The 21st-Century Bureau*

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THE 21ST CENTURY UNIVERSE

As geologists, when we look to the future, we first consider the past. Our past provides perspective, context, and analogs concerning such things as scale, population, and time and human advancement.

Scale

In terms of scale, Earth is larger than our neighboring rocky planets, but it is some 1,300 times smaller, by volume, than Jupiter, the largest planet. It is 1.3 million times smaller, by volume, than our Sun. Of course our Sun is smaller than some of the giant stars; for example, Antares has a radius over 400 times that of our Sun, making its volume over 100 million times greater than that of the Sun! Earth is small indeed.

If we look beyond our solar system, although the number of stars cannot actually be counted, astronomers and physicists use the amount of light in the Milky Way Galaxy (luminosity) and the mass of the galaxy to estimate its number of stars, which is somewhere between 100 and 200 billion! Even more mind boggling is the estimated number of galaxies in the universe—around 100 billion. To visualize this number, venture to the NASA/IPAC Extragalactic Database (http://nedwww.ipac.caltech.edu/). The scale of the universe is so astounding that it makes me want to come back to Earth! On Earth we encounter something else that is counted in billions—human beings.

Population

Earth's population today is approaching 7 billion (fig. 1). To gain perspective on that number, 7 billion seconds ago the year was 1787! For a different perspective on the magnitude of 7 billion, if every person on Earth were to stand shoulder to shoulder at the equator, they would encircle the Earth approximately 100 times! When the Bureau was formed in 1909, the Earth's population would have encircled the Earth only about 30 times; it was not until 1927 that global population reached 2 billion. In the 90 years since, we have added almost 5 billion people to Earth's population. We are adding a billion people every 13 years. That is about 150 "net" (births minus deaths) humans every minute of every hour of every day of every year. Said differently, it would take only 2 minutes to fill the 300 seats in an auditorium with new people. In the half hour it takes you to read this article, we would fill fifteen 300-seat auditoriums with additional people on Earth!

As we look to the future, it is not just the number of people that is important, but also how they are distributed. Only about 15 percent of the world's people live in economically developed countries. Another 75 percent live in nations that are "developing," and the remaining 10 percent live in under- or undeveloped nations. In the developed nations, the mode is represented by the 35 to 45 age group. Not so in the developing nations, where the mode is the under-10 age group. In other words, we have a very large number of very young people on Earth, in nations that are now industrializing.

There is much that can be drawn from these trends. But for our purposes, we must recognize that a growing global population, compounded by a greater percentage of people in developing nations requiring energy and water, presents a resource challenge that cannot be ignored. World population growth rates, which hovered mostly between 1.5 and 2 percent from 1950 to 1990, have now begun to decline and are expected to continue to do so until around 2080. In 2080, the global population growth rate, for the first time, should go negative. Population is projected to be somewhere in the vicinity of 12 billion. Resource demand, environmental stress, and economic implications of declining population growth define some of the grand human challenges of the 21st century. To understand how we might handle these in the future, it is instructive to look at the past.

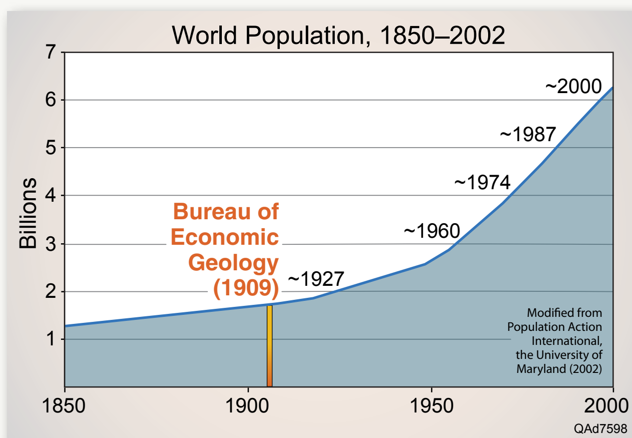

Figure 1.

* Text of a talk given by Director Scott W.Tinker at the Centennial Symposium.

Time and Human Advancement

Let us briefly examine the age of the Earth, with a specific longer-term view of climate and a nearer-term look at the technological advancements of humans. Earth is just over 4.5 billion years old. The oldest microbial fossils are dated around 3.5 billion years before present. Animal life evolved and migrated from the sea onto land in the Paleozoic Era.

Climate has been changing since the Earth began. The early Paleozoic Era was a greenhouse time, during which temperatures were significantly warmer and greenhouse gases more elevated than today. The late Paleozoic saw icehouse conditions, in which temperatures were cooler and polar ice advanced to lower latitudes. The Mesozoic was again a greenhouse time during which elevated CO_2 levels contributed to the growth of large plants and animals, such as dinosaurs!

Cooling began again in the Cenozoic, and in the last 4 million years, which represents less than 0.1 percent of Earth's total history, we observe an overall cooling trend with approximately 50 northern hemisphere glaciation cycles, each lasting between 60 and 100 thousand years. It was during this time that the first evidence of the genus *Homo* occurred, documented by struck stone tools found in East Africa dating back 2.4 million years (Ma). Subsequent discoveries include a knife in Ethiopia dating back 1.4 Ma, and spears in Germany, 400 thousand years (ka).

Focusing on the last 400,000 years (0.01 percent of Earth's history), we see four well-documented glacial-interglacial cycles (fig. 2), with the interglacial warm component representing only about 20 percent of the total cycle. Human advancements include evidence of burial in Africa around 200 ka, lithic blades in Africa and the ancient Near East around 100 ka, ships used by settlers of New Guinea around 60 ka, and mining (the first geologists!) in Swaziland and Hungary around 40 ka.

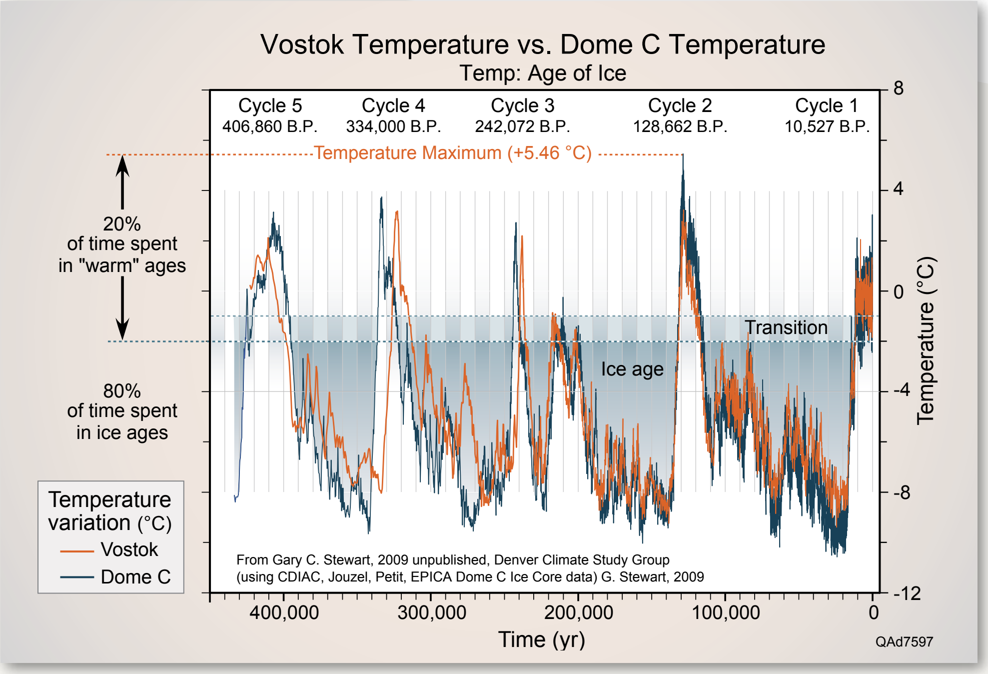

Figure 2.

Focusing on the period from 40,000 (0.001 percent of Earth's history) to 4,000 years ago, we see the later stages of the glacial component of climate cycle 2, followed by the present-day interglacial period that we enjoy today, which began some 16,000 years ago (fig. 3). During the glacial component, ice advanced to lower latitudes (the states of Wisconsin, Minnesota, and Michigan were partly covered by ice), and global sea level was considerably lower than its present level, which opened land bridges and allowed human migration between continents.

The point of this brief climate look back is that it is during the warm climate that we have enjoyed for over 11,000 years that humankind has seen its most remarkable technological advancements. Highlights of advancements that relate specifically to water, energy, and "protogeologists" in rough chronology include ceramics (Moravia), agriculture and alcohol (Fertile Crescent), metalworking (Mesopotamia), irrigation (Fertile Crescent), beer (Sumer), stone-paved streets (Iraq), writing (Sumer), cement (Egypt), wheel and axle combination (Mesopotamia), plumbing (Indus Valley), step pyramids (Egypt), and the aqueduct (Egypt and India).

If we focus further on the period from 4,000 (0.0001 percent of Earth's history) to 400 years ago, we begin to see the evolution of "modern" technology. Inventions include coins (China), maps (Greece), water wheels (India), the compass (China), a rudimentary seismometer (China), water purification (Arabian chemists), the water turbine (Arab Empire), oil wells (Azerbaijan), kerosene (Iraq), bridges, milling and diversion dams (Iran), the magnifying glass (Ibn al-Haytham), the magnetic compass (Shen Kuo in China), the hydropowered forge (Al-Andalus), the programmable analog computer (Al-Jazar), the astronomical compass (Yemeni sultan al-Ashraf), the terrestrial globe (Martin Behaim), and the compound microscope (Zacharias Janssen).

Finally we come to the past 400 years (less than 0.00001 percent of Earth's history). To put that proportion in perspective, 400 years in the life of the 4.5-billion-year-old Earth is equivalent to just under 2.4 minutes in the life of a 50-year-old person. Selected energy, water, and science highlights from the past 400 years of human advancement appear in table 1.

What can be learned from this brief glimpse of scale, time, population, and human advancement that might help develop a better sense of where we are headed? Looking into the future 100 years to 2109, we might ask: Will there be cars? What fuel will they run on? Will the primary electricity "fuel" be renewable? Will climate have

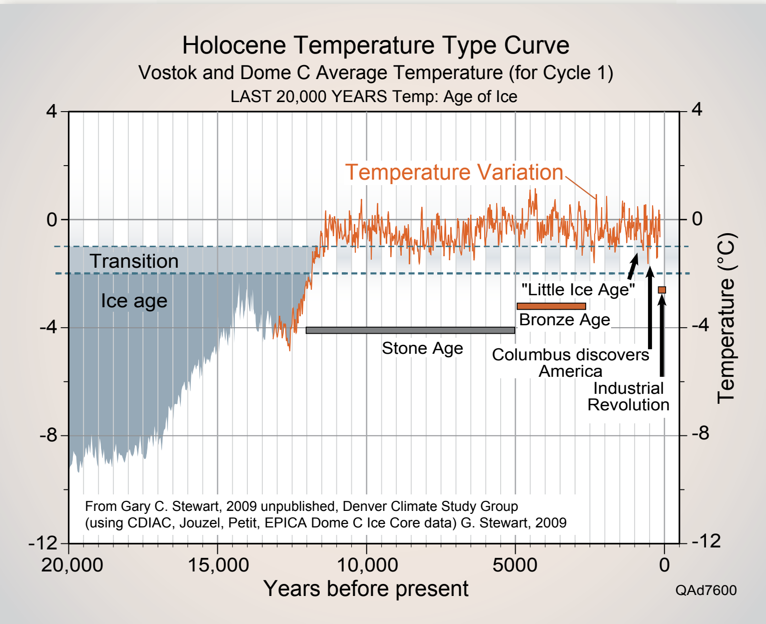

FIGURE 3.

TABLE 1.
400 YEARS OF HUMAN ADVANCEMENT

1600's: Slide rule: William Oughtred
1700's: Watt steam engine: James Watt
1700's: Oil lamp: Aimé Argand
1804: Locomotive: Richard Trevithick

1 BILLION PEOPLE ON EARTH

1821: Electric motor: Michael Faraday
1826: Internal combustion engine: Samuel Morey
1831: Electrical generator: Michael Faraday, Ányos Jedlik
1835: Incandescent light bulb: James Bowman Lindsay
1859: Oil drill: Edwin L. Drake
1876: Gasoline carburetor: Gottlieb Daimler
1880: Seismograph: John Milne
1883: Two-phase (alternating current) induction motor: Nikola Tesla
1886: Gasoline engine: Gottlieb Daimler
1893: Radio: Nikola Tesla
1895: Diesel engine: Rudolf Diesel
1902: Air conditioner: Willis Carrier
1907: Helicopter: Paul Cornu
1908: Geiger counter: Hans Geiger and Ernest Rutherford
1909: Bureau of Economic Geology established!
1914: Liquid fuel rocket: Robert Goddard
1922: Radar: Robert Watson-Watt, A. H. Taylor, L. C. Young

2 BILLION PEOPLE ON EARTH

1937: Jet engine: Frank Whittle and Hans von Ohain
1941: Computer: Konrad Zuse
1942: Nuclear reactor: Enrico Fermi
1942: Undersea oil pipeline: Arthur Hartley, Anglo-Iranian Oil Company
1945: Nuclear weapons: Manhattan Project
1947: Transistor: William Shockley, Walter Brattain, John Bardeen
1949: Radiocarbon dating: Willard Libby
1952: Fusion bomb: Edward Teller and Stanislaw Ulam
1955: Hard drive: Reynold Johnson, IBM
1958: Integrated circuit: Jack Kilby and Robert Noyce
1959: Bureau of Economic Geology turns 50

3 BILLION PEOPLE ON EARTH

1960: Laser: Theodore Harold Maiman
1961: Human spaceflight: Yuri Gagarin, Sergey Korolyov, Kerim Kerimov
1969: First astronaut moon walk: Neil Armstrong
1971: Space station: Kerim Kerimov
1971: Microprocessor: Federico Faggin and Ted Hoff
1971: Magnetic resonance imaging: Raymond V. Damadian
1972: Computed tomography: Godfrey Newbold Hounsfield
1973: Ethernet: Bob Metcalfe and David Boggs
1973: Personal computer: Xerox PARC

4 BILLION PEOPLE ON EARTH

1974: Hybrid vehicle: Victor Wouk
1980: Compact disc: Philips Electronics, Sony Corporation
1982: Artificial heart: Robert Jarvik
1983: Internet: first TCP/IP network: Robert E. Kahn

5 BILLION PEOPLE ON EARTH

1990: World-Wide Web: Tim Berners-Lee
1993: Global Positioning System: U.S. Department of Defense

6 BILLION PEOPLE ON EARTH

2001: Human genome sequenced: U.S. DOE and NIH warmed and polar ice melted or will natural cooling have begun? Will global population be controlled by policy (can economic growth happen without population growth)? Will there have been a world war and, if yes, over what will it have been fought: idealism, religion, resources, human error, or some combination of these? Will resources be rationed and according to what international laws? Will we mine resources from other planets? Will humans colonize the sea, Moon, Mars, or space? Will we prescribe our health future? Will major league athletes be completely genetically enhanced? Will the U.S. still be a major economy? What other countries will rise as "superpowers," if superpowers exist at all?

Baseball great Yogi Berra is credited with saying "Forecasting is hard, especially about the future!" Certainly any attempt to predict key inventions at the turn of the 22nd century is folly, at best. However, in the spirit of good fun, at the turn of the 21st century might we see technology such as language chip implants? Hydrogen hover cars? Solar-charged super capacitors? Optically implanted PDAs? A three-pill-a-day nutrition plan? Marine colonization? Thought-controlled homes? Or perhaps might we see the first power line installed in rural Liberia?!

A Global Context

I have been fortunate in my 50 years to have traveled the world extensively, having visited some 40 countries on 6 continents. From these experiences I have observed that humans, individually, are fundamentally good, even though in groups we have demonstrated the willingness to hide behind large organizational constructs—government, religion, and industry—to propagate harm against one another and to the environment. I also recognize that today the world is culturally, economically, socially, and politically connected.

As we look to the coming century, I see a few fundamental trends that could drive human behavior and perhaps provide some context into the global challenges that we will face. Again, these trends are simply my thoughts by way of establishing context.

Cultural blending as Asia expands

For the past few decades the people of Asia, particularly China and India, have been slowly and predictably expanding their presence around the world. Over one-third of the world's population is Chinese and Indian, so the quest for land and resources should come as no surprise. As this peaceful expansion continues, it is inevitable that cultural blending will occur as people from historically different cultures interact.

Religious convergence *and* extremism

Along with cultural blending will come religious convergence. Already there is a growing global trend toward secularity (about 16 percent—and growing—of the global population declares no religion) as global interconnectedness allows for a broadening awareness of other faiths and systems of belief. This trend will most likely cause continued angst in religious extremists, but most likely in ever-smaller factions, to a level where violent acts based on religious extremism will be minimized.

Redistribution of wealth

As the economies of Asia (including Russia) grow, European and U.S. economies will become relatively less dominant. Combined with physical relocation and cultural and religious blending, there will most likely be a marked redistribution of global wealth. This could come as a contraction in U.S. wealth or as overall global economic growth, such that other countries rise to the level of U.S. prosperity. Much depends on the ability of political leaders to resist building walls (nationalism) and instead build cross-cultural bridges.

Redefinition of class boundaries

As cultural blending and redistribution of wealth proceed, historical class boundaries will be redefined. Currently over 1.5 billion people are without 20th-century conveniences, such as on-demand electricity and water. Most of these people live in undeveloped or underdeveloped nations and are very young. The successful redistribution of wealth will result in a growing global middle class.

Educational expansion

One of the results of cultural, religious, and economic blending will be continued access to education. This is a very positive outcome because education is correlated to economic prosperity, cultural and religious tolerance, life expectancy, reduction in family size, and environmental awareness.

Increased life expectancy

With increased education and continued medical advances will come increased life expectancy, partly from better nutrition and exercise and partly from advancements in medicine and genetics. More people will be living longer—healthier lives are both a challenge and an opportunity.

Natural resource stress and demands

One of the great challenges of the coming century, as the world levels out at a population of around 12 billion people, will be access to natural resources. Certain natural resources are finite, by which I mean resources that, once used, are converted to something else that is not usable in the same form. Combusted gasoline is one such resource. Aluminum is not, as it can be recycled and used again. The world contains the natural resources to sustain human life on Earth, but these resources must be used very differently than how we have used them in the past. Efficiency and sustainability must become the mantra of the future, which does not mean a reduction in quality of life necessarily, but it does mean adapting the way we do things going forward.

Nuclear energy (and nuclear weapons) expansion

In terms of energy, we will transition slowly away from the combustion of certain fossil fuels (coal and oil) toward alternate energy forms representing more continuous sources of motion and heat but with substantially lower energy density: solar power, wind, hydro power, waves, tides, geothermal energy, and some forms of cellulosic biomass. These low-energy -density alternate-energy fuels require much greater surface infrastructure. I believe natural gas and nuclear energy will play a very prominent role. Both are globally abundant and have the potential to serve as large-scale, “base-load” (continuous) sources of electricity. These base-load fuels will be required until we develop the technology to store and transmit electricity more efficiently, thus allowing industrial-scale solar power, wind, and other low-density fuels to serve the continuing needs of a growing population.

I hold out hope that cultural blending, religious convergence, redistribution of wealth, and expansion of education will allow this energy transition to be smooth.

Other presenters at the Centennial Symposium

Dr. Sharon Mosher, Dean, Jackson School of Geosciences

Dr. William Fisher, Professor and Barrow Chair, Jackson School of Geosciences

The Honorable Victor Carrillo, Chairman, Railroad Commission of Texas

Dr. Steve Koonin, Undersecretary for Science in the Department of Energy

Dr. Peter Gleick, President, Pacific Institute

The Honorable Elizabeth Ames Jones, Commissioner, Railroad Commission of Texas

Dr. Chip Groat, Director, Center for International Energy and Environmental Policy (CIEEP)

Mr. Mark Vickery, Executive Director, Texas Commission on Environmental Quality (TCEQ)

Dr. Robert Mace, Deputy Executive Administrator, Texas Water Development Board (TWDB)

Dr. Tad Patzek, Chair, Petroleum & Geosystems Engineering, The University of Texas at Austin

Dr. Chuck Williamson, CEO (ret.), Union Oil Company of California (UNOCAL)

Ms. Amy Hardberger, Attorney, JD, Environmental Defense Fund

Dr. Juan Sanchez, Vice President for Research, The University of Texas at Austin

CHALLENGES AND TIMELESS CHARACTERISTICS

The global context that I have discussed suggests two challenges that the world will face as we move through the 21st century.

The first is natural resources, including energy, water, food, minerals, aggregates, and the environment, and the second is natural processes, including natural and induced hazards, climate variability, coastal change, marine development, and competition of species. Resources and processes are at the heart of Bureau expertise and interest. As such, we are actively engaged in energy research (including oil, natural gas, coal, geothermal energy, geologic approaches to energy storage, and energy economics), hydrogeology, natural hazards, and carbon sequestration. By way of example:

- We own and operate airborne and ground-based lidar that collects continuous topographic position information and allows for the reconstruction of continuous outcrop data.
- We are working with ever-higher resolution 3-D, 4-D, and multicomponent seismic data and pushing the limits of seismic imaging to enhance oil and natural gas recovery, including resource recovery from unconventionals.
- We are integrating surface and space-based remote sensing data to provide for significantly enhanced interpretation and analysis of near-surface hazards, such as sinkholes, subsidence, and coastal change.
- We are working at the very small micro- and nanoscale, to try to develop small, smart sensors to help characterize the interwell space in the subsurface more accurately.

Equally important are the human characteristics that have allowed the Bureau to excel during the past century and that will allow us to remain at the front of the pack in the coming century. These include curiosity and the willingness to engage in debate; the drive to stay current and relevant; a work ethic driven by curiosity and the hunger to attract external funding; the desire and ability to work at the boundaries of disciplines and to integrate results into a common whole; the flexibility to adapt to change; and, finally, a passion for the rocks and the Earth.

These are the timeless attributes of the men and women who have worked successfully at the Bureau for the past century, and these are also undoubtedly the traits of those who will be successful at the Bureau in the next 100 years.

Happy 100th Birthday, Bureau of Economic Geology!