GEOLOGY at SMU

An occasional newsletter for alumni and friends: December 2005.

Blackwell Pushes New Applications
Geothermal Energy from Deep Wells

With the realities of the current energy market hitting home everytime we buy a tank of gasoline, it is interesting to note the lack of interest in geothermal energy as part of an overall U.S. energy strategy. Geothermal energy is hardly mentioned in the recently passed energy bill. This comes at a time when energy prices suggest a future for power generation from geothermal energy.

Research Assistant Professor Dr. Jason McKenna (MS 1998; PhD. 2002) working with Professor David Blackwell and engineering colleagues from Moyes & Co., Dallas, in an article for the *Oil and Gas Journal* entitled, "Geothermal Electric Power Supply Possible from Gulf Coast and Mid-continent Oil Field Waters," presents the case for using heat transported from deep oil & gas wells to generate electricity. The analysis suggests the feasibility of generating megawatts of power from small groups of wells.

Electricity generation from geothermal systems is most often associated with recent sites of igneous activity, located in the western United States or in Japan, Italy, New Zealand, and Iceland. The Basin and Range province, because of its high heat flow (see the *Geothermal Map of North America* on pages 4-5) has been an area of considerable recent development of geothermal energy.

However, large areas of the United States have heat flows above 75 mW/m^2, including Texas. Such heat fluxes yield bottom hole temperatures in excess of 125 ^{o}C at 3 km depth. At 6 km depth (see Figure 2, page 3), the prospects are even better. These Texas areas have several advantages over development in the desert regions of the west, the most important of which is water. In the west, water is a scarce commodity whereas water in the oil and gas fields is a waste byproduct that must *already* be disposed of by reinjection into the ground or by being hauled away (Figure 3, page 6). In the west, the population density is low and the infrastructure to transport the power must be built, whereas in the Texas oil fields the electrical infrastructure is largely in place.

The heat from existing oil and gas wells is an energy source with a very high load factor that contrasts with wind and solar power that can only be used for a fraction of the day. It utilizes existing infrastructure to minimize the startup costs of electrical production. All that is required to capitalize on this energy source is to fit existing wells with heat exchangers and small power plants. McKenna *et al*. estimate the power generating potential at the gigawatt level for the states of Texas and Oklahoma, with significant potential for the Gulf Coast states and Arkansas.

In perhaps, the most novel use of geothermal energy, heat from the Earth powers an ammonia-based refrigeration system that cools the "Ice Hotel" at Chena Hot Springs, Alaska, during the heat of the summer. The heat extracted from waters not much more than 60 ^{o}C is sufficient to run the compressor in the refrigeration unit that keeps the gigantic igloo frozen. Photo courtesy of Gwen Holdman.

Hamilton Chair Holder David Blackwell

Research Interests

- **Heat flow & heat production, thermal conductivity, continental heat flow measurements**
- **Geothermal energy and exploration**
- **Effect of tectonic setting on crustal geotherms**
- **Regional tectonics**

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Chairman's Report

Taking the Earth's Temperature: Heat Flow a Renewable Source of Energy

By Robert T. Gregory

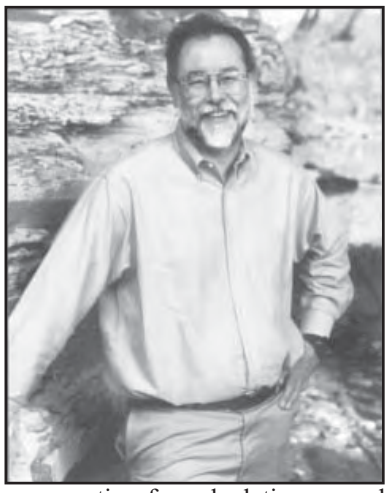


Photo by Hillsman B. Jackson

This newsletter features some of the activities of our Geothermal Laboratory, operated by Professor David Blackwell since 1968. The *Geothermal Map of North America, 2004,* edited by Blackwell and Maria Richards of the Geothermal Laboratory is the centerfold feature that summarizes our knowledge of heat flow in North America. Our cover story reports on a novel idea for using waste heat from deep wells, mainly oil and gas wells, to generate electricity that was recently published in the *Oil and Gas Journal* by SMU's Research Professor Jason McKenna, Dave Blackwell and Christopher Moyes and R. Dee Patterson of Moyes & Co., Dallas.

Heat flow is simply the energy output of the Earth, formerly reported in heat flow units, but now measured in milliwatts per meter squared. Recall that a watt is a joule per second; it takes 4.18 joules to make a calorie and a 1000 calories to make the Calorie that appears on the package of your favorite food. In the old experimental units, the average square centimeter of the Earth's surface released a bit more than a microcalorie per second, or about 1 heat flow unit. The conversion factor to the standard international units is 41.84 milliwatts per meter^2 = 1 heat flow unit. The green areas of the map on pages 5 and 6 represent average values of terrestrial heat flow.

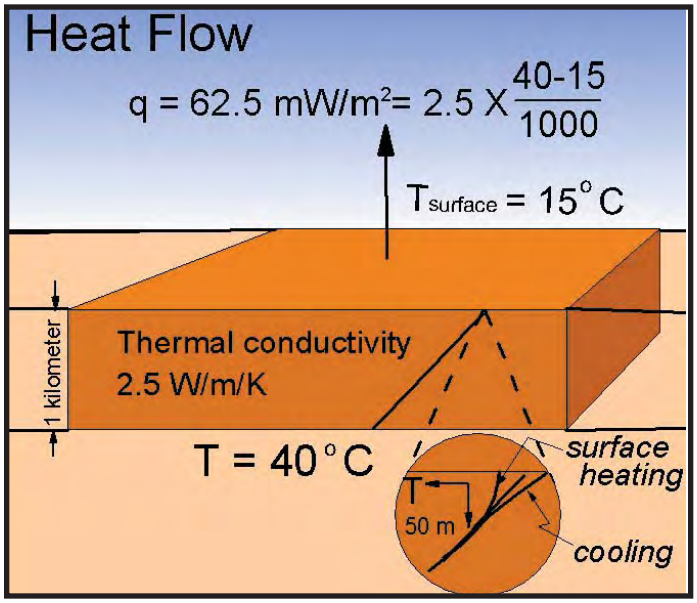
The product of the thermal conductivity and the change in temperature with depth is the heat flow (Figure 1).The latter factor is called the geothermal gradient or geotherm. When there are no sources or sinks for heat, the geotherm is a straight line; the gradient is reported in degrees per kilometer (°C/km). A curved geotherm means that there are sources or sinks for heat or that the temperature is changing with time (see the inset, Figure 1).

Lord Kelvin made use of the latter phenomena to estimate the age of the Earth from measurements of the geotherm. Because he didn't know about radioactivity, he misinterpreted the significance of the curvature of the geotherm as only the result of time dependent cooling of the Earth and not in terms of internal heat sources.

In the 1960's, David Blackwell was one of the co-discoverers of the relationship between measured heat production in continental surface rocks due to their internal radioactivity and the surface heat flow. This empirical relationship when analyzed mathematically gives an equation for calculating curved geotherms in the crust. Through the surface of the continental crust, the heat flow is due mainly to the sum of a background mantle heat flux and the heat produced from the *in-situ* decay of heat producing elements that are concentrated in the continental crust, in particular potassium 40 and uranium.

Heat flow varies from maximum values greater than150 mW/m^2 in active volcanic terrains, most notably mid-ocean ridges, to values of less than 20 mW/m^2, either billion year old cratonal crust, forearcs or mature oceanic crust. From the patterns on the map, there is a clear relationship between plate tectonics and the distribution of heat flow on the Earth; this works particularly well for the oceanic crust. The symmetry of the heat flow around the mid-ocean ridges is predicted by mathematical models for the time dependent cooling of the oceanic lithosphere (examine the Mid-Atlantic ridge south of Iceland to observe the effect). Hot new lithosphere cools as it spreads away from the ridge crest. Mantle convection (the solid state flow of mantle rocks) is critical for moving heat from hotter deeper regions towards the surface so that time dependent cooling dominates the oceanic heat flow distribution.

The small amount of heat coming out of the Earth locally is not too impressive, about the energy output of a night light shining on a bathroom floor. However, the Earth by comparison is a big place; its surface area is 5.1 X 10^{14} m^2 or 510 million kilometers



Department of Geological Sciences
Southern Methodist University
P.O. Box 750395
Dallas, Texas 75275
214 768-2770; Fax 214 768-2701
E-mail: geol@.smu.edu
http://www.smu.edu/geology

Figure 1: For a slab with uniform conductivity and no internal heat sources or sinks, the heat flow or the energy flow through the top surface is the conductivity times the temperature difference, here 25 °C, divided by the thickness of the slab, 1 kilometer. With this typical geothermal gradient, and remembering that the kilometer thickness of slab must be converted to meters before doing the multiplication, the heat flow, q, is 62.5 mW/m^2. The inset shows curvature of the geotherm from changes in surface T.

Continued from Page 2

squared. Using approximately 60 mW/m^2 for the average output, the global heat flux is 3 X 10^{13} watts or 30 terajoules each second! This compares with the 12 terajoule per second usage of hydrocarbons as an energy source by humans. So why aren't business and government leaders flocking to geothermal energy? The answer is energy density, convenience, and cost.

A barrel of light oil contains the chemical energy equivalent of 6 gigajoules. As liquid, this form of energy is easily transported to where it's needed. At $60 per barrel, crude oil is almost 5x less expensive (22 cents) than a bottle of water purchased out of a vending machine ($1.00)! Gasoline, at a retail price of $2 per gallon, is 36% of the price of that vending machine bottle of water. For price and convenience, liquid hydrocarbons are steep competition, until we run out or they become too valuable to burn. Recall that the "Babyboom" generation will see 80% of the recoverable oil burned over their lifetimes.

The action for heat flow is clearly where the magma is. Mid-ocean ridges must produce about 18 km^3/yr of magma to account for current spreading rates. Picritic magma coming into the ridge system is approaching 1400 ^{o}C and the heat capacity of silicates is about 1kJ/kg/^{o}K. Added to this supply is the latent heat of crystallization; the heat released when magma solidifies is 400 kJ/kg of energy. As the conversion factor for cubic kilometers to cubic meters is a billion, the ridge systems put out terawatts of energy (~2 TW), a little less than 10% of global heat flux.

Blacksmoker hot springs (~350 ^{o}C) at mid-ocean ridges are a consequence of hydrothermal convection driven by the mid-ocean ridge heat engine. The second part of the geothermal energy equation is the availability and movement of fluid to transport and concentate the heat. Perhaps, in this century, we will develop the technology to tap into this tremendous source of energy available for billions of years of Earth history while recognizing that capture of the entire ridge system heat flux could only offset about 16% of our current global demand for energy.

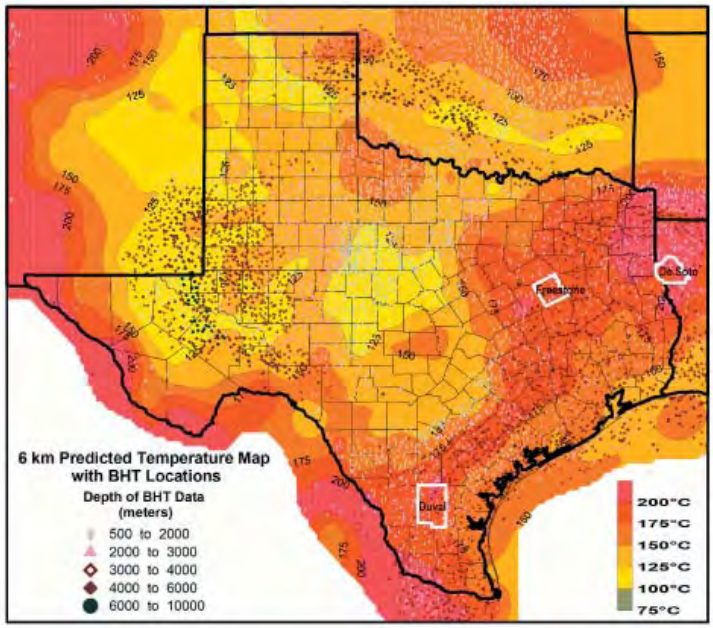


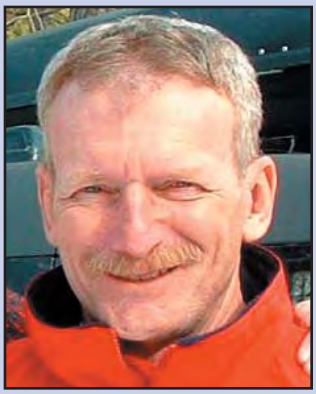
Figure 2: A contour map of estimated temperatures at 6 km depth using bottom hole temperatures (BHT) from wells at a variety of depths. This map from McKenna et al. (2005) combines the measurements with inferred heat flows to project the temperature data onto a common datum level, here 6 km depth (~20,000 ft). The number of deep wells and areas with temperatures above 125 ^{o}C suggest a great potential for geothermal energy.

For the moment, *the Geothermal Map of North America* demonstrates that there are many regions where waters may be hot enough to generate electricity when brought to the surface (Figure 2, and Figure 3 on page 6). The irony is that many of these geothermal prospects result from activities that produce the energy source that we would like to be able to conserve or replace.

SMU Alumnus, Professor Will Gosnold, Jr., Uses Temperature Logs from Boreholes to Record Climate Change

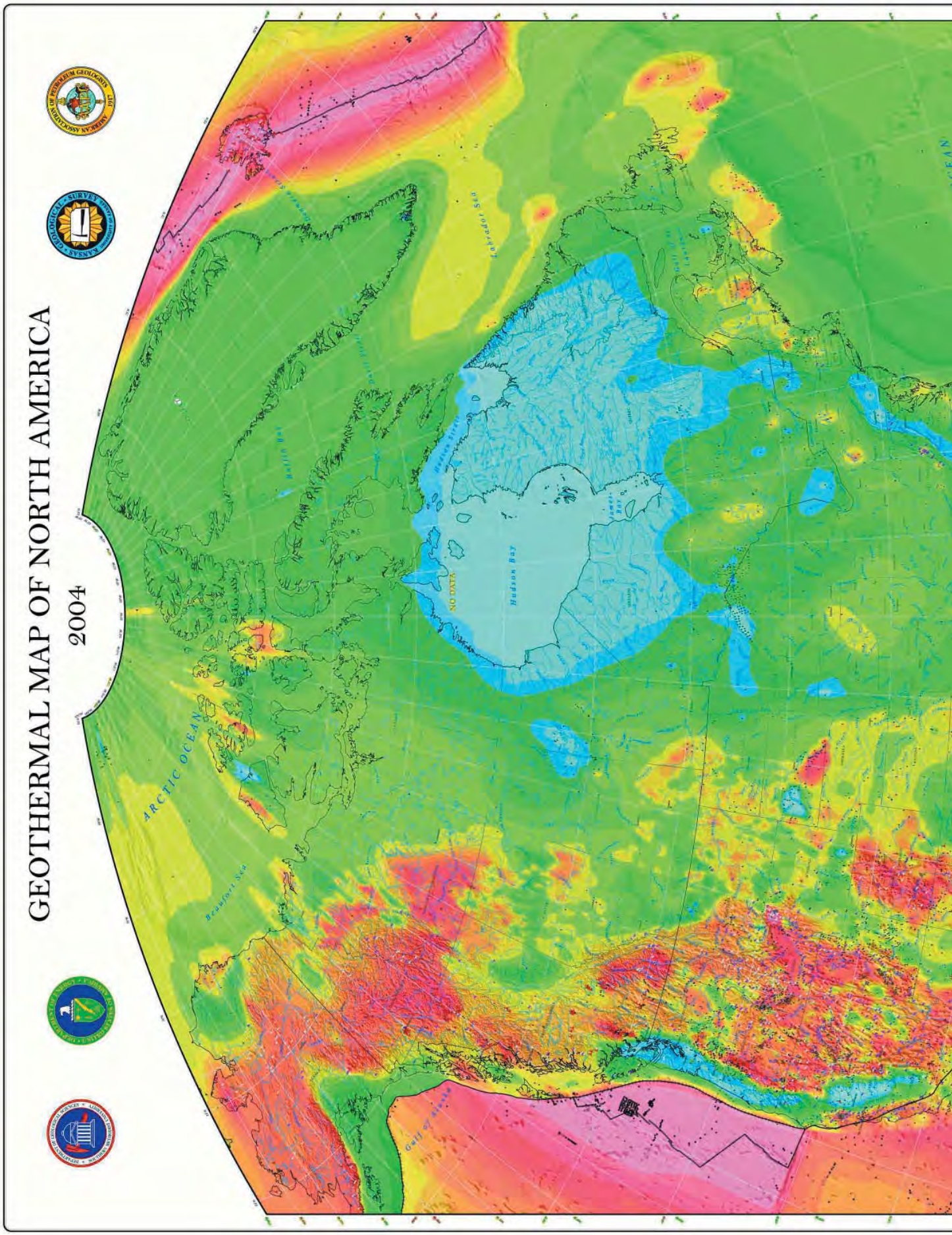
Will Gosnold, Jr. (Ph.D., 1976), Professor of Geophysics and Chairman of the Department of Geology and Geological Engineering at the University of North Dakota, is making use of temperature (T) logs from boreholes over the northern Great Plains to document climate change on multiple timescales. A major problem for understanding climate change is to get a long enough record at the proper sensitivity.

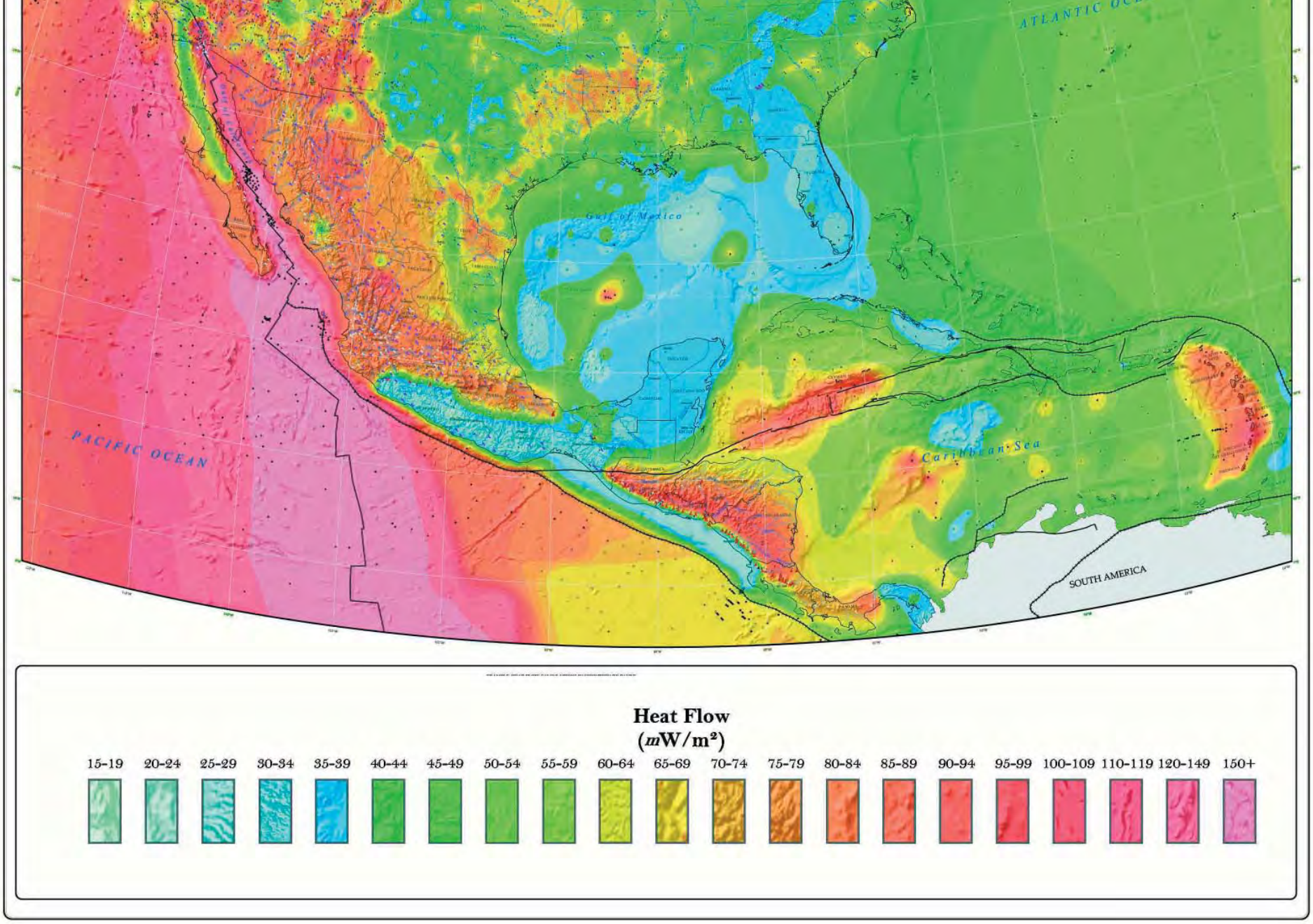
The Sun's luminosity (~1360 W/m^2) is the major driving force for climate. The interaction of this radiative heat flux with the atmosphere determines the climate. Carbon dioxide and methane, trace constituents in the atmosphere, are greenhouse gases that are naturally occurring while at the same time affected by human activities. Warming induced by anthropogenic sources of greenhouse gases must be separated from changes in the solar heat flux.



Seasonal and decadal changes in surface T are faithfully recorded by the ground as a sinusoidal temperature wave migrates into the subsurface. This signal is superimposed on the long term steady state geotherm and can be inferred by mathematical analysis.

Logs that monitor the surface changes in borehole temperatures suggest *both* an increase in the solar constant and forcing from anthropogenic sources of greenhouse gases. The effect is a turning of the T curve towards higher temperature (e.g inset in Figure 1) in the upper ten's of meters in boreholes from 46 to 50 ^{o}N.


GEOTHERMAL MAP OF NORTH AMERICA
2004
ARCTIC OCEAN
Hudson Bay
NO DATA
Beaufort Sea
Gulf of Alaska



David Blackwell and Maria Richards (editors)

Canadian Editors: Trevor Lewis, Jacek Majorowicz, Jean-Claude Mareschal
U.S. and Middle America Editor: David Blackwell
Ocean Basin Compiliation Editor: William D. Gosnold, Jr.

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Geothermal Map of North America, AAPG, 2004

Types of Data	*Measurements*
BHT Data from AAPG calibrated sites:	14,605 sites
Geothermal exploration sites:	4,045 sites
Conventional heat flow holes:	3,750 sites
Oceanic heat flow	3,740 sites

Contour interval: ~5 mW/m^2

The 2004 map published by the American Association of Petroleum Geologists is the framework for heat flow studies in North America for the 21st century. Heat flow measurements form the basis for determining the thickness of the thermal lithosphere, the transition from the surface of the Earth to the interior region where the temperature grows slowly with depth (from 10's °C/km to 0.1's °C/km).

The large scale features result from plate tectonic effects: high heat flow along mid-ocean ridges; cold zones near recent subduction zones, the western active margin; the hot Basin & Range, USA, as part of a back arc stretching from the Bering Sea to Central America, and the coldest zone associated with the thickest lithosphere near Hudson Bay.

Many subregional to small scale patterns are shown for the first time on this map because of the additional detail available at the 5 mW/m^2 contour interval. These patterns, in many cases, need to be investigated in detail to understand their significance and origin. Factors such as large scale aquifers and crustal radioactivity variations may give rise to this scale of anomalies.

The EARTHSCOPE project forms an obvious vehicle to provide new insights and detail on the horizontal scale of major heat flow variations.

Starkey Wilson Joins ISEM Board

By Louis L. Jacobs
President of I.S.E.M.

Starkey A.Wilson (B.S., 1951) was voted onto the Board of the Institute for the Study of Earth and Man last spring. He brings an eclectic resource perspective to the table having worked in oil, gas, coal and mineral exploration,, and most recently renewable energy. He also has been involved in coal and gold mining.

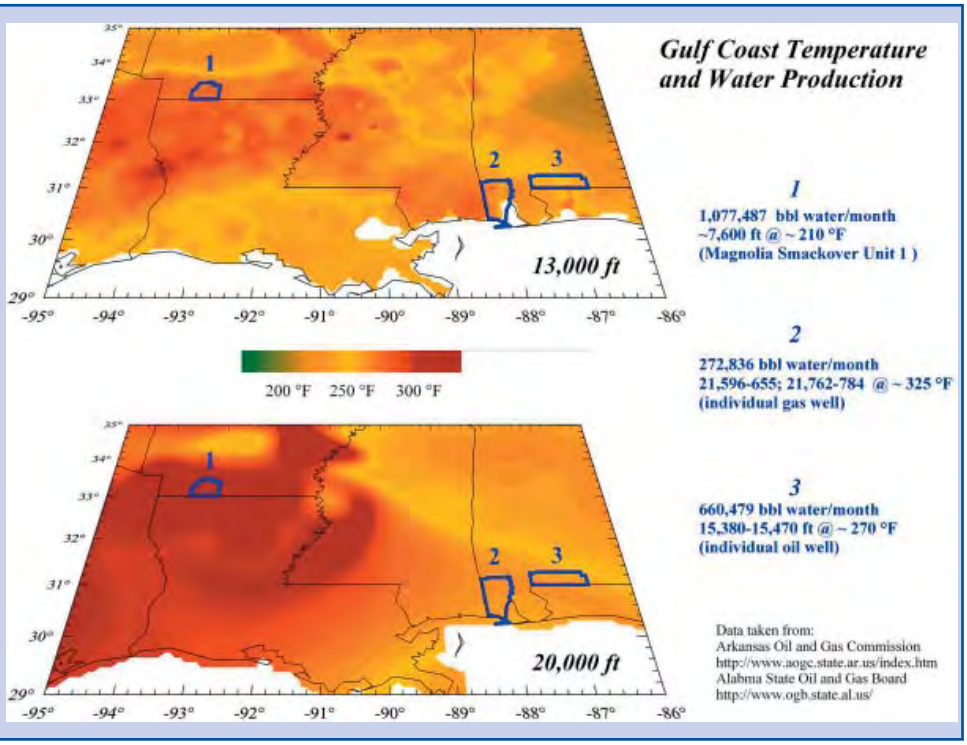
Starkey Wilson

Wilson's currrent passion is a project to bring electrical power generated from renewable resources to Akutan Island, part of the Aleutian volcanic belt. The island is home to the 2nd largest fish processing plant in the U.S which currently gets its power from diesel generators. Initially, the plan is to provide electricity and direct heat for the town of Akutan from the geothermal system present there and to use wind power for supplementary electricity generation.

In the future, Wilson envisions the possibility of using excess energy to split hydrogen from water that can be compressed and transported by sea to where its needed, a textbook economic geology exercise. Currently, much of the world's hydrogen is produced industrially by some variation of reforming steam at high temperature (water-gas reaction) using natural gas as a heat source; it consumes fossil fuel producing CO_2 that contributes to global warming.

continued from page 1

Figure 3: Inferred temperatures at the 13,000 ft and 20,000 ft levels for Louisiana and adjacent areas contoured in Fahrenheit using BHT and available geologic data. The warmest colors indicate temperatures in excess of 300 °F. Records from Arkansas and Alabama demonstrate sufficient water flows to sustain generation of electricity. With current technology, 1.5 MW of electricity generation requires approximately 10^6 barrels (bbl) of water production per month at a well temperature of 300 °F (McKenna et al. 2005).



News of alumni, faculty, & friends

Undergraduate Natalie Seaman (B.A., 5/2006) spent SMU's spring term at James Curtin University, Perth, Western Australia, as part of SMU's overseas exchange program. On a Curtin Geology Department field excursion, Natalie visited the famous Shark Bay locality, along the Indian Ocean, home of some of the world's best examples of stromatolites. The single celled cyanobacteria live on the surface of the carbonate mounds. They are reputed to be the first organisms to use photosynthesis to store part of the 1360 W/m^2 of energy from the Sun by splitting water to combine it with carbon dioxide to make carbohydrate. The release of oxygen into the atmosphere set the stage for aerobic respiration, the major source of energy for the animal kingdom.

Professor Louis Jacobs was recently awarded the Joseph T. Gregory Award for distinguished service by the Society of Vertebrate Paleontologists at its 2005 Annual Meeting in Phoenix.

Leslie Bleamaster, III, (PhD., 2003) saw the publication of his "*Atlas of Venus: Ovda Regio Quadrangle (V-35)*" and a paper on his new work on the canyons of Mars in *Geophysical Research Letters*. Les continues on at the Planetary Science Institute, Tucson, AZ., as a Research Scientist with funding from NASA.

Jerry C. Ingels, (B.S., 1955; M.S., 1957), Ergco, Inc., Dallas, presented a departmental seminar on *"Fracture Zones in Dallas County: Implications for the Extending the Balcones Fault Zone through Dallas County."*

Nancy McMillan (Ph.D., 1986), Professor at New Mexico State University spoke in the fall seminar series on the topic of "*Flat-slab subduction and the origin of Laramide magmatism in the Southwestern U.S.*"

Jason McKenna (M.S., 1998; Ph.D., 2002) accepted a position with the Army's research lab, ERDC, in Vicksburg, Mississippi, doing research in near-surface geophysical techniques. Jason most recently set up a local seismic network in Iraq.

S. Mihan House McKenna (Ph.D., 2005) defended her thesis in June which contained ground breaking work on infrasound that included an analysis of the Space Shuttle breakup over Texas. She is now a research scientist at ERDC, Vicksburg, Mississippi.

Petru Negaru (Ph.D., 2005) defended his three part thesis in April that concentrated on the coupling between air to ground waves at the Nevada Seismic Array and heat flow studies at Yellowstone Lake and in the Fort Worth Basin, TX. He is continuing on as a post-doctoral fellow in the department.

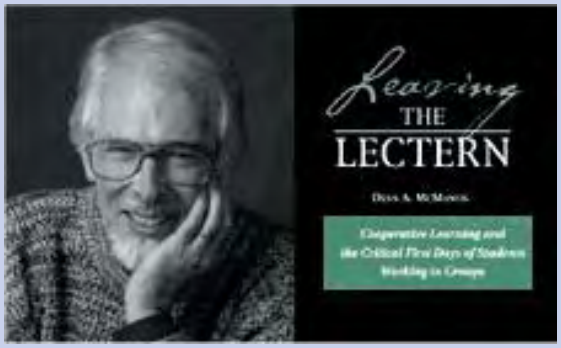
Douglas Oliver (Ph.D., 1996) presented a paper at the *Earth Systems 2* conference in Calgary, Alberta, this August. He continues his work on the angular momentum history of the Earth-Moon system.

Aaron Pan, current graduate student, presented an invited lecture at the Linnaean Society in Britain last spring.

Peter Rose (M.S., 2004) returned in June to participate in the opening of the new dinosaur exhibit that featured his thesis material at the Fort Worth Museum of Natural History.

Patrick Stepp (B.S., 12/2005) attended the SAGE field geophysics camp; he also did an internship at Sandia National Lab in geothermal energy.

Leighton Steward (B.S. 1957; M.S. 1959) became chairman of the Dedman College Advisory Board. He is the first to succeed the late Robert Dedman as Chair of the Board



Dr. Dean McManus (B.S., 1954), Professor *Emeritus* of Oceanography, University of Washington, reports the publication of his new book documenting his transformation from a classical university lecturer to a professional mentor in a cooperative learning environment. The journey is all the more remarkable because he accomplished the change in a large state research university environment. The book, "*Leaving the Lecturn: Cooperative Learning and the Critical First Days of Students Working in Groups*." is available from Anker Publishing, ISBN 1882982651.

Please share any career news and interesting photos with us for use in our newsletter. Contact Lisa Halliburton.
****All prior issues of Geology at SMU can be found online at***
http://www.smu.edu/geology

Geological Sciences Faculty, Southern Methodist University

David D. Blackwell, Hamilton Professor, Ph.D., Harvard. Geothermal studies and their application to plate tectonics, energy resource estimates and geothermal exploration.

James E. Brooks, Professor *Emeritus,* Ph.D., University of Washington. Stratigraphy and Sedimentology

Robert T. Gregory, Professor, Chair, Ph.D., California Institute of Technology. Stable isotope geology and geochemistry, evolution of earth's fluid envelope and lithosphere.

Eugene T. Herrin, Shuler-Foscue Professor, Ph.D., Harvard. Theoretical and applied seismology, solid earth properties, computer analysis of geophysical data.

Louis L. Jacobs, Professor, Ph.D., University of Arizona. President of the Institute for the Study of Earth and Man. Vertebrate paleontology, evolution.

Bonnie F. Jacobs, Assistant Professor and Chair of the Environmental Science Program, Ph.D., Arizona. Paleobotany & palynology of the Cenozoic. bjacobs@smu.edu.

A. Lee McAlester, Professor, Ph.D.,Yale University. Marine ecology-paleoecology, evolutionary theory, Paleozoic geology, petroleum geology.

Jason R. McKenna, Research Assistant Professor, Ph.D., Southern Methodist University. Thermal mechanical evolution of subduction zones.

Brian W. Stump, Albritton Professor, Ph.D., University of California, Berkeley. Seismology, seismic source theory, regional waves, seismic and infrasonic instrumentation.

Neil J. Tabor, Assistant Professor, Ph.D., University of California, Davis. Sedimentology, paleosols, stable isotopes and paleoclimate.

John V. Walther, Matthews Professor, Ph.D., University of California, Berkeley. Experimental and theoretical aqueous geochemistry, fluid-mineral interactions in the crust.

Crayton J. Yapp, Professor, Ph.D., California Institute of Technology. Stable isotope geochemistry applied to the study of paleoclimates, paleoatmospheres, and the hydrologic cycle.

Adjunct Faculty

Steve Bergman, Adjunct Assistant Professor, Ph.D., Princeton University. Tectonics, petrology & geochronology .

Anthony Fiorillo, Research Associate Professor, Ph.D., Pennsylvania. Curator of Paleontology, Dallas Museum of Natural History. Vertebrate paleontology.

Troy Stuckey, Adjunct Assistant Professor, Ph.D., University of North Texas, EPA, Environmental Science and Policy.

John Wagner, Adjunct Assistant Professor, Ph.D., University of Texas, Dallas. Chief Geologist, Nexen Petroleum, USA.

Alisa J. Winkler, Research Associate Professor, Ph.D., Southern Methodist University, Mammalian paleontology, anatomy.

Dale A. Winkler, Adjunct Associate Professor and Director, Shuler Museum of Paleontology, Ph.D., University of Texas at Austin. Paleontology, paleoecology, stratigraphy.

GEOLOGY FACULTY
EMAIL ADDRESSES

David Blackwell
blackwel@smu.edu
Robert Gregory
bgregory@smu.edu
Eugene Herrin
gloria@smu.edu
Louis L. Jacobs
jacobs@mail.smu.edu
Lee McAlester
mcaleste@smu.edu
Jason McKenna
jmckenna@smu.edu
Brian Stump
bstump@smu.edu
Neil J. Tabor
ntabor@smu.edu
John Walther
walther@smu.edu
Crayton J. Yapp
cjyapp@smu.edu

SOUTHERN METHODIST UNIVERSITY
Dedman College
Department of Geological Sciences
P.O. Box 750395
Dallas, Texas 75275-0395