UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 35, Number 3 August 2003

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Design by Vicky Clarke

Cover: *Sunset over Stansbury Island on Great Salt Lake. Photograph by Kent Vaughn.*

ISSN 1061-7930

The Director's Perspective

by Richard G. Allis

This issue of Survey Notes describes two UGS projects that investigate using geological formations for fluid storage. The artificial ground-water recharge project on the Weber River alluvial fan east of the city of Ogden will assess the effectiveness of diverting some river flow onto surface gravel deposits near the base of the Wasatch Range. The area is known to be the main recharge zone for a confined aquifer farther west from the mountain front. The consequences of continued urban growth, increased water usage, and the difficulties of developing new surface water storage (i.e., dams and reservoirs), make short-term subsurface water storage an increasingly attractive alternative. Most of the water diversion would occur during spring when excess snowmelt flows via streams into Great Salt Lake. Most of the municipal demand for water occurs during the months of July to September, so the additional, temporary ground-water recharge would help meet the subsequent seasonal demand peak. A similar aquifer storage project began in 2000 in the Jordan Valley Water Conservancy District (JVWCD) in southeastern Salt Lake Valley. However, in contrast to the natural surface recharge in the proposed Weber River project, the JVWCD project treats excess runoff water and injects it using wells directly into the underlying semi-confined aquifer.

The second UGS project investigates natural carbon dioxide (CO_2) occurrences beneath the Colorado Plateau as reservoir analogs for long-term, subsurface storage of CO_2. This assumes the gas can be economically separated from the flue gases of coal-fired power plants and can then be compressed and injected nearby into deep wells (likely to be more than 1000 m deep). In contrast to ground-water storage projects in which water is "stored" temporarily underground for near-future use, it is essential that the CO_2 remain trapped for at least the order of 1000 years to realize a long-term benefit from reduced CO_2 emissions to the atmosphere. In addition, the injected CO_2 must not contaminate near-surface ground-water resources. Long-term trapping requires the presence of excellent seal rocks overlying the CO_2 reservoir, and knowledge of where the relatively light CO_2 will migrate on this time scale. An added complication is that CO_2 is a reactive, acidic fluid that partially dissolves in the surrounding ground water, and reacts with minerals such as feldspars and carbonates in the reservoir host rock.

Both projects are outstanding examples of how geology has the potential to provide new solutions to environmental and resource issues confronting society in the 21st century.

Survey Notes is published three times yearly by Utah Geological Survey, 1594 W. North Temple, Suite 3110, Salt Lake City, Utah 84116; (801) 537-3300. The UGS is an applied scientific agency that creates, evaluates, and distributes information about Utah's geologic environment, resources, and hazards to promote safe, beneficial, and wise use of land. The UGS is a division of the Department of Natural Resources. Single copies of Survey Notes are distributed free of charge to residents within the United States and Canada and reproduction is encouraged with recognition of source.

New Aquifer Storage and Recovery Project to Augment Ground-Water Supplies in the Ogden Area

by Mike Lowe

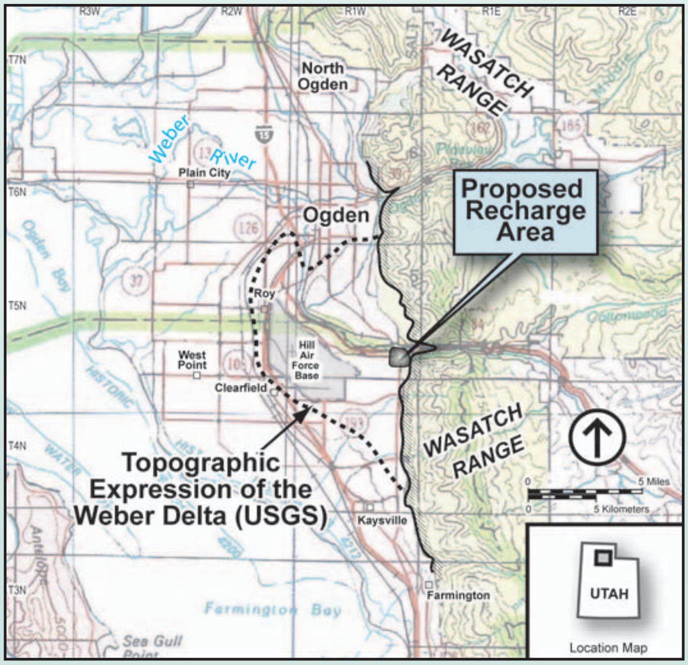
What is Aquifer Storage and Recovery?

Artificial ground-water recharge has long been recognized as a means of introducing water into the ground-water system to store water, reduce pumping lifts, salvage storm-water runoff, or enhance ground-water quality. Basically, ground-water aquifers (saturated rock or sediment that yield water in economic quantities to wells or springs) are used as water-storage facilities instead of constructing surface-water reservoirs. Artificial ground-water recharge can be accomplished by surface spreading or ponding of water in areas where surficial deposits are highly permeable, or by injection of surface water into an aquifer using wells. Interest in artificial ground-water recharge has increased in recent years due to declining water levels in many aquifer systems around the world, including Utah. Aquifer storage and recovery projects involve the storage of water in an aquifer via artificial ground-water recharge when water is available (usually during spring runoff), and recovery of the stored water from the aquifer when water is needed (usually late summer). Although losses of water stored via artificial ground-water recharge do occur, principally by water moving vertically or laterally out of the target aquifer before recovery, the sometimes significant losses of water through evaporation from surface-water storage facilities are largely avoided.

View looking east to mouth of Weber Canyon. Aquifer storage and recovery site at middle right margin of photo.

Ground Water in the Ogden Area

The most important ground-water resources in the Ogden area occur in unconsolidated to semi-consolidated Quaternary basin-fill deposits. These deposits consist of overall coarser grained alluvial-fan and stream-



Location of proposed aquifer storage and recovery project.

channel sediments near the mountain front, and overall finer grained lake and stream sediments westward away from the mountains. Two principal aquifers, the Sunset and Delta, have been delineated in the Ogden area. The Delta aquifer is the primary source of ground water in the Ogden area, and is composed mostly of coarse-grained, Tertiary-age stream and delta sediments. The top of the Delta aquifer is 500-700 feet below the ground surface in the Ogden area, and the aquifer is about 50-200 feet thick. The shallower Sunset aquifer has a lower permeability and is used to a lesser extent as a source of ground water. Fine-grained confining intervals overlie both aquifers away from the mountain front. However, these confining intervals are absent in a narrow band along the mountain front; this area where the confining layers are absent is called a recharge area. The recharge area in the Ogden area is widest at the mouth of Weber Canyon; most of the recharge to both the Delta and Sunset aquifers is from the Weber River in this ground-water recharge area.

The Problem

Ground-water levels in the Ogden area have declined since 1953, probably related to increased withdrawals from wells for municipal and industrial use. From 1953 to 1985, water levels declined an average of 27 feet in the Ogden area, with a maximum drop of 50 feet in the vicinity of Hill Air Force Base, Sunset, and Clearfield. Water levels in wells in the recharge area near the mouth of Weber Canyon declined as much as 40 feet during the same time period. The trend in declining water levels does not appear to have slowed; water-level declines of up to 30.8 feet were documented by the U.S. Geological Survey from 1970 to 2000. This overdraft of the aquifer has not only increased pumping lifts and hence operational costs, but could also initiate land subsidence or salt water intrusion from Great Salt Lake.

A Potential Solution

Aquifer storage and recovery within the Delta aquifer, either via land-surface infiltration or injection wells, offers a potential solution to the problems associated with the water-level decline in the Ogden area. During the 1950s, the U.S. Bureau of Reclamation conducted a series of on-site aquifer recharge experiments in the gravel pits at the mouth of Weber Canyon. Each of the experiments resulted in an increase in water levels in observation wells, and the experiments were deemed successful by Utah Water Research Laboratory investigators who reviewed the data in the 1980s. Now personnel from the U.S. Bureau of Reclamation, Weber Basin Water Conservancy District, Utah Division of Water Resources, Weber State University Department of Geosciences, and Utah Geological Survey are engaged in designing an initial pilot project at the mouth of Weber Canyon to determine the feasibility of full-scale aquifer storage and recovery in the Delta aquifer. During the initial phases of the project, personnel from these agencies are collecting water-level and water-quality data. These data will be used to provide a benchmark for measuring the success of the project after artificial recharge is initiated, likely through diversion of the Weber River into gravel pits or specially constructed ponding areas sometime between April and June 2004. The UGS is participating in the interpretation of water-quality data, water-level data (collected through a microgravity survey as well as measuring water levels in wells) and in writing the final report which will likely be published by the UGS. It is hoped that this project will not only provide a means of stabilizing water levels in wells completed in the Delta aquifer, but that it will also provide water planners and managers with increased flexibility in managing and perhaps increasing ground-water resources.

The Wolverine Petrified Forest

by Sidney Ash

Introduction

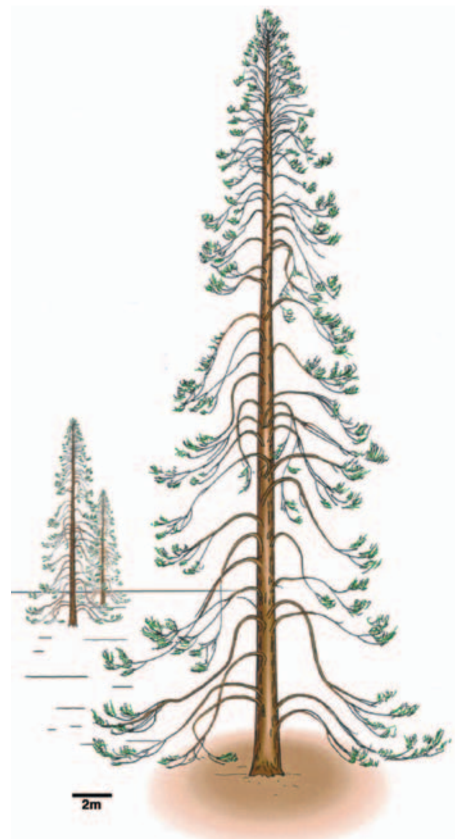
The second-largest fossil forest of its age in North America, if not the entire world, is in the Circle Cliffs portion of Grand Staircase–Escalante National Monument in southern Utah. However, because of its remote location, very few people know of its existence, much less have ever visited it. Furthermore, this forest has never been scientifically documented. Nevertheless, the Bureau of Land Management recognized its significance long ago and designated six sections of land as the Wolverine Petrified Wood Natural Area. The forest itself does not have an official name, but is sometimes called the Wolverine Petrified Forest. It lies about 15 miles southeast of the town of Boulder and 20 miles east of Escalante. Although the Wolverine Petrified Wood Natural Area includes about 3,800 acres, most of the exposed petrified wood and the largest logs are on the floor of an unnamed dry wash that drains into Wolverine Creek. Here the logs are mostly preserved in place and exposed by erosion; it is this deposit that is called the Wolverine Petrified Forest. Elsewhere in the Natural Area the wood consists mainly of small isolated blocks that were transported relatively longer distances after exposure. In some places, the gentle slopes are densely littered with blocks of all sizes.

Chinle Formation

The fossil wood preserved in the Wolverine Petrified Wood Natural Area originates from the Late Triassic Chinle Formation, which forms the generally reddish-colored slopes below striking vertical cliffs of tan sandstone here and throughout the Circle Cliffs region. This formation was deposited about 225 million years ago, at the beginning of the Age of Dinosaurs (Mesozoic Era), by rivers and streams on the floor of a broad basin on the western edge of the ancient supercontinent called Pangaea. At that time, Utah was geographically situated farther south than today, probably near the latitude of present-day Cuba. Streams in the Chinle basin were generally flowing in a north to northwesterly direction toward the sea, which occupied what is now eastern Nevada and California. The now-fossilized wood found in the Wolverine Petrified Wood Area came from trees that grew along the banks of one of these streams and possibly from adjacent highlands.

Although the Chinle Formation is reported to be about 550 feet thick in this area, most of the petrified wood it contains seems to be near the middle of the formation in a distinctive bed of pinkish sandstone about 10 feet thick. This bed is in the Petrified Forest Member and probably correlates with the Black Forest Bed in the upper part of the same member in Petrified Forest National Park, Arizona. Evidence for this correlation is based on bedding similarity and the presence of black fossil wood, some of which is restricted to the Black Forest Bed and equivalent rock units.

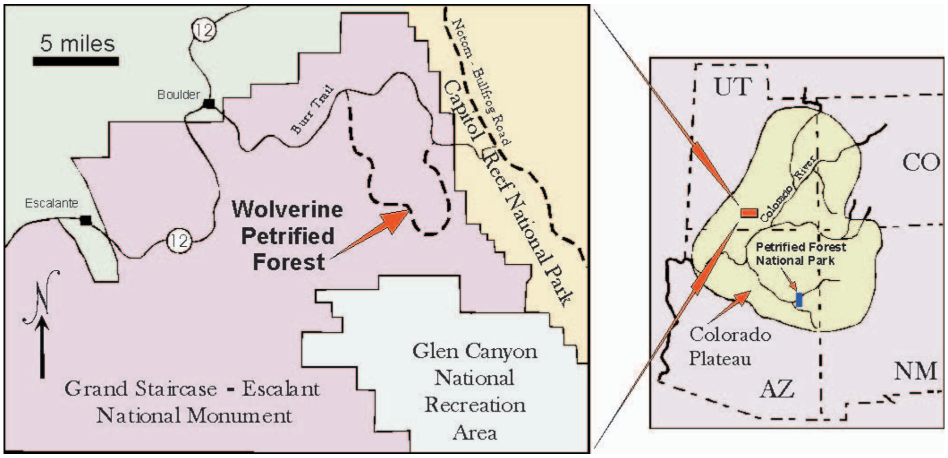
The bed of pinkish sandstone was deposited by only one of the many north-flowing streams that formed the Chinle Formation. The orientation of the logs seems to be random, although about one-quarter of them are oriented generally northeast. This may indicate that stream flow followed the same general trend. There are places in the bed of sandstone where as many as three logs overlap each other, suggesting that logs probably were carried into the area not just once but at several times during a relatively short interval during the Late Triassic.



Reconstruction of the living Araucarioxylon arizonicum *tree.*

Characteristics of the Fossil Wood

Unlike most of the fossil wood in the Chinle Formation elsewhere in Utah and in the more famous and much larger Petrified Forest National Park, the wood in the Wolverine Petrified Wood Natural Area is typically black on fresh surfaces. The original dark



Location of the Wolverine Petrified Forest in the northeastern corner of Grand Staircase-Escalante National Monument, Utah. The index map shows the location of the area in relation to the Colorado Plateau and of Petrified Forest National Park in Arizona.

Lower Jurassic		Wingate Sandstone
Upper Triassic	Chinle Formation	Church Rock Member
		Owl Rock Member
		Petrified Forest Member "Wolverine Petrified Forest"
		Monitor Butte Member
		Shinarump Member
Middle and Lower Triassic		Moenkopi Formation

Stratigraphic chart showing the geologic units exposed in the vicinity of Wolverine Petrified Forest and the approximate position of the petrified wood preserved in it.

General view of the strata exposed near the Wolverine Petrified Forest. Compare with the chart above. The strata in the steep cliffs are assigned to the Wingate Sandstone and all of the strata below the cliffs are assigned to the Chinle Formation. The arrow indicates the bed of pinkish sandstone that contains the petrified wood exposed in the forest and vicinity.

color of the specimens has been enhanced by the dark patina termed "desert varnish" that commonly develops on exposed rock surfaces in the southwestern United States and in other arid regions of the world. The surfaces of many of the logs are brownish when they are first exposed by erosion, but weathering soon removes the brown coloring and reveals the characteristic black color of the wood.

Most of the fossil wood in the Wolverine Petrified Wood Natural Area results from the petrification process called permineralization. In this process, empty spaces in the original wood have been filled with quartz and the original cell structure is visible with a microscope. The remaining organic matter in some of the wood was subsequently completely destroyed and then replaced by the same mineral; as a result, these fossils lack cell structure.

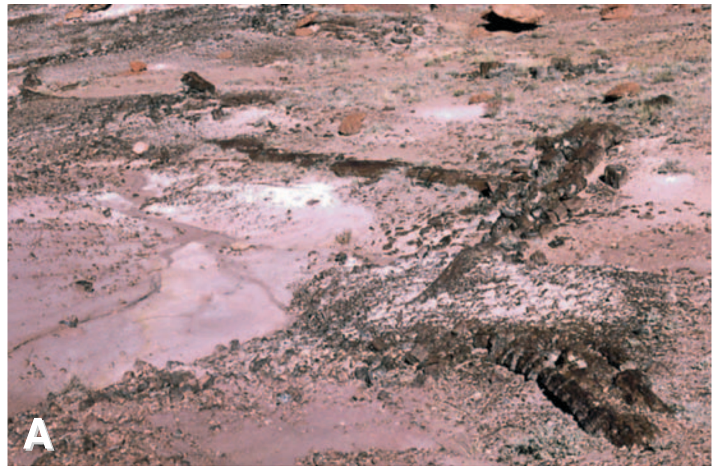
These fossils are clearly the remains of trees, because they look like tree trunks or fragments of tree trunks that have lost their bark as well as their limbs and roots. This similarity was not lost on the local Native Americans who traditionally considered them to be the spent arrow shafts of one of their gods. The stumps of limbs and roots are still attached to some of the trunks in the Wolverine Petrified Forest. Loss of the limbs and roots probably occurred mostly as the trees floated downstream. Many of the trees probably fell into the streams when the riverbanks they were growing on were undercut by channel erosion.

At least some of the trees in the Wolverine Petrified Forest were attacked by bark beetles and killed. The evidence for this consists of narrow, transverse ridges around the trunks that resemble structures formed by modern bark beetles between the bark and the wood of trees. Such girdling undoubtedly caused the deaths of some of these ancient trees just as it results in the death of modern trees. Eventually, the ancient trees that had been attacked would have fallen over after they died. Then, because of natural decay, they lost their limbs and roots on the forest floor before being washed into streams that formed this deposit.

The longest and most complete logs in the Wolverine Petrified Wood Natural Area occur in the Wolverine Petrified Forest. Here, the logs are up to nearly 100 feet long and range from about 1.5 - 3 feet in diameter. Because they are still partially buried, the logs evidently have not been moved by erosion since they were exposed many years ago, although parts of them have broken off and disappeared. A recent search of the Wolverine Petrified Forest revealed nearly 100 such in-place logs. Scattered between these more-or-less intact logs are hundreds of small blocks of petrified wood that were transported some distance after exposure and breaking off the large logs. This process is ongoing and the fossil wood continues to be broken into still smaller and smaller pieces. In many places along the walls of the wash, more logs and small fragments of logs are just now being slowly exposed to view by erosion.

Extinct Trees of the Forest

Most of the fossil wood appears to represent *Araucarioxylon arizonicum*, a species of fossil wood common throughout the Chinle Formation at many localities in Utah, Arizona, and New Mexico. A small amount of a second species of wood called *Woodworthia arizonica* is also present in Wolverine Petrified Forest. It has a much more limited distribution and occurs mostly in Petrified Forest National Park in a bed that probably was deposited at the same time as the petrified wood-bearing bed in the Wolverine Petrified Wood Natural Area. Both species are extinct, and we can only surmise what they looked like when living.



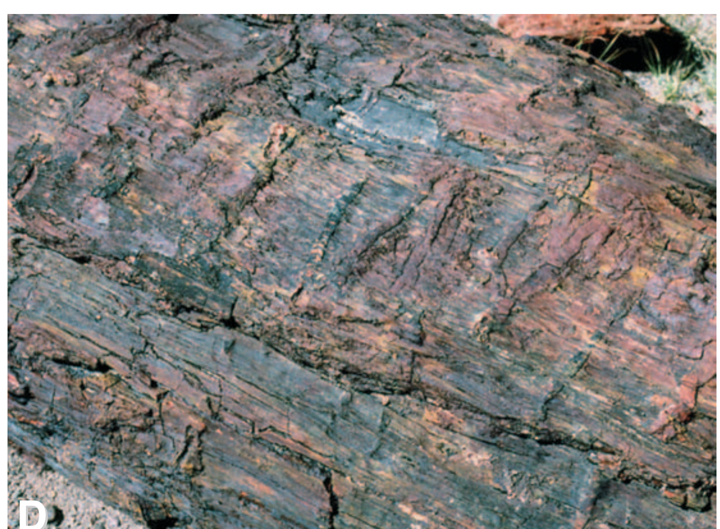
A. View of an ancient "log jam" in the process of being exposed by erosion in the Wolverine Petrified Forest. These logs still retain the brown coloring that is found on the exterior of the wood before it has been subjected to weathering after exposure.

B. Close-up of a log showing the stump of a large lateral branch. The surface of the log is still brown in color because it has just been exposed by erosion. Black wood is exposed where the end of the lateral branch has been broken off. Note the pick for scale.

C. A large trunk of the Araucarioxylon arizonicum *tree showing a lateral root protruding upward in front of the figure (arrow).*

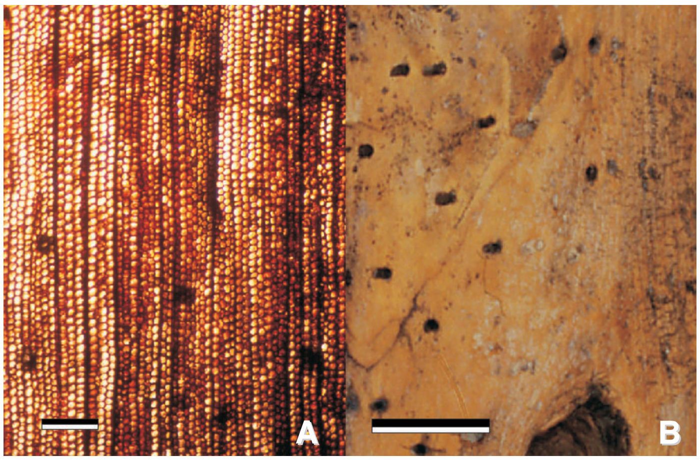
D. Transverse ridges on a log of Araucarioxylon arizonicum *formed by bark beetles between the bark and the wood of the tree. The ridges are about 1/2 inch wide.*

E. Slightly expanded root structure on the base of the trunk of an Araucarioxylon arizonicum *tree which is overlapped by a second trunk in the Wolverine Petrified Forest.*



The Wolverine Petrified Forest can be reached from the town of Boulder by driving about 18 miles east on the Burr Trail, which is paved in this section, to a rough unpaved side road that travels south. The forest is about 8 miles south of this junction on the south side of the road in the area where the road crosses the usually dry Wolverine Wash. A small parking area is provided here and the forest is briefly described on a nearby sign. For peace of mind on visits to the area, a high-clearance or four-wheel-drive vehicle is recommended, especially in wet weather or shortly after rainstorms.

Visitors to the Wolverine Petrified Wood Natural Area are reminded to leave the petrified wood for others to enjoy. In fact, collecting of anything, including petrified wood, in Grand Staircase – Escalante National Monument is now illegal to all but permitted researchers. Qualified researchers can obtain the exact location of the Wolverine Petrified Forest from representatives of the Bureau of Land Management.



A. Cross section of the wood of the Araucarioxylon arizonicum *tree showing the cells as seen through the microscope. This is an example of permineralization mode of preservation. Scale bar equals 150 microns. B. Surface of the trunk of a* Woodworthia arizonica *tree showing the small branch scars characteristic of this fossil. Scale bar equals 2 centimeters.*

However, a recent study of the trunks identified as *Araucarioxylon arizonicum* that are exposed in Petrified Forest National Park showed that the mature tree had a diameter of nearly 10 feet about 5 feet above the base and stood as much as 180 feet tall. The trunk of the tree tapered evenly from a slightly expanded base to the top. A ring of steeply inclined roots grew into the ground at steep angles and a long, stout taproot held the tree upright. Lateral branches had no systematic arrangement on the trunk and diverged from it at steep upward angles. Presumably, the branches swept downward and outward so as to present a large area of foliage to solar radiation. The apices of the branches may have turned upwards slightly like certain modern trees. Most of the branches likely carried viable foliage until the tree died. The bark was relatively thin and modern looking. As is typical of modern trees growing in the tropics, the wood did not contain annual growth rings, although it did show evidence of occasional growth interruptions. Unfortunately, the leaves and reproductive structures are unknown. The taxonomic relationships of the tree are unknown beyond saying it is an extinct conifer of some type.

Unlike the smooth surfaces of the trunks of the *Araucarioxylon arizonicum* trees, the fossil trunks of the *Woodworthia arizonica* tree are covered with distinctive small, shallow holes about 1/4 inch in diameter. These holes apparently represent small branches that never fully developed. The tree was about half the height of the *Araucarioxylon arizonicum* and also had lateral branches irregularly arranged along the trunk. Like the wood of the *Araucarioxylon arizonicum* trees, the wood of the *Woodworthia arizonica* tree does not have annual growth rings and its leaves and reproductive structures are unknown. Thus, it can only be treated as another type of extinct conifer.

No fossil leaves, cones, or seeds have been found in the bed of sandstone that contains the Wolverine Petrified Forest, but other beds in the Chinle Formation in the area do contain such fossils. These fossils indicate that a variety of ferns, cycadophytes, conifers, and other small plants inhabited this part of Utah at other times during the Late Triassic. Similar plants probably grew beside the trees now represented by the fossil trunks in the Wolverine Petrified Forest but for some unknown reasons were not preserved.

Summary

The 225-million-year-old Wolverine Petrified Forest of southern Utah documents one brief episode in the long geologic history of the state. The forest contains the fossilized remains of several elements of an ancient terrestrial ecosystem that existed in southern Utah at the beginning of the Age of Dinosaurs. These fossils and the rocks that contain them indicate that the climate has changed over the years and that this area was not always a desert. In fact, this was a moist tropical environment in which large trees and probably other plants grew along the banks of many streams and rivers.

About the author:

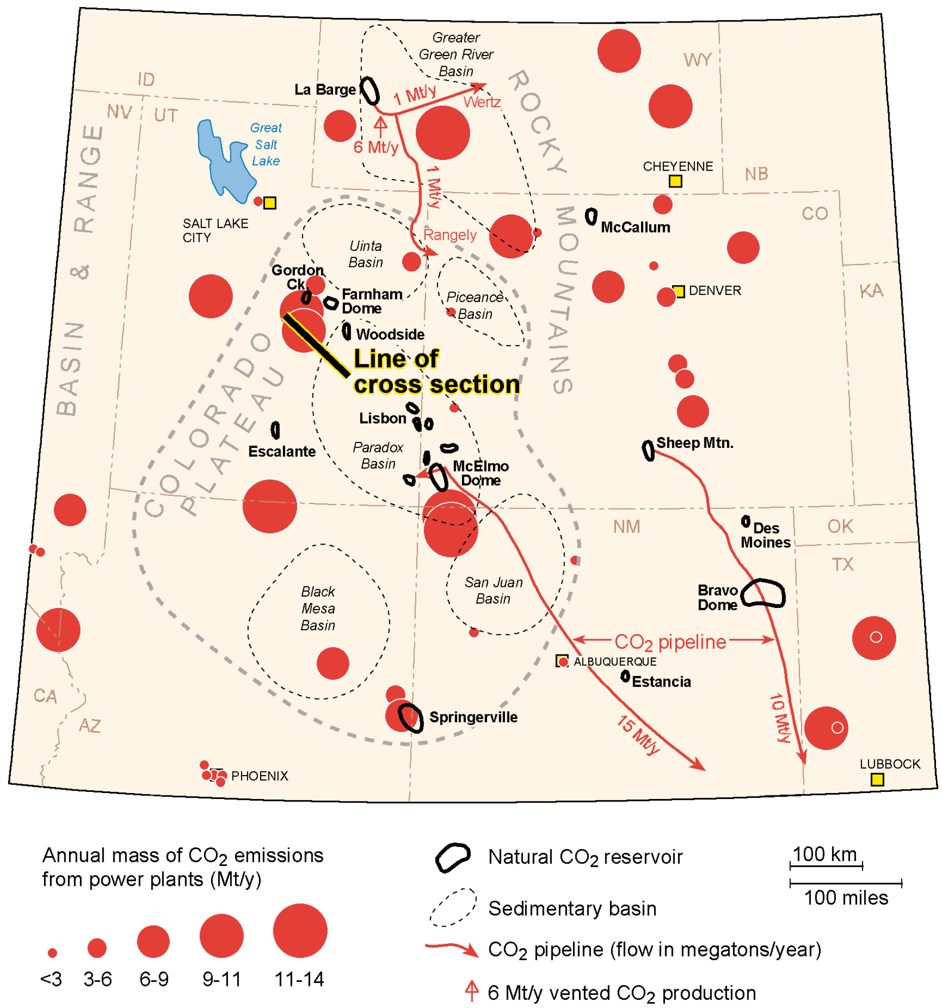
Dr. Sidney Ash is an adjunct professor of Earth and Planetary Sciences at the University of New Mexico in Albuquerque. Prior to retirement a few years ago he was Professor of Geosciences at Weber State University in Ogden, Utah. Ash specializes in the study of the plants of the Age of Dinosaurs and has published many articles about them in professional journals. He first visited the Wolverine Petrified Wood Area in 1972 while searching for plant fossils in the Chinle Formation.

Storing Carbon Dioxide Beneath the Colorado Plateau

By R.G. Allis

Last year the President announced a "Global Climate Change Initiative" goal of reducing the nation's greenhouse gas intensity by 18% between 2002 and 2012. The greenhouse gas intensity is the ratio of total annual greenhouse gas emissions (mostly carbon dioxide [CO_2], plus methane, nitrous oxide, and other gases) divided by the gross domestic product. This ratio is considered to be an indicator of the reduction in gas emissions that can occur without affecting economic growth. The underlying philosophy is that stimulating and applying the technologies required for stabilizing and ultimately reducing greenhouse gas concentrations is best achieved by sustained economic growth. Between 1990 and 2000 the U.S. reduced its greenhouse gas intensity by 12%, so the target for the next decade is a challenging one.

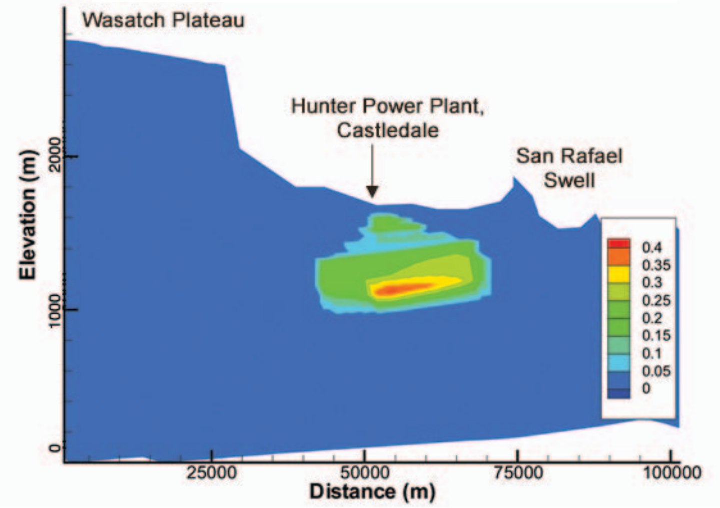
A growing priority for the Department of Energy (DOE) is the development of technologies that will assist carbon sequestration, including carbon capture, separation and storage, and reuse ("sequestration" implies the long-term storage of CO_2). For the past three years the Utah Geological Survey, together with colleagues from the Energy and Geoscience Institute (University of Utah), and Industrial Research Limited (New Zealand), have been involved in a carbon sequestration project supported by the DOE. This project investigates the probable fate of CO_2 if it can be economically separated from power plant flue gases and injected beneath the Colorado Plateau. A critical issue is how long it will remain trapped in the subsurface. Effective sequestration requires a time scale of about 1,000 years without significant leakage back to the surface.



Map shows the major occurrences of known gas fields having high concentrations of CO_2. Red dots are the point sources of CO_2 emissions from power plants with dots sized according to the amount of annual CO_2 emissions (in million metric tons). The line of cross section is the location of the modeling profile shown in the accompanying figure.

The Colorado Plateau has several factors that make it attractive as a possible sequestration region. It has broad, relatively simple, geologic structures with proven reservoir-seal rock layers and potentially large storage capacity; many nearby large coal-fired power plants that represent major point sources of CO_2 emissions suitable for capture and separation; and natural CO_2 fields that prove it is possible to store the gas in the subsurface on a geological time scale (see map above; Mt/y is the flux of CO_2 in units of million tons per year). It also contains two pipeline networks that transport CO_2 from several of these natural fields to enhanced oil recov-

Gas saturation 1000 years after CO_2 injection into White Rim Sandstone beneath Hunter Power Plant



Colors on profile show the computed fraction of CO_2 gas residing in the rock pores 1000 years after a 30-year period of injection of CO_2. The peak fraction of 0.4 means that 40% of the pore volume is occupied by CO_2 gas. CO_2 will also be present dissolved in the pore water and locally in the form of precipitated carbonate minerals. The modeled rate CO_2 injection is equivalent to the emissions from a 500 MW coal-fired power plant. This modeling indicates that most of the CO_2 is still trapped underground after 1000 years.

ery projects in southern Wyoming, western Colorado, and west Texas. Power plants in the region presently emit over 100 million tons per year of CO_2 to the atmosphere, and there is an additional 30 million tons per year of production from the natural CO_2 fields. This amounts to roughly half the total CO_2 emissions in the region.

Our study of the natural CO_2 fields shows they are similar to conventional natural gas fields, with gas trapped in dome-like structures. The most common reservoir lithologies are sandstone and dolomite, with mudstone, shale, and anhydrite being the most common sealing rocks. The horizontal dimensions of the gas reservoirs (~ 10 kilometers or 6 miles) are typically 100 times larger than the thickness. Stacked CO_2 reservoirs (or occurrences) are not uncommon, indicating that gas has migrated up through the rock section. In the CO_2 fields where petrological and geochemical work on rock and fluids has been possible (some central Utah fields and Springerville field, southeast Arizona), the present-day fluids are supersaturated in dolomite and calcite. At Springerville, the influx of CO_2 appears to have caused early precipitation of dawsonite (sodium-aluminum-carbonate). These CO_2 fields indicate that natural, long-term storage of carbon has occurred as precipitated carbonate minerals (mineral trapping) as well as by hydrodynamic trapping of gas and dissolved CO_2 in the pore water.

Modeling of the fate of injected CO_2 has been carried out using a computer program that considers both the two-phase behavior of CO_2 and fluid-rock reactions. The models have been applied to cross sections through typical geologic structures of central Utah, incorporating the mineralogy and physical properties of the units (for example, permeability, porosity, mineral thermodynamics, and capillary pressure functions for seal rocks) in the sedimentary sections. An important finding of the modeling is that structural traps are not essential for sequestration of the CO_2, as shown in the adjacent figure, and all three trapping mechanisms (as solid, liquid, and gas) are important.

In the model shown here, CO_2 has been injected into the White Rim Sandstone at about 1 kilometer (0.6 mi) depth for 30 years and at a rate equivalent to that emitted by a 500 megawatt, coal-fired power plant. Although there is a regional dip to the section and the CO_2 gas tends to move up-dip (to the east) as well as up-section with time, after 1,000 years 70 percent of the injected CO_2 remains trapped subsurface. The colors show the fraction of gas in the pores (gas saturation). The modeling suggests that there is ample storage in geologic structures beneath the Colorado Plateau, but a critical factor is whether the reactions that precipitate CO_2 have time to occur. These reactions typically require time scales of hundreds of years, so subsurface trapping for at least 500 years is essential. If major, high-permeability faults are present then loss of CO_2 to the surface could make the injection site unsuitable for CO_2 sequestration.

Preliminary findings from this work have been presented at the 1st and 2nd National Conferences on Carbon Sequestration in Washington, DC (2001 and 2003), and are available on the UGS website at http://geology.utah.gov/emp/co2sequest/index.htm.

- **Natural CO_2 Reservoirs on the Colorado Plateau and Southern Rocky Mountains: Candidates for CO_2 Sequestration.** Allis, R., White, S., Chidsey, T., Gwynn, W., Morgan, C., Adams, M., Moore, J.: Proceedings of the First National Conference on Carbon Sequestration, Washington DC, May 2001.
- **CO_2 injection potential beneath large power plants in the Colorado Plateau-Southern Rocky Mountain region, USA.** Allis, R.G., Chidsey, T.C., Morgan, C., Moore, J. and White, S. P.: Proceedings of the 2nd National Conference on Carbon Sequestration, Washington DC, May 2003.
- **Investigations of CO_2 mobility in natural reservoirs beneath the Colorado Plateau and Southern Rocky Mountains.** Moore, J.N. Allis, R.G., Lutz, S., Adams, M.: Proceedings of the 2nd National Conference on Carbon Sequestration, Washington DC, May 2003.
- **Injection of CO_2 into an Unconfined Aquifer Located beneath the Colorado Plateau, Central Utah, USA.** White, S.P., Allis, R.G., Moore, J.N., Chidsey, T.C., Morgan, C., Gwynn, W., Adams, M.: Proceedings of the 2nd National Conference on Carbon Sequestration, Washington DC, May 2003.

Petroleum Geologist's Convention a Big Success

Salt Lake City was the site of the 2003 American Association of Petroleum Geologists (AAPG) Annual Convention this past May. The AAPG is the largest geological society in the world with over 32,000 members. Overcoming a heightened terrorism level, fears of SARS, war jitters, and a shaky economy, nearly 5,000 geologists, including representatives from 48 states and 77 countries, attended the convention to exchange the latest petroleum research results, learn about state-of-the-art technology, network, and make drilling deals. The Utah Geological Survey (UGS) played a major role in the success of this event.

Using the convention theme "Energy – Our Monumental Task" depicted on a backdrop of famous Monument Valley in Arizona and Utah, UGS geologist and Convention General Chairman Tom Chidsey opened the convention with a welcoming address that promoted the geology, exploration history, and future potential of petroleum in Utah. Holding a torch from the relay for the 2002 Winter Olympic Games, Chidsey symbolically declared, "Let the Convention Begin!"

Utah was selected by AAPG for the convention because it has consistently remained in the top 15 oil- and gas-producing states in the U.S and, most importantly, the rocks so well exposed in Utah make for one of the best natural laboratories in the world for petroleum geologists. The convention included 17 field trips with over 350 geologists examining rocks all over Utah. Many of the field trip leaders were UGS geologists showing the attendees (some braving heavy rain and snow!) areas where the Survey has conducted mapping and petroleum projects such as the Uinta Basin, Ferron Sandstone, and several national parks; Mark Milligan (UGS) served as the field trip chairman.

Over 800 technical presentations were given at the convention – the main purpose of the meeting. Several UGS geologists presented results of Survey petroleum projects (Paradox Basin horizontal drilling study, carbon dioxide sequestration, and coalbed methane) and served as session chairs. The teacher program was also a big success and was co-sponsored by the UGS; Sandy Eldredge (UGS) served as the chairperson. Eighty-five Utah teachers attended field trips and a special workshop called "More Rocks in Your Head" (held at the Department of Natural Resources) where they received accreditation. The UGS also sponsored a very well attended short course at the Utah Core Research Center where the drilling potential of ancient reef-like mounds in southeastern Utah was presented through examination of oil-well cores (see article in the previous Survey Notes). Finally, the UGS prepared a wonderful display of historical photographs from the early days of oil and gas exploration in Utah.

In summary, geologists from around the world left Salt Lake City knowing that Utah is a great host, whether you are an Olympic athlete or someone who searches for energy, and that Utah is a great place to study geology and conduct an energy search.

Convention General Chairman Tom Chidsey welcomes AAPG geologists to Salt Lake City with an Olympic Torch.

UGS geologist Craig Morgan leads a field trip to the Uinta Basin to present project results of a study of the Green River Formation, a major oil producer in the basin.

Energy News

Natural Gas Development Continues to Expand in Utah as Energy Prices Surge

by Roger Bon

Almost everyone who has been involved with or studied Utah's oil and gas industry lately knows that the trend in exploration and development over the past few years has been toward natural gas. What is not generally known is the degree to which natural gas drilling has dominated the industry in Utah since 1991, the first year that gas well completions exceeded oil well completions, and that the focus today is almost totally on natural gas.

Until the natural gas market was deregulated in 1976, gas occurrences were mostly regarded as an impediment to oil production, and, other than local or regional gas companies, there were few explorers and even fewer outlets for natural gas production. That situation has changed dramatically over the ensuing 27 years. According to the Utah Division of Oil, Gas and Mining, Utah fields produced 77.1 billion cubic feet (BCF) of gas in 1976, compared to 293 BCF in 2002, an almost four-fold increase. On the other hand, oil production in 1976 was 35.4 million barrels, peaked in 1985 at 41.1 million barrels, and has steadily declined ever since. Oil production in 2002 was about 13.7 million barrels, and at the current rate of decline will be below 10 million barrels by 2010.

At the end of 2002, about 2,640 oil wells and 3,538 gas wells were producing or capable of production. This is nearly half of the oil and gas wells that have been drilled since the completion of Utah's first commercial oil well in 1948. A look at drilling activity over the past five years (see data chart) provides further evidence of the relative dominance of the natural gas industry in Utah. Applications for a Permit to Drill (APD) varied from a low of 339 in 1999 to an all-time high of 880 in 2001, and averaged 635 permits per year. Four hundred permits were issued in the first six months of 2003, indicating a higher than average year.

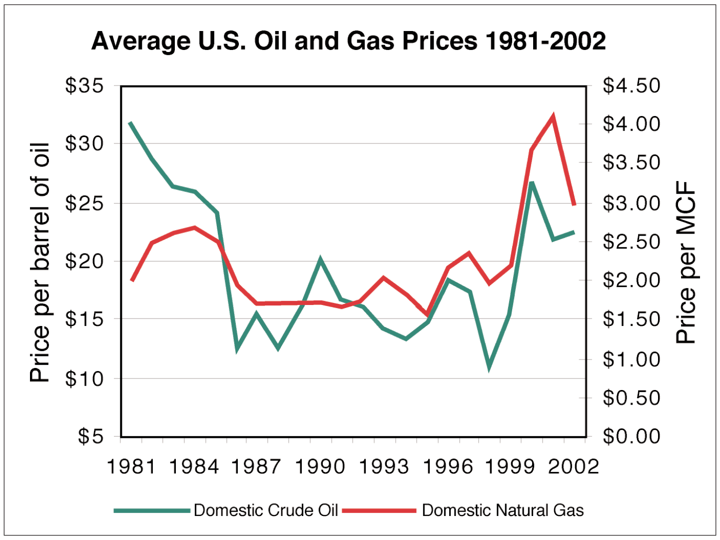
During this five-year period, 1,668 wells were completed as natural gas wells compared to 410 that were completed as oil wells. Oil well completions have fallen from 159 wells in 1998 to 43 wells in 2002. A look at the type of successful wildcat wells is just as telling, as successful wildcats almost always result in new sources for production. For the period 1998 through 2002, only eight wildcat oil wells were successfully completed, compared to 71 successful wildcat gas wells.

DATA CHART

PRODUCTION[1]	1998	1999	2000	2001	2002
OIL (000 BBLS)	19,218	16,362	15,609	15,253	13,734
GAS (000 MCF)	297,503	277,494	281,171	301,453	293,123
NUMBER OF APPLICATIONS FOR PERMIT TO DRILL (APD)[1]	655	339	673	880	627
WELL COMPLETIONS[1]					
OIL	159	11	87	110	43
GAS	273	235	332	479	349
TOTAL	432	246	419	589	392
COMPLETED WILDCAT WELLS[1]					
OIL	6	1	0	0	1
GAS	10	6	13	15	27
AVERAGE UTAH WELLHEAD PRICE[2]					
OIL ($ PER BARREL)	12.52	17.69	28.53	24.09	23.87
GAS ($ PER MCF)	1.73	2.31	3.28	3.52	*

* Not Available
[1] Data from Utah Division of Oil, Gas and Mining
[2] Data from Energy Information Administration

One reason for the increase in gas activity and decrease in oil is that, until recently, oil prices have been depressed whereas natural gas prices have increased substantially over the past eight years. The graph below shows the range of average domestic oil and gas prices from 1981 through 2002. After peaking at nearly $32 per barrel in 1981, oil prices dropped sharply in 1986, and generally remained in the range of about $12 to $19 per barrel until 1999. In Utah, crude oil prices rose from $12.52 per barrel in 1998 to the current (June 2003) price of $30.66 per barrel, but have only been above $20 per barrel since 2000. The long period of sustained low prices led not only to a stagnation of drilling activity, but also to a hastened decline in



oil production as marginally economic wells were shut-in and oil recovery technologies were not utilized. Other reasons for the surge in natural gas development include the availability of land that is more favorable for gas than oil. The increased demand for natural gas in industrial applications is also an important factor in the recent surge in prices. The fact that Utah's major oil provinces (Thrust Belt, Uinta Basin, and Paradox Basin) are mature is also a factor in the decline of oil exploration.

In contrast to oil prices, domestic wellhead natural gas prices bottomed out at $1.55 per MCF in 1995 and have increased substantially since then, reaching a high of $4.12 per MCF in 2001. Utah wellhead natural gas prices, which have been lower than the national average due to infrastructure constraints, have risen similarly from $1.73 per MCF in 1998 to $3.52 per MCF in 2001. The average Utah wellhead price is not available for 2002, but spot prices (daily market prices) indicate that the average will be about $3 per MCF in 2002, and spot prices for 2003 are currently above $5 per MCF.

The infrastructure to move gas from the field to the marketplace is still lacking, especially in the Rocky Mountain region, but progress is being made. An example of this is the recently expanded Kern River gas transmission line that carries gas from Wyoming and Utah to markets in Nevada and California. The $1.2 billion expansion, completed in May 2003, added 717 miles of pipeline and doubled the line's capacity to 1.7 BCF per day. This expansion has already reduced the price differential between Utah producers and the rest of the country.

The switch to natural gas development in Utah is typical of other oil and gas producing states, as nationwide the long-term trend is less oil production and more natural gas production. Utah has many areas that remain to be explored for both oil and gas, but the present trend is definitely toward natural gas.

Additional statistical and individual well data are available on the Utah Division of Oil, Gas and Mining's web site at <http://www.ogm.utah.gov/>. Nationwide oil and gas production and market data can be found on the Energy Information Administration's web site at <http://www.eia.doe.gov/>.

Survey News

The Board of the Utah Geological Survey Welcomes New "Public at Large" Member

On March 1, 2003, Governor Leavitt officially appointed Kathleen Ochsenbein (pronounced Oxenbine) as the new Public at Large member for the Board of the Utah Geological Survey. She holds a Masters Degree in Education from the University of Utah's Department of Instructional Technology with an emphasis on curriculum development.

Kathleen is a science teacher and wears the hats of School Web Site Administrator, member of Steering Committee – Utah School's Trust Land, School Safety Representative, Inservice Selection committee member, Inclusion Committee member, "Invention Convention" Founder, and Science Fair Teacher Advisor for local, regional, and international events for Roy Junior High School.

Last year Kathleen was awarded a Governor's medal for Science and Technology, and she has been recognized with numerous prestigious teaching awards in Utah, including the Outstanding Middle School Science Teacher, and Outstanding Service to Education Awards.

Because of Kathleen's affiliation with the Weber Education Association, Utah Education Association, National Education Association, Association of Presidential Awardees of Science, National Science Teacher's Association, Delta Kappa Gamma Society International, and the Utah Science Teacher's Association, her knowledge and professional experience will be a great asset to the Board of the Utah Geological Survey.

New Publications

Ground-water sensitivity and vulnerability to pesticides in Utah, by Mike Lowe, Janae Wallace, Hugh A. Hurlow, Ivan D. Sanderson, and Matt Butler, CD-ROM (40 p., 2 pl., 1:750,000) MP-03-3 . . . . **$14.95**

Ground-water sensitivity and vulnerability to pesticides, Heber/Round Valleys, Wasatch County, Utah, by Mike Lowe and Matt Butler, CD-ROM (23 p., 2 pl., 1:50,000) MP-03-5 . . . . **$14.95**

Utah Core Research Center catalog of samples, by Carolyn Olsen and W.F. Case, CD-ROM, OFR-413 . . . . **$14.95**

Data include API number, sample location in longitude/latitude or UTM, sample type, sample intervals, elevations, production zones, formations, and map quadrangles.

Tintic Special Folio, Utah (reprint CD-ROM) **$14.95**

published in 1900 by the United States Geological Survey as "Geologic Atlas of the United States: Tintic Special Folio, Utah" folio 65, explanation and 6 pl. 1: 62,500.

Geologic maps of Utah, 1 x 2-degree (1:250,000) (reprint CD-ROM) **$14.95**

These images are compiled from U.S. Geological Survey maps to provide the fullest geologic coverage of Utah at this time, and at this scale. 1° x 2° maps: Cortez, Escalante, Grand Junction, Moab, Preston, Price, Richfield, Salina, Salt Lake City, Tooele, Vernal. An index map for the quadrangles is included.

Geologic maps of Utah, 30′ x 60′ (1:100,000 scale) (reprint CD-ROM) **$14.95**

These images are compiled from U.S. Geological Survey and Utah Geological Survey maps to provide the fullest geologic coverage of Utah at this time, and at this scale. 30' x 60' maps: Delta, Dutch John, Escalante, Huntington, Kanab, Logan, Lynndyl, Manti, Moab, Nephi, Ogden, Panguitch, Price, Provo, Salt Lake City, San Rafael Desert, Smoky Mountain, Tule Valley, Vernal, Wah Wah Mountains North, Westwater.

Geologic hazards of Moab-Spanish Valley, Grand County, Utah, by Michael D. Hylland and William E. Mulvey, digital compilation by Justin P. Johnson and Matt Butler, 25 p. + 1 CD-ROM, ISBN 1-55791-697-7, SS-107 . . . . $12.95

The accompanying CD has the complete report plus four plates, all in pdf format, and the complete GIS package for the plates. These plates can be used in a variety of ways by homeowners, developers, and local governments: to show what hazards may occur and where, to be used in real estate disclosure, and to show where site-specific hazard studies are needed prior to development.

Geologic map of Utah, 1:250,000 (published 1961-1963 in four parts) (reprint CD-ROM) **$14.95**

These images are scans from the original Utah Geological Survey maps.

Northwest Quarter, compiler William L. Stokes, 1962
Northeast Quarter, compiler W.L. Stokes & J.H. Madsen Jr., 1961
Southwest Quarter, compiler Lehi F. Hintze, 1963
Southeast Quarter, compiler L.F. Hintze & W.L. Stokes, 1963

The Bluebell oil field, Uinta Basin, Duchesne and Uintah Counties, Utah: Characterization and oil well demonstration, edited by Craig D. Morgan, 95 p., ISBN 1-55791-690-X, SS-106 . . . . **$13.75**

Reservoir characterization of the Lower Green River Formation, Uinta Basin, Utah, by Craig D. Morgan, Thomas C. Chidsey Jr., Kevin McClure, S. Robert Bereskin, and Milind D. Deo, CD-ROM (140 p. + 76 p. appen., 28 pl.), OFR-411 . **$14.95**

Interpreted regional photomosaics and cross section, Cretaceous Ferron Sandstone, east-central, Utah, by Paul B. Anderson, Kevin McClure, Thomas C. Chidsey, Jr., Thomas A. Ryer, Thomas H. Morris, John A. Dewey, Jr., and Roy D. Adams, CD-ROM (29 p., 8 pl., 228 photomosaics), OFR-412 . . . . **$14.95**

The photomosaics cover about 80 miles (160 km) of the Upper Cretaceous Ferron Sandstone outcrop belt in east-central Utah. Also included are 43 measured stratigraphic sections, and core descriptions and photographs from the four UGS Ivie Creek drill holes.

Guidelines for evaluating surface-faulting-rupture hazards in Utah, by Gary E. Christenson, L. Darlene Batatian, and Craig V Nelson, 14 p., 8/03, MP-03-6 . . . . **$5.50**

The UGS hopes that these guidelines help set a uniform statewide standard for surface-fault-rupture-hazard studies, and provide engineering geologists with a common basis for preparing proposals, conducting investigations, and recommending setbacks.

Generalized color maps showing where the liquefaction potential and/or susceptibility is in these two areas.

Liquefaction susceptibility map for Tooele Valley, Tooele County, Utah, 1 p., 8/03 . . . . **Free**

Liquefaction potential map for Cache Valley, Cache County, Utah, 1 p., 8/03 . . . . **Free**

Interim geologic map of the Jordan Narrows quadrangle, Salt Lake and Utah Counties, Utah, by Robert F. Biek, 2 pl., scale 1:24,000, OFR-415 (with OFR-416) **$14.00**

Interim geologic map of the Lehi quadrangle, Salt Lake and Utah Counties, Utah, by Robert F. Biek, 2 pl., scale 1:24,000, OFR-416 (with OFR-415) **$14.00**

Interim geologic map of the Little Creek Mountain quadrangle, Washington County, Utah, by Janice M. Hayden, 2 pl., scale 1:24,000, OFR-417 . . . . **$6.50**

"Glad You Asked"

by J. Wallace Gwynn

What Causes the Foam on Great Salt Lake?

Deep piles of white, pillowed foam are a common sight along the shores of Great Salt Lake, especially during and after windstorms that cause waves to crash against its shores. The question is often asked, "What causes the foam, and does this mean that the lake is polluted?"

If we look at a fresh-water lake during windstorms, we do not see deep piles of long-lasting foam along its shores like we do on Great Salt Lake, which is very salty. From this observation we might conclude that the formation of foam must have something to do with fresh versus salty water.

In reality, the formation of foam is dependent on a fluid property called surface tension. Fresh water has a high surface tension, somewhat like a strong, thin, invisible film on its surface. It is this property that allows insects like water skaters to walk on the water, or for a needle to be supported if it is carefully placed flat on the water's surface. When crashing waves form bubbles in fresh-water lakes, the bubbles rise quickly and immediately pop when they reach the surface. This happens because the high surface tension of fresh water prevents the bubble's surface from stretching once it reaches the surface of the water.

The lake's high salt content does not appear to be the reason for the creation of foam. When salt is added to fresh water, experiments show that the surface tension of the resulting solution becomes higher than that of fresh water, and will further inhibit the formation of stable bubbles. This being the case, one wonders how foam forms at all on Great Salt Lake.

The formation of stable foam on Great Salt Lake is likely caused by the presence of naturally occurring surfactants in the lake water. Surfactants are organic compounds, similar to soap, that lower the surface tension of the water. When crashing waves create bubbles in Great Salt Lake water, the bubbles rise to the surface but do not disappear by popping because the surfactants in the water allow the bubble's surface to stretch once it reaches the lake's surface. The bubble's surface can remain stretched for long periods of time, and as millions of bubbles form, they build up into deep piles of long-lasting foam.

The largest source of surfactants in Great Salt Lake is the abundant phytoplankton that lives in the water. In Great Salt Lake, the most common type of phytoplankton is *Dunaliella viridis*, a salt-loving, green-pigmented variety of algae. These algae exude surfactants as part of their natural metabolic process. The surfactants are also released as the algae die and decay. Because the surfactants are part of the natural processes that occur in the lake and are not related to human activity, they are not considered pollutants in the lake.

GeoSights

Big Rock Candy Mountain – a colorful reminder of Utah's volcanic past

by Carl Ege

Oh the buzzin' of the bees
In the cigarette trees
Near the soda water fountain
At the lemonade springs
Where the bluebird sings
On the big rock candy mountain

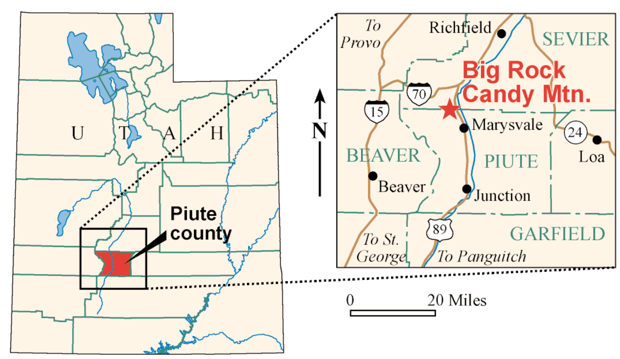
View of Big Rock Candy Mountain from the north.

You may recognize this chorus from the folk song, "Big Rock Candy Mountain," attributed to Harry "Haywire Mac" McClintock and made famous in a 1950s recording by Burl Ives. Shortly after the release of the song in 1928, some local residents, as a joke, placed a sign at the base of a colorful mountain in Utah naming it "Big Rock Candy Mountain." They also placed a sign next to a nearby spring proclaiming it "Lemon Springs." These names stuck, and the mythical Big Rock Candy Mountain of the song became perhaps one of the most recognized geologic sites in west-central Utah.

Geologic Information:

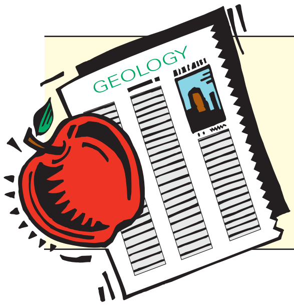
Located a few miles north of Marysvale in Piute County, Big Rock Candy Mountain consists of altered volcanic rock in various shades of yellow, orange, red, and white.

Approximately 22 to 35 million years ago, a cluster of stratovolcanoes (volcanoes similar to Mount St. Helens) erupted, depositing large volumes of lava and ash. Known as the Bullion Canyon Volcanics, these volcanic rocks are more than 3,000 feet thick. Approximately 21 million years ago, at least six magma bodies intruded the overlying Bullion Canyon Volcanics. Through a complex chemical process involving hydrogen sulfide, steam, ground water, and oxygen, the original volcanic rock was partially altered or totally replaced. The vivid colors that one sees at Big Rock Candy Mountain are the direct result of this mineralization. The yellow, orange, and red colors are from the presence of iron minerals, such as jarosite, hematite, and pyrite. The white color is due to the presence of alunite and kaolinite, minerals rich in potassium. Over the past 15 million years, erosion has removed the distinct shapes of the former volcanoes, and within the past several million years has exposed the altered volcanic rocks in Marysvale Canyon along the Sevier River.



How to get there:

From Salt Lake City, travel south on I-15 to I-70 (exit 132). Turn left (east) onto I-70 and travel 22.4 miles to exit 23. Turn right (south) onto U.S. Highway 89 for 7.6 miles to view Big Rock Candy Mountain from a distance. If you want a closer view, travel an additional 0.6 miles to the Big Rock Candy Mountain Resort. Please respect private property when at the resort.



Teacher's Corner

Earth Science Week 2003

Utah Geological Survey
Utah Core Research Center
240 North Redwood Road
Salt Lake City

October 20 – 24, 2003
9:00 a.m. – 5:00 p.m.
Hands-on activities for school/educational groups

The Utah Geological Survey will be celebrating Earth Science Week during October 20-24, 2003 by offering hands-on science activities for educational groups.

The goal of Earth Science Week, now celebrated throughout the nation as well as in other countries, is to increase public understanding and appreciation of the Earth sciences. Launched six years ago by the American Geological Institute (AGI), efforts have grown on local, national, and international levels to highlight the vital role Earth sciences play in society's use of resources and interaction with the environment.

The hands-on activities offered at the UGS typically include gold panning, observing erosion and deposition with a stream table, identifying rocks and minerals, and touring the paleontology lab. Careful planning - led by Carolyn Olsen, Core Research Center Curator - has enabled the UGS to accommodate over 500 students during the week, and this year we may be able to squeeze in as many as 800 students for their 1 1/2 -hour experience here! Contact Carolyn (537-3359) to make a reservation. Time slots fill up quickly, so some groups may have to schedule for next year.

Teachers Note! National contests, including a Lesson Plan Design contest for teachers and several contests for students, are now conducted by the AGI. Although by the time you read this it will be too late to compete this year on the theme of "Eyes on Planet Earth: Monitoring Our Changing World," please visit the AGI's Earth Science Week website (http://www.earthsciweek.org) to find out more and be prepared for next year. Already, AGI is inviting photo submissions on next year's Earth Science Week theme, "Living on a Restless Earth: Natural Hazards and Mitigation." The winning photo will be used in the 2004 Earth Science Week logo.

May 2003 Workshop and Field Trips Attended by 80 Teachers

Enthusiastic teachers participated in an American Association of Petroleum Geologists (AAPG)- and ConocoPhillips-sponsored Teacher Program during the AAPG conference held in May in Salt Lake City. The program, organized by the UGS staff, targeted 4th- and 5th-grade teachers and offered local field trips and a nationally acclaimed "More! Rocks in Your Head" workshop. The sponsorships allowed for greatly reduced registration fees, so that a large number of teachers were able to participate in the high-quality learning sessions in both the field and the classroom, and earn credit at the same time.

Teachers measuring GSL water density during the Antelope Island field trip.

Come visit us at our website: geology.utah.gov

Utah Geological Survey

New Web Pages

- Earthquake-Hazards Working Groups & Mapping Plans
- Carbon Sequestration Project
- Frontier Areas for Coalbed-Gas Exploration in Utah
- Frontier Coalbed-Gas Plays in Utah
- Rainbow of Rocks: mysteries of sandstone colors and concretions in Colorado Plateau Canyon Country
- Smokey Quartz and Feldspar Crystals, Beaver County
- Utah's Sevier Thrust System
- How do geologists identify minerals?
- Nature's version of a playground slide - Devils Slide, Morgan County, Utah
- How was Utah's topography formed?
- Sinkholes in Big Round Valley, Washington County
- Why does the eastern border of Utah have a kink in it?
- What gemstone is found in Utah that is rarer than diamond and more valuable than gold?
- Inverted Topography in the St. George Area of Washington County
- New Utah minerals
- Are there glaciers in Utah's mountains?
- Pink Water, White Salt Crystals, Black Boulders, and the Return of Spiral Jetty!
- Utah's Wildlife in the Ice Age
- Photos of fossils in the Grand Staircase-Escalante National Monument
- The Wasatch Fault (pdf) Public Information Series #40

Closeup view of sinkhole near the Virgin River in Washington County.
From Survey Notes Geosights article.

Aerial view of Spiral Jetty.
From Survey Notes Geosights article.

Mount Ellen, seen from Goblin Valley State Park.
From The geology of Goblin Valley State Park (pdf).

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