopes and a variety of other attributes for use in planning purposes. The information displayed on these maps exceeded that seen elsewhere.

The 24<sup>th</sup> session of the International Geological Congress in Montreal, 1972, continued with the emphasis on engineering geology that was started in India. "Engineering Geology" again was a prominent section, Section 13. The three themes were "Urban and Environmental Geology," "Slope Stability" and "Communications" (Crawford and Scott, 1972). A lengthy field trip, similar to the one in Czechoslovakia, featured engineering developments having national importance such as the ongoing construction of large dams for power generation. The IAEG is the most international of engineering geologist organizations.

### **Application of Engineering Geology in Life Support Systems 1980-Present (Modern Trends)**

These last 35 years of engineering geology and related disciplines have been years of great advancements. Faculty and courses of study relative to engineering geology flourished. A review of the library holdings of scientific books, professional journals and other source materials finds almost every subject about engineering, environmental, or urban geology represented. In the field, in spite of excessive delays with some large waste sites, more clean up or initial site investigations of large

facilities were completed than in any 25 previous years. New tools and techniques were developed and used. The ASTM, D18 Committee, developed new guidelines and some standards relative to these tools and techniques (ASTM 2005). State and federal scientific organizations have made significant contributions. A few state geological surveys have increased site investigation roles to full time efforts. However, most continue to focus on their research activities and with a water resources component being added to that activity. The U. S. Geological Survey has followed that trend with a research emphasis. More private sector firms with geologist managers came into being than in all previous years. More engineering firms added geologists than ever before. Those geologists were expected to be trained and experienced in engineering geology or associated disciplines. The geological engineer, some with a balance of geology and engineering, others mostly trained as engineers, are finding increased employment in government and engineering firms. Early in this 1980-present period, the working relationships of geologists and engineers drew closer together (Williams and Swenty). Unfortunately as previously noted, that mutual relationship of respect has deteriorated to some extent.

Legget and Hatheway (1988) in *Geology and Engineering*) anticipated these trends as engineering geology increasingly merged with engineering in site investigations including bridges, dams, waste handling, water supplies, tunnels and underground space. These became increasingly important as the profession of engineering geology rose in prominence during the latter portion of the 20<sup>th</sup> century.

The 1980-present period has seen advancements and difficulties on many life support system fronts. The Channel Tunnel, which completed a transportation link beneath the English Channel, was a long envisioned project that was finally accomplished. In California, major difficulties included increases in coastal area landslides and significant beach erosion northward along the coasts of Oregon and Washington. Washington has its share of land failure risks ranging from high mountains, lahars, and volcanoes such as Mount St. Helens (Lasmanus-1994 and Pringle-1994). Engineering geology essentially “cut its post 1960 teeth” with work extending all along and near the west coast. By the 1980s and later, continued growth into these areas created even more hazards, thus increasing the needs for engineering geology work. Similar teeth cutting training was also forced by the urgencies and complexities of pollution from very large waste disposal locations in many locations in the U. S and elsewhere. Some of these have lingered on with few conclusions or fixes. Others have been successfully remediated.

The expanded upgraded Panama Canal has new locks that are of sufficient width to accommodate much larger ocean cargo ships. Also some channels have been widened and deepened. Cargo capacity is expected to increase significantly. This massive age old water related transportation system receives little widespread notice yet of great global economic importance and heralds the contribution of many disciplines including geology.

Waste sites requiring remediation were much larger beginning in the general 1980 timeframe. This coupled with the emerging awareness of environmental and terrain safety needs created job opportunities for many engineering geologists in the government and private sector. This also was the time and probably the cause that environmental geologists and hydrogeologists became known separately from engineering geologists. It was also the time when complexities of site remediation and new site considerations demanded more of the participating geologists than in the past. With those time and more stringent investigative needs, the generalist geologist with broad experience either left or some became technical administrative managers. This also was the time that the engineering geologist came onto the stage as an equal professional with engineers and others.

Hatheway and Kanaori (1999), commenting on engineering geology in Japan, cite systematic detailed engineering geology mapping for critical engineering works. Large and successful projects such as hydroelectric and nuclear power plants are given as examples. Applied geologic research is emphasized with many engineering geologists working within government or in independent administration organizations. Reference to geomechanics work includes mention of the work by T. Watanabe. Hydrogeology is included along with a significant listing of works described as “Disaster Geology”.

Overall it appears that China is finally recognizing its lack of emphasis on life support systems. Large projects, such as the Three Gorges Dam, involve geologic site characterization. However, effective environmental geology and related sub disciplines, soil science and sustainable agriculture practices, and waste handling are inadequate to maintain life support systems. Similarly some other Asian, Southeast Asian nations with their large populations and lagging life support systems continue to create risks for their populations and the world (Diamond (2004). Hong Kong has, by contrast, a well-developed Geotechnical Control Office that lists numerous publications ranging from technical manuals on slopes to site investigation guides (Hong Kong).

The U. S. remains mostly stagnant in passenger rail transportation with some exceptions as the Northeast and greater San Francisco areas. This is not the situation in Europe and Japan (Hatheway and others 2003-04, p. 633). One project of particular interest involves the world’s largest tunnel boring machine in the Amsterdam to Brussels High Speed Rail Link.

North Africa and the Middle East are experiencing increasingly difficult circumstances concerning life support settings. Circumstances and causes as cited by Lowdermilk (1953) are centuries old. Climate transition from wet to dry beginning about 5000 BC (Leng) increases the hardships on what at best are subsistence economies in many countries in this area. To characterize what can happen over a much longer period of time, geological time, the early example of the youngest human ancestor child found in present Ethiopia lived in an environment conducive to life. While predators existed, nothing parallels the example of Ethiopia today, desolate in desert and “shoot outs between rival ethnic groups” (Sloan). Human life today in this setting barely exists with absence of effective government. Other nations in similar physical conditions but having effective governments are able to include most if not all the sub disciplines of geology as a part of their life support systems.

All aspects of engineering geology not to mention other aspects of life support systems must have something to work with, economic stability, abilities to advance beyond subsistence, and a reasonable assurance of a stable future. A few nations in the area referenced by Lowdermilk more than sixty years ago yet today cannot provide these assurances. The same exists beyond the area studied by Lowdermilk, portions of central Africa and South America as examples. All have hardships caused by long term life support systems neglect, wars and ethnic clashes, and inabilities or desires by some governments to focus on basic life support needs especially clean public water supplies and safe waste disposal handling. Geologic contributions are of little value if not supported by a stable government. Destabilization can cause immediate serious difficulties. Even in the Darcy era, a change of French governmental authorities decided Darcy was a danger to society. That later was corrected, but the example remains. Cost estimates of \$15 billion (Hatheway and others 2003) to replace the dams, roads, bridges, irrigation facilities, and wells, plus countless other related structures destroyed by the Russians, and later more destruction by the Taliban in Afghanistan provide one of a multitude reasons that life support systems fixes in these countries will be exceedingly difficult. Recent events in Afghanistan and Iraq show the cost estimates are much greater than estimated by Hatheway and others.

Japan, a major timber importer, is by virtue of its contractual relationships with other countries is the leading cause for deforestation of the Tropical Third World (Diamond, p. 518). Such actions leaves these countries stripped of their resources and subject to severe environmental damages to already fragile life support systems that might allow engineering geologists to work along side of others in attempts to repair the deforestation and other damages. Little expectation remains for professional growth opportunities including engineering geology.

Increasingly large and complex waste disposal landfills continue to be built in the U. S. and elsewhere. Engineering geologists have essentially permanent job residences with firms involved in waste site exploration and operation. One of the largest proposed sites in the California Mojave desert will accept 20,000 tons per day (Hatheway and others 2004-5, p. 33).

Iceland, long remote from large industrial complexes, is now supporting the relocation of an Alcoa aluminum plant from the U. S. to Iceland (Hatheway and others (2004-5). Diamond (2005 p. 203) reports how the early Icelandic civilization, existing in a fragile environment, still survived but the settlement of Greenland failed at least in part by not adapting needed life support system changes from their Old World to Greenland. Considering both the geologic conditions of Iceland and citizen concerns, engineering geologists fortunate enough to obtain employment concerning the aluminum plant be well rewarded in many ways. This is certainly a location where the best of engineering geology expertise will be required and may be a worthy note for future histories of engineering geology.

Water resources in the High Plains of the U. S. and westward to the Pacific Ocean may be taxed in multiple ways as future developments, population growth, and other high-volume water uses continue to increase. Entrepreneurs are purchasing or seeking to purchase extensive water rights of underground aquifers in these areas. Also, Hatheway and others (2002-3) comment that three of the largest water companies in the U. S. are now foreign owned. Similarly the agricultural news media report that the largest chicken and pork processing organization in the US has China as the principal owner. The commonly accepted reason, better assurance of food safety for the Chinese consumer. The point here of interest, agriculture is generally the major user of water supplies, especially groundwater.

Brownfields, or as brownfields, lower case, within the text, is the EPA administrative process to hasten hazardous waste site cleanup and return to commercial, residential and other uses (Brownfield News). This represent a federal and government transition of thinking and management directions relative to many *Superfund* sites. In this transition, two specific items of life support systems and engineering geology are important. First, brownfields requirements relative to site contaminants are limited to a minimum and perhaps no intrusive investigations. Surface examinations and site history reviews are the primary investigative steps. As work progresses on site, surface observation of material removed is usually acceptable. All in all, this means considerably less involvement of engineering geologists in site renovation and cleanup. Furthermore, along with that, the person responsible for observing and evaluating geologic and groundwater conditions can be a registered geologist, licensed engineer or be certified by the federal government, state, tribe or territory. Certification eligibility does not require that the person be a geologist or engineer. Brownfields are one of the few government programs in the U. S. and the UK that are well financed jointly by the federal government and state. The brownfields process is and will continue to rapidly remove sites from the federal lists of hazardous sites that were awaiting cleanup. Although a few contaminated sites will not meet brownfields cleanup standards, within a few years there will be much fewer job opportunities for engineering geologists. The long term life support system affects with these changes are unknown at this time. .

Global warming does call for engineering geologists as well. Melting permafrost in places as Fairbanks, Alaska, and elsewhere around the world is causing increasing foundation difficulties. Houses, larger buildings, roads, railways, pipelines and all manner of structures are being adversely affected. This is a somewhat new situation for all professions attempting to remediate the damages including the engineering geologist. It is a current problem that will continue to worsen.

The Weyburn Project, a cooperative venture between the state of North Dakota and the provincial agencies of Manitoba and Saskatchewan, is the largest carbon-sequestration project currently underway anywhere in the world. The leader of this project which started some 12 years ago was the North Dakota State Geologist. The carbon dioxide being sequestered is captured at a coal gasification plant in North Dakota. It is piped to Weyburn in the Williston Basin in southern Saskatchewan. Enhanced oil recovery was also a part of the venture along with carbon dioxide storage. Such projects as this, and several are in the planning stages, mean considerable challenging employment for engineering geologists, probably those having hydrogeology experience with other geologists.

Early engineering geology maps, for example a Military Engineering Map of Western Europe (U. S. Geological Survey) defined units based on physical properties. More complex procedures were used in Czechoslovakia as during the 1960 decade. During the last 15 years the Missouri Geological Survey has been mapping surficial materials as a part of the National Geologic Map Initiative of the U. S. Geological Survey in a manner that incorporates the overburden, topography and bedrock. Formation names are assigned for designation purposes. The procedures follow those established for bedrock formation nomenclature (Whitfield)

The digital geologic map of North America as a part of the Decade of North American Geology, DNAG, (Reed et al, 2005) includes a detail of geology never before compiled over such a large area. The extensive advancements since the last such map was published in 1965 allow for greater interpretative uses. Associated support advancements that aid all aspects of geologic map making include the Geographic Information Systems (GIS) and Global Positioning System (GPS). Light Detection and Ranging (LIDAR) employs air borne laser scanning procedures that can produce slope maps and other terrain images. The Iowa Geological Survey in cooperation with the U. S. Geological Survey and several state agencies has a several year state wide LIDAR project in progress which will include among many other attributes a two foot contour interval display of the state's topography. Maps whether those used centuries ago or the precise georeferenced maps of today are essential in the applications of geology in all its forms.

Investigative equipment for subsurface studies is a continuous improvement change and one where historical comments are limited to a few of a multitude of examples. Ground penetrating radar, a myriad of geophysical exploration tools and the direct push methods are few of these examples. The data gathered represents more than just a look at the soil and rock samples and laboratory testing for strength and permeability. The Cone Penetrometer technology for characterization of petroleum contaminated sites with nitrogen laser-induced fluorescence (ASTM D6187, 1997) is an example of almost complete in-field chemical and contaminant determinations that have markedly reduced the laborious and time consuming field subsurface investigations.

Another change affecting the engineering geology profession, this is for the worse, is the lack of time and talent available to do thorough site investigations. Time is needed to properly complete site characterizations including consideration of the regional geologic setting. Economic priorities are changing to the extent that the professional sent out to do site characterization too frequently is one at the lower end of the pay scale and therefore limited in experience. Site characterization is a skill

learned though much field experience, something becoming an increasingly rare commodity. The training of persons making site determinations is also changing in some areas for the worse. Excessive focus either on narrowly defined theoretical training or at the other end of the spectrum, inadequate fundamental geologic training does not bode well. These two concerns are cited here because of serious life support system concerns.

## **Education**

The process to become a registered or practicing engineer, including the geological engineer is clearly defined relative to education requirements. This includes accreditation or a set of standards judged by various sorts of review or oversight groups. For Canadians, it is the Canadian Accreditation Board (CAB) of the Canadian Council of Professional Engineers (VanDine 1984). In the United States, the accreditation is by the Accreditation Board for Engineering and Technology (ABET). The Board annually appoints individuals who inspect selected teaching facilities to review subjects taught, faculty qualifications and other related aspects that pertain to the teaching of students seeking degrees in engineering. Japan has a similar accreditation board review procedure although tailored differently for the specific needs of that nation. Hatheway and Kanaori (p. 60, 2001) report that the Washington Accord of eight nations and several associated provisional nations including Japan should by 2003 or 2005 have an enlarged group of full members, perhaps 12 to 15.

The road to travel for an engineering geology degree has many uncertainties that do not exist for the much more structured and defined pathway for a geological engineer degree. Williams (1984) outlines some of these uncertainties. Williams also comments on additional uncertainties that exist within some universities, including academic conflicts between the classical and applied geology faculty staff. That difference is real and can be found today in the practice of geology where some classical geologists do not regard applied or engineering geology as true geology. This is most unfortunate as some classical geology courses are essential for a well educated and professionally prepared engineering geologist. Williams emphasizes that a geological engineer is trained as an engineer with supplemental geology education. The engineering geologist is trained as a geologist with supplemental engineering education. He also notes that cross profession supplemental training is essential for better communication between members of both professions. However, Williams also points out that some schools have a geotechnical degree curriculum with an excessively limited number of geology courses. Thus the geological or geotechnical engineer is ill prepared for geological related work. The reply to that by some geotechnical engineers is that all civil engineering courses teach the essence of geology and thereby are sufficient even for geological registration.

Elifrits (2004) recognized the uncertainties of what would constitute a reasonably uniformly structured curriculum for a degree in engineering geology. He offered some options toward creating and developing a formal accreditation process. He also pointed out several difficulties, for example essential financial and technical professional development guidance. Professional societies are critical for both initiating the accreditation process and for continuing participation including financial support. This would greatly aid the engineering geology profession, but there are many obstacles besides time and money. The universities themselves are one obstacle, some leaning toward teaching a mix of courses with limited core fundamentals; others tending toward excessively narrow theoretical curricula.

Some schools offer degrees in engineering geology and list courses for those degrees that would provide the graduate with an excellent starting career point. Others however, that have a smattering of everything labeled under environmental education. A graduate of these schools lacks both the

fundamentals and the specifics needed to be qualified as a practicing engineering geologist. This difficulty is further exacerbated if this person seeks registration or certification. Besides having to meet the academic requirements of states having registration, the ill prepared applicant must also pass the national examination test requirements of the Association of State Boards of Geology (ASBOG). The examination consists of two separate tests, Fundamentals and Principles and Practice. These have defined Task Statements that provide a basic outline of what constitutes an appropriate education program for an aspiring geology student. While specific courses are not listed, one can readily see that the classic geology courses are found in the Task Statements for the Fundamentals. The practice portion tends to emphasize the engineering geology aspect, but also contains what would be expected knowledge of a well trained student with at least three years of professional experience. A general environmental science courses with limited geology studies does not provide the student with the needed education for the registration process. A broad array of science courses is an excellent course of study such as for a science teacher. It is not a course of study for persons seeking to specialize in one science such as geology.

The loss of core disciplines in the fundamentals of geology teaching is also a concern in the United Kingdom (Hatheway and others p. 21, 2004-5). The trend is toward more generalized centers of learning that encompass atmospheric sciences and other non geologic science courses. There also is the loss of identity for the core geology curriculum and supplemental education training such as field trips. Uncertainty exists as veteran teachers retire: who will be hired as replacements? An equally important concern in the United Kingdom is the increasing inadequacy of research funds being made available by the Natural Environmental Research Council for engineering geology and hydrogeology research.” (Griffiths and Culshaw, 2004)

### **Certification, Codification, Registration and Standards**

Certification, codification, registration and ASTM Standards all have affected the history of engineering geology. While certification and the other controlling procedures are thought of as irritants by some, nonetheless, life support systems could not be sustained without some sense of orderliness such as these procedures offer. Europeans and some other nations have embraced certification as opposed to registration for engineering geologists.

Norbury (2003, p. 3) notes that the growth of engineering geology in Europe began about 70 years ago, about the same time as in the U. S, Canada and elsewhere. Norbury, Secretary General of the European Federation of Geologists, considers engineering geology to be an international practice driven by the internationalism of the construction industry. He considers engineering geologists to belong to the profession of Ground Engineering. Norbury believes that codification of engineering geologist’s technical qualifications will continue. The codification intent as described by Norbury is one of technical standard comparisons, perhaps somewhat like ASTM standards and standard guides. However, Norbury also refers to the ISO, International Order of Standardization in his address. While ASTM has been supportive of the ISO process for years, the two differ considerably. ASTM standards and standard guides consisting of individual technical procedures can be used by a broad array of professionals and technicians. The ASTM standards and guides are not written or intended for the measurements of organization performances or integrity as are ISO requirements. Both are intended to provide confidence in the quality work for clients and the public, but each serves a different audience and in a different manner. Norbury uses as one example, the Canadian Securities Administration where an individual must belong to a professional organization with disciplinary powers recognized by statute. Norbury also introduces registration as another means to assure standardization of engineering

geology work procedures and products. However, he goes on to question registration because of his belief that it is job protection.

Certification, Codification, Registration and Standards each differ in purpose, administration and legal authority. Codification, certification, and ASTM Standards have some basic similarities. Each addresses the performance of individuals relative to technical procedures pertinent to their professions. Codification and certification have an additional similarity in that individuals are directly affected in the sense of organization membership or following rules specifically set by a governing body. It is important that the two not be confused with registration as there are distinct differences. Certification by professional organizations does not create a process that is supported by law. Certification sets certain standards of education and experience for individual members. Certified members can be chastised or dismissed if professional breaches of conduct warrant such actions. However, no legal sanction authority exists. The public has no say in the matter either membership qualifications or alleged professional misconduct. ASTM sets standards and suggests guides but ASTM also is not an enforcing organization. If enforcement comes about, regarding some dispute where an ASTM standard or guide is relevant, legal proceedings would be between the disputants, ASTM would not be involved. ASTM is only a provider of standards or standard guides.

As the name indicates, the ISO addresses standards, but it differs greatly from ASTM. While both are international in scope, ISO is made up of “member bodies” for each member country. The purpose of ISO is to set business or industry-wide standardization with the standards set by member bodies through consensus agreement. One of several purposes is globalization of products, services and specifications that have wide acceptance in their sectors. The overall process and purpose has basic similarities to ASTM, but that comparison is more metaphoric than precise. ISO is at the corporation level. It does not extend down to individuals or have individual participation except as representatives of member bodies.

Codification is less confusing and more frequently encountered by many including engineering geologists. One would think building codes where such issues as ground stability are a concern would be constructed somewhat like the Chinese did some 900 years ago. In the U. S. professional pressures exerted by engineers have removed engineering geology or simply geology from consideration whether it be earthquake or landslide related. Some exceptions to that blanket removal exist and in those circumstances, the public is better protected. Codes as applied in the U. S. also exist to more precisely detail legislative statutes. Codes are created for laws such as geologist registration. The writing of codes normally includes public hearings allowing for comments and recommendations. For geologists, the ethics code is an important portion. State government regulatory rules, for example the definition of a qualified professional for brownfields investigations, also are established using the codification process. Such rules have the force of law although several blankets of hearing options exist before alleged violations would reach a level requiring legal representatives. It behooves the engineering geologist to closely follow code development as by states DNR’s such as the brownfields example.

Registration is addressed separately because it is uniquely different. A registration law if established in a state has gone through the same process as all other laws. As such it has the force of law as defined in the regulation. Alleged violations can be punished in various ways from written warnings to fines and loss of license. The registration is established by the legislature to protect the public, not the registrant such as the geologist. It is appropriate to keep that in mind. The public through the process of legislation actions and rule makings can participate. Usually boards have public members. The public can lodge complaints directly with the board. The board is required to take action. All board actions

except personnel actions and investigations of reported infractions or legal testimony preparations are open to the public. The U. S. has registration of geologists in 30 states, each state having slightly different requirements. All use the national Association of State Boards of Geologist examination (2006). The number of states having registration can change year to year due to legislative actions.

The registration law defines engineering geology and hydrogeologist in several states as previously noted. For most states with registration, only geology and geologist are defined. In all states, with certain exceptions, no person may perform responsible duties as a geologist unless registered in that state or has reciprocity. Registration can range from a select spectrum of geologists, for example where only those geologists practicing in health, safety and welfare issues, to the regulation of all geologists regardless of their professional work.

### **Summary and Future**

*Visioning the Future of Engineering Geology* (Tepel, 2004), was a symposium theme selected by Robert E. Tepel, convener, at the Association of Engineering Geology and American Institute of Professional Geologists 2002 Annual Meeting. The future in part depends on understanding historical development and scope of the practice of engineering geology. Other future controlling factors include the nurturing influences by individuals within the profession.

It is unlikely the future of engineering geology will again reach the halcyon days of the last three to four decades. During that period, population growth into surrounding country sides, a variety of industrial and agriculture advancements, and a large number of contaminated site investigations all came together. There were numerous job opportunities for geologists and engineers also involved in response to these expanding life support and safety needs. The associated job opportunities especially in response to past failures to recognize the consequence of poor development and industrial actions are in a sense all the better other than fewer job opportunities. However the changing into a more orderly and life sustaining system of growth is one of recognizing the importance of the engineering geologist and associated engineering disciplines...

Some engineering managers with the narrow view of the engineer only appear to be sliding back to earlier days of life supportive systems failures. Not new. Recall the failures of dams in the 1920s without the input of appropriately well trained geologists. Yet here we are today, either no geologist contribution or the limiting of investigative time given to the work of the geologist. These limitations affect both the long term adequacy of the completed investigation reports and in the related sense loss of geologist employment opportunities. In sharp contrast, engineering and geology firms, usually including both professionals and others as the biologist, the soil scientist and others are stable and growing... The safety of societal system trends in the long run depends on the success of thoroughness. Somewhat related the engineer and the geologist, those working in water supplies, be it surface or groundwater, have perhaps the most stable of working futures. The employee at most risk is the government geologist. Here instability continues to increase. This increasing stress on the government geologist community translates to increase hindrances and delays plus limitations to basic geological information gathering and access needed by the private sector.

A geologic history written with life support systems as a theme reveals how closely civilization prosperity, history and geology are intertwined. It was apparent that the more successful civilizations were using geologic principles as a life support system. Civilizations rose and fell for several reasons. Regardless of the causes, the geologic principles remained. With the passage of time, William Smith,

James Hutton and Henry Darcy and a host of others brought the science of geology and especially engineering or applied geology into being and embodied the essence of life support systems.

Innovative procedures also make a university learning environment more attractive for students seeking new challenging research opportunities and the means to apply geology in practice (Culshaw, 2005). However that attraction is being severely challenged with the political anti public education attitudes and lessening financial support, some states more so than others. Missouri and Kansas are examples where public education lack of support and verbal abuse are taking their toll, primary and secondary schools through the university level. Earth science teaching is one of the first to be lost. The discipline most harmed of all, geology.

The one aspect of the Life Support Theme that touches all rise and fall where geology and engineering co existed education. Education in my view, from Ancient Sumer, 3200 BC to electronic, or if using the nomadic to settled civilization, knowledge through education was the essential life sustaining force. The U. S. and especially Missouri and Kansas are walking the path of diminishing life support systems.

## Glossary

**Applied geology:** The applications of geologic principals to all manner of works and natural conditions that could or would affect health, safety and welfare.

**ASTM:** An acronym that stands alone in the use of identifying ASTM International, a world wide organization that establishes standards for precise procedures as laboratory and guides for other suggested non precise practice procedures.

**Brownfields:** A procedure authorized by Congress and administered by the Environmental Protection Agency (EPA) to hasten the clean up of selected hazardous waste sites and return to various commercial uses. Requires private sector financial support

**Certification:** A means usually used by professional organizations to certify professionally qualified persons, geologists for example, who meet levels of experience and education and abide by established ethical standards as set by a professional organization. Does not have the force of law. Also can mean qualified persons having various levels of training and experience who meet certain criteria established by a government agency and supported by the force of law.

**Codification:** Specific regulatory procedures established by a government agency to administer the general requirements of a law.

**D 18 Committee:** A sub committee within ASTM International whose members of engineering and geology disciplines considers standards and guides as related to soil and rock properties.

**Darcy's law:** Fundamental to the determination of groundwater flows within subsurface materials having a general uniform porosity and permeability. Generally applied to predominantly sand deposits having lateral and vertical continuity, but is applicable with certain limitations to less uniform unconsolidated materials and some fractured rock conditions.

**Engineering geology:** The application of the geological sciences to engineering practice to assure that geologic conditions affecting the location, design, and construction of engineering works are recognized and adequately provided for. Formerly included environmental geology, hydrogeology and urban geology, and considered by some to adequately address these sub disciplines.

**Environmental geology:** Geology practice with emphasis on the health aspects that could or would be associated with or affected by natural geologic conditions separate from or together with proposed or existing works of man. Terms like geoecology, envirogeology and urban geology have been used and except for urban geology currently considered synonymous.

**Ground engineering:** Term used by some in Europe rather than engineering geology.

**GPS:** Acronym for geographical positioning system; a surveying method to precisely locate positions on the ground.

**Geological Engineering:** A branch of engineering that deals with the application of engineering methods and concepts in construction involving geological materials.

**LIDAR:** An acronym for Light Detection and Ranging. The procedure employs air borne laser scanning procedures that can produce slope maps and other terrain images. Requires precise GPS data to meet required accuracy standards.

**Life Support Systems:** Geologic resources of earthen materials together with potable and adequate water resources required sustain the basic necessities of life. Also requires the existence of a governmental structure having authorities and abilities to administer and assure continued adequacy and sustainability.

**National Environmental Protection Act:** A general federal law that requires any development subject to a federal agency action includes an environmental impact statement (EIS). Relevant laws include the Superfund Act and the Resource Recovery and Compensation Act along with the Formerly Utilized Sites Remedial Action Program and the Coal Gasification Protection Act.

**Registration:** A law established normally by a state agency that requires certain professionals to meet standards established by an elected body that would include education and professional experience along with ethical standards. Geologist registration is limited to certain states in the U. S.

**Urban geology:** The application of geologic knowledge and principles to the planning and management of cities, communities and their surroundings. It includes geologic studies for physical planning, waste disposal, land use, and water resource management plus availability of useable economic geology resource materials.

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