

U T A H   G E O L O G I C A L   S U R V E Y

# SURVEY NOTES

Volume 42, Number 3

September 2010



## Utah's Glacial Geology

# THE DIRECTOR'S PERSPECTIVE



by Richard G. Allis

This issue of *Survey Notes* highlights the outstanding examples of the effects of past glaciations preserved in Utah's geologic record. The last 2.5 million years on Earth are known to have been relatively cool and composed of glacial and interglacial periods. For the last 11,000 years we have been in an interglacial period, which has caused Utah's alpine glaciers to melt and Lake Bonneville to shrink to become the saline Great Salt Lake. The articles in this issue provide a backdrop to the current discussion about global warming. Clearly, large-scale climate change has occurred in Utah (and elsewhere) over all geologic timescales, so obvious questions arising from the current discussion are: What is the evidence for change in Utah over the last century, and if there is change, what is the cause?

The first question is easier to answer than the second one. The National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) maintains statistics on temperature trends at weather stations, and one product that has a long

history in each state is the trends in "heating and cooling degree days." These trends are designed to provide up-to-date information on potential cooling fuel demands (from cooling degree days) and heating fuel demands (from heating degree days). Both trends are monitored by the energy utilities. A base temperature of 65°F is assumed, so temperatures above 65°F contribute to the cooling-degree compilation, and temperatures below 65°F contribute to the heating-degree compilation

The cooling-degree compilation, which is derived from the summer months, shows a pronounced warming trend since about 1970. However, the trend for heating degree days (mostly derived from the winter months) is less clear, with a possible warming trend from about 1970 to 2000, but a return to cooler winters since then. The two trends highlight the difficulties in trying to discern trends in a parameter like air temperature, which varies greatly on a daily and seasonal basis due to many factors. Fluctuations over a few years may not be representative of longer-term trends.

One set of data that naturally filters out the short-term air temperature fluctuations is the temperature observed at depth in boreholes. In northern Utah, the depth for potential freezing of the ground each winter extends to about 3 feet, and by about 30 feet depth, the temperature reflects the average annual temperature of about 50°F. Dr. David Chapman and his student Michael Davis, at the University of Utah Department of Geology and Geophysics, have been studying the longer-term air temperature changes inferred

from boreholes extending to over 1000 feet depth. A recent compilation of data from boreholes around Utah shows a systematic trend of recent warming above about 300 feet depth (see figure). When this is modeled, the simplest, best-fit trend in air temperature is a steady warming of about 1.8°F since 1915. The boreholes are in fairly remote locations and should not have been subject to heat-island effects that sometimes have influenced air temperatures near major cities.

Another climate dataset with a long history for Utah is the snow pack. Has it shown any signs of shrinkage that might be attributable to warming over the last century? Randall Julander of the Natural Resources Conservation Service has studied Utah's snow pack trends and concludes that the data since the early 1930s are equivocal. If there has been a warming trend of 1–2°F, he suggests that it may not be enough to affect the snow pack, which is dominated by precipitation trends (for accumulation) and by short-wave radiation trends (for melting).

For the second question raised at the beginning of this article about the cause of this warming, the majority of climate scientists attribute the warming to human activities such as increased greenhouse gas emissions from fossil fuel combustion. Other possible natural drivers of global warming, which caused past glacial and interglacial periods, do not fit the observed trends. Where there is no agreement, however, is on the politics of whether and how to act on global warming. ■

See figures on page 6.

## CONTENTS

Utah's Glacial Geology .....	1
Utah's Pleistocene Fossils: Keys for Assessing Climate and Environmental Change .....	5
Glad You Asked.....	7
Survey News .....	8
Teacher's Corner .....	9
Geosights.....	10
Energy News .....	12
New Publications.....	13

**Design:** Richard Austin

**Cover:** View west down the glacially sculpted, U-shaped valley of Little Cottonwood Canyon, with Salt Lake Valley and the Oquirrh Mountains in the distance. Photo by Taylor Boden.

### State of Utah

Gary R. Herbert, *Governor*

### Department of Natural Resources

Michael Styler, *Executive Director*

### UGS Board

Kenneth Puchlik, *Chair*  
 William Loughlin Jack Hamilton  
 Tom Tripp Alisa Schofield  
 Mark Bunnell Donald Harris  
 Kevin Carter (*Trust Lands Administration-ex officio*)

### UGS Staff

#### Administration

Richard G. Allis, *Director*  
 Kimm Harty, *Deputy Director*  
 John Kingsley, *Associate Director*  
 Starr Losee, *Secretary/Receptionist*  
 Dianne Davis, *Administrative Secretary*  
 Kathi Galusha, *Accounting Officer*  
 Linda Bennett, *Accounting Technician*  
 Michael Hylland, *Technical Reviewer*  
 Robert Ressetar, *Technical Reviewer*

### Editorial Staff Vicky Clarke

Lori Douglas, Stevie Emerson,  
 Richard Austin, Jay Hill

### Utah State Energy Program Jason Berry

Denise Beaudoin, Elise Brown,  
 Chris Tallackson, Jerriann Ernsten,  
 Brandon Malman, Will Chatwin,  
 Alex Dalpé-Charron, Jim Levy,  
 Deborah Boren, Sherry Childers,  
 Stefan Wilson, Alair Emory

### Geologic Hazards Steve Bowman

Richard Giraud, William Lund,  
 Greg McDonald, Jessica Castleton,  
 Gregg Beukelman, Chris DuRoss,  
 Tyler Knudsen, Corey Unger,  
 Lisa Brown, Ashley Elliott,  
 Barry Solomon

### Geologic Information and Outreach Sandra Eldredge

Christine Wilkerson, Patricia Stokes,  
 Mark Milligan, Stephanie Earls,  
 Emily Chapman, Lance Weaver,  
 Gentry Hammerschmid, Jim Davis

### Geologic Mapping Grant Willis

Jon King, Douglas Sprinkel,  
 Janice Hayden, J. Buck Ehler,  
 Kent Brown, Basia Matyjasik,  
 Don Clark, Bob Biek, Paul Kuehne

### Ground Water and Paleontology

**Michael Lowe**  
 James Kirkland, Janae Wallace,  
 Martha Hayden, Hugh Hurlow,  
 Don DeBlieux, Kim Nay,  
 Paul Inkenbrandt, Lucy Jordan,  
 Kevin Thomas, Rebecca Medina,  
 Walid Sabbah, Rich Emerson,  
 Stefan Kirby, Scott Madsen,  
 Toby Hooker

### Energy and Minerals David Tabet

Robert Blackett, Craig Morgan,  
 Mike Laine, Jeff Quick, Taylor Boden,  
 Thomas Chidsey, Cheryl Gustin,  
 Tom Dempster, Brigitte Hucka,  
 Stephanie Carney, Ammon McDonald,  
 Ken Krahulec, Valerie Davis,  
 Brad Wolverton, Sonja Heuscher,  
 Mike Vanden Berg, Andrew Rupke



Note to reader:  
This issue of *Survey Notes* includes several articles that discuss geologic features related to glaciers; see the “Geosights” article on page 10 for definitions and illustrations of many of these features.

# UTAH'S GLACIAL GEOLOGY

by Bob Biek, Grant Willis, and Buck Ehler

## Introduction

It is a humbling experience to drive up the Mirror Lake Highway, following the Provo River canyon deep into the heart of the western Uinta Mountains, and realize that, in the not-too-distant past, the canyon and alpine basins above were filled with hundreds of feet of glacial ice. Yet this canyon is just one of dozens in Utah's highest mountain ranges that held alpine glaciers during the Last Glacial Maximum (LGM), about 32,000 to 14,000 years ago. The glaciers also left behind stunning alpine scenery in the Wasatch Range, the high mountains and plateaus of central and southwest Utah, the La Sal Mountains, and even in some isolated mountains of the west desert.

The newly published *Glacial Geologic Map of the Uinta Mountains Area, Utah and Wyoming* (UGS Miscellaneous Publication 09-4DM) by Jeffrey Munroe (Middlebury College) and Benjamin Laabs (SUNY – Geneseo) gives us an opportunity to reflect on the state's glacial history and what it reveals about past climate change. This map is the first comprehensive inventory of glacial deposits of the Uintas since Wallace W. Atwood published his seminal *Glaciation of the Uinta and Wasatch Mountains* a century ago in 1909. With renewed interest during the past decade spurred by development of new dating techniques, other researchers began investigating glacial deposits of the High Plateaus and Wasatch Range, collectively painting a portrait of the climate and landscape during the LGM.

Alpine glacial deposits are remarkably hard to date. And, because younger glacial advances typically scour away or cover deposits of older advances, the alpine glacial record is remarkably incomplete.

View northwest from Dead Horse Pass in the Uinta Mountains (at the head of the West Fork of the Blacks Fork drainage basin); Deadhorse Lake is in the foreground. Note the smooth talus slopes on the left compared to the wrinkled surface formed by rock glaciers in the center of the photo. At the right side of the rock glacier complex, a rock avalanche deposit cuts across an older, subdued, grass-covered moraine and is itself partly covered by a younger moraine that formed about 1600 years ago. Recent work in this basin indicates that small glaciers were likely active at this location about 3500, 2500, and 1800 years ago, as well as during the Little Ice Age (150 to ~500 years ago). The large snowfield in the distance merges with a steep-fronted rock glacier; ongoing research will attempt to determine whether or not that rock glacier is active. Photo by Jeffrey Monroe.

Of the dozens of glacial advances that have occurred worldwide over the past 2 to 3 million years, only the last two are widely recognized in the Rocky Mountain region. Traditionally, researchers have used radiocarbon dating of plant debris associated with glacial deposits to determine the age of younger (less than about 60,000 years) glacial deposits. Recently, a new dating technique that uses cosmogenic exposure ages has proven useful (the technique measures the amount of time a glacier-deposited boulder has been exposed to the sun since last being moved), enabling more robust age control and correlation to other glacial deposits throughout the region.

Ironically, the best places to learn about glaciation are not in the spectacular glacier-carved U-shaped valleys themselves, but in nearby lake basins that preserve a more complete sedimentary record. In 1970, a 1000-foot-long sediment core was retrieved from Great Salt Lake. Known as the Burmester core (after the railroad causeway platform from which it was drilled), the core revealed evidence of



Aerial view east to Little Cottonwood and Bells Canyons, which display prominent lateral and terminal moraines of the Last Glacial Maximum. These are the only two canyons in which glaciers extended all the way down to Lake Bonneville, a result of their favorably situated high-elevation upper basins and lake-enhanced snowfall. Photo courtesy of the late Kenneth Hamblin, Brigham Young University.

four large freshwater lakes that occupied the Bonneville basin in the past 780,000 years. Lake Bonneville was the last of these, occupying the basin from about 28,000 to 12,000 years ago; older lake deposits include those of the Little Valley Lake (150,000 years ago), Pokes Point Lake (420,000 years ago), and Lava Creek Lake (620,000 years ago). Lake Bonneville existed during the latest glaciation of nearby mountain ranges, and in fact had a profound effect on glacier development as described below. Similar glacial episodes likely correlated with the older lakes as well.

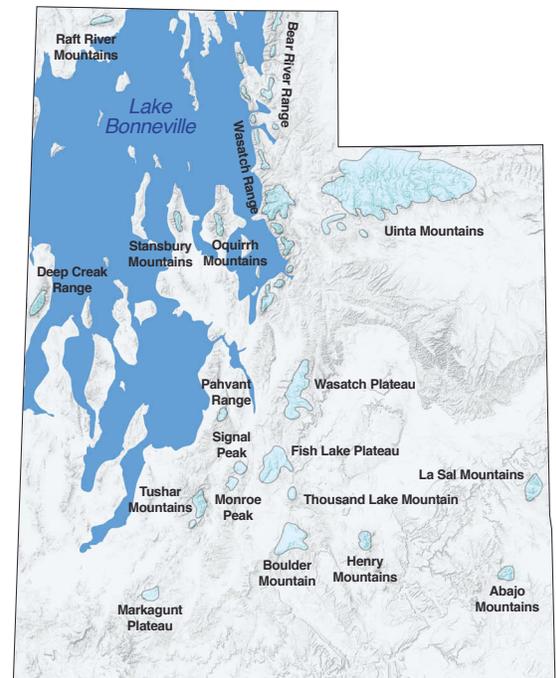
### Uinta Mountains

The spectacular Uinta Mountains, Utah's highest mountain range, held the state's largest alpine glaciers. Terminal moraines—arcuate ridges of unsorted rock and sediment that mark the farthest advance of a glacier—are among the most obvious glacial features. Heading up the characteristic U-shaped valleys, one may see recessional and lateral moraines, hanging valleys once occupied by smaller tributary glaciers, and amphitheater-like cirque basins studded with cirque and kettle lakes, striated and polished bedrock surfaces, glacial erratics, relict rock glaciers, and other glacial and neoglacial features. Downstream, valleys are choked with sediment deposited by glacial meltwater streams and rivers, which left behind terraced river chan-

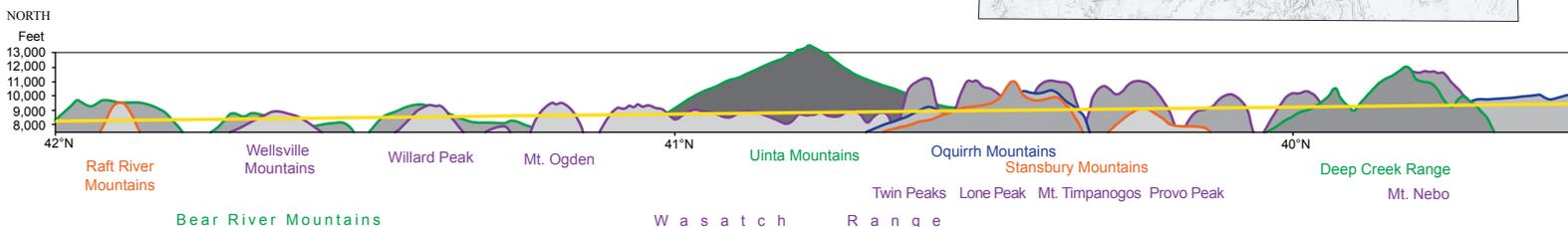
nels and outwash plains now occupied by relatively small, "underfit" streams. Such features are dramatic evidence not only of the latest glaciation, but also reflect scouring by repeated glacial advances over the past 2 to 3 million years.

The north side of the range held numerous long valley glaciers (the longest was the Blacks Fork glacier at 22 miles long), whereas the south side was dominated by six larger but shorter glaciers. The larger southern glaciers resulted from bigger snow accumulation areas, a result of the gentle dip of bedrock strata in this area compared to steeper dips on the north side of the range. The gently dipping strata were more easily eroded laterally by glacial action, enabling the carving of broad, high-elevation cirque basins on the south side of the range—favorable areas for accumulation of large amounts of glacial ice.

One of the most remarkable features of Uinta Mountain glaciation is the profound effect that Lake Bonneville had on glacier development. As a result of lake-enhanced precipitation from Lake Bonneville, glaciers grew larger and extended to lower elevations in the western part of the Uintas, which was closer



Utah map and north-south profile showing mountain and plateau crests high enough to have been glaciated during the Last Glacial Maximum (LGM). In northern Utah, glacial ice accumulated above elevations of about 8200 feet, whereas in southern Utah mountains needed to be above 10,000 feet to collect ice. Glaciologists use the term "equilibrium-line altitude" (ELA) to refer to the elevation above which snowfall will accumulate faster than it will melt (averaged over multiple years), thus thickening, compacting, and crystallizing into glacial ice. The position of an ELA is controlled by climate and thus varies over time, but when it is below mountain crests for long periods of time, glaciers develop. ELAs can also be used as a proxy to estimate temperature and precipitation during glacial advances. At the height of the LGM, central Utah was on average 7°F to 25°F (4–14°C) colder than today.





called the Younger Dryas (at this same time, a nearly desiccated Lake Bonneville rose to about 60 feet above the average level of today's Great Salt Lake, forming the Gilbert shoreline).

Just south of Little Cottonwood Canyon, the much larger Bells Canyon moraine shows that its glacier remained stationary for a longer time, indicating that it was less influenced by events that caused the Little Cottonwood glacier to undergo several minor advances and retreats. In addition to providing clues about the last glaciation, the Bells and Little Cottonwood Canyon moraines provide other important geologic information. Both are cut by the Wasatch fault, and studies of the faulted deposits have revealed valuable information on the recurrence history of major earthquakes that shook Salt Lake Valley.

### Does Mount Timpanogos Have a Glacier Today?

Mount Timpanogos, the second-highest mountain in the Wasatch Range, dominates the eastern skyline of Utah Valley. During the late 1800s and early 1900s, the cirque basin below the peak of Mount Timpanogos held a permanent snowfield that has been called "Utah's glacier" or "Timp glacier"; since then, a small snowfield commonly remains in that area throughout the year. Whether or not glacial ice was ever present in recent historical time has not been rigorously documented, but is doubtful. The site now appears to be a relict rock glacier, but ice could still be present at its core.

### Other High Mountain Ranges and Plateaus of Utah

Most of Utah's highest mountain ranges and plateaus, those soaring over 8200 feet in elevation in northern Utah and over 10,000 feet in southern Utah, show evidence of glaciation. Isolated ranges in western Utah, including the Stansbury Mountains, Deep Creek Range, and Raft River Mountains, show evidence of significant alpine glaciers. Towering over the redrock desert near Moab, the La Sal, Henry, and Abajo Mountains also held glaciers during the LGM. Among the best studied glacial deposits outside of the Uinta Mountains and Wasatch Range are those in the High Plateaus of central and southern Utah. This region is the focus of recent work by Western State College of Colorado geologist David Marchetti, who combines geologic mapping and cosmogenic dating techniques to tease apart the history and past climates recorded by these deposits. The Wasatch, Sevier, Markagunt, and Aquarius Plateaus, and the Pahvant Range, Tushar Mountains,

and Boulder Mountain all have documented evidence of glaciation during the LGM, and many show evidence of an earlier glaciation. Other slightly lower ranges may have had small glaciers.

The Crystal and Lowder Creek basins east of Brian Head on the Markagunt Plateau hold the southernmost glacial deposits in Utah. Recessional and lateral moraines and hummocky, stagnant ice topography are locally well developed, but sculpted bedrock is absent or inconspicuous, probably owing to the relatively small size and suspected short duration of the glaciers. Recent mapping by the UGS has revealed an older terminal moraine in front of these LGM deposits.

### Ancient Glaciers

Utah's mountains also contain ancient deposits associated with the world's most severe ice age, which occurred during the Precambrian Cryogenian Period, a time commonly referred to as snowball earth. Glacial deposits from this time are present in bedrock in Big and Little Cottonwood Canyons, on Antelope and Fremont Islands, and in several other western Utah mountain ranges. In the Wasatch Range, these 700- to 750-million-year-old deposits are known as the Mineral Fork Formation, poorly sorted and now-lithified sediment deposited from a retreating Greenland-like continental ice sheet that cut across underlying coastal-plain, estuarine, and tidal-flat sediments of the Big Cottonwood Formation.

### Summary

The stunning alpine scenery of Utah's highest mountains is the cumulative effect of repeated alpine glaciations over the past 2 to 3 million years that is linked to a worldwide pattern of glacial and interglacial cycles. Because successive glaciers typically overrode or buried older glacial deposits and landforms, only those of the last two glacial episodes are well documented in the state. Utah was largely ice-free by about 14,000 years ago, but younger glacial deposits from small ice advances associated with more recent minor climate fluctuations are known in the Uinta Mountains and High Plateaus of southwest Utah, and suspected in other areas. No glaciers are present in Utah today, but rock glaciers are known in many ranges; most are doubtless dormant, but some may still be active, including several in the Uinta Mountains. ■

## ABOUT THE AUTHORS

**Bob Biek** is a Senior Scientist with the UGS's Geologic Mapping Program. Since joining the Survey in 1996, he has published over two dozen geologic maps of 7.5' quadrangles along Utah's Wasatch Front and in the Heber Valley area, as well as in southwestern Utah. He was the lead author on the recently published St. George 30' x 60' quadrangle geologic map, and is currently in the middle of a four-year effort to compile a geologic map of the Panguitch 30' x 60' quadrangle.

**Grant Willis** has been a mapping geologist with the UGS for 27 years, including 16 years as manager of the Geologic Mapping Program. He has authored or coauthored over 40 geologic maps, and is currently mapping Glen Canyon National Recreation Area.

**J. Buck Ehler** has been a Geographic Information Systems (GIS) Analyst/Cartographer with the UGS Geologic Mapping Program for five years. He is a proud Utah native who grew up in Emery County. Buck graduated from Utah State University with a bachelor's degree in Geography with minors in Geology and GIS.





# UTAH'S PLEISTOCENE FOSSILS: KEYS FOR ASSESSING CLIMATE AND ENVIRONMENTAL CHANGE

by Don DeBlieux

As highlighted in this issue of *Survey Notes*, Utah is an outstanding place to study the geology of the Pleistocene Epoch, the so-called Ice Age. In addition to documenting the physical changes to the landscape, the geologic record also preserves evidence of Pleistocene plant and animal life. Many of Utah's Pleistocene species still live here today, but others no longer inhabit Utah or have disappeared completely. Investigation of Utah's Ice Age fossils provides important information on how plants and animals responded to past changes in climate. In this respect, it is not only fascinating to explore but is also pertinent to the issue of modern global climate change. By studying the effects of past climate change we can get a better idea of what changes we might expect in the future.

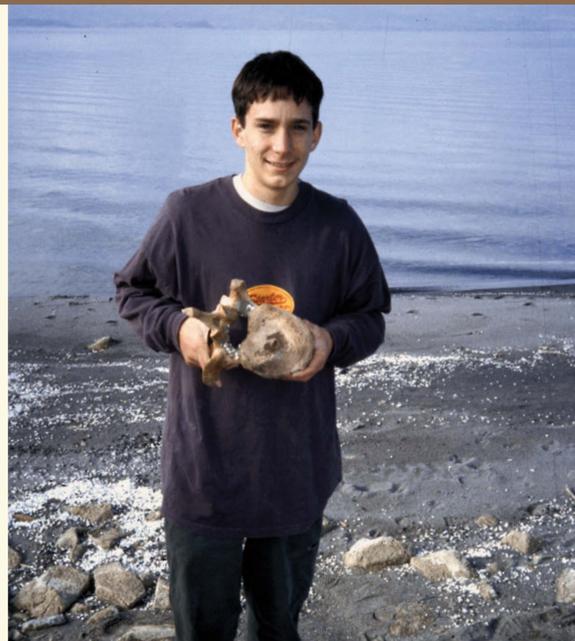
Dramatic climate fluctuations occurred throughout the Pleistocene. Glaciers advanced during colder and wetter times and retreated during warmer and drier times, and glacial lakes including Lake Bonneville expanded and contracted. These climate fluctuations changed the distributions of plants and animals as their preferred habitats were disrupted. Similarly, the distributions of plants and animals are changing today as cold-adapted species are forced to move farther north or to higher elevations, and species better suited to warm climates take their place. If climate change and habitat disruption occur slowly, then it is more likely that plants and animals can move to more favorable habitats. If environmental change proceeds quickly,

then there may not be enough time for these movements and the result may be the local, and in some cases total, extinction of species.

Much of what we know about the large animals that inhabited Utah during the Ice Age comes from fossils unearthed from sediments that were deposited along the shores of Lake Bonneville. Gravel-quarrying operations along the Wasatch Front occasionally expose the bones of Pleistocene mammals such as the mammoth, musk ox, giant bison, ground sloth, and giant short-faced bear (see *Survey Notes*, v. 28, no. 3, May 1996). The fossils also include bones of animals such as horses and camels that went extinct in North America at the end of the Ice Age but survived in Asia.

One of Utah's most famous Pleistocene fossil discoveries was a Colombian mammoth skeleton excavated in 1988 from Huntington Canyon by former Utah State Paleontologist David Gillette. This fossil is exceptional because it is nearly complete, very well preserved, and found at a higher elevation than any other known mammoth. The skeleton is housed at the College of Eastern Utah Prehistoric Museum in Price. Casts of this specimen are on exhibit in a number of museums including the University of Utah Museum of Natural History (UMNH).

Over the past 10 years several significant Ice Age fossil finds have been reported to the UGS. Two musk ox horns were discovered in 2001 in Lake Bonneville sediments in a



Tobin Warner on the shore of Bear Lake with the mammoth vertebra he discovered.

Tooele neighborhood by high school student Wendy Whitehead. She donated these specimens to the UMNH. A mammoth vertebra was discovered in 2004 on the shore of Bear Lake in northern Utah by Tobin Warner while he was attending a Boy Scout camp. Like Wendy, Tobin gave his fossil to the UMNH. To thank them for donating their finds to the museum where they are available for study, I made casts of the specimens so that they could have replicas for their personal collections. Casts of these specimens are also included in our Ice Age teaching kit (see



Scientists Dave Madsen, Don Grayson, and Jeff Hunt examining Homestead Cave deposits for small animal fossils. Photo by Monson Shaver.

tion about climate and the environment because we know more about the habitat preferences of the small, still extant species. Most of what we know about Utah's smaller Ice Age animals comes from just a handful of sites. Several of these are caves located in Utah's west desert, such as Crystal Ball Cave in Millard County and Homestead Cave in Box Elder County. The bones of tens of thousands of animals, including small mammals, birds, and fish, have been recovered from these caves. Most of the bones are thought to have been brought to the caves by birds of prey and other carnivores. Packrat middens in the caves preserve a record of plants that grew in the area. Ongoing research on the materials from these caves is helping to paint a picture of ecosystem change in the context of changing climate and, because they were near Lake Bonneville, changing lake levels.

Scientists are also studying how living animals are responding to the challenges presented by a changing climate. One animal that is being studied in this regard is the pika. This small relative of the rabbit inhabits mountain talus slopes in much of the Rocky Mountains and some mountain ranges of the Great Basin. We know from the Pleistocene fossil record that pikas once inhabited valleys and lowlands in the Great Basin. Because pikas cannot withstand the high temperatures or eat the vegetation

associated with today's valleys and lowlands, their populations are restricted to isolated mountain ranges. A number of pika populations have become locally extinct from mountain ranges in the Great Basin over the past several decades as a result of climate change and human impacts.

We know from the study of the past that our climate is highly variable and subject to dramatic shifts. We also know that these changes can take place relatively quickly, sometimes at a pace that is faster than the capacity of plants and animals to adapt. The study of Utah's Pleistocene geology and paleontology gives us information critical to assessing past environmental changes and can be used to evaluate the effects of future changes. ■

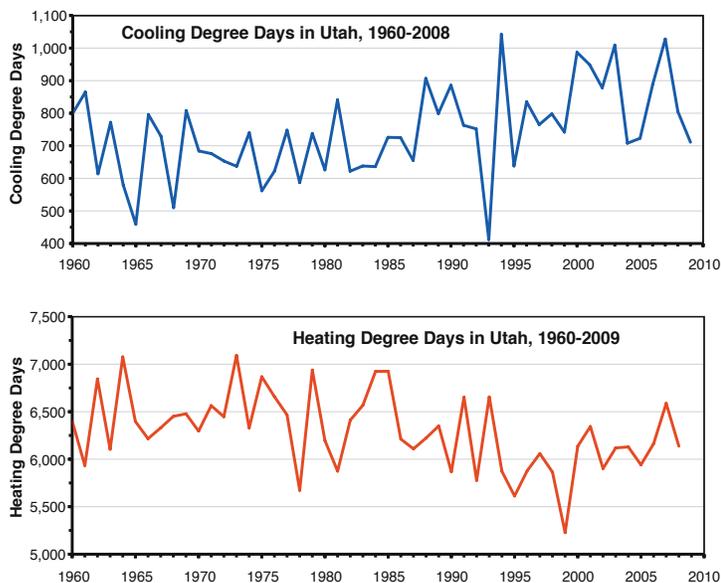
"Teachers Corner" in this issue of *Survey Notes*). In 2004, we received a call from Earl and Elaine Gowin who informed us that a mammoth tusk was found during gravel quarrying on their ranch near Fillmore. We excavated the tusk and brought it back to our lab in Salt Lake City to be cleaned and stabilized. The Gowins also donated their fossil, and the tusk is now on public display at the Fillmore Library.

Large animals like the Columbian mammoth excite the imagination, but the small animals provide a great deal of informa-

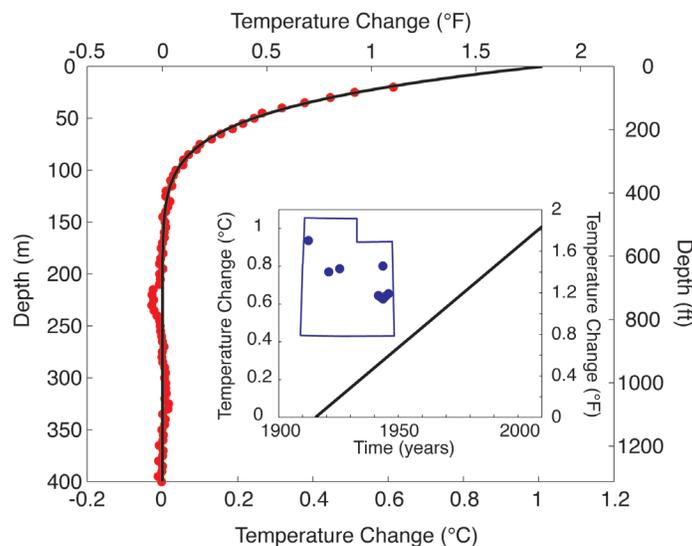


A pika on alpine talus. Photo courtesy of Mike Hylland.

## THE DIRECTOR'S *continued* PERSPECTIVE



Trends in cooling degree days (summertime) and heating degree days (wintertime) monitored by NCDC, and plotted on the UGS Web page: [geology.utah.gov/emp/energydata/hcdegreedata.htm](http://geology.utah.gov/emp/energydata/hcdegreedata.htm). This page contains links to the NOAA Web site.



Temperature change in Utah as determined from an average of borehole temperature measurements (red dots; map inset shows borehole locations). A linear ramp temperature fit to the observed data shows a surface warming of about  $1^{\circ}\text{C}$  ( $1.8^{\circ}\text{F}$ ) for Utah that began around the time of the first World War (inset) (Davis and Chapman, written communication).

# GLAD YOU ASKED

## Ice Ages – What are they and what causes them?

by Sandy Eldredge and Bob Biek

### What is an ice age?

An ice age is a long interval of time (millions to tens of millions of years) when global temperatures are relatively cold and large areas of the Earth are covered by continental ice sheets and alpine glaciers. Within an ice age are multiple shorter-term periods of warmer temperatures when glaciers retreat (called interglacials or interglacial cycles) and colder temperatures when glaciers advance (called glacials or glacial cycles).

At least five major ice ages have occurred throughout Earth's history: the earliest was over 2 billion years ago, and the most recent one began approximately 3 million years ago and continues today (yes, we live in an ice age!). Currently, we are in a warm interglacial that began about 11,000 years ago. The last period of glaciation, which is often informally called the "Ice Age," peaked about 20,000 years ago. At that time, the world was on average probably about 10°F (5°C) colder than today, and locally as much as 40°F (22°C) colder.

### What causes an ice age and glacial-interglacial cycles?

Many factors contribute to climate variations, including changes in ocean and atmosphere circulation patterns, varying concentrations of atmospheric carbon dioxide, and even volcanic eruptions. The following discusses key factors in (1) initiating ice ages and (2) the timing of glacial-interglacial cycles.

One significant trigger in initiating ice ages is the changing positions of Earth's ever-moving continents, which affect ocean and atmospheric circulation patterns. When plate-tectonic movement causes continents to be arranged such that warm water flow from the equator to the poles is blocked or reduced, ice sheets may arise and set another ice age in motion. Today's ice age most likely began when the land bridge between North

and South America (Isthmus of Panama) formed and ended the exchange of tropical water between the Atlantic and Pacific Oceans, significantly altering ocean currents.

Glacials and interglacials occur in fairly regular repeated cycles. The timing is governed to a large degree by predictable cyclic changes in Earth's orbit, which affect the amount of sunlight reaching different parts of Earth's surface. The three orbital variations are: (1) changes in Earth's orbit around the Sun (*eccentricity*), (2) shifts in the tilt of Earth's axis (*obliquity*), and (3) the wobbling motion of Earth's axis (*precession*).

### How do we know about past ice ages?

Scientists have reconstructed past ice ages by piecing together information derived from studying ice cores, deep sea sediments, fossils, and landforms.

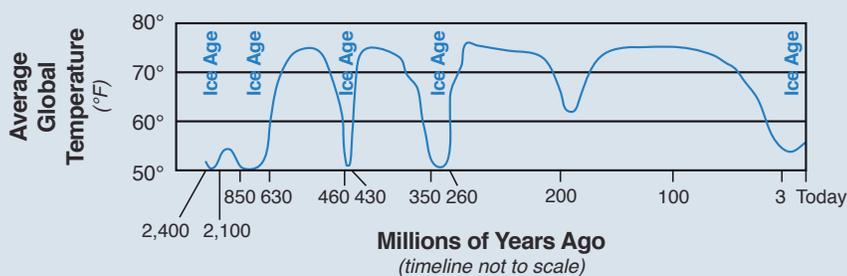
Ice and sediment cores reveal an impressive detailed history of global climate. Cores are collected by driving long hollow tubes as much as 2 miles deep into glacial ice or ocean floor sediments. Ice cores provide annual and even seasonal climate records for up to hundreds of thousands of years, complementing the millions of years of climate records in ocean sediment cores.

Within just the past couple of decades, ice cores recovered from Earth's two existing ice sheets, Greenland and Antarctica, have revealed the most detailed climate records yet.

### Do ice ages come and go slowly or rapidly?

Records show that ice ages typically develop slowly, whereas they end more abruptly. Glacials and interglacials within an ice age display this same trend.

### Ice Ages during the past 2.4 billion years



Simplified chart showing when the five major ice ages occurred in the past 2.4 billion years of Earth's history. Modified from several sources including *Dynamical Paleoclimatology: Generalized Theory of Global Climate Change, 2002*, by Barry Saltzman.

On a shorter time scale, global temperatures fluctuate often and rapidly. Various records reveal numerous large, widespread, abrupt climate changes over the past 100,000 years. One of the more recent intriguing findings is the remarkable speed of these changes. Within the incredibly short time span (by geologic standards) of only a few decades or even a few years, global temperatures have fluctuated by as much as 15°F (8°C) or more. For example, as Earth was emerging

out of the last glacial cycle, the warming trend was interrupted 12,800 years ago when temperatures dropped dramatically in only several decades. A mere 1,300 years later, temperatures locally spiked as much as 20°F (11°C) within just several years. Sudden changes like this occurred at least 24 times during the past 100,000 years. In a relative sense, we are in a time of unusually stable temperatures today—how long will it last? ■

### Glacial-interglacial cycles over the past 450,000 years



Four fairly regular glacial-interglacial cycles occurred during the past 450,000 years. The shorter interglacial cycles (10,000 to 30,000 years) were about as warm as present and alternated with much longer (70,000 to 90,000 years) glacial cycles substantially colder than present. Notice the longer time with jagged cooling events dropping into the colder glacials followed by the faster abrupt temperature swings to the warmer interglacials. This graph combines several ice-core records from Antarctica and is modified from several sources including Evidence for Warmer Interglacials in East Antarctic Ice Cores, 2009, L.C. Sime and others. Note the shorter time scale of 450,000 years compared to the previous figure, as well as the colder temperatures, which are latitude-specific (e.g., Antarctica, Alaska, Greenland) temperature changes inferred from the Antarctic ice cores (and not global averages).

#### FOR MORE INFORMATION:

*Abrupt climate change : inevitable surprises*, 2002, published by the National Academy of Sciences—a report from the Committee on Abrupt Climate Change, including members of the Ocean Studies Board, Polar Research Board, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, and National Research Council. Available online at [www.nap.edu/openbook.php?record\\_id=10136](http://www.nap.edu/openbook.php?record_id=10136)

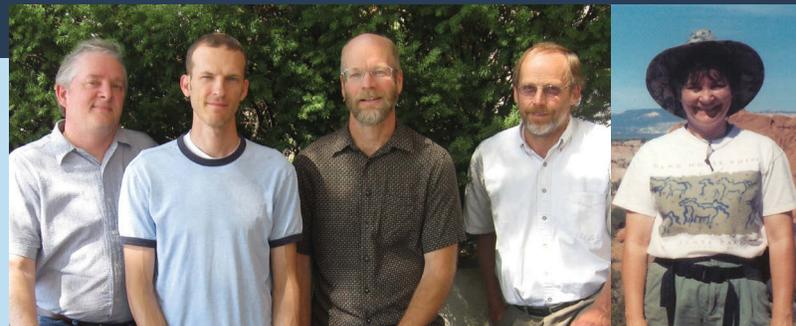
*North Greenland Eemian Ice Drilling project*— data from the 2010 NEEM project at [www.neem.ku.dk](http://www.neem.ku.dk)

## SURVEY NEWS

### 2010 CRAWFORD AWARD

The Utah Geological Survey awarded its prestigious 2010 Crawford Award to UGS geologists **Bob Biek**, **Grant Willis**, **Janice Hayden**, and **Lance Weaver**, and UGS senior GIS analyst **Kent Brown** in recognition of their outstanding geologic map and interactive Web version of the *Geologic Map of the St. George and East Part of the Clover Mountains 30' x 60' Quadrangles, Washington and Iron Counties, Utah* (UGS Map 242).

This map is one of the most impressive the UGS has ever published. It has an incredible 228 different geologic units. The process of combining new mapping with older existing maps greatly improved the understanding of several geologic enigmas that have stood for decades. The team was particularly innovative at finding ways to present essential explanatory information in one supporting plate and a booklet, as well as the new interactive Web-based 3-D format. You can view the interactive 3-D version at [geology.utah.gov/geo\\_guides/st\\_george/index.htm](http://geology.utah.gov/geo_guides/st_george/index.htm).



2010 Crawford Award winners (left to right) Kent Brown, Lance Weaver, Bob Biek, Grant Willis, and Janice Hayden (inset).

The Crawford Award was established in 1999 to commemorate the 50-year anniversary of the Utah Geological Survey. The award recognizes outstanding achievement, accomplishments, or contributions by a current UGS scientist to the understanding of some aspect of Utah geology or Earth science. The award is named in honor of Arthur L. Crawford, first director of the UGS.

# EMPLOYEE NEWS

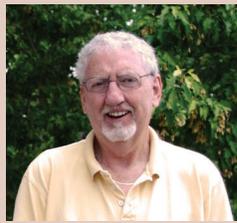
**NEW EMPLOYEES:** **Gregg Beukelman** has joined the Geologic Hazards Program as a Project Geologist. Gregg received his M.S. in Geology from Boise State University, and has worked with the U.S. Geological Survey and as an engineering geologist in Idaho. **Stephanie Earls** has accepted the position as librarian for the Department of Natural Resources Library. She recently graduated with a Master of Library Science degree from the University of Washington, and also has a B.S. in Geology from the University of Utah.

The Utah State Energy Program (USEP) has three new employees: **Sherry Childers**, **Alair Emory**, and **Stefan Wilson**. Sherry has a B.S. in Behavioral Sciences from the University of Utah and many years of experience in project management in the engineering, oil and gas, and computer science industries. Alair has a B.S. in Chemistry and an M.S. in Mechanical Engineering from the University of Washington and over 20 years experience working on energy, biotech, and defense projects. Stefan has a B.S. in Economics from the University of Utah and has worked for several years in the healthcare industry doing project management and marketing. They will be assisting USEP with the American Recovery and Reinvestment Act programs.

**RETIREMENTS:** **Roger Bon** recently retired from the UGS after 21 years of service. His work focused on the coal resources of Utah, but he also investigated oil and gas, industrial minerals, and uranium/vanadium deposits, produced small and large mine permit maps, and published annual Utah mineral activity summaries. Roger was instrumental in launching the Industry Outreach Program where he was responsible for providing information, updates, and results of UGS energy and mineral projects to the industry through UGS co-sponsored confer-



ences, exhibit booths, newsletters, Web site, and his many established contacts. He also served as President of the Utah Geological Association (UGA) and senior editor of UGA Publication 32, "Mining Districts of Utah." Roger's knowledge, expertise, and amiable personality will be greatly missed. We wish him well in his retirement!



**Bill Case** retired in June after 29 years of service with the UGS. Bill's geologic career with the UGS began with the former Applied Geology Program, where he worked on earthquake and landslide hazards. In the mid-1980s, Bill took the lead to develop and coordinate the Program's growing computer needs. By 1990, Bill's computer skills were employed full-time to coordinate and manage all of UGS's computers, thus becoming the UGS computer guru (to whom we all ran numerous times every day until his final day in June). Bill also worked as a geologist in the Geologic Information and Outreach Program. Bill's patience and incredible dedication to his job, along with his great camaraderie and sense of humor, will be greatly missed.



**Mage Yonetani** retired in June after 31 years of managing the UGS Library. Mage started as the librarian when the UGS was located in Research Park, and mustered through two major office moves—to Foothill Drive in 1991 and to the current location in the Department of Natural Resources (DNR) building in 1996, where her position expanded and she became the DNR Librarian. Mage's knowledge and professionalism combined with her cooperative, friendly spirit will be greatly missed. We wish Mage and Bill well in their retirement years together! ■

## teacher's corner

### Teaching Kits Available for Loan

The UGS first offered three rock and mineral kits (assembled by the son of a UGS employee as an Eagle Scout project) back in 1993—essentially the beginning of UGS's education outreach program. Since then, the UGS has expanded its education outreach, including the number and variety of teaching kits offered. Currently, four different kits are available: Rock, Mineral, and Fossil; Landforms; Ice Age; and Dinosaur.

 **Rock, Mineral, and Fossil kits** contain over 60 specimens (26 rocks, 27 minerals, and 16 fossils), a fossil environment map for Utah, and mineral testing tools. Teaching manual and activities geared to 4th and 8th grade science core curricula.

*Kits available: 10      Loan period: one month      Deposit: \$50 refundable*

 **Landforms kits** contain fault blocks, Wasatch fault fly-by video, maps, posters, a tectonics model, PowerPoint presentation, and a new teaching manual with numerous activities addressing the 5th grade science core curriculum.

*Kits available: 3      Loan period: two weeks      Deposit: \$50 refundable*



**Ice Age kits** contain 14 fossil specimens, including a Saber-toothed cat tooth and jaw, a musk ox horn, and a giant sloth claw; a raised relief map of Utah showing locations of glaciers and Lake Bonneville; a PowerPoint presentation; and a teaching manual with suggested activities for most grade levels.

*Kits available: 3      Loan period: two weeks      Deposit: \$50 refundable*



**Dinosaur kits** contain 36 cast specimens, including dinosaur bones, skulls, horns, skin impressions, teeth, claws, and a Stegosaurus plate; nine mini dinosaur replicas; teaching aids; a teaching manual; and activities for most grade levels.

*Kits available: 4      Loan period: two weeks      Deposit: \$100 refundable*



**Stream tables** are also available for loan and include a tray approximately 4 feet long by 1 foot wide by 2 inches deep, sand, and easy-to-use gravity plumbing. Tables are self contained, providing a mess-free stream erosion and deposition model for classroom use.

*Tables available: 3      Loan period: two weeks      Deposit: (a) none required if loaned with a landform kit, or (b) \$20 refundable without a kit.*

### Don't forget Earth Science Week!

Earth Science Week activities will be held this year October 4–7 (for activity details and further information, see [geology.utah.gov/teacher/esweek.htm](http://geology.utah.gov/teacher/esweek.htm)). Call 801-537-3300 to make reservations.

# GEO SIGHTS

## GLACIAL LANDFORMS IN BIG AND LITTLE COTTONWOOD CANYONS, SALT LAKE COUNTY, UTAH

by Sandy Eldredge

Big and Little Cottonwood Canyons contain some of the most dramatic glacial scenery in the Wasatch Range. This article highlights some of the numerous and varied glacial features in both canyons.

### Geologic Information

The Cottonwood Canyons and many of their tributaries and high-elevation basins were filled with hundreds of feet of glacial ice between 30,000 and 10,000 years ago. The Little Cottonwood Canyon glacier reached beyond the mouth of the canyon and extended into Lake Bonneville, calving ice bergs into the Ice Age lake. The Big Cottonwood Canyon glacier, however, advanced only about 5 miles down its canyon. Presumably this was due to less snow accumulation in Big Cottonwood's catchment area.

**Valley** (alpine) **glaciers** originate at the head of valleys in high mountain ranges and then flow down preexisting stream valleys. They erode and transport considerable amounts of rock debris, enabling them to significantly modify the landscape. Many distinctive erosional and depositional landforms result; however, this article addresses only the more prominent local features. Beautiful granitic rock that has been sculpted by glacial ice in both canyons enhances the spectacular rugged, mountainous scenery.

### Erosional Landforms and Features

Glaciers pluck and abrade a staggering amount of rock from the canyon walls and floors, which is then carried along with the moving ice. Thus, the hefty mass of rock material and ice perform some serious erosion. The valley bottom and walls are scoured vigorously, creating a deeper and much wider **U-shaped canyon**—one of the most distinctive valley glacial features.

At the head of canyons where glacial ice originates, glaciers carve out amphitheater-shaped basins (**cirques**) partially bounded by high, steep walls. Typically, small lakes (**tarns**) form in these depressions after the glaciers have retreated. Headward erosion cutting into the sides of a mountain peak by two or more glaciers chisels it into a sharp, often pyramid-shaped peak (**horn**). Between two adjacent glacial valleys or cirques, the dividing rock wall is eroded into a serrated, narrow ridge (**arête**).

Where tributary glaciers merge with the main glacier, the glaciers' surfaces are at the same level. However, the thicker main glacier erodes its canyon floor deeper than the tributaries so that when the glaciers recede, the floors of the tributaries are higher than the floor of the main valley—hanging above the deeper main canyon (**hanging valleys**).

*The Pfeifferhorn is an appropriately named peak; glaciers in Maybird Gulch (location of photo) and Hogum Fork to the west (photo right) carved the peak into a horn. The cirque at the head of Maybird Gulch is backed by a steep curved wall. The arête separating the tributary glaciers displays the characteristic narrow, jagged, and sharp ridge features often described as resembling the blade of a serrated knife. The glacial tributaries feed northward into Little Cottonwood Canyon.*



*Glacial striations have been etched into smooth slabs of bedrock around Lake Blanche (tarn) in Mill B South Fork, a southern tributary of Big Cottonwood Canyon. Sundial Peak is in the background.*

Rock fragments embedded in the base of a glacier will carve multiple, parallel linear grooves into underlying bedrock (**glacial striations**) and clearly show the direction of glacier flow. Striations are abundant in both canyons, although most are not close to the roads. Several good places to see these features are around Secret Lake at the head of Little Cottonwood Canyon in Albion Basin and around Lake Blanche in a tributary of Big Cottonwood Canyon.

### Depositional Landforms and Features

Glaciers deposit a chaotic mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape (**glacial till**). At the end of a glacier where melting dominates, the till is usually deposited in the form of a ridge (**end moraine**); a **terminal moraine** is the outermost end moraine marking the glacier's farthest point of advance. Similar ridge-like landforms are created along the sides of a glacier (**lateral moraines**).

Rocks, including house-size boulders that are carried by glacial ice, may be deposited far from their source (**glacial erratics**). Erratics are often found scattered on top of different bedrock than what they originated from.

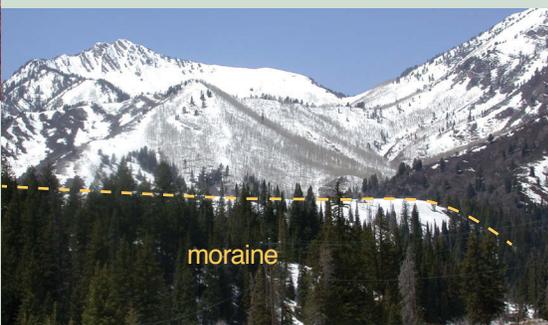
### Big Cottonwood Canyon

*(14.2 miles to Brighton, mileage begins at the junction with Wasatch Boulevard)*



The Big Cottonwood Canyon glacier reached only about 5 miles down the canyon where it abruptly ended. The lower 9 miles of the canyon are narrow and very twisty, which is a characteristic result of stream erosion.

At mile 9.0 (Reynolds Flat), the canyon suddenly widens and straightens, clear evidence that glaciers occupied the canyon from this point on up the canyon. The main glacier ranged in depth from 500 to 800 feet. **Glacial tributaries** (side canyons) add to the alpine scenery that now dominates. The first example is to the south where the U-shaped Mill D South Fork tributary leads up to a sharp, jagged ridgeline. This tributary glacier met the Big Cottonwood glacier at Reynolds Flat where they both stalled and did not advance below the tributary's terminal moraine here.



moraine

Looking down canyon from Reynolds Flat at the **terminal moraine** deposited by the Mill D South Fork tributary glacier.

Along the upper canyon are **moraines** (including a one-mile-long lateral moraine that is an aspen-covered 280-foot-high ridge, along the northeast side of the road below Brighton) and scattered white-colored granitic **glacial erratics**.

### Little Cottonwood Canyon

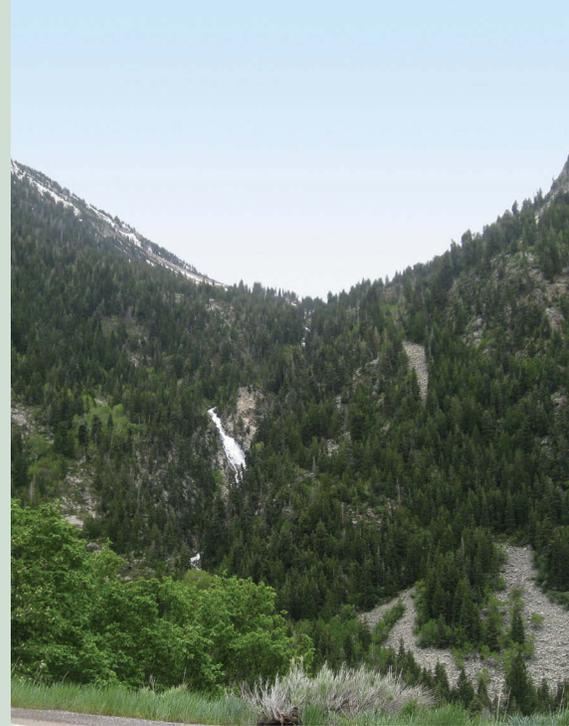
(8.5 miles to Alta, mileage begins at the UT-210 and UT-209 junction)

The Little Cottonwood Canyon glacier was the longest (12 miles) glacier in the Wasatch Range, extending beyond the canyon mouth and entering Lake Bonneville. The glacier ranged in depth from about 450 to 850 feet.

The first most obvious glacial feature is Little Cottonwood Canyon's world-class **U-shaped valley**. A photo and description of observable features at the canyon mouth are in "Utah's Glacial Geology" in this issue of *Survey Notes*. Also, see [geology.utah.gov/surveynotes/geosights/gilbertpark.htm](http://geology.utah.gov/surveynotes/geosights/gilbertpark.htm), which describes the G.K. Gilbert Geologic View Park just to the west of the canyon mouth.

**Hanging valleys**, often displaying scenic waterfalls, begin to appear within several miles on the south side of the canyon.

Other glacial features in the canyon include moraine remnants and glacial erratics. Also, cirques, arêtes, and horns can be seen up the glacial tributaries on the canyon's south side



Maybird Gulch shows the glacial tributary's U-shape and a waterfall cascading down from the hanging valley 3.5 miles up the canyon. Photo courtesy of Cali Mayer.

and near Albion Basin (accessible by vehicles in the summer) above Alta at the head of the canyon.

For additional information and more detailed maps about the Cottonwood Canyons, see [geology.utah.gov/geo\\_guides/c\\_wasatch/index.php](http://geology.utah.gov/geo_guides/c_wasatch/index.php).

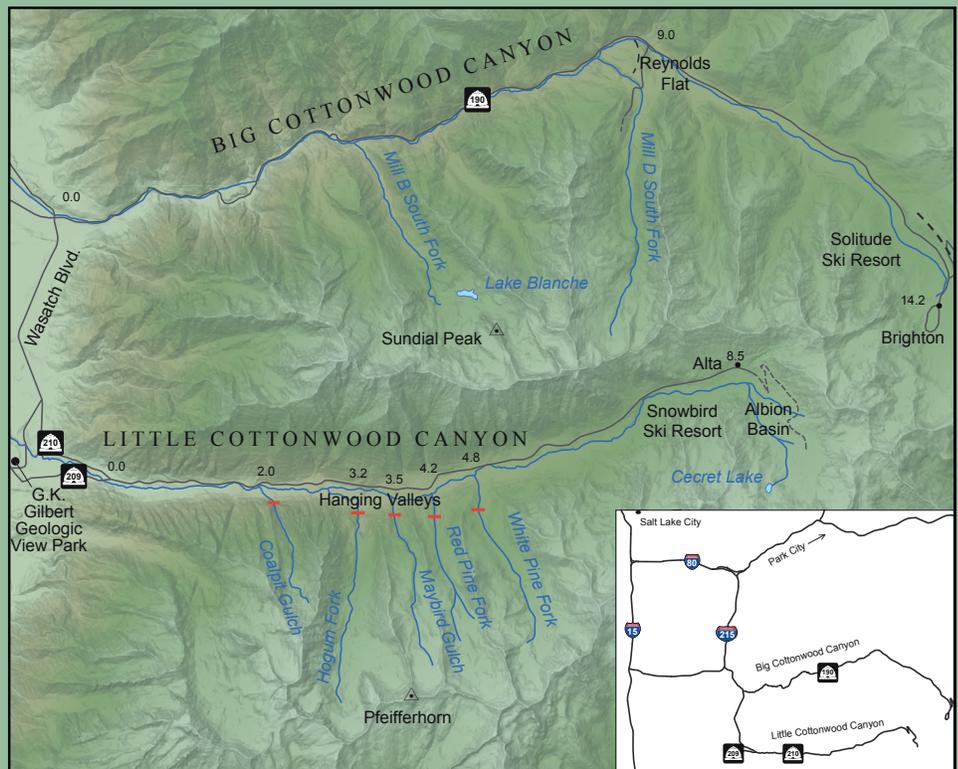
**How to get there:** From Salt Lake City, take exit #304 from I-15 onto eastbound I-80, and after 5 miles bear right at exit #128 onto southbound I-215. Travel 5.9 miles, take exit #6 at 6200 South and turn left (east). Within 1 mile the road becomes Wasatch Boulevard near a gravel pit. Travel 1 more mile to a stoplight. Go left to enter Big Cottonwood Canyon, or continue straight (south) to go to Little Cottonwood Canyon.

From the mouth of Big Cottonwood Canyon, head south on Wasatch Boulevard 2.1 miles to a stoplight. Continue straight for over 1 mile on UT-210 to the mouth of Little Cottonwood Canyon.

- Moraine Crest
- ~ Stream
- Gravel Road
- Road
- 0.0 Road Mileage



0 1 2 3 4 Miles



## URANIUM— FUEL FOR THE 21ST CENTURY?

by Roger Bon

World demand for uranium is increasing rapidly as the demand for electricity increases and more countries consider alternatives to carbon-based fuels. Over the past three decades, the U.S. has seen very little construction of new nuclear power plants, due in large part to public reaction following the incident at Three Mile Island in 1979. However, that may be changing as new energy legislation is being debated in Congress and incentives have recently been given to construct several nuclear facilities.

Prior to a surge in uranium prices beginning in 2004, all of Utah's 15 uranium mines were inactive or nearing permanent closure; most had been inactive since the early 1990s. The yearly average spot or short-term uranium price, which was about \$8/lb in 2001, rose to \$88/lb in 2007. The weekly spot price peaked at \$137/lb in late 2007 before entering a precipitous decline that appears to have stabilized with the current price near \$40/lb. These dramatic price fluctuations have affected uranium production and mine developments in Utah. As prices surged in 2004 and 2005, numerous mines and properties changed hands, and several inactive mines were being rehabilitated in preparation for production. The two leading companies in this endeavor were Denison Mines Corporation of Canada and White Canyon Uranium Ltd., of Australia.

International Uranium Corporation (IUC), a Canadian-based company with a long history of mining and milling on the Colorado Plateau, owned five uranium mines and the White



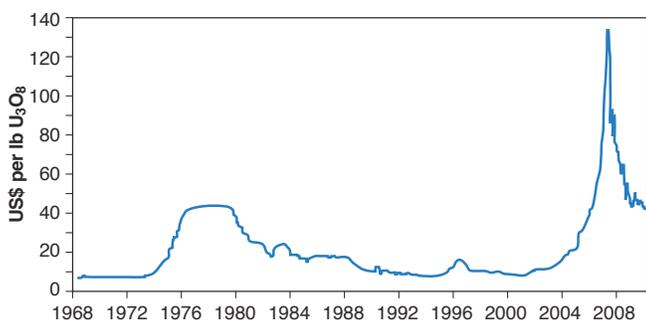
Newly developed Daneros mine entries. The mine is in the White Canyon district about 60 miles west of Blanding, Utah. The White Canyon district ores are in the basal Shinarump Conglomerate Member of the Upper Triassic Chinle Formation.

Mesa mill in Utah. IUC merged its operations with Denison Mines in 2005 to form Denison Mines Corporation. In September 2006, Denison's Pandora mine was the first to go into production, and it is still operating. Denison next began rehabilitating its Rim mine late in 2007, and it was brought into production in early 2008. The Rim operated until early 2009, when it was idled. Denison's third mine to go into production, the Beaver, was rehabilitated in late 2008, went into production in early 2009, and is still active. Denison's fourth mine, the Tony M, hosts the largest remaining uranium reserve in Utah. When Denison acquired the Tony M mine in 2005, the mine had nearly 17 miles of developed workings, most of which were flooded. Mine development began in early 2007, and in addition to rehabilitating the mine, most of the surface facilities were rebuilt. The Tony M produced from September 2007 to November 2008, when it was idled. Denison's fifth mine, the Redd Block, remains inactive. Denison's mines in Colorado have undergone a similar history: rehabilitation, limited or no production, and then idled. As of July 2010, Denison's only operating mines on the Colorado Plateau were the Pandora and Beaver. However, Denison also has one operating uranium mine in northern Arizona that opened in late 2009, and produces a higher grade ore than the mines in Utah.

uranium mines. The mine is ramping up production to about 50,000 tons per year. The ore is trucked to the White Mesa mill near Blanding, Utah, for processing under a toll milling agreement with Denison. The company is actively drilling properties near the Daneros for potential mine expansion.

All of the ore produced from the Colorado Plateau and northern Arizona is trucked to Denison's White Mesa mill for processing. Although relatively easy to mine, the Colorado Plateau uranium ore is of a lower grade than uranium ore mined elsewhere—typically 0.15 to 0.35 percent  $U_3O_8$  and about 1 percent  $V_2O_5$  (vanadium pentoxide). The mill, which began operating in the early 1980s, recovers both uranium and vanadium from ore, as well as from an alternate feed waste material that also contains relatively high-grade uranium. The 1800-ton-per-day mill can produce about 3 million lb of  $U_3O_8$ , often referred to as yellowcake due to its color, and 4.5 million lb of  $V_2O_5$ , or black flake, annually. White Mesa began processing alternate feed material in 2005, and stockpiled ore from its own mines and other mines on the Colorado Plateau in 2008. The mill produced 614,000 lb of  $U_3O_8$  and 501,000 lb of  $V_2O_5$  from conventional ore and alternate feed material in 2009, and although spot uranium prices remain low, the mill will continue to operate because of long-term contract commitments at higher prices, relatively high vanadium prices, and low-cost alternate feed material. Uranium ore production in Utah went from 1200 tons from one mine in 2006 to 138,000 tons from four mines in 2008, and then to 103,000 tons from four mines in 2009.

While there is a lull in mining activity in the U.S., world demand for uranium continues to grow as new nuclear power plants are being built overseas, most notably in China, India, and Russia. In 2009, 436 nuclear reactors operated in 30 countries that produced about 15 percent



Uranium spot prices from 1968 through mid-2010. Data courtesy of Trade Tech, ([www.uranium.info](http://www.uranium.info)).

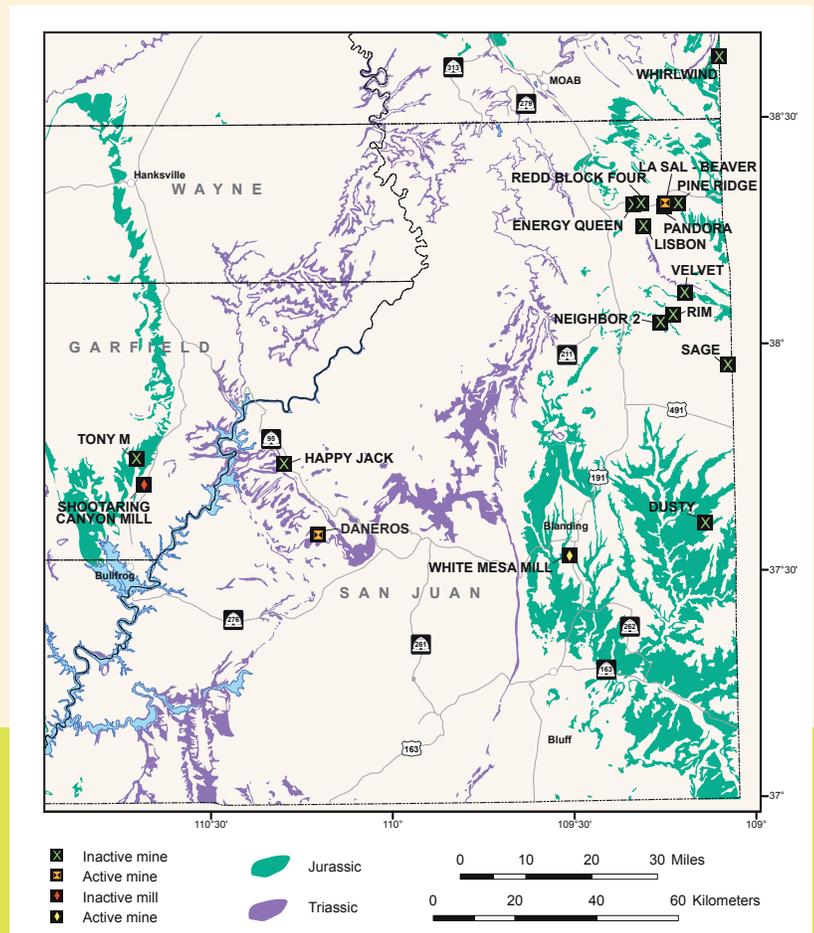
White Canyon Uranium has done a remarkable job of development in a short period of time. White Canyon's Daneros mine was permitted in May 2009, development began in July, and mining began in December. The Daneros is a relatively small, moderate-grade mine located near several historic

of the world's supply of electricity. In addition, 56 nuclear reactors are under construction in 13 countries. Denison estimates that 570 nuclear reactors will be operating worldwide by 2020, which would represent an increase in nuclear generating capacity of more than 30 percent in just 10 years. Based on this scenario, Ux Consulting Company LLC (UxC), one of the nuclear industry's leading consulting companies, recently estimated that uranium demand will grow from 185 million lb of  $U_3O_8$  in 2009 to 247 million lb in 2020. The World Nuclear Association reports that about 76 percent of current world demand is met from mined uranium, while the remainder is provided by reprocessed nuclear fuel, blending down of highly enriched uranium, and stockpiled reserves.

Could uranium become the "new" green fuel of the future? Is the current lull in mining in the U.S. the calm before the next boom? Will international suppliers step in to fill the demand? The answer to these questions will be answered in the next 10 to 20 years as the unrelenting demand for more carbon-free energy continues. Only time will tell how Utah's uranium industry will respond to these events. ■

#### FOR MORE INFORMATION:

Additional information on uranium and nuclear power can be found on the following Web sites: Energy Information Administration ([eia.doe.gov](http://eia.doe.gov)), International Atomic Energy Agency ([iaea.org](http://iaea.org)), U.S. Nuclear Regulatory Commission ([nrc.gov](http://nrc.gov)), UxC ([uxc.com](http://uxc.com)), and World Nuclear Association ([world-nuclear.org](http://world-nuclear.org)). For additional information on Utah's mining industry, go to [geology.utah.gov/utahgeo/rockmineral/index.htm#minactivity](http://geology.utah.gov/utahgeo/rockmineral/index.htm#minactivity).



Location and status of uranium mines and mills in Utah. Most uranium produced in Utah is from Mesozoic Jurassic (green) and Triassic (purple) sandstone and conglomerate.

## NEW PUBLICATIONS



**Geologic map of the Clear Creek Mountain quadrangle, Kane County, Utah**, by Michael D. Hylland, CD (2 pl.), scale 1:24,000, ISBN 978-1-55791-834-5, M-245 ..... \$14.95



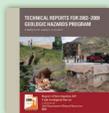
**Geologic map and coloration facies of the Jurassic Navajo Sandstone, Snow Canyon State Park and areas of the Red Cliffs Desert Reserve, Washington County, Utah**, by Gregory B. Nielsen and Marjorie A. Chan, CD (15 p., 2 pl.), OFR-561 ..... \$14.95



**Interim geologic map of the Shearing Corral quadrangle, Morgan, Rich, and Summit Counties, Utah**, by Jon K. King, 12 p., 1 pl., scale 1:24,000, OFR-565 ..... \$13.95



**Interim geologic map of the Vernon quadrangle, Tooele County, Utah**, by Stefan M. Kirby, 18 p., 2 pl., scale 1:24,000, OFR-564 ..... \$13.95



**Technical reports for 2002–2009 Geologic Hazards Program**, compiled by Ashley H. Elliott, CD (421 p.), RI-269 ..... \$19.95



**Interim geologic map of the Vernon NE quadrangle, Tooele County, Utah**, by Stefan M. Kirby, 10 p., 2 pl., scale 1:24,000, OFR-562 ..... \$13.95



**Interim geologic map of the Lofgreen quadrangle, Tooele County, Utah**, by Stefan M. Kirby, 17 p., 2 pl., scale 1:24,000, OFR-563 ..... \$13.95



**New techniques for new hydrocarbon discoveries—surface geochemical surveys in the Lisbon and Lightning Draw southeast field areas, San Juan County, Utah**, by David M. Seneshen, Thomas C. Chidsey, Jr., Craig D. Morgan, and Michael D. Vanden Berg, CD (61 p.), ISBN 978-1-55791-826-0, MP-10-2 ..... \$14.95



**Sunnyside tar sand deposit: Data and references from industrial exploration projects**, compiled by J. Wallace Gwynn, DVD (5 p. + 24 data folders), OFR-566 ..... \$14.95



**2009 Summary of mineral activity in Utah**, by Roger L. Bon and Ken Krahulec, 13 p., ISBN 978-1-55791-835-2, C-III ..... \$6.95



**Water-quality assessment of the principal valley-fill aquifers in southern Sanpete and central Sevier Valleys, Sanpete County, Utah**, by Janae Wallace, CD (132 p., 6 pl.), ISBN 978-1-55791-828-4, SS-132 ..... \$19.95



**Wetlands in northern Salt Lake Valley, Salt Lake County, Utah—an evaluation of threats posed by ground-water development and drought**, by Sandow M. Yidana, Mike Lowe, and Richard L. Emerson, 40 p., 6 pl., RI-268 ..... \$14.95

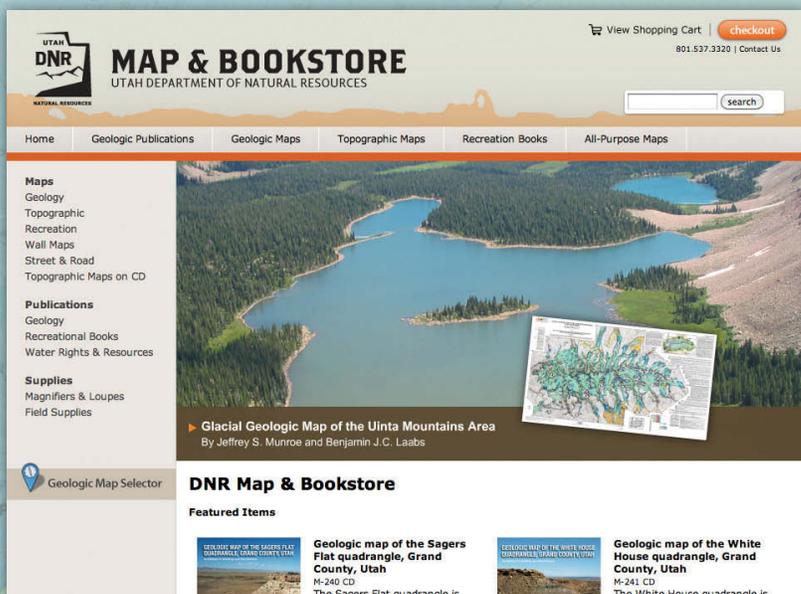


### UTAH GEOLOGICAL SURVEY

1594 W. North Temple, Suite 3110  
Box 146100  
Salt Lake City, UT 84114-6100

Address service requested  
**Survey Notes**

PRSR STD  
U.S. Postage  
PAID  
Salt Lake City, UT  
Permit No. 4728



## ONLINE SHOPPING IS COMING THIS FALL

### with the new Natural Resources Map & Bookstore Web site!

The new shopping cart will allow secure online purchasing of all maps, geologic publications, and recreational books. The easily searchable Web site features the entire inventory of Utah's topographic and geologic maps in an easy-to-use index system that shows the location of every map. For those who can't stop by in person, you can now conveniently shop online.

[www.mapstore.utah.gov](http://www.mapstore.utah.gov)

Order maps, publications, books, and more, easily online!

### NATURAL RESOURCES MAP & BOOKSTORE

1594 W North Temple      801-537-3320 or 1-888-UTAHMAP  
Salt Lake City, UT 84116      [mapstore.utah.gov](http://mapstore.utah.gov)

MONDAY-THURSDAY 7:00 A.M.-6:00 P.M.

## ORDER NOW!

### 2011 Calendar of Utah Geology

Featuring scenic photographs highlighting interesting and unique geology from around Utah. The calendar will be available in October. Order now and don't miss out!

**801-537-3320 or 1-888-UTAHMAP**

