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ARIZONA GEOLOGICAL SURVEY

THE STATE AGENCY FOR GEOLOGIC INFORMATION

MISSION

To inform the public about geologic processes, materials, and resources in Arizona and assist citizens, businesses, governmental agencies, and elected officials in making informed decisions about managing Arizona's land, water, mineral, and energy resources.

GOALS

- Inform the public about geologic processes, materials, and resources in a timely, courteous manner.
- Map and describe the bedrock and surficial geology of Arizona.
- Investigate and document geologic processes and materials that might be hazardous to the public or have adverse impact on land use and resource management.
- Administer the rules, regulations, and policies established by the Arizona Oil and Gas Conservation Commission.

Global Warming: A Geological Perspective

John P. Bluemle
State Geologist and Director
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The average surface temperature of Earth is increasing. Continued increase could cause profound impacts on Earth and its inhabitants (Figure 1).

The average surface temperature increased from the mid-1880s until about 1940, declined until about 1980, and has been increasing since then (Figure 2). Some believe that the current warming rate is unusually high, is being caused by the burning of fossil fuels that produce carbon dioxide (CO_2), creating a "greenhouse effect," and can be slowed or even reversed. To evaluate the significance of the current warming, one must compare it with temperatures and variations that occurred prior to human activities. If the current warming is greater than in the past, human activities may be a cause. If past tempera-

(continued on page 2)

Figure 1. Many glaciers in North America and Scandinavia, including the two in this photograph (Isfallsglaciären and Storglaciären in the Tarfala Valley in Sweden), have receded since the early eighteenth century. If global warming continues, glaciers and ice caps will melt, sea level will rise, and many population centers will be submerged. There would likely be an increase in icebergs, which would endanger maritime commerce. The list of possible effects of continued global warming is long and uncertain.

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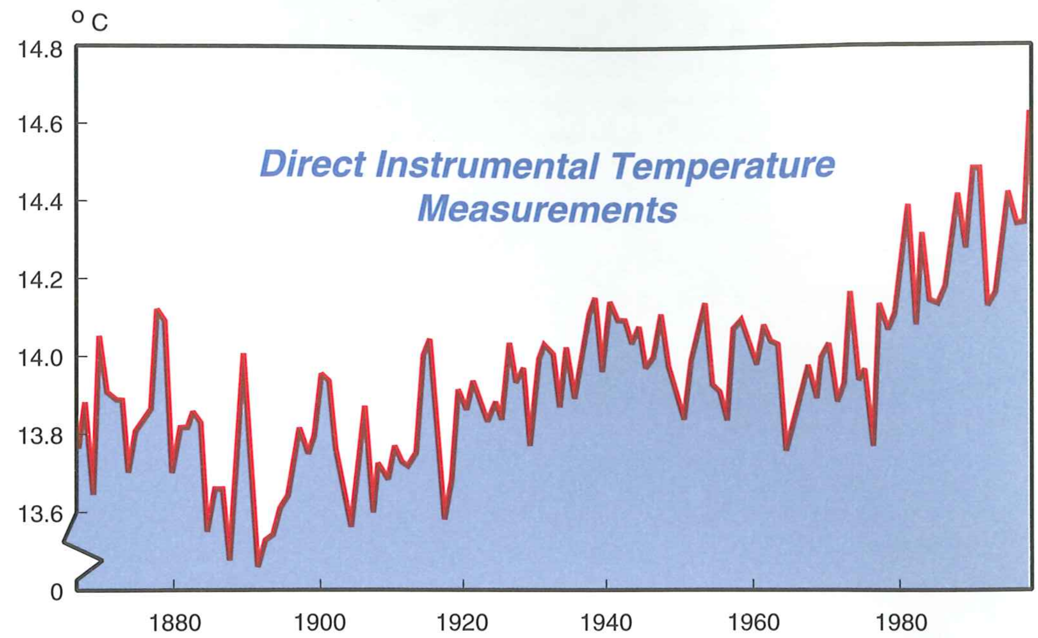

Figure 2. Direct instrumental temperature measurements show that the average temperature at Earth's surface increased from 13.8°C in 1866 to 14.6°C in 1998. Note that the temperature increased from about 1885 until 1940, decreased until about 1978, and has been increasing since then. Modified from a graph provided by the Goddard Institute for Space Studies.

tures and variations were comparable to or larger than the current warming, however, human activities may not be significant.

Two colleagues and I reviewed published articles to compare past temperatures and variations with the current warming. Much research has been done on this subject in the past 30 years, especially the last decade. Scientists have completed investigations in widely distributed parts of the world and used varied methods to interpret past temperatures and changes. Independent research has been done on topics such as glacial advance and retreat, ice cores, pollen distribution, lichen growth, tree rings, sediment layers in glacial lakes, sediment on the sea floor, the composition of sea shells and corals, and the composition of cave deposits. Information about past temperatures, variations, and trends is summarized below.

Temperature variations during the Ice Age. The global temperature declined at least 10°C during the Ice Age (Pleistocene Epoch), which began two to three million years ago. In addition, the temperature cooled 15-20°C in central Europe in the 55 million years or so that preceded the Pleistocene (Figure 3).

Extensive continental glaciation took place in North America and northern Europe during the Pleistocene. Ice sheets advanced and retreated repeatedly, reaching as far south as the Missouri and Ohio Rivers in the United States. At least six major glacial advances and retreats occurred in North Dakota. Each major glacial and interglacial episode lasted about 100,000 to 200,000 years, during which the temperature decreased roughly 10°C during glaciation and increased by a comparable amount during the interglacial period.

Studies of ice cores from Greenland indicate that temperatures there rose and fell abruptly during the Pleistocene. On two occasions between 135,000 and 110,000 years before present (BP), temperatures dropped from 2°C warmer than they are today to 5°C cooler in less than a few centuries. In one instance the temperature dropped 14°C in a decade and returned to its former level 70 years later.

During the Wisconsinan glacial maximum, between 20,000 and 14,000 years BP, glacial ice covered about 27 percent of Earth's land surface. During that time, sea level was about 130 m lower than it is today. Sea level rose to current levels when the ice melted. Only about ten percent of the land surface is covered by ice today.

The most recent interglacial age. We are living in the most recent of many interglacial ages. Geologists call it the Holocene Epoch. Frequent and rapid climate fluctuations have occurred throughout the Holocene, which began about 13,000 – 10,000 years BP and includes all of recorded history. Ice core studies show that, about 9500 years ago, temperatures in Greenland changed from warmer than today to full glacial severity within 100 years. All glacial ice in North Dakota had probably melted by 8000 years BP; the Scandinavian ice sheet had almost completely disintegrated before about 7000 years BP. The last remnants of the once huge Laurentide ice sheet in the Hudson Bay region had melted by 5000 years BP.

Temperatures have fluctuated rapidly during the last 2000 years, although not to the extent they did during the Pleistocene interglacial periods. A time of relatively warm temperatures, the Medieval Warm Period (Figure 4), is well documented in Europe and the western hemisphere between about 1100 and 600 years ago (900-1400 AD). It was followed immediately by a period of cooling from about 600 years ago until 200 years ago (1400 to 1800 AD) that included a particularly cold interval, the Little Ice Age, between 400 and 250 years BP (1600-1750 AD).

The entirety of Holocene climatic history can be characterized as a sequence of 10 or more global-scale "little ice ages," fairly irregularly spaced, each lasting a few centuries, and separated by global warming events.

Direct instrumental measurements. Direct instrumental measurements indicate that the average temperature at the Earth's surface increased about 0.8°C from 1866 until 1998 (Figure 2). During this same time, the concentration of CO_2 in the atmosphere increased from 280 to 353 parts per million volume. Because this period of time very nearly coincides with the industrial revolution, the supposition arose that the warming was caused by human activities. Most of the warming, however, took place before most of the CO_2 increase occurred. Statistical analyses of the climate record since 1860 show that significant interannual and interdecadal variability occurred. This suggests that the warming had causes other than an increase in greenhouse gases alone.

The increase in temperatures recorded by direct measurements may be part of a longer-term warming trend that began after the Little Ice Age and before the Industrial Epoch. Many poorly understood factors influence atmospheric CO_2 concentrations. For example, because the current increase follows a 300-year warming trend, the observed

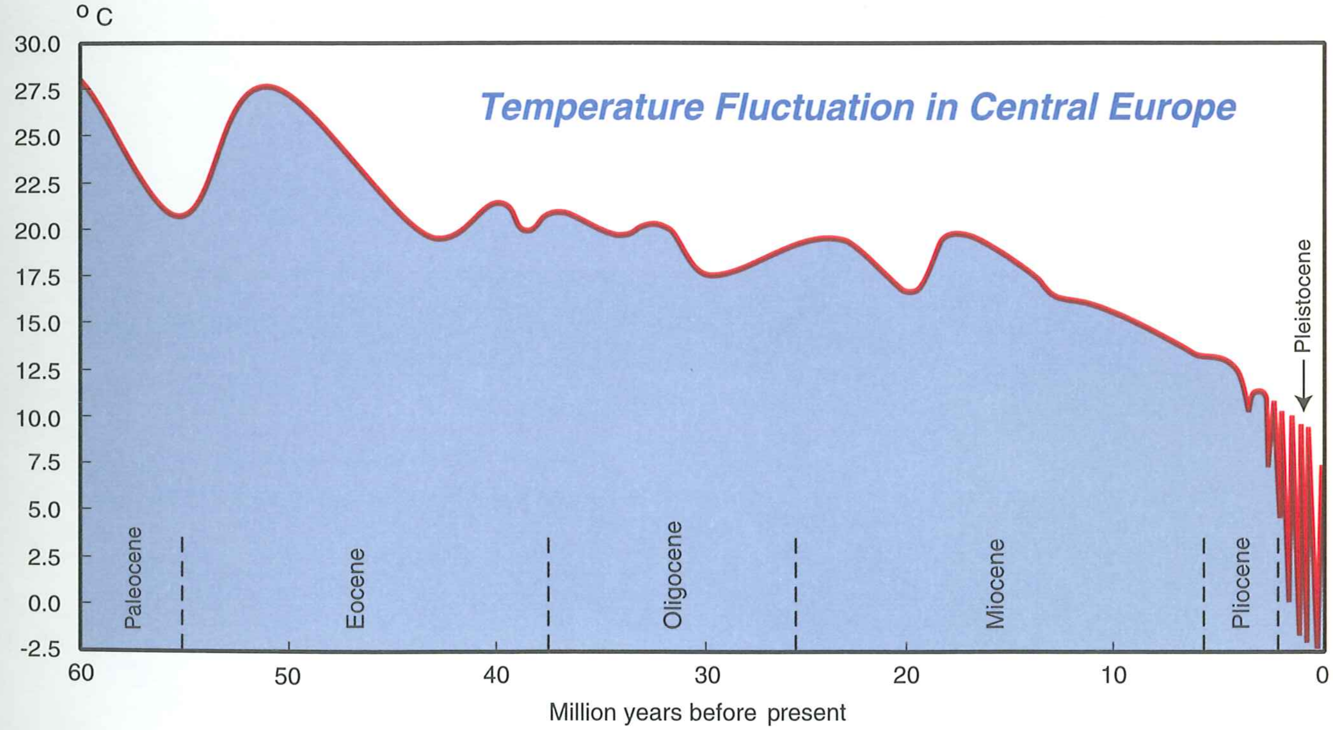

Figure 3. Temperature fluctuation (mean annual temperatures) in central Europe during the past 60 million years. Except for a peak about 50 million years ago, temperatures decreased about 15°C prior to the Pleistocene Epoch, which began about three million years ago. At that time glacial conditions began and temperatures fluctuated widely, ranging from full glacial to interglacial conditions. The modern condition is approximately +4 to +5 degrees Celsius. Graph is modified and adapted from Anderson, B. G. and Borns, H. W., 1997, The ice age world: Oslo, Scandinavian University Press.

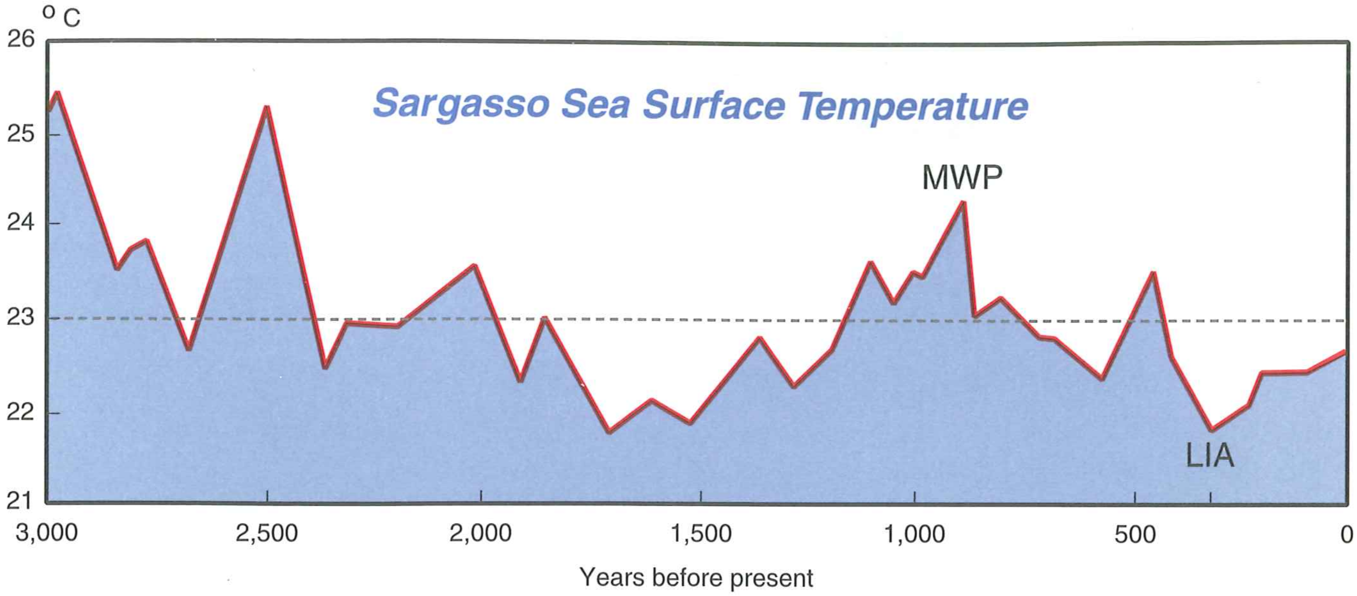

Figure 4. This graph shows the Sargasso Sea surface temperature, which was derived from oxygen isotope ratios. This is an indicator of evaporation and, therefore, a proxy for sea-surface temperature. The Sargasso Sea is a two-million-mi^2 body of water in the North Atlantic Ocean that lies roughly between the West Indies and the Azores from approximately 20-35°N. It is relatively static through its vertical column so that potential interference from mixing with other water masses and sediment sources is minimal. The isotopic ratios are derived from biotic debris that has precipitated onto the sea floor. Wide and abrupt variations in temperature are indicated. The relative temperature variations of the Little Ice Age (LIA) and the Medieval Warm Period (MWP) are prominently recorded in the data. Note that the temperature has been increasing since about 300 years before present (1700 A.D.) The horizontal line is the average temperature for this 3000-year period. After Keigwin, L. D., 1996, The Little Ice Age and Medieval Warm Period in the Sargasso Sea: Science, v. 274, p. 1504-1508.

increases in CO_2 are of a magnitude that can be explained by oceans giving off gases naturally as temperatures rise.

Conclusions. A review of research on past temperatures and variations led us to the following conclusions:

1. Climate is in continual flux: the average annual temperature is usually either rising or falling and the temperature is never static for a long period of time.

2. Observed climatic changes occurred over widespread areas, probably on the global scale.

3. Climate changes must be judged against the natural climatic variability that occurs on a comparable time scale. The Little Ice Age, Medieval Warm Period, and similar events are part of this natural variability. These events correspond to global changes of 1-2°C.

4. Global temperatures appear to be rising, irrespective of any human influence, as Earth continues to emerge from the Little Ice Age. If the temperature increase during the past 130 years reflects recovery from the Little Ice Age, it is not unreasonable to expect the temperature to rise another 2 to 2.5 degrees Celsius to a level comparable with that of the Medieval Warm Period about 800 years ago. The Holocene Epoch, as a whole, has been a remarkably stable period with few extremes of either rising or falling temperatures, as were common during Pleistocene glacial and interglacial periods. Nevertheless, the Holocene has been, and still is, a time of fluctuating climate.

5. Climatic changes measured during the last 100 years are not unique or even unusual when compared with the frequency, rate, and magnitude of changes that have taken place since the beginning of the Holocene Epoch. Recent fluctuations in temperature, both upward and downward, are well within the limits observed in nature prior to human influence.

Editors note: This article was summarized from "Rate and Magnitude of Past Global Climate Changes," which was published in *Environmental Geosciences,* volume 6, number 2, 1999, pages 63-75. The authors are John P. Bluemle (State Geologist of North Dakota, Bismarck, ND), Joseph M. Sabel (geologist with the U.S. Coast Guard in Oakland, CA), and Wibjörn Karlén (Professor of Physical Geography at the University of Stockholm, Sweden). In the *Environmental Geosciences* article the authors include citations to more than 70 peer-reviewed reports.

Bluemle earned a B.S. degree from Iowa State University, M.S. from Montana State University, and Ph.D. in geology from the University of North Dakota. He has worked on the glacial geology, geomorphology, and economic geology of the northern Great Plains and Williston Basin for nearly 40 years. Bluemle, who has worked at the North Dakota Geological Survey since 1962, has been State Geologist and Director since 1991.

Just Released

Geologic map of the Horseshoe Dam 7.5' quadrangle, Maricopa County, Arizona: C.A. Ferguson, W.G. Gilbert, S.J. Skotnicki, C.T. Wrucke, and C.M. Conway, 1999, Arizona Geological Survey Open-File Report 99-15 (Pub. number OFR 99-15), 11 p., scale 1:24,000. $5.00

Geologic map of the Sawtooth Mountains and the north end of the West Silver Bell Mountains, Pinal and Pima Counties, southern Arizona: C.A. Ferguson, W.G. Gilbert, J.A. Klawon, and P.A. Pearthree, 1999, Arizona Geological Survey Open-File Report 99-16 (Pub. number OFR 99-16), 25 p., scale 1:24,000. $7.50

Geologic map of the Samaniego Hills, Pinal and Pima Counties, southern Arizona: C.A. Ferguson, W.G. Gilbert, T.R. Orr, J.E. Spencer, S.M. Richard, and P.A. Pearthree, 1999, Arizona Geological Survey Open-File Report 99-17 (Pub. number OFR 99-17), 15 p., scale 1:24,000. $6.00

Geologic map of the Picacho Mountains and Picacho Peak, Pinal County, southern Arizona: S.M. Richard, J.E. Spencer, C.A. Ferguson, and P.A. Pearthree, 1999, Arizona Geological Survey Open-File Report 99-18 (Pub. number OFR 99-18), 43 p., 2 sheets, scale 1:24,000. $10.00

Geology and geomorphology of the San Bernardino Valley, southeastern Arizona: T.H. Biggs, R.S. Leighty, S.J. Skotnicki, and P.A. Pearthree, 1999, Arizona Geological Survey Open-File Report 99-19 (Pub. number OFR 99-19), 20 p., 3 sheets, map scale 1:32,000. $9.00

Geologic map of the Ninetysix Hills, Pinal County, Arizona: S.J. Skotnicki, 1999, Arizona Geological Survey Open-File Report 99-20 (Pub. number OFR 99-20), 14 p., 4 sheets, scale 1:24,000. $10.00

Geologic map of the Picture Mountain Quadrangle, Gila County, Arizona: S.J. Skotnicki, 1999, Arizona Geological Survey Open-File Report 99-23 (Pub. number OFR 99-23), 12 p., scale 1:24,000. $4.00

Geologic map of the Copper Mountain Quadrangle, Gila County, Arizona: S.J. Skotnicki, 1999, Arizona Geological Survey Open-File Report 99-24 (Pub. number OFR 99-24), 9 p., scale 1:24,000. $4.00

Field guide to earth fissures and other land-subsidence features in Picacho basin, Pinal County, Arizona: R.C. Harris, 1999, Arizona Geological Survey Open-File Report 99-26 (Pub. number OFR 99-26), 54 p., $10.00

Data structure for the digital geomorphic surface map of the southern Animas Creek Valley, Hidalgo County, New Mexico: T.R. Orr and S.M. Richard, 1999, Arizona Geological Survey Digital Information Series 16 (Pub. number DI-16), three 3.5 inch disks. $30.00

A bibliography and review of water-quality studies in the upper Gila River watershed, Arizona: R.C. Harris, 1999, Arizona Geological Survey Open-File Report 99-25 (Pub. number OFR 99-25), 67 p., $11.00

Geologic map of the New River quadrangle and part of the Daisy Mountain quadrangle, Maricopa and Yavapai Counties, Arizona: Bruce Bryant, 1999, Arizona Geological Survey Contributed Map 99-C (Pub. number CM 99-C), 32 p., scale 1:24,000. $9.00

Reminder

The AZGS has complete coverage of the State in the standard 7.5-minute series topographic maps at 1:24,000 scale. We also have nontechnical publications in the Down-to-Earth Series on energy resources of Arizona, radon, land subsidence and earth fissures, how geologists tell time, "things geologic," Ice Age mammals in southeastern Arizona, northern Arizona geology, and the Chiricahua National Monument. Contact us or visit our web site for more information (**www.azgs.state.az.us**).

Ordering Information

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If you purchase Open-File Reports, Contributed Maps, or Contributed Reports at the AZGS office, allow up to two days for photocopying.

Gem and Mineral Show

The Tucson Gem and Mineral Society Show will be February 10-13, 2000. Stop at the AZGS booth on the upper level of the Convention Center, or at our office just up the street.

Earth Science Week

We express our appreciation to Governor Jane Dee Hull for proclaiming October 10-16 as Earth Science Week in Arizona. Many people volunteered their time and talent to tell the public about the importance of earth science in their lives.

Dawn Garcia of the Arizona Section of the American Institute of Professional Geologists (AIPG) coordinated Earth Science Week activities, with assistance by Mike Conway, Genie Howell, Paul Lindberg, Steve Maslansky, Rheta Smith, and Larry Thrasher. Events were held in Flagstaff, metropolitan Phoenix, Prescott, Safford, Sedona, Thatcher, Tucson, and Yuma. The AIPG generously provided refreshments for the Arizona Geological Survey open house.

Earth Science Week will be celebrated October 8-14, 2000. Mark your calendars now and begin thinking about how to use this opportunity to show the public how important earth science is.

WSSPC Director

The Board of Directors of the Western States Seismic Policy Council (WSSPC) recently appointed Patricia (Patti) Sutch as Executive Director. Sutch earned a B.A. degree in earth sciences and anthropology from Case Western Reserve University and a M.S. degree in engineering geology, with a seismic hazard focus, from Stanford University. She has had 20 years of experience in the geoscience field, nonprofit-organization management, and business administration. Patti is a California Registered Geologist, Certified Hydrogeologist, and Certified Engineering Geologist.

WSSPC provides a forum to advance earthquake-hazard-reduction programs and develops, recommends, and presents seismic policies and programs. For more information visit the WSSPC web page (www.wsspc.org).

Board of Technical Registration

Governor Jane Dee Hull appointed William M. Greenslade to a three-year term as the geologist member on the Arizona Board of Technical Registration. He replaces Frank S. Turek, who served since 1992.

Oil and Gas Update

A permit to reenter the 26-1 State well in Coconino County near Meteor Crater was issued to Gus Berry of Okmulgee, Oklahoma in September. The well was drilled from its previous total depth of 2950 ft to granite at about 3900 ft. Casing was set in the hole in October.

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