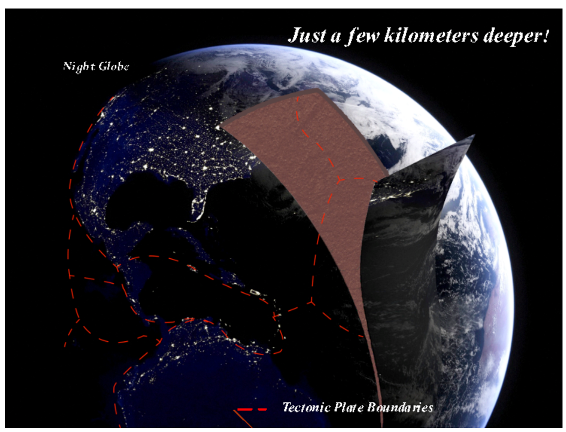
ARMA e-NEWSLETTER
FALL 2014

Editor's Note: *With this issue of the ARMA e-newsletter we are initiating a new type of article. From time to time we will publish an essay by a veteran rock mechanics/geomechanics scientist or engineer, on a timely subject of great importance nationally and even internationally, and which may affect most ARMA members one way or another.*

We inaugurate this series with an essay by Charles Fairhurst, one of the fathers of rock mechanics in this country, an ARMA Fellow, former President of the International Society of Rock Mechanics, adviser to several dozen graduate students who are now at the highest echelons of the rock mechanics field both here and abroad, and recently appointed to the uniquely prestigious rank of Officer in the French Legion of Honor. His essay is guaranteed to arouse interest among most readers of this newsletter.

Thinking Deeper

By Charles Fairhurst



The Earth's solid crust beneath continents is typically 40 ~ 50 km deep, but engineering activities, primarily petroleum extraction, have been limited to ~10 km; most are much shallower. The world's deepest mine [1] is almost 4 km deep, but high rock temperatures and pressures pose severe problems.

Earth Resources Engineering. Engineering applied to the discovery, development and environmentally responsible production of subsurface earth resources.[2]

'Underground.' The term tends to provoke, universally, an innately negative first reaction, an impression of darkness and danger. But 'the Earth beneath our feet,' has been the source of many of Man's essential needs throughout the development of civilization -- and we need to deal with 'the underground' if society is to continue to prosper. Although less evident in today's technologically dense world, the resources of the subsurface are as essential as ever. We ignore this fact at our peril. These notes are intended to provide some details to support this opinion.

While contemplating the future relevance of Earth Resources Engineering -- of which rock mechanics (my special interest) is an essential component, a recent report of the U.S. National Research Council caught my attention. It provides a valuable context.

(continued)

[1] Tau Tona Gold Mine, South Africa. The vertical rock pressure is over 100MPa (15,000 p.s.i.) and rock temperature is 60°C.The mine air is conditioned to 28°C (80F).

[2] Definition adopted by the US. National Academy of Engineering, Jan 2006. Formerly designated 'Petroleum, Mining and Geological Engineering,' which emphasized resource *extraction*, the name was changed to recognize that the rock subsurface itself is a major engineering resource.

In this issue

ARMA E-NEWSLETTER

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The report, entitled "*Can Earth's and Society's Systems Meet the Needs of 10 Billion People? Summary of a Workshop*," [3] opens with the following statement:

> "The Earth's population, currently 7.2 billion, is expected to rise at a rapid rate over the next 40 years. Current projections state that the Earth will need to support 9.6 billion people by the year 2050, a figure that climbs to nearly 11 billion by the year 2100. At the same time, most people envision a future Earth with a greater average standard of living than we currently have -- and, as a result, greater consumption of our planetary resources. How do we prepare our planet for a future population of 10 billion? How can this population growth be achieved in a manner that is sustainable from an economic, social, and environmental perspective?" (Intro. p.1 of 102)

Figure 1 illustrates how much more this population change is taking place today than in the past. Population remained stable at around 300 million from1 AD to 10000 AD, concentrated in Asia and Europe, then accelerated.[4]

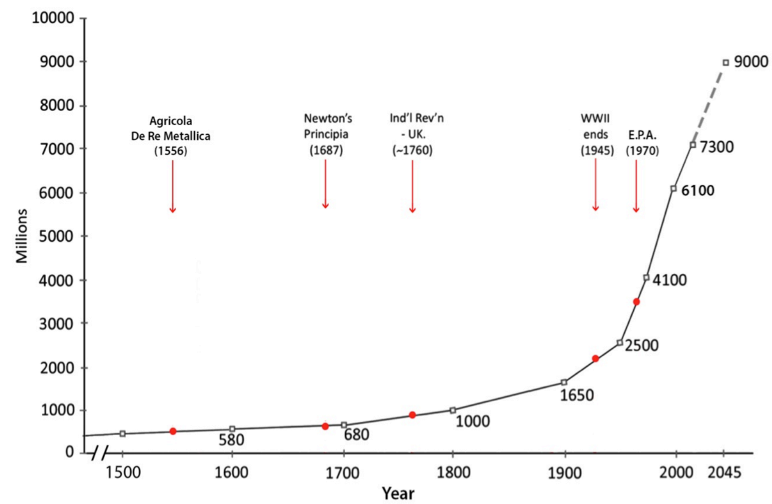

Figure 1. World Population, 1500-2045.

Technological innovation[5] has played the major role in driving the rate of population increase over the past three centuries. The Industrial Revolution[6] began in England in the second half of the 18th century, and spread to the U.S. and other countries in the 19th century; it has yet to arrive in some regions of the world. It started a shift from predominantly agrarian/rural living to industrial/urban society. Steam–powered machines[7] allowed for mechanization and mass production of goods and services.

Demand for coal as a fuel and iron for construction and industry led to the expansion of mining. In the United States, machines, locomotives and steamships helped develop manufacturing, open up the vast interior of the country and stimulate international trade. The world population started to increase significantly. The Revolution was by no means an unmitigated blessing. Intolerable working conditions and exploitation of workers in factories and mines, and serious environmental damage stimulated social protest,[8] legislation and reforms that continue to evolve to the present day.

(continued)

[3] The Workshop was held at the National Academy of Sciences, Washington, DC, 30 Sept. and 1 October, 2013. The 102 page report is available on-line at http://www.nap.edu/catalog.php?record_id=18817

[4] See http://chartsbin.com/view/g7e

[5] This includes advances in Medicine and Public Health.

[6] See http://history-world.org/Industrial%20Intro.htm

[7] On land, the horse was the principal source of power and transport; on water, oars and sails predominated.

[8] Karl Marx's Das Kapital (Capitalism) was published in 1867. http://en.wikipedia.org/wiki/Karl_Marx

Fairhurst "Think Deeper" Continued

Although Newton's major work, the Principia (1687), in which he presented his three Laws of Motion, appeared more than 70 years before the start of the Industrial Revolution, this scientific work had very little influence on the industrial technologies that drove the Revolution. The same is true for the work of the Wright brothers, leading to the first successful powered airplane flight in 1903. All of these accomplishments evolved through the time honored tradition of Empiricism.

Newton's concepts and continuum mechanics were the central topic of discussion by mathematicians and physicists, but found application to engineering only much later. Timoshenko's 'Theory of Elasticity,' the first widely available[9] presentation of mechanics for engineers, did not appear in English until 1934. Integration of "theory and practice" developed and was stimulated during World War II, which ended in 1945 with two initially destructive world-changing technological developments; (1) the V2 rocket, the world's first ICBM (Inter-Continental Ballistic Missile) developed by Germany and used from September 1944 to bomb London; and (2) the Atomic Bomb, dropped by the USA on Hiroshima and Nagasaki, forcing the surrender of Japan.

The end of the war saw the Soviet Union (USSR) committed to Communism, and the West (led by the USA) seeing this system as a threat to Democracy. This 'Cold War' period of mutual suspicion and fear between the two groups lasted for almost four decades. The potential of ICBM's to deliver nuclear warheads across the globe was evident to both, and intensive research and testing to develop both rockets and nuclear weapons was pursued intensively by both groups. The leader of the V2 rocket program, Dr. Wernher von Braun, and many of his team, were brought to the US to develop rockets for the USA. Other scientists and engineers from the German team were recruited by the USSR for a similar purpose.

On 4 October, 1957, the USSR scored a major public relations 'coup' when Sputnik 1 was launched into orbit around the Earth. Emitting a beep signal, this satellite was visible at night to the naked eye, and caught the attention of the world. Sputnik 1 was followed on 3 November, 1957 by Sputnik 2, an Earth- orbiting capsule containing the dog Laika. The world marveled and watched in awe. The Soviet Union was widely perceived to be ahead of the USA with respect to rocket development.

On 25 May, 1961, President Kennedy, who had been inaugurated in January of that year, informed a joint meeting of Congress of his goal of "landing a man on the moon and returning him safely to the Earth," within a decade.[10] His inspirational "We choose the moon,"[11] speech on 12 September, 1962 clearly resonated with the public and stimulated its general fascination with the challenge and potential benefits of outer space exploration. Approximately eight years after his first announcement, on 20 July, 1969, some 600 million people world-wide watched in awe on TV in real time as Apollo 11 astronaut Neil Armstrong set his foot on the moon, almost 384,000 km (240,000 miles) away from Earth.[12]

Four days later, the astronauts returned and splashed down safely in the Pacific Ocean. A new era had dawned. The resulting developments and general global impact, both technological and social, from the 'moon program' have indeed been transformative to an extent that could not have been imagined. Orbiting satellites made instant data transfer and global communication a reality. The entire planet Earth could now be viewed from above looking down. The 'Blue Marble' photo of Earth from Outer Space was in high demand.[13] The world suddenly became much smaller. Computers became more and more powerful. Technological innovation accelerated and is still developing vigorously.[14]

Grand Challenges for Engineering

In 2007, Dr. Charles (Chuck) Vest, a former President of MIT, was elected President of the U.S. National Academy of Engineering.[15] One of his first acts was to convene an international group of distinguished engineers, under the direction of Dr. William Perry, former Secretary of Defense,[16] to define a group of Grand Challenges for Engineering.

Dr. Vest defined a Grand Challenge as, "one that is visionary, but do-able with the right influx of work and resources over the next few decades -- a challenge that if met, would be game-changing and have a 'transformative' effect on technology." Although not cited as such, President Kennedy's moon commitment of 1961 was an excellent example. The Committee issued its report in 2008, listing 14 such Challenges.[17] Publication of the Challenges has stimulated considerable activity, both within the US[18] and internationally.

(continued)

[9] Timoshenko had published books on Elasticity in Russian from 1909-16.The book *Applied Elasticity*, with co-author J.M. Lessells was published in 1925, while at Westinghouse. See biography by Simha (2002). http://www.ias.ac.in/resonance/Volumes/07/10/0045-0053

[10] http://www.space.com/11772-president-kennedy-historic-speech-moon-space.html

[11] http://er.jsc.nasa.gov/seh/ricetalk.htm.

[12] The entire journey to the Moon and return to Earth had been controlled by a computer system less powerful than today's cell phones. The total cost of project Apollo was reported to Congress in 1973 as $25.4 billion; or $128 billion in 2014 dollars.

[13] http://visibleearth.nasa.gov/view.php?id=57723

[14] On 12 September, 2013, NASA announced that Spacecraft Voyager 1, launched in 1977, had left the Solar galaxy and entered 'Interstellar Space', more than 17 billion km (11 billion miles) from the Sun.

[15] http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=02152008

[16] http://en.wikipedia.org/wiki/William_Perry

[17] http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=02152008

[18] http://www.whitehouse.gov/administration/eop/ostp/grand-challenges

Fairhurst "Think Deeper" Continued

Although the 14 Challenges all address major issues facing society, the Earth Resources Engineering section of NAE noted that there was little explicit recognition of the important challenges facing Earth Resources (i.e. 'Subsurface) Engineering.' In some sense, it seemed that the Perry Committee was absorbed by the truly immense potential of developing outer space- from the Earth's surface to the heavens. Challenges presented by development of 'inner space' were perhaps 'out of sight and out of mind' to the Committee.

A Committee of the Earth Resources Engineering Section of NAE was convened to identify some such challenges. In 2010, the Committee presented the following four specific challenges -- felt to be comparable to the original 14.

1. Making the Earth Transparent; 2. Quantifying Subsurface Processes; 3. Achieving Minimally Invasive Extraction; 4. Protecting People and the Environment.

- '***Transparent Earth'*** implies, in essence, the development of technologies that can do for the subsurface what imaging has done for the practice of medicine. Much of this development will involve a broader understanding of wave phenomena in rock; how to interpret them when they are generated by rock as it responds to changes in applied load; and how to use waves to interrogate rock. Considerable progress is being made, especially in petroleum engineering (e.g., 3D seismic definition of large faults[19]), but it is still not possible to 'see' just a few meters into a rock face in real time, to determine from a borehole the fracture systems in a rock that control the deformation of the rock, or how fractures develop from the hole by hydraulic fracturing. Voice communication with underground workers is another aspect of this challenge. Progress on this challenge is being made.[20]
- ***Quantifying Subsurface Processes.*** Mechanical stresses and fluid pressures in rock increase with depth; flow of fluids (liquids and gases) may occur through interconnected pores and via fractures in the rock, or in the case of heat, also through the solid rock; at depth, high temperatures may make the fluids chemically aggressive, provoking dissolution of chemicals from the rock, and precipitation at cooler locations. This, in turn, will change flow impedance along fractures, etc.[21]

  These coupled thermal, hydraulic, mechanical, chemical (THMC) interactions are not well understood but govern mineral development processes and the design of borehole systems for mineral extraction. These processes are of particular importance to design of effective Enhanced Geothermal Systems; and to reduction of adverse post–mining chemical effects on the environment.[22]
- ***Minimally Invasive Extraction*** is a broad challenge to reduce the footprint of mining, both physically and environmentally. Development of borehole techniques of chemical extraction of minerals is a possibility in some cases. Efforts to develop 'environmentally benign' chemical procedures are being pursued.
- ***Protecting the People and the Environment*** is a broad general challenge, covering issues ranging from use of the subsurface for isolation of hazardous materials from the biosphere; protection of the population from severe climatic and other effects, both natural (e.g., earthquakes) and hostile acts on the surface; to general sustainability considerations.[23]

As with the original 14 Challenges, the Committee would identify a group of challenges of comparable significance. These topics indicate that engineering of the subsurface presents Grand Challenges that if solved, would indeed be game-changing.

Global Grand Challenge Summit, 2013

Dr Vest's initiative, directed broadly to draw attention to the importance of engineering -- and to the fact that engineers would be needed to address many of the challenges that must be met to assure the health and prosperity of the world's rapidly rising population – stimulated the attention of the international engineering community**.**

On 12-13 March, 2013 the first Global Grand Challenges Summit took place in London, hosted by the Royal Academy of Engineering, UK, and co-sponsored by the Chinese Academy of Engineering (CAE), the Royal Academy of Engineering, UK (RAEng) and the US National Academy of Engineering (NAE). I was privileged to attend this very exciting and well-organized event, which featured presentations by international leaders in engineering and applied science, and provided excellent insights as to the nature of Challenges and progress being made to address them.

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[19] These 3D images can take several weeks to process

[20] http://en.wikipedia.org/wiki/Through-the-earth_mine_communications

[21] Yow, J.L and J.R. Hunt (2002). *Coupled processes in rock mass performance with emphasis on nuclear waste isolation.* Int'l. J. Rock Mech. & Min. Sci. V. 39 pp. 143–150.

[22] http://en.wikipedia.org/wiki/Berkeley_Pit

[23] See also - Arscott, R.L. C. Fairhurst and L. Lake (2013). *Grand Challenger for Earth Resource Engineering* Jour. Pet. Tech. June 2012, pp 66-71.

Full details of this meeting, including televised recordings of the principal speakers and discussions are available on the RAEng website.[24] It is well worth taking the time to listen to the presentations and discussions.

Once again, very little attention was paid to challenges of the Subsurface and Earth Resources Engineering.[25]

Emphasis also was given at the Summit on ways to increase student interest in engineering as a career, a topic of particular concern in the United States. As noted by current NAE President, Dr. Dan Mote, in his address[26] at the NAE 2013 Annual Meeting:

> "...according to a 2012 National Science Board report, the percentage of undergraduate engineering degrees among all undergraduate degrees in the U.S. was 4%, among the smallest national percentages in the world. For a sense of scale, the average percentage in key Asian countries (India, Japan, China, Taiwan, South Korea, and Singapore) is 23%, and in European countries (United Kingdom, Sweden, Finland, Denmark, Germany, and France) it's 13%. In short, the percentage of U.S. engineering graduates among all its graduates is 1/3 of the European average and 1/6 of the Asian competitor average. Recruitment of talented international students over the past half century, mostly at the graduate level, has contributed remarkably to U.S. engineering, and has compensated for this deficiency in undergraduate degree numbers. The large number of first- and second- generation Americans that founded start-up companies reflects this understanding. However, times have changed. For one thing, virtually every society globally, friend and adversary alike, is recruiting engineering talent aggressively, and particularly the "in-demand" talent with current skills. Talent is the coin of the global engineering realm. Increasingly, attractive opportunities for engineers that offer excellent salaries, facilities, and economic growth potential are in Asia and the Middle East, and soon in Africa. Countries in those regions are substantially increasing the competition for international talent. In 2007, the former President of China, Hu Jintao, stated, 'The worldwide competition of overall national strength is actually a competition for talents, especially innovative talents.' I read this as primarily "engineering talents -- those who create value for humanity and society."

When the populations[27] of some of the countries mentioned (i.e., China, (1.37 billion.); India (1.25 billion); USA, (0.32 billion.) are considered, then it seems that more and more engineering advances are likely to come from outside the United States.[28] Even so, it is important for the United States to increase the supply of scientists and engineers, if for no other reason than to address severe domestic problems.

How important is 'Engineering of the Subsurface' to the Challenges of the 21st Century and beyond?

The writer asserts that it is critically important -- but not generally recognized as such by the public, nor by many in the scientific and engineering community in general.

Earth Resources Engineers, including colleagues in Rock Mechanics and Rock Engineering, need to change this situation.

Earth Resources Engineering and Global Challenges

The following discussion presents several examples -- there are others -- to illustrate the relevance of Earth Resources Engineering to a number of issues that are important, both nationally and internationally.

Minerals

> "...none of the arts is older than agriculture, but that of metals [minerals] is no less ancient...for no mortal man ever tilled a field without implements. If we remove metals (minerals) from the service of man, all methods of protecting and sustaining health and more carefully preserving the course of life are done away with." (Agricola 1556)[29]

(continued)

[24] http://www.raeng.org.uk/policy/international-policy-and-development/international-policy/current-issues/global-grand-challenges-summit-2013 Civil Engineering Professor Robert Mair, Cambridge University, presented an interesting lecture on developments in monitoring systems in metro transit tunnels in the Resiliency session

[25] Colleagues have explained that organizers had framed the Summit around the original 14 Challenges.

[26] http://www.nae.edu/Projects/Events/AnnualMeetings/2013AnnualMeeting/89114.aspx

[27] http://en.wikipedia.org/wiki/List_of_countries_by_population

[28] Increasingly restrictive immigration regulations have reduced the inflow to the US of highly qualified scientists and engineers from other countries - compared to earlier times.

[29] Considered to be the world's first textbook in mining, used for almost 200 years. Translated into English in 1912 by Herbert Hoover (US President, 1929-1933) and his wife Lou Henry Hoover. See http://en.wikipedia.org/wiki/De_re_metallica and http://www.gutenberg.org/files/38015/38015-h/38015-h.htm Metal' and 'mineral' were considered synonymous in the time of Agricola. Interestingly, the earliest mines discovered in Europe, at Spiennes, Belgium, which date from 4300 BCE, mined flint nodules in chalk to a depth of 16 m. Excavation tools included picks made from the flint, but also others using deer antlers. See http://en.wikipedia.org/wiki/Neolithic_ Author of a series of publications flint_mines_of_Spiennes http://whc.unesco.org/en/list/1006

The central importance of minerals throughout the history of civilization is evident in the names given to the periods of human development, i.e., Stone Age (2.5 million - 3000 BC); Bronze Age (3000 -1000 BC); Iron Age (1000 BC –present).[30] Although less evident today, minerals remain the foundation of national economies. This was demonstrated in the U.S. during the Rare Earth's scare of 2010.[31] At the time, it seemed that China, in possession of almost all of the world's supply of so-called 'rare-earth' elements, was considering to reduce its exports. These minerals are essential components of many high-tech devices[32] used in both civilian and defense applications.

Why is this not recognized by the public-and by their elected representatives?

> "The fundamental importance and economic impact of minerals appears to diminish with greater population and affluence. In the US, the ratio of the entire manufacturing sector to the mining sector was 52 to 1, whereas in Australia, a much less populous but similarly affluent country with a comparable mining industry, the ratio is 1 to 1." (Freeman and Highsmith, (2014)[33]

Even though essentially invisible in the national economy of the US, it remains true that minerals are the foundation -- remove the foundation and the entire superstructure can collapse. In 2013, the US was totally dependent on imports for 19 critical minerals and over 50% dependent for an additional 21 minerals.[34] This dependence will increase as the rising world population seeks to raise its standard of living. Demand for minerals will increase with *both* population growth and with growth in affluence of that population. Thus,

> "Over the next generation (2010–2040), global affluence as represented by average annual GDP per capita will increase from $10,000 to $26,000, a 160 percent increase. Over the same period the world's population will increase by 30 percent, from 6.9 billion to 9.0 billion (UN 2013)." Freeman and Highsmith (2014)
>
> "….to support 10 billion people in 2050, the world gross domestic product (GDP) would need to increase by a factor of eight."(Polansky)[35]. This is a consequence of the expectation that worldwide affluence will also rise in the 'developing countries' and affluence implies a demand for minerals."

Africa is currently the most rapidly growing region and will be the largest contributor to population growth in this century.

Minerals are distributed geologically throughout the globe, so the US will always need to depend to some extent on imports, preferably from sources in countries that are stable and friendly to the US. One way to maintain a 'place at the table' in the global minerals arena is to be at the technological forefront of Earth Resources Engineering. We will return to this topic later.

Groundwater

Although the Perry Committee did not mention groundwater specifically, providing access to clean water is one of their 14 Challenges. About 90 percent of U.S. supplies of freshwater lie underground. Currently less than 27 percent of the water used in the US comes from underground sources.[36] Worldwide, the use of groundwater varies considerably.[37] With 'climate change' leading to exceptional drought in many regions, use of groundwater for drinking, agricultural and industrial uses will certainly increase. Bredhoeft and Alley[38] note that, "water differs from other ground-based resources in that it is renewable: other extractive resources are expected to be depleted eventually, whereas it is possible to develop groundwater so that it will last indefinitely, a very attractive possibility." The authors note an important constraint -- "the incompatibility of the time horizon of human decision making (years or decades) with the dynamic response of [groundwater] systems over a much longer period (often hundreds of years). The pressure is invariably to pump more rather than less, and this is unlikely to change as population and resource needs continue to grow. Effects on surface water, water quality, and surface subsidence can also limit groundwater development."

(continued)

[30] http://www.essential-humanities.net/history-overview/stone-bronze-iron-ages/

[31] http://www.smh.com.au/federal-politics/political-opinion/scare-over-rareearth-minerals-underlines-fear-of-a-rising-china-20100927-15u0j.html

[32] http://www.bbc.com/news/world-17357863

[33] https://www.nae.edu/Publications/Bridge/110801.aspx Supplying Society with Natural Resources.

[34] See Mineral Commodity Summaries 2014 USGS http://minerals.usgs.gov/minerals/pubs/mcs/2014/mcs2014.pdf (Table p.6)

[35] http://www.nap.edu/openbook.php?record_id=18817&page=37

[36] Estimated Use of Water in the United States in 2005, U.S. Geological Survey Circular 1344, October 2009 http://www.ngwa.org/Fundamentals/use/Pages/Groundwater-facts.aspx

[37] http://www.ngwa.org/Fundamentals/use/Documents/global-groundwater-use-fact-sheet.pdf

[38] https://www.nae.edu/Publications/Bridge/110801/111067.aspx

Climate Change

On 6 May of this year, the White House released the latest National Climate Assessment.[39] "Climate change is here and getting worse," was the general interpretation of the report[40].

Carbon dioxide (CO_2) emissions into the atmosphere from use of fossil fuels are widely regarded as the culprit, responsible for an increase in extreme weather and other adverse effects. A variety of alternative, non-CO_2 producing energy options have been suggested and are in various stages of development.

In 2004, Pacala and Socolow suggested a strategy for addressing the problem explained in terms of 'Socolow Stabilization Wedges.' Their goal is stated clearly in the title of their paper, "Solving the Climate Problem for the Next 50 years with Current Technologies."[41] Recognizing that no single alternative energy source will be sufficient, at least in the near-term (i.e., ~ 50 years), the authors recommend that a suite of existing technologies be employed simultaneously in order to hold CO_2 emissions to current levels while more ambitious novel options are developed. Several 'current technologies' involve the subsurface.

The following discussion provides examples to illustrate just how central is consideration of the 'Subsurface' and Earth Resources Engineering to the challenge of Climate Change.

Protection

The ability of the subsurface to provide protection from adverse effects of climate is well recognized for some shallow applications. Domestic water lines to and from homes are usually buried at depths of a few meters i.e. 'below the frost line' - to ensure that the systems do not freeze in the winter. Communication, gas and electrical power lines to homes and offices are often placed underground in communities to avoid damage and interruption of services due to severe storms -- and for aesthetics. Addition of a basement to homes provides significant protection in regions subject to tornadoes, hurricanes, and earthquakes. Use of underground shelters to protect communities from potential hostile attack is well known.

The 'Cold War' era (1945-1991) helped stimulate some interesting protective measures in Scandinavia -- neutral countries on the potential flight path of ICBM's should hostilities erupt between the two major powers of the time. Blessed with an abundance of high quality granites and crystalline rock, these countries took the lead in developing underground facilities and integrating them as part of the daily life of communities; e.g., museums; concert halls, sports facilities, etc.[42]; (The Gjøvik Arena in Norway – the world's largest man-made underground free span excavation [91m (299ft) long by 61m (200ft) wide, and 25m (82 ft high)] hosted the Ice Hockey competition at the 1994 Lillehammer Winter Olympics[43].)

In large cities, underground mass transit systems are recognized increasingly as a necessity for effective transportation. Underground systems can have a significant additional advantage in cities in earthquake prone regions. As noted by Duke and Leeds (1961),[44]

> "Severe tunnel damage appears to be inevitable when a tunnel is crossed by a fault or fault fissures which slip during the earthquake. Tunnels outside the epicentral region and well -constructed tunnels in this region can be expected to suffer little or no damage in strong earthquakes. Within the usual range of destructive earthquake periods, intensity of shaking below ground is less severe than on the surface."

The Los Angeles Metro opened in 1963. Observations during the Northridge Earthquake (M_W 6.7) 1994 (near Los Angeles) include the following:[45]

> "Freeway exchanges and overpasses on the surface collapsed, disrupting the highway system. The subway tunnels have not suffered any damage; train service was quick to return[46]."

This suggests that the subway system could serve as a main component of the emergency response system for earthquake prone cities.

The merits of the relatively shallow subsurface for protection against earthquakes are discussed further in these notes, with relation to underground nuclear power plants.

(continued)

[39] http://www.cnn.com/interactive/2014/05/politics/document-climate-change/

[40] http://www.cnn.com/2014/05/06/politics/white-house-climate-energy/

[41] Implicit in this title is the recognition that although innovative forms of energy are to be encouraged, it is probable and prudent to assume that it will require several decades before such innovations are sufficiently advanced to be available on the large scale required. Since 2004, when the paper was published, world production of carbon emissions has continued to increase essentially at the same rate (approx. 14%/year), although the US has decreased its overall contribution by about 10% over the past decade due mainly to energy conservation and increased efficiency of vehicles, substitution of natural gas for coal.

http://www.epa.gov/climatechange/ghgemissions/inventoryexplorer/#allsectors/allgas/gas/all

[42] See Winquist,T and K.E Mellgren (1988) *Going Underground,* Royal Swedish Academy of Engineering Sciences 177p. Bergman S.M (Ed). (1978) *Rockstore 77.* Proc. First Inter'l Symp. on Storage in Excavated Rock Caverns, Stockholm, 5-8 Sept. 1977; 3 Vol. Pergamon (Oxford); Bergman S.M. (Ed). (1980) Proc..ISRM Int'l Symp. *Rockstore 80* (Stockholm, June 23-27). Subsurface space: environment protection, low cost storage, energy savings. 3 Vol. Pergamon (Oxford).

[43] http://en.wikipedia.org/wiki/Gj%C3%B8vik_Olympic_Cavern_Hall

[44] Duke, C.M and D.J .Leeds,(1961) Effects of Earthquakes on Tunnels. Protective Construction in a Nuclear Age; Vol.1 (of 2), pp.303-328, McMillan (New York) 885p.

[45] www.utsandiego.com/photos/galleries/2014/jan/15/remembering-northridge

[46] Apparently, the subway system ceased operation for some time after the Northridge event, but this was because electrical power to the subway system was lost. The power station was on the surface (Personal communication.)

Energy Conservation

It is commonly recognized that winter to summer seasonal extremes of temperature, and associated heating and cooling demands, are responsible for significant energy consumption, especially in developed countries. These extremes are quickly attenuated with depth. In Minnesota, for example, surface temperatures can exceed 30°C (86°F) in summer and drop to -30°C (-22°F) in winter, but at just 10-m depth the temperature is constant year round at 12°C (52°F)[47]. In other regions, summer temperatures become oppressively high. This feature of the shallow subsurface provides opportunities for significant energy conservation (e.g., geothermal heat pumps; underground building construction).

Nuclear Power

Although scarred by accidents such as Three Mile Island, USA (1979)[48]; Chernobyl, USSR (1986)[49]; and Fukushima, Japan (2012)[50], nuclear power is still a potentially important alternative energy source. In some countries (e.g., Japan), lack of domestic fossil fuel resources places extra emphasis on nuclear power.

France, for example, currently generates 80% of its electrical energy from nuclear power. The primary engineering obstacle to greater use of nuclear power is to find suitable geological locations for long-term containment of highly radioactive nuclear waste. Finland, France and Sweden are now proceeding with construction of permanent underground repositories. The U.S. in 1957 was the first[51] country to decide that geological isolation of high-level waste was the safest option of alternatives. After extensive review of alternatives, the Yucca Mountain site in Nevada[52] (approximately 150 km (100 miles) northwest of Las Vegas) was designated as the most appropriate site. The site was opposed politically in Nevada. In May 2009, Secretary of Energy Steven Chu declared Yucca Mountain "no longer an option." The site is now closed, and the U.S. is currently without a plan for long-term isolation of nuclear waste.

Underground Siting of Nuclear Power Plants

Underground siting of nuclear power plants has been proposed almost from the time that nuclear power generation was introduced. Myers and Elkins (2004)[53] provide a good review. There are several inherent advantages to underground location of nuclear power plants. Thousands of underground nuclear tests have been conducted by the nuclear powers without venting of radionuclides to the atmosphere, so the depth requirements are well established.[54] Neretnieks[55] has proposed a design to allow filtering/trapping of radionuclides in tunnels to ensure no release to the surface atmosphere in the event of an accident. More recently, Myers and Mahar (2012)[56] have discussed design of underground nuclear power plants[57] based on small (150MW) modular nuclear reactors, already available commercially. It is well known that the shallow subsurface (within a depth of $\lambda/4$ where λ is the dominant wavelength of an earthquake event) is subject to reduced strain due to incident and reflected wave interaction. Underground structures are inherently more robust than surface structures with respect to earthquakes and especially within the above-mentioned depth range.[58] The ISRM[59] has also established, in 2013, a Commission on Underground Nuclear Power Plants, led by Prof. S. Sakurai of Japan. The overall goal is to establish the considerable safety advantages of underground nuclear power plants and make this 'green energy' option more widely accepted. A paper presented by Varun et al;[60] at the ARMS8 (Eighth Asian Rock Mechanics Symposium, 14-16 October, 2014) discusses the reasons why facilities located at moderate depths in rock are less liable to earthquake damage than facilities on the surface.

Geothermal Energy

An MIT report in 2006[61] stimulated the U.S. Dept. of Energy to develop a vigorous program to develop EGS. Most recently, a decision to develop an underground research site FORGE[62] (Frontier Observatory for Research in Geothermal Energy).

(continued)

[47] The peaks and lows in temperature also shift progressively in phase over the 10m or so over which seasonal temperature variation is not fully attenuated. This feature is used in some shallow geothermal heat extraction systems.

[48] http://en.wikipedia.org/wiki/Three_Mile_Island_accident

[49] http://en.wikipedia.org/wiki/Chernobyl_disaster

[50] http://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaster

[51] http://www.nap.edu/catalog.php?record_id=10294

[52] http://en.wikipedia.org/wiki/Yucca_Mountain

[53] http://www.w2agz.com/Documents/Myers%20&%20Elkins,%20Nuclear%20News,%20December%202004.pdf See also http://www.conferences.uiuc.edu/supergrid/PDF/SG2_Meyers.pdf

[54] There were releases (venting) in early days e.g., Baneberry (1970) http://en.wikipedia.org/wiki/Yucca_Flat

[55] Neretnieks I (1980). Safety Tunnel for Core Melting in Nuclear Power Plants. Underground Space, Vol. 5 p.179-180

[56] Myers, C.W. and J. M. Mahar, (2011) Underground Siting of Small Modular Reactors: Rationale, Concepts, and Applications. ASME Small Modular Reactor Symposium 28-30 September, 2011 Washington, DC. http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-11-04777

[57] The Fukushima accident clearly indicates that nuclear plants in seismically active regions should be located at elevations above ~ (40-50) m in coastal areas.

[58] Varun, M. Pierce and C. Fairhursr (2014). Underground Nuclear Power Plants. The Seismic Advantage. ARMS8 Symposium Sapporo ,Japan,14-16 Oct,2014

[59] International Society for Rock Mechanics

[60] Varun, M. Pierce and C. Fairhurst, "Underground Nuclear Power Plants: The Seismic Advantage", Paper 0363, ARMS8, 8th Asian Rock Mechanics Symposium, 14-16 October 2014, Sapporo, Japan.

[61] Tester, J.F.et al. (2006) "The Future of Geothermal Energy," MIT. Synopsis -p.5(5)

[62] http://www1.eere.energy.gov/geothermal/news_detail.html?news_id=21286\

The report presented the following optimistic conclusion,

> "We estimate the extractable portion [of geothermal energy] to exceed 200,000 EJ* or about 2,000 times the annual consumption of primary energy...."

The above statement in the Tester et al. report is followed by the observation,

> "At this point, the main constraint is creating sufficient connectivity within the injection and production well system in the stimulated region of the EGS reservoir to allow for high per-well production rates without reducing reservoir life by rapid cooling." [Synopsis. p.5 (5)]

This is a major challenge for EGS. It is also at the heart of the development of borehole techniques to extract resources at depth (e.g., "Minimally invasive mining"; extraction of oil and gas from tight shales; or injection of wastewater from drilling).

Horne and Tester (2014)[63] observe,

> "The prospect for major expansion of geothermal development lies in EGS when one or more of the three critical ingredients for an operable system are lacking: sufficient reservoir permeability and porosity, sufficient quantities of natural steam or hot water in the reservoir, and sufficiently high temperatures."

Carbon Capture and Storage (CCS)

Capturing carbon dioxide (CO_2) in power plant emissions so that it is not released into the atmosphere is an option that is technically feasible -- but raises the question of how to isolate the CO_2 permanently from the environment. As with radioactive waste, geological isolation appears to be an option and is being pursed. Realistically, it can be a partial solution only.

As noted by Benson and Friedman,[64]

> "Today, over 20 Mt/yr of CO_2 are captured from anthropogenic sources and injected underground; this will likely increase by 50% in the middle of this decade [20Mt/yr represents ~ 0.4% of total US emissions of CO_2 annually]*.
> "A fifty-fold scale-up in deployment of today's CCUS [Carbon Capture and Underground Storage] would be needed to reduce emissions by a billion tonnes per year " [1 billion tonnes per year (i.e.1Gt/yr" = 18.5% of current CO_2 emissions in the United States[65]]."

A recent study (October 2013) on induced seismicity by the National Research Council includes the following statement, and may pose a serious problem for CCS:

> "CCS [Carbon Capture and Storage] … due to the large net volumes of injected fluids, may have potential for inducing larger seismic events. Induced seismicity associated with fluid injection or withdrawal in energy projects seems to be caused in most cases by a change in pore pressure that contributes to change in stress in the subsurface in the presence of faults with specific properties and orientations and a critical state of stress."

Hydropower

Although not largely pursued in the United States, the possibility of hydropower as a clean alternative energy source is under active development in other regions of the world, e.g., China. The topic of reservoir-induced seismicity was debated vigorously in the 1960's and 1970's when dams for hydropower were being constructed in several countries. Although the increase in pore pressure at a depth of several kilometers is of the order of a few percent only, it is argued that this could be sufficient to trigger a large earthquake, especially if the region is seismically active. Again, the characteristics of the subsurface in specific locations assume critical importance.

(continued)

[63] See https://www.nae.edu/Publications/Bridge/110801.aspx

[64] See footnote 48

[65] Assumes current US emissions to be 5.4 Gt/yr

Hydraulic Fracturing

The impressive developments of directional drilling and associated stimulation techniques (i.e. primarily hydraulic fracturing) have already transformed the (hydrocarbon-based) U.S. energy outlook from a net importer to self-sufficiency, and potentially an exporter of oil and gas. Hydraulic fracturing -- and the potential of contamination of groundwater and of induced seismicity ('earthquakes') -- has raised serious public concern, both in the U.S. and internationally. France has banned the use of hydraulic fracturing. The potential of developing "tight shale' resources outside the U.S. is huge -- and has considerable political implications e.g., for the nations of Eastern and Western Europe.

Research to ensure that this technology is developed and applied responsibly is in the domain of Earth Resources (Science and Engineering). This includes the associated major task of Carbon Capture and Storage (CCS).

Subsurface and Surface Water

In essentially all applications of underground engineering there is one danger that must be given serious attention during the planning phase; the possibility of flooding of the underground, e.g., during extreme storms. It is important that surface access pathways to the underground facilities be located and designed to guard against this potentially catastrophic event. In some cases entrances can be located at a surface elevation that is significantly higher than any expected flood level. In other cases more costly options (e.g., bulkheads) may be required.

Conclusion

Other examples could be cited, but it is hoped that the above discussion will be sufficient to convince the reader that the subsurface and subsurface engineering (Earth Resources Engineering) are very relevant to many of the engineering challenges presented by the projected rapid increases in world population in this century. These challenges are complex and will require substantially more resources, both human and financial, if they are to be addressed responsibly. Rock Mechanics is a central component of many of the problems to be addressed. This is not generally appreciated by the public - and even by many colleagues in engineering. It is our responsibility to correct this situation.

The overall aim of these notes is to stimulate critical discussion –and a plan of action to draw attention to the critical importance of Earth Resource Engineering – and Rock Mechanics - in addressing Global Challenges of the 21st Century.

NOTE: *It is planned to present a discussion of some specific technological challenges in rock mechanics that deserve early attention in a future edition of the ARMA e-Newsletter.*

48th U.S. Rock Mechanics/Geomechanics Symposium at the University of Minnesota

Submitted by
Joe Labuz, Chair, 48th Symposium
University of Minnesota

The University of Minnesota, Minneapolis campus was the location of the 48th U.S. Rock Mechanics /Geomechanics Symposium, from 1-4 June, 2014. The sponsor of the meeting, the American Rock Mechanics Association (ARMA), supported the return of the symposium to a university setting, where years ago, it was typical for the meeting to be held on a campus. For example, the University of Minnesota was home to the 5th in 1961, 8th in 1966, 16th in 1975, and 29th in 1988.

492 registrants with 40% of those representing 32 countries

The theme of the symposium was *Rock Mechanics across Length and Time Scales,* to focus on the role of scaling in a variety of natural and engineered processes. Scaling topics ranged from the very fast, such as acoustic emission, to the very slow, such as salt creep, and from the very small, such as microcracking in rock fracture, to the very large, such as a reservoir for CO_2 sequestration. The symposium drew 492 registrants, with 40% of the attendees being international from 32 countries. The format of the meeting involved 48 concurrent sessions and two poster sessions, with 224 oral presentations and 38 posters, for a total of 262 papers; each paper received two independent reviews.

The symposium opened on 1 June with the MTS Lecture delivered by R. Zimmerman, featuring a retrospection on rock mechanics. Two keynote lectures, one in mid-morning and one in the afternoon, were presented on each of the three days: on 2 June, energy technologies were reviewed by E. Eide and R. Jung; on 3 June, induced seismicity at various scales was considered by S. Shapiro and S. Maxwell; on 4 June, hydraulic fracturing was examined by N. Warpinski in the context of unconventional reservoirs and R. Jeffrey in mining and petroleum industries. The Theater in Coffman Memorial Union provided the ideal venue for presentation and discussion.

Technical tours included a visit to the Soudan Mine in northern Minnesota led by L. Petersen, a tour of Taylors Falls on the St. Croix River led by G. Brick, and Cold Spring Granite Quarry & Manufacturing led by A. Sourdif. One short course, Multiphysical Geomechanics, taught by L. Laloui and A. Ferrari, and three workshops preceded the symposium; all drew significant numbers. The workshop on Petroleum Geomechanics Testing was organized by T. Addis. R. Ewy and the Role of Geomechanics in Geothermal Reservoirs was organized by Itasca Consulting. How to Give an Effective and Engaging Presentation was delivered by the Future Leaders.

The technical sessions were noteworthy in both depth and breath. The timely topic area of hydraulic fracturing headed the symposium with 33 papers, followed by salt mechanics with 23, and wellbore mechanics with 19; traditional areas were solid contributors, as underground mining had 16 papers, fracture mechanics had 15, rock physics had 13, and novel testing had 12. The title of the manuscript selected for the best paper award, "Scaling of Fatigue Crack Kinetics of Sandstone," exemplified the theme. Several other contributions were identified by the scientific committee as award caliber, including: On the Water Retention Behaviour of Shales; Numerical Simulations of Convection Cells in Sedimentary Basins with Application to Geothermal Energy; Robustness of Interference Fractures that Promote Simultaneous Growth of Multiple Hydraulic Fractures; Experimental Determination of Thermophysical Properties of Reconsolidated Crushed Salt; Investigation of Rock Bolts in Karst; and In-situ Stress Measurements at Earthquake Prone Areas in South African Gold Mines -- to name a few. These and other papers will be invited to submit an expanded manuscript for review and possible publication in a special issue of *Rock Mechanics and Rock Engineering*.

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Social events were a major part of the symposium, with strong support from industrial sponsors: the Welcome Reception on 1 June (Schlumberger-Doll Research); the Great American Barbeque on 2 June (MTS Systems); the Symposium Social & Banquet on 3 June (Itasca Consulting & Agapito Associates); and the closing event on 4 June, a tribute to S. Crouch, P. Cundall, and C. Fairhurst (Itasca, MTS, Shell, TerraTek, Schlumberger). Other highlights were lunches served in the Great Hall of Coffman Memorial Union on the three days of the technical sessions and the breaks at the Great Hall and Tate Laboratory (Golder, MetaRock, Rocscience). Chevron sponsored student registrations and ConocoPhilips hosted poster presentations.

The symposium served also as an informal reunion of former University of Minnesota graduate students in rock mechanics, all advisees of Professor Charles Fairhust.

Above: Charles Fairhurst and his former advisees. *From left to right: Wolfgang Wawersik, Jaak Daeman, Bezalel Haimson, Francois Cornet, John Hudson, Emmanuel Detournay, Charles Fairhurst, Michael Hardy, Jean Claude Roegiers, Steven Crouch.*

The local organizing committee worked tirelessly to develop a scientific program worthy of the symposium name. J. Labuz and E. Detournay were co-chairs, and along with W. Pettitt, L. Petersen, and R. Sterling, were co-editors. Other committee members were W. Dershowitz, C.E. Fairhurst, L. Lorig, S. Mogilevskaya, and G. Pence. The Scientific Advisory Committee provided significant review support, and the Technical Chairs worked to make the sessions illuminating. The symposium is a considerable effort, and the commitment and dedication from P. Smeallie, Executive Director of ARMA, is recognized.

Things You Might Know About ARMA (or would like to know)….

Based on a presentation by Antonio Bobet, President of American Rock Mechanics Association (ARMA) at the US Rock Mechanics/Geomechanics Symposium, Minneapolis, 3 June, 2014

Q: What is the mission and purpose of ARMA?
A: ARMA was founded in 1995 to serve as the organization in which members may conduct research, perform academic functions, provide services, and lead in discussion on matters relating to rock mechanics, geoengineering, and related disciplines. It is the nature of rock mechanics to be inter-disciplinary. The membership reflects that diversity and desire for connections among fields of knowledge.

Q: How does ARMA function?
A: ARMA is led by an elected Board of Directors, with active participation by an Executive Committee. The Board meets three times each year, to discuss policy matters and provide direction to the organization. One major undertaking is the planning for and hosting the Annual ARMA Symposium. The Executive Director of ARMA, Peter Smeallie, provides support and organization to the Board.

The organization has a related entity, the ARMA Foundation, created as a sister organization. It is a tax-exempt entity that promotes rock mechanics and rock engineering through education activities, dissemination of rock mechanics knowledge, and engagement activities (such as ARMA Sustaining Members and other fundraising activities).

Q: How has membership grown? How many members?
A: The graph tells the story, with about 300 members a decade ago and growing to almost 1000 members now. It is interesting to note that at the most recent Symposium over 40 countries were represented. ARMA is closely associated with ISRM, and many members may join both organizations. There has always been collaboration between the two, and more recently, active joint undertakings and sponsorship.

Figure 1. Growth of ARMA membership, 2005-2014

Q: In addition to the Symposium, what are some of the activities of ARMA?
A: There are a number of things. First, ARMA recognizes significant accomplishments, either in rock mechanics/ geomechanics or through service to the organization, to the discipline, and its professional development. That recognition is provided through the work of an Awards Committee (chaired by S. Brandon). The ARMA Awards are:

- Rock Mechanics Research Award
- Case History Award
- M.S Thesis in Rock Mechanics Award
- Applied Rock Mechanics Research Award
- Dr. N.G. W. Cook Ph.D. Thesis Award
- Outstanding Contributions to Rock Mechanics Award

Q: What else is there?
A: Second, the Publications Committee (chaired by B. Haimson) provides timely technical articles and newsworthy items about the association and its members through its e-Newsletter. It recently produced its first special issue on "Geomechanics of Hydraulic Fracturing in Shale Formation," with a number of articles focused on the same topic.

And third, through the OnePetro website, (hosted by the Society of Petroleum Engineers, http://www.onepetro.org) most papers from the Symposia are posted in a digital library; these papers date back as far as 1957. The database of articles is searchable, and made available to the members at a modest service charge.

We should add a fourth source of information, the ARMA website (http://www.armarocks.org). Current news of events, association activities, and full editions of articles and papers – including past issues of the e-Newsletter -- can be accessed through the site.

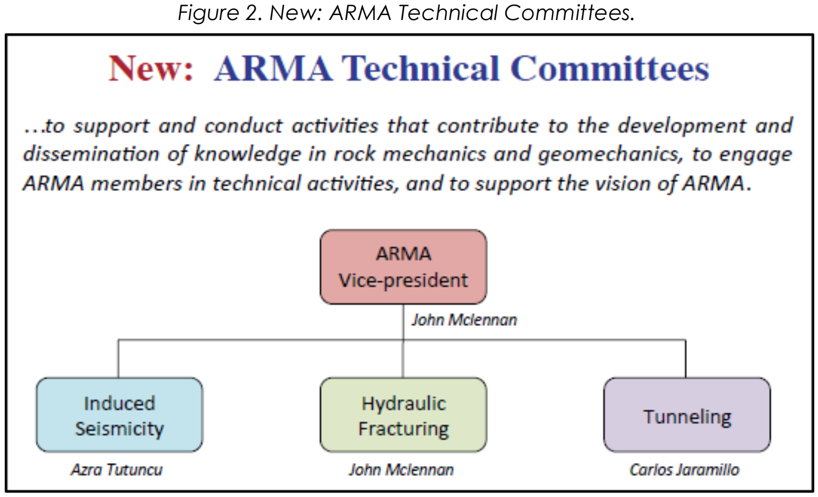
Q: What is the "Future Leaders" group about?
A: It occurred to the Board of Directors that while many of the founders of the organization were active and fully engaged in ARMA activities, there was concern that the organization needed to ensure its continued relevance and to have access to the most recent research, development, and innovation. This led to the formation of the ARMA Future Leaders Program, established for motivated younger members of ARMA with outstanding promise to discuss issues and ideas for the development of ARMA. Some of the activities of those selected to serve in the group are:

- Organizing a workshop on professional skills (namely "How to give an Effective and Engaging Presentation.")
- Career Corner (an information exchange between job seekers and potential employers)
- Student Trivia Contest, where teams of members compete in a fun contest testing knowledge and experience of rock mechanics
- Aid in organizing professional events, such as the ISRM meeting in Montreal and the ARMA Symposium in San Francisco in 2015.

Q: What are ARMA Fellows?
A: As the discipline has matured and the organization has grown, it became clear that certain distinguished members should be recognized. The honorific of ARMA Fellows was created for this purpose. The existing members elect additional members on a periodic basis; the roster has increased to 20 members since the formation in 2008.

Q: What is new? Anything important?
A: One significant addition to the continued development of the association is the formation of subject matter committees, to allow focus by members on areas of their particular interest. It is envisioned that Symposium topics, newsletter articles, and exchange of professional information will be enhanced through the work of the technical committees. These committees are currently being organized and will be reported on in future e-Newsletter issues. The purpose, structure and leadership of these committees is displayed in Figure 2, right.

Figure 2. New: ARMA Technical Committees.



My Career in Rock Mechanics

By
Charles Fairhurst, University of Minnesota/Itasca Consulting Group

Part Four: How I Came into Rock Mechanics (Conclusion)

The previous installments in this account of my career have gone well beyond the original intent to describe how I became associated with rock mechanics. This essentially was covered in the first installment. The two following issues provided details of my career over the four decades until retirement in 1997. Remarkably, in retrospect, it seems that retirement brought little change except that I did not have classes to teach and I was no longer paid by the university. My 'buoyancy' on retiring in 1997 was, alas, short-lived, tempered by the collapse of the dot.com bubble in 1999-2000.

With two years remaining on my 1995-1999 term as ISRM President, I still was committed to considerable travel to various parts of the world. Preparation for the 8th ISRM Congress, held in Tokyo in August 1999, was a primary concern. It was handled very capably by our Japanese colleagues. Margaret and I will not forget the truly exceptional hospitality of our hosts. Margaret was provided with a personal guide, a charming young Japanese woman, fluent in English. *"Where did you learn to speak English so well?"* Margaret inquired. She replied, "*I was an exchange student at Bloomington High School.*" Bloomington is a suburb of Minneapolis! Another surprise awaited us when the time came to leave the hotel. A limousine was there to take us to the airport. Our path to the car was defined by a carpet that was lined on each side by what seemed to be the entire staff of the hotel, all in uniform and wearing white gloves, applauding gently to wish us "Bon Voyage!" In some respects, this was the highlight of my term as ISRM President. In fact, I was no longer President, having handed over the reins to Professor Shunsuke Sakurai the previous day! But I was not about to break the spell. For one brief moment, I basked in the belief that Margaret and I were important.

Update: Part Three of this series, which appeared in the Winter, 2014 Issue 11 of the ARMA e-Newsletter, concluded with a comment on the work of the International Geomechanical Commission (IGC), a study of the effects of underground nuclear tests by France on the atolls of Mururoa and Fangataufa in the South Pacific, and my retirement from the University of Minnesota in June 1997. By way of postscript, I am pleased to note that the IGC report, "Underground Nuclear Testing in French Polynesia — Stability and Hydrology Issues. Vol. 1 General Results; Vol.2 Technical Analyses; Vol.3 French Translation." is now available on-line from the University of Minnesota, by kind permission of the publisher, La Documentation Française. The report contains detailed analyses and discussions of rock mechanics and hydrological phenomena involved in underground nuclear testing — information not readily available elsewhere. This is a valuable reference, and I recommend it to all interested in rock mechanics. It also is a tribute to the exceptional group of colleagues associated with the study.

Starting with Project Salt Vault, in Lyons, Kansas in 1971 and the Bedrock Disposal program (designed to dispose of high-level liquid waste directly beneath the Savannah River Plant (also in 1971)), I had maintained more-or-less continuous involvement in research on the geological isolation of high-level radioactive waste throughout the world. The topic was of particular interest, as it was essential to conduct tests in situ at the dedicated Underground Research Laboratories (URL). Different countries selected different rock types, and several were of special interest. In Canada, the URL at Pinawa was located in Lac du Bonnet granite, with almost no apparent large-scale fracturing; in northern France, it was located in Bure, in argillite; in the U.S., the two principal locations were the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, in bedded salt, and Yucca Mountain in Nevada, in volcanic tuff. Each case contributed significantly to our understanding of scale effects, both with respect to length and time scales, and assessment of uncertainty in rock engineering, especially with respect to extrapolation many thousands of years into the future.
Occasionally, I was reminded that not all of our colleagues were as excited by 'the underground' as I. One day I had been trying to organize a visit to the underground site at WIPP. Turning to one of the more senior members of our group, distinguished physicist Dr. Karl Cohen[1], I asked, *"Karl, will you be joining us?" "No,"* he replied, *"I shall be underground soon enough!"*

Dissolution of the Soviet Union in December 1991 by President Gorbachev led to the formation of a large number of independent States.[2] This created a serious problem with respect to high-level nuclear waste. The USSR had been responsible for handling all high-level nuclear waste produced from nuclear power plants in that nation. Overnight, this responsibly was shifted to each state that had nuclear power plants within its borders. In one case, power from a single plant was distributed to two adjacent states, so each was responsible for part of the waste produced. Apart from the question of economics (The small amount of waste in some cases did not warrant a classical geological repository.), several states had little or no experience of the problem — and no experienced professionals. The International Atomic Energy Agency (IAEA) in Vienna introduced the "International Centres of Excellence Network — Waste Disposal Technologies" to address this problem. I accepted an invitation to chair the program, and served in this capacity from 2003-2007. IAEA invited states in the Former Soviet Union (FSU) to nominate scientists and engineers to join the Center. Our role was to link these individuals with organizations and laboratories in countries with established nuclear-waste programs and help facilitate courses, presented by international experts and programs, for 'students' from FSU states. A rewarding experience, the program is — to my knowledge — still in force.

From 1992 -2003, I was a member of the group G3S[3], at Ecole Polytechnique, Palaiseau, France; from 1993-2005, I was a member of the Scientific Counsel of ANDRA, the French National Agency for radioactive waste isolation. Today, France is one of three countries, with Finland and Sweden, that have moved from the URL stage and is moving forward with government approval to develop a full-scale high-level

(continued)

[1] Dr Karl Cohen http://www.oac.cdlib.org/findaid/ark:/13030/c8k938h2/ It was a privilege and a joy to serve on the WIPP Committee with him. On one occasion, a young, somewhat brash researcher was asked a question about his presentation. He began to reply "*Well, if you understand the Scientific Method....*" at which point Karl intervened, gently: "*Young man, I will have you know that some around this table* [the Committee] *have a passing acquaintance with the Scientific Method!"*
[2] http://en.wikipedia.org/wiki/Post-Soviet_states.
[3] Groupement pour l'etude des Structures Souterraines de Stockages [Group for study of underground structures for (nuclear waste) storage].

How I Came into Rock Mechanics (Part 4) Continued

By
Charles Fairhurst
University of Minnesota/Itasca

waste repository in argillite in the Bure region. France generates approximately 80% of its electric energy from nuclear power, and has an excellent electrically powered TGV (High Speed Train) system linking all major regions of France and extending to London, via the Channel Tunnel.

The U.S. was the first country to develop, open and operate an underground repository. The WIPP[4] facility in bedded salt opened to receive transuranic nuclear waste[5] in 1999. Yucca Mountain[6], the facility selected for study as the nation's first repository for high-level waste, was progressing toward review until 2010, when it was closed by the current administration — the victim of politics rather than demonstrated technical inadequacy. As the nation that first proposed deep geological isolation in 1957[7] and the nation with the largest inventory of high-level waste awaiting a repository, the U.S. is currently back to the beginning.

In 2003, I was honored to receive the Müller Award[8] and to present the Müller Lecture at the 8th ISRM Congress, in Johannesburg, South Africa. The title, *"One Small Step for Geology; One Giant Leap for Rock Mechanics!"*, was intended to emphasize that, while the thousands of years of isolation required for geological repositories is much longer than typically involved in rock engineering, it is still a small period in the history of planet Earth. No fabricated material can be demonstrated to have this long-term isolation capacity. This feature of the subsurface is likely to be called upon more in the future to allow, for example, isolation of noxious products from the biosphere. The 'underground option' is now considered an option for CCS (carbon capture and storage).

I maintain an active interest in the development of Itasca, the consulting group that I helped found in 1981, as Itasca Consulting Group, Inc. (ICG). ICG would not have survived without the dedicated and tireless efforts of friends Magnus Bergman and John Markham, both now retired. Established to test the validity of Peter Cundall's Discrete Element Method in practice, the company, which consisted primarily of recent graduates, endured early financial difficulties, but survived. Thirty-three years later, ICG is now the Minneapolis branch of Itasca International Inc (III), led by CEO Loren Lorig, a Ph.D. graduate of Minnesota. III has over 175 employees in 16 offices and 12 countries — and continues to grow. More than 50 employees have PhDs.

Although no longer teaching or supervising graduate students, I maintain close contact with faculty colleagues in Geo-Engineering. This talented and stimulating group is at the international forefront of rock mechanics/engineering and is known both by industry and academia for the high caliber of their graduates. The Center of Excellence CEFoR (Center for Engineered Fracturing of Rock, www.cefor.umn.edu) is developing well. As seen from the description on its website, CEFoR is a three-way partnership between the UMN, Itasca, and MTS Systems Inc.[9] Interaction between the UMN and MTS began in the late 1960s with the development of servo-controlled stiff-testing systems for rock, stimulated by the research of Dr. Wolfgang Wawersik, then a graduate student.

The MTS Professorship in Rock Mechanics, established by the company in December 1987, allows the Geo-Engineering group to invite distinguished colleagues from all corners of the globe to spend periods in residence in the Department in order to interact with faculty and students — to the benefit of all.

In closing, I would like to mention three especially memorable recent events.

In 2010, Margaret and I were surprised to receive an invitation from former post-doctoral student Professor Yoshi Mizuta — totally unexpected — to visit Japan as the guest of Yoshi and his wife Keiko. We accepted, and were welcomed with hospitality similar to the 'royal' treatment described earlier in these notes.

In July 2013, I received a letter from Monsieur François Delattre, French Ambassador to the United States, informing me that I had been appointed to the rank of Officer in the Legion of Honor. Never in my wildest dreams had I even contemplated such recognition. Gradually, I learned of the dedicated effort on my behalf by French colleagues. I have always had a special affection for France and admiration for French scholarship, and I now have this testimony to their remarkable generosity. The Legion d'Honneur Croix officially was conferred by M. Edouard Brézin, former President of the French Academy of Sciences, in Paris, 3 December, 2013, before family members and many friends from France and the U.S.

The ARMA Symposium, held 1-3 June this year on the University of Minnesota campus, was the result of a long, intensive and very successful effort by many. A special dinner to honor Steve Crouch (now Dean of the College of Science and Engineering at Minnesota), Peter Cundall, and me drew a large attendance. Particularly touching was the presence of a large fraction of the initial group of graduate students that established the rock-mechanics tradition and standard at Minnesota. All are now recognized leaders in rock mechanics; several are now retired. Many kind words were expressed at the dinner concerning my role in establishing the Minnesota tradition. As I commented then, none of this would have come to pass without this group and, subsequently, faculty colleagues in Geo-Engineering and what was then 'Mechanics and Materials.[10] *"If I have seen further it is by standing on the shoulders of giants,"* is a comment sometimes attributed to Isaac Newton;[11] although in a very different context, the same comment is true here. The photography on Page 12, ARMA e-Newsletter, shows a large number of the first group.

So, my story essentially has been told. Inevitably, there are other colleagues, events and contributions that could and should be mentioned. Some I may have forgotten, but many come to mind frequently. To all, I wish simply to say '*Thank You*' for a remarkably fulfilling and enjoyable life-long journey.

In the words of Minnesota's Garrison Keillor, *"Be well, do good work, and keep in touch."*[12]

[4] http://en.wikipedia.org/wiki/Waste_Isolation_Pilot_Plant.
[5] http://en.wikipedia.org/wiki/Transuranic_waste.
[6] http://en.wikipedia.org/wiki/Yucca_Mountain_nuclear_waste_repository.
[7] The Disposal of Radioactive Waste on Land (1957) Nat. Acad. Sci. http://www1.eere.energy.gov/geothermal/contacts.html.
[8] See http://www.isrm.net/gca/?id=287.
[9] http://www.mts.com/en/index.htm.
[10] Now the Department of Aerospace and Engineering Mechanics
[11] http://en.wikipedia.org/wiki/Standing_on_the_shoulders_of_giants.
[12] http://en.wikipedia.org/wiki/The_Writer's_Almanac.

ARMA News Briefs

Call for Abstracts, 49th US Rock Mechanics/Geomechanics Symposium

The 49th U.S. Rock Mechanics/Geomechanics Symposium will be held in San Francisco, California from 28 June through 1 July, 2015. The deadline for submission of abstracts to be considered for the Symposium is **1 November, 2014.**

The focus of the symposium is on fundamental, practical and educational issues facing our profession. The main subjects of the Symposium (all in relation to rock mechanics/geomechanics) are:

- Interdisciplinary
- Civil
- Mining
- Petroleum

The complete list of suggested topics is presented below and may be viewed at http://www.armasymposium.org (click on "abstract submission"). Abstracts of 250-500 words, in English, can be submitted online at http://submissions.mirasmart.com/ARMA2015. Abstracts should include a brief description of work performed, results, and significance. Figures may be included as necessary to explain the abstract. All abstracts will be peer-reviewed by experts in respective subject areas through an online process. To facilitate travel arrangements, invitation letters to attend and participate in the symposium may be issued upon request after acceptance of an abstract. A presentation slot will be tentatively assigned at that time, with final confirmation after approval of the paper.

Suggest topics for ARMA papers, 49th Symposium

Interdisciplinary

- Coupled Process Modeling
- Salt Rock Mechanics-Experimental Characterization, Theoretical Modeling and Geological Storage Applications
- Transport and Coupled Processes in Fractures
- Geothermal: Hurdles to a Successful EGS Operation-Closing Critical Knowledge Gaps
- Uncertainty: Assessment and Quantification for Rock Engineering Design
- Geophysical Properties of Rock and Their Characterization
- Acoustic Emission: Fracture Monitoring from Laboratory to Field Scale
- Multiphase, Multi-component and Particulate Fluid Flow in Fractured Rock
- Coupled Processes in CO2 Sequestration and Hydraulic Fracturing
- Thermal, Hydrological, Mechanical, Chemical and Biological Influences upon Rock
- Measurement/Modeling of Rock Properties
- New Developments in Computational Rock Mechanics/High-Performance Computing
- Rock Heterogeneity and Scaling
- Geologic Repository Issues for Nuclear Waste Disposal
- General: Interdisciplinary

Civil

- Laboratory Testing
- Field Testing
- Failure Behavior and Constitutive Modeling
- Rock Mass Characterization
- Rock Mass Strength and Deformability
- Fracture Network Statistics
- Slope Stability and Landslides
- Ground Subsidence
- Induced Seismicity
- Other Hazard Prediction and Mitigation
- Environmental Issues
- Ground Improvement
- Tunnels and Caverns
- Dams and Foundations
- Other Rock Mechanics for Infrastructure

Petroleum

- 3D Simulation of Complex Fracture Growth
- Cap Rock Integrity
- Coastal Subsidence
- Constitutive Models
- Coupled Process
- Discrete Fracture Networks
- Experimental Rock Mechanics
- Fracture Mechanics
- Geomechanics for Unconventionals
- Hydraulic Fracture-Novel Technologies
- Hydraulic Fracture-Simulations
- Hydraulic Fractures-Monitoring
- Petroleum-Related Salt Mechanics
- Reservoir Geomechanics
- Wellbore and Drilling Mechanics
- In Situ Stress Measurement
- Pore Pressure Prediction
- Geomechanics for Near-Surface and Shallow Hazards
- Carbonates
- Geomechanics and Reservoir Surveillance
- Geomechanics and Enhanced Oil Recovery
- General: Petroleum

Mining

- Deep Mine Rock Mechanics
- Hard Rock Ground Control
- Coal Mining Ground Control
- Cave Mining Geomechanics
- Mining Geomechanics
- Numerical Modeling-Mining
- Case Histories-Coal
- Case Histories-Mining
- Mining-Induced Seismicity
- Outbursts and Bumps
- Subsidence Geomechanics
- Ground Support Design
- Mining Rock Slopes
- General: Mining

Special Symposium at the 2015 ISRM Congress, Montreal

Herbert Einstein, ARMA Fellow, would like to invite you to participate in the Symposium "Shale and Rock Mechanics - As Applied to Slopes, Tunnels, Mines and Hydrocarbon Extraction," which will be held as part of the 2015 International Society for Rock Mechanics Congress, in Montreal. This event is jointly organized by CARMA and ARMA. For further information, contact einstein@mit.edu or at www.isrm2015.com.