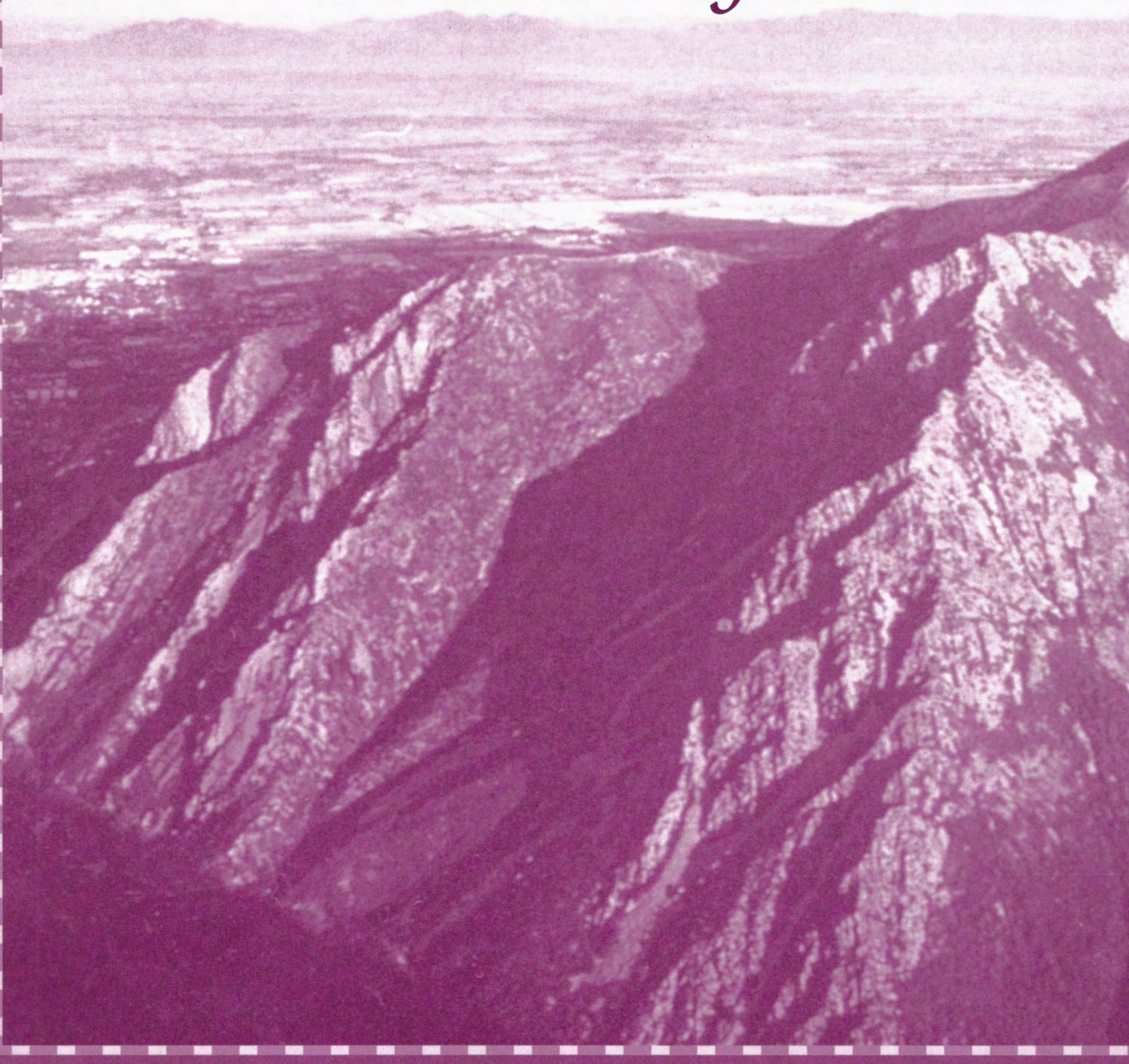
UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 32, Number 1 January 2000

Utah's Thrust System



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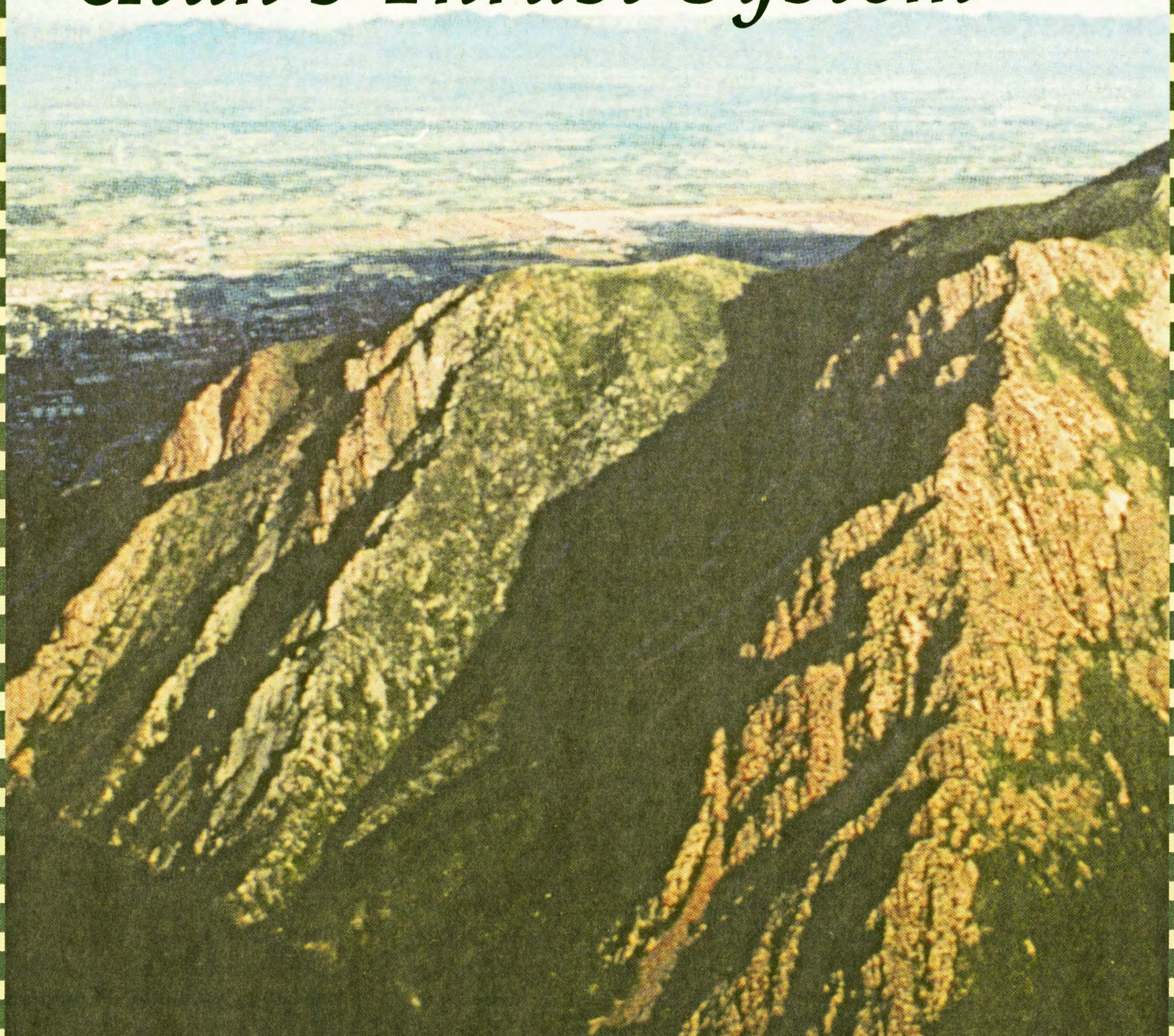


TABLE OF CONTENTS

Design by Vicky Clarke

Cover: Aerial view, looking northwest toward the north side of Ogden Canyon showing east-dipping Ogden thrust repeating Cambrian Tintic Quartzite. Photo by Thomas Chidsey.

ISSN 1061-7930

The Director's Perspective

by Kimm Harty

Acting Director's Comments

Yes, as you can see, there's a new face in the Director's photo box. Since July 1999 I have been Acting Director of the UGS, and will continue to serve in this role until a new Director is named by Kathleen Clarke, Executive Director of the Department of Natural Resources (DNR). At this time, the search for a new director has been temporarily suspended, as it has recently become apparent that the UGS is facing some budget issues that will require immediate action. For those of you who don't know me, I've been Deputy Director of the UGS since 1996. Before that I was the UGS Technical Reviewer and Program Manager of the Geologic Extension Service for a few years. And, even prior to that I worked nine years in the Applied Geology Program of the UGS.

As we settle into this "new millennium," the DNR and the UGS, its stakeholders, board, managers, and employees are looking at the growing need for geologic services, the shrinking availability of funding, and the resulting decisions that need to be made. As you read this, we are busy examining our agency's mission, the importance of its programs to Utah society, its funding sources, and future direction. Funding shortages, including falling mineral-lease revenues last year, remind us of how we must continue to "work smart" during these times of tight state budgets.

In this coming year, we will be making the changes necessary to guide us through tough financial times and lead us into the next century and millennium. First, we anticipate having a new director some time in 2000. Second, we are revisiting our programs and functions to see how they fulfill our mission and the needs of the state of Utah. Third, we are looking at our sources of funding to identify ways to complete our work using existing, new, and different sources over the coming years.

Geology is a critical factor, albeit a generally quiet component in everyday life. Geology provides the basic needs of energy, mineral, and water resources and only takes center stage during "extreme" events or "not so subtle reminders" like landslides or flood emergencies, or when "fault" structures are found below planned buildings. A challenge to the agency is to cultivate advocates of geology and to step up efforts to more effectively show our citizens and our leaders how important this science is, and will continue to be, in everyday life in Utah. As geologists, we already know this, but many others do not. Our challenge is to work to see to it that they do.

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 inventories the geologic resources of the state, identifies its geologic hazards, disseminates information concerning Utah's geology, and advises policymakers on geologic issues. 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.

Knowledge of Utah Thrust System Pushes Forward

by Grant C. Willis

Over the past few decades, study of the geometry, tectonic forces, and dating of thrust systems produced some of the most exciting advances in geology. Utah has been at the center of some of this work. This is a brief overview of the development and evolution of the Utah thrust system, synthesizing the work of many geologists.

The western or Cordilleran thrust system extends from Mexico to Alaska, and formed mostly in the Middle Jurassic to early Tertiary (170 to 40 million years ago). It formed as dense oceanic crust beneath the Pacific Ocean (Farallon plate) converged with, and slid beneath the more buoyant continental crust of the North American plate during a mountain-building episode called the Sevier orogeny (the Sevier River area of central Utah is the namesake of this event). The Utah part of the Cordilleran thrust system is called the Sevier thrust system.

Though the basic geometry and age of the Sevier thrust system in Utah have been known for more than 50 years, knowledge of the timing, method, and sequence of emplacement of individual thrust sheets has advanced slowly.

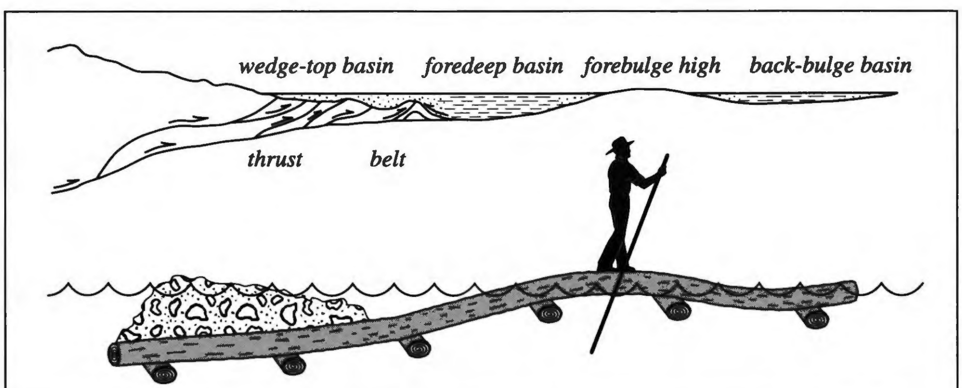
Advances

Probably the biggest advance in Utah thrust system studies has come through improved dating and correlation methods. In an active thrust system, coarse alluvium is shed from rapidly eroding mountains formed by the thrusted rock. In some cases, soon after deposition, the advancing thrust plates override, fold, and fault these "synorogenic deposits." To unravel thrust history, it is essential to accurately date these rocks.

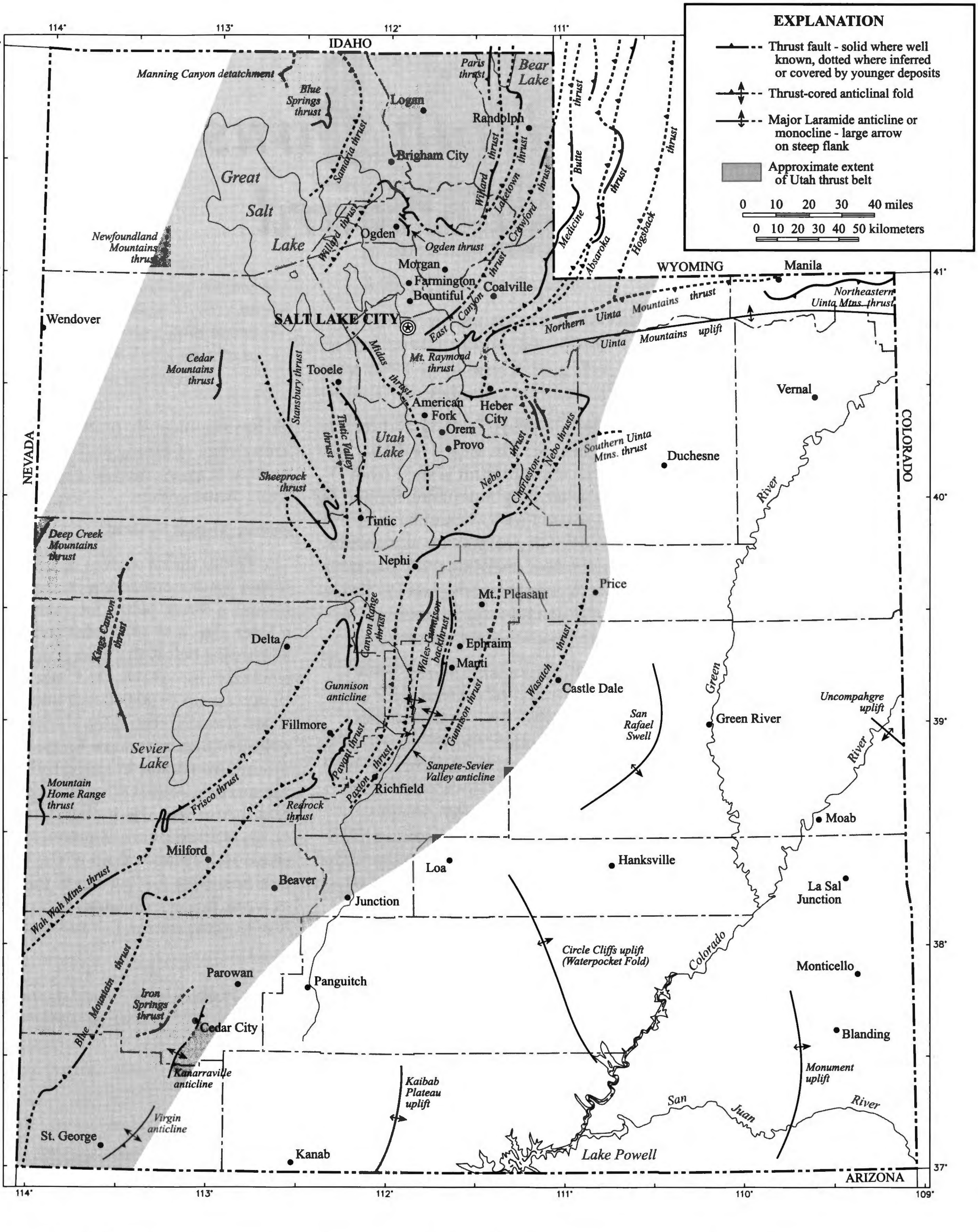
In Utah, geologists scoured many miles of outcrops searching for datable materials. They collected and identified pollen, spores, and volcanic ash, then correlated the samples with well-dated strata elsewhere. They also mapped the conglomerates, unconformities, and cross-cutting relationships, and matched conglomerate clasts with the formations from which they were derived. Analyzing this data with new tools and thrust models has significantly refined our knowledge of timing and the sequence of events that formed the Utah thrust system.

Sevier Thrust System

The Sevier thrust system is a typical thrust system consisting of, from west to east, a thrust belt, a foredeep basin, a forebulge, and a back-bulge basin. The thrust belt is the wedge of stacked thrust plates. In Utah, single plates are up to 50,000 feet thick and, when thrusted into thick stacks or culminations, may have formed mountains similar in magnitude to the modern Andes Mountains of South America. The tremendous load of the stacked plates depressed the crust under and in front of the thrust belt (visualize forcing down the end of a raft floating on water by loading it with rock) forming a "foredeep"



Typical parts of a thrust system. The thickened thrust wedge overloads the earth's crust, which flexes in response, similar to loading rock on a wooden raft floating on water (from Willis, 1999).



Location of Utah's Sevier thrust belt, major thrust faults and thrust-cored folds, and large Laramide basement-cored uplifts. From Willis, 1999 (UGA Guidebook 27) and sources listed therein.

basin into which thousands of feet of coarse synorogenic sediment was shed. Foredeep-basin deposits in Utah commonly exceed 10,000 feet. Farther east, the land bowed upward, a counter-response to the depressed foredeep basin, forming a forebulge, a relatively high area with minor or no deposition. At times, the Utah forebulge was an area of erosion. Still farther east, a second, much shallower basin formed, the back-bulge basin.

The Farallon plate, subducting beneath the continental crust in the approximate position of modern central California, was the driving force behind the Sevier thrust system. The collision produced deformation that started in the west and migrated eastward. Thus, each of these four parts of the thrust system migrated eastward over time. Back-bulge basin deposits provide the earliest evidence of thrusting in Utah.

Middle Jurassic Back-bulge Basin

During the Middle to early Late Jurassic epochs, most of Utah was a broad, shallow back-bulge basin. The basin was covered by a shallow sea, tidal flats, sabkhas (flat evaporating pans), and coastal sand dunes (Twin Creek and Pruess Formations in northern Utah; Twin Creek, Arapien, and Twist Gulch Formations in central Utah; Carmel, Entrada, Curtis, and Summerville Formations in east-central and southern Utah), and later, by broad, low-elevation river floodplains (Stump and Morrison Formations in northern Utah, Morrison Formation in central and southern Utah, among others).

Late Jurassic to Early Cretaceous Forebulge High

By the Late Jurassic epoch, the back-bulge basin had migrated east of Utah, and Utah was mostly a forebulge high. Modest erosion across this broad, gentle uplift produced an unconformity beveled across the Jurassic strata. The forebulge gradually migrated east of Utah during the Early Cretaceous. As the bulge subsided, sporadic deposition produced the late Early Cretaceous Cedar Mountain Formation (Kelvin Formation in northern Utah), a discontinuous unit noted for many minor internal unconformities and ancient soil horizons. This unit is also the most important producer of early Cretaceous dinosaurs in North America.

Early Cretaceous Thrust Faulting

Thrust faulting began in northwestern Utah in the latest Jurassic or earliest Cretaceous. Sparse evidence is found in Emigration Canyon near Salt Lake City, where boulder conglomerate strata near the base of the Kelvin Formation were derived from the westernmost and oldest thrust sheet. Additional evidence is preserved in synorogenic conglomerate beds in southern Idaho and western Wyoming.

Late Cretaceous Thrust Faulting

Thrust faulting reached its zenith in Utah during the Late Cretaceous when most of the major thrust plates were emplaced. By this time, most of the forebulge high had migrated east of Utah. Many plates were pushed eastward 25 to 30 miles, and in some cases, more than 50 miles. Drill holes have penetrated up to five stacked plates at single locations. Thrusted rock was folded, faulted, overturned, brecciated, and metamorphosed to a low grade as it was pushed eastward, forming large mountains and creating the spectacular tilted and complexly folded formations now exposed in many of the ranges of northern, central, and southwestern Utah (for example: Devils Slide in Weber Canyon, the complexly folded rocks in Parleys Canyon, and the great block of overturned strata that forms Mount Nebo).

The Late Cretaceous was also the time of peak oil and gas generation in the thrust belt. For example, Cretaceous organic-rich rocks buried by thrust sheets near the Wyoming border generated the oil and gas that migrated into reservoirs in the thrust-created folds in the Coalville area. A few of these folds became some of the best oil and gas fields in Utah (for example: the Pineview and Anshutz Ranch fields).

As the "thrust front" migrated eastward, it abandoned one thrust fault as the "wedge" of thrusted rock became too thick, and "stepped" forward to a new fault. Thrust faults to the rear "locked" into place or experienced only minor renewed movement. In general, thrust plates in the eastern part of the Sevier belt didn't move as far as western plates. Likewise, the eastern plates were thinner and deformed into folds of smaller amplitude between wider spaced thrust faults than the thick western plates.

Because the Late Cretaceous was the time of peak thrusting, it was also the time of peak synorogenic sedimentation in wedge-top basins on the thrust plates and in the foredeep basin in front of the thrust belt. These deposits include the thick conglomerate beds along Interstate Highways 80 and 84 (Echo Canyon, Weber Canyon, and Evanston Conglomerates), near U.S. Highway 6 in Spanish Fork Canyon (Indianola and Price River Formation), in the mountains near Cedar City (Iron Springs Formation), and at several other places in Utah.

In general, synorogenic conglomerate beds grade eastward into fluvial sandstone and shale, coastal-plain deposits, and deltaic deposits comprising the extensive coal-bearing deposits of Utah (parts of the Frontier Formation of northern Utah, the Blackhawk Formation of central Utah, and the Straight Cliffs Formation of southern Utah, among others). These in turn grade eastward into fine sand, mud, and clay shallow-marine deposits (parts of the Mancos Shale of central and southern Utah, and most of the Frontier Formation and the Hilliard Shale north of the Uinta Mountains).

Late-Phase Thrusting

Thrust faulting continued into middle to late Eocene time. In the northern Sevier thrust belt, the late-phase faults are mostly in western Wyoming. In many areas near the front edge of the thrust belt in central and southern Utah, duplicated strata are present only within individual formations, making the deformation more difficult to recognize and map in the field. In addition, the frontal thrust faults are typically covered by younger undeformed deposits, and extend well east of the easternmost major thrust faults that break the surface. The shortening in this frontal zone is taken up by folds that decrease in amplitude to the east. The Sanpete-Sevier Valley anticline (the white hills along I-70 near Salina) and the Virgin anticline (the tilted rock east of I-15 near St. George) are two examples of large thrust-cored folds in the frontal part of the thrust belt.

The End of Thrusting

The most recent evidence of thrust faulting is about 50 million years old in northern Utah, and about 40 million years old in central and southern Utah. However, the end of thrust faulting is not clearly defined in the rock record because compression declined gradually as the rate of convergence between oceanic and continental crust decreased. As the compressional forces declined, the Cordilleran thrust system (including the Sevier thrust belt) was left unsupported. Many of the original thrust faults "relaxed" and slid backwards (to the west). In general, this backsliding was not extensive, but it was enough to complicate the evidence that geologists have had to unravel.

I THOUGHT THAT WAS THE LARAMIDE OROGENY!

The Sevier orogeny is often confused with the Laramide orogeny, even by geologists, because they overlap in time and location. The Laramide orogeny developed in the Late Cretaceous and continued into the Oligocene epoch, mostly synchronous with late stages of the Sevier orogeny. Laramide structures were produced in central and eastern Utah, western Colorado, and most of Wyoming -- thus, some overlap eastern Sevier thrust belt structures. Classic Laramide structures in Utah include the Uinta Mountains uplift, the San Rafael Swell, and the Circle Cliffs (Waterpocket Fold). Some structures, such as the Uinta Mountains, were affected by both events. The two orogenies were produced by the same crustal shortening event, collision of the Farallon and North American plates, but they are distinguished by style of deformation. The Sevier orogeny defines a more western event that took advantage of weak bedding planes in thick Paleozoic and Mesozoic sedimentary rock. Shortening in basement metamorphic and igneous rocks was transferred tens of miles eastward along the weak shale and evaporite layers, producing "thin-skinned" thrust faulting that, in its eastern part, only involved sedimentary strata. In contrast, the Laramide orogeny produced "basement-cored" uplifts because thin sedimentary rock in those areas did not easily "decouple" from the basement rock.

This paper is extracted from: Willis, G.C., 1999, The Utah Thrust System - An Overview, in Spangler, L.W., and Allen, C.J., editors, Geology of northern Utah and vicinity: Utah Geological Association Publication 27, p. 1-9. Sources used to prepare this paper are listed in that publication.

New Publications

Geology and geologic hazards of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah, by Bill D. Black, Barry J. Solomon, and Kimm M. Harty, 65 p., 6 pl., scale 1:100,000, 12/99 SS-96 .... **$12.75**

Redefining the Lower Cretaceous stratigraphy within the central Utah foreland basin by Douglas A. Sprinkel, Malcolm P. Weiss, Robert W. Fleming, and Gerald L.. Waanders, 21 p., 11/99, SS-97 .... **$5.50**

Minerals of the Utahlite Claim, Lucin, Box Elder County, Utah, by Joe Marty, Donald G. Howard, and Henry Barwood, 13 p., 11/99, MP-99-6 .... **$1.95**

Preliminary hydrogeologic framework characterization - groundwater resources along the western side of the northern Wasatch Range, eastern Box Elder County, Utah, by Hugh A. Hurlow, 50 p., 11/99, C-101 .... **$8.25**

Guidelines for preparing hydrogeologic and soil reports addressing suitability for alternative wastewater disposal systems in Weber County, Utah, by Mike Lowe and Darwin Sorensen, 10 p., 10/99, C-102 .... **$3.95**

Small mine permits in Utah, by Roger Bon and Sharon Wakefield, 5 pages, 1 plate (approximate scale is 1"= 13 miles), PI-68 .... **$3.50**

The geology of Goblin Valley State Park, by Mark Milligan, 21 pages, PI-65 .... **$3.65**

Geologic maps - what are you standing on? by Robert F. Biek, 7 p., 12/99, PI-66 .... **$1.75**

Large mine permits in Utah, by Roger Bon and Sharon Wakefield, 3 pages, 1 plate (approximate scale is 1"= 14 miles), PI-67 .... **$3.50**

Petroleum geology of the Harley Dome field, Grand County, Utah, by Roger L. Bon, 2 pl., 6/99, OG-21 .... **$6.70**

Petroleum geology of the Cisco Townsite and Cisco Wash areas, Grand County, Utah, by Craig D. Morgan, 2 pl., 11/99, OG-22 . **$6.70**

Geologic Mapping News

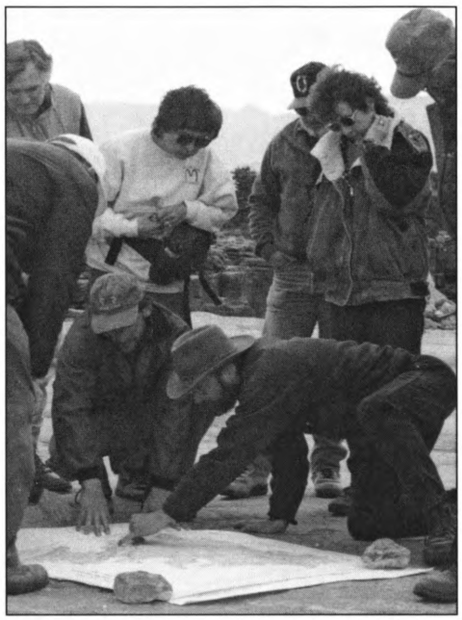
Digital Geologic Map of Utah!

We've all been waiting for it. The Mapping Program completed and and is now releasing the digital geologic map of Utah! This map is a digital version of the 1:500,000 geologic map of Utah by Lehi F. Hintze completed in 1980. It is the result of many thousands of hours of work in a cooperative project funded by the Utah Geological Survey and the U.S. Geological Survey.

Optronics Specialty Co., Inc. of Northridge, California completed the main phase of the project on contract with the U.S. Geological Survey. The Utah Geological Survey then took over the project and completed the extensive editing and reviewing phase. Optronics Specialty noted that this is by far the most detailed and complex geologic map they have ever worked on. The map contains 22,647 map units or, in digital terminology, "map polygons," about double most other comparable maps.

The digital map is considered more accurate than the published map since many cartographic errors were discovered and corrected during the digital work. However, the map was not updated to incorporate extensive new geologic mapping completed since 1980. That level of revision is planned for a few years down the road.

The map will be available on CD from the Natural Resources Map/Bookstore. The "user-friendly" CD will contain three versions of the map and two types of installable viewing software designed for a variety of users.



Utah Geological Survey and Bureau of Land Management geologists and officials examine the new geologic map of the GSENM while reviewing the geology of the Sunset Flat area southeast of Escalante.

A menu provides step-by-step instructions for installing the software and guides the user to the software appropriate for their skill level. In addition, a full Geographic Information System (GIS) version of the map is provided for users who own GIS software (for example: ESRI ARC/View™ software). Explanatory information is included in a variety of formats.

New 30'x60' Quadrangle Maps

The Mapping Program is throwing all available resources into completing digital and printed geologic maps of the entire state at 1:100,000 scale. These maps are published on the USGS 30'x60' quadrangle topographic map series. Forty-six quadrangles (plus a thin strip of ten others along the Utah-Nevada border) cover Utah. Nine published maps were available at the start of this initiative. In the last four years, the UGS has completed preliminary versions of seven new maps: Smoky Mountain, Escalante, Kanab, Moab, La Sal, Delta, and Ogden. These are planned for release on CD and in printed form. We are currently mapping five additional quadrangles: Tule Valley, Richfield, Wah Wah Mountains North, San Rafael Desert, and Dutch John, which should be available in the next two years. In addition, we are digitizing the existing published maps to create digital versions.

While some of these new geologic maps can be compiled from existing mapping, most, such as the San Rafael Desert and Dutch John quadrangles, have large areas that have never been mapped in sufficient detail and require several years of extensive field work to complete.

7.5' Quadrangle Maps

Of the 1,512 quadrangles in Utah at 7.5' scale, only about 400 have been mapped in adequate detail. It takes a geologist working full-time 6 to 12 months to complete a map and explanatory materials for a typical quadrangle. Therefore, the UGS focuses on quadrangles with pressing geologic concerns, such as those in rapidly growing urban areas with known or suspected geologic hazards, and maps that are requested by large numbers of map users. UGS geologists are currently working on about a dozen quadrangles throughout Utah.

To stretch our mapping dollars, we seek cooperative funding projects, and also try to support outside projects. For example, the UGS is currently working on a cooperative project to map the quadrangles for Zion National Park. This project is partially funded by the National Park Service and meets their need for detailed mapping of the park area while enabling the UGS to map the rapidly growing areas surrounding the park. The UGS also actively encourages and supports EDMAP projects (mapping projects by universities and colleges funded through an educational component of the National Geologic Mapping Act). Currently, the UGS is helping support two EDMAP projects in Utah: the Payson Lakes and Santaquin quadrangles in Utah County, and the northern part of the Canyon Range. In addition, over 24 other quadrangle projects are in various stages by non-UGS geologists.

Mapping Program Awarded New STATEMAP Grant

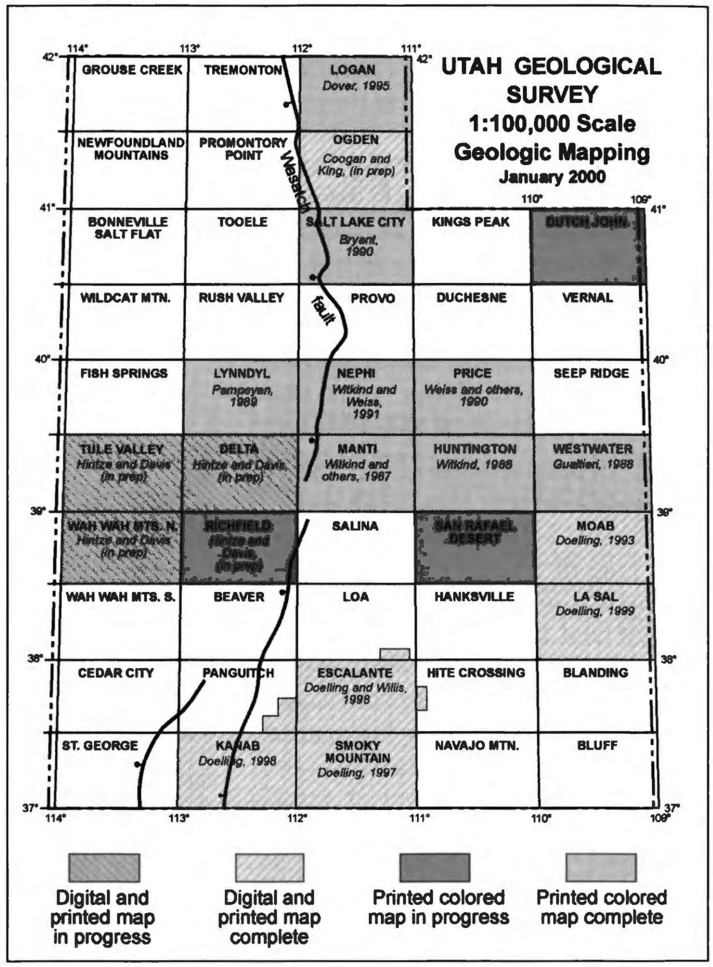
In December 1999, the UGS Mapping Program was awarded a new STATEMAP grant to conduct new geologic mapping in Utah. The STATEMAP program is part of the federally funded National Geologic Mapping Program administered through the U.S. Geological Survey.

The funds are matched with state funds and will be used to map the San Rafael Desert and Dutch John 30'x60' quadrangles, to digitize the Tule Valley and Nephi 30'x60' quadrangles, and to map the Saratoga Springs, Farmington, and Snow Basin 7.5' quadrangles in northern Utah. All of these projects were identified as high-priority projects by the State Mapping Advisory Committee.

Currently, using STATEMAP funds, we are completing the first year of mapping on the Provo and Dutch John 30'x60' quadrangles, mapping the Pintura 7.5' quadrangle in the St. George area, and digitizing the Wah Wah Mountains North 30'x60' quadrangle in western Utah. In previous years, the Mapping Program completed the Smoky Mountain, Kanab, Escalante, Ogden, La Sal, Moab, and Delta 30'x60' quadrangles, and many 7.5' quadrangle maps through STATEMAP.

Geologic Mapping Questionnaire

New mapping projects are prioritized by the UGS and a State Mapping Advisory Committee, representing most types of map users in Utah. Input from the public is essential to selecting new projects. We would appreciate knowing which 30'x60' and 7.5' quadrangles you would like to see mapped next. To have your interests considered, please take a minute to send us your vote for three quadrangles in each series (7.5' and 30'x60'). List the quadrangles by name and their importance. Mail your responses to: UGS Mapping Program, Utah Geological Survey, PO Box 146100, Salt Lake City, Utah 84114; or e-mail us at: nrugs.gwillis@state.ut.us.



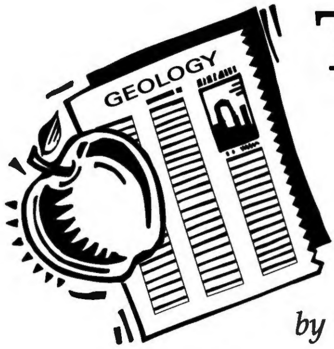
Index map: Status of 30'x60' quadrangle geologic mapping in Utah.

Field Reviews

The UGS Mapping Program commonly holds public reviews of recently completed geologic maps. This gives the public and local government officials the opportunity to learn more about the geology of the map area, and geologists (and anyone else) the opportunity to critique the work and make suggestions for improvements before maps are published. The public is welcome to attend these reviews. Most reviews are one day from 8:00 a.m. to 5:00 p.m. Watch the UGS home page for announcements about upcoming reviews (www.ugs.ut.us).

Digital Geologic Map of Grand Staircase- Escalante National Monument

In November, 1998, UGS presented the Grand Staircase -Escalante National Monument planning team with new digital and printed geologic maps of the monument. To make the maps, the Mapping Program completed three 30'x60' quadrangles that cover most of the monument, and small parts of three other quadrangles that cover small extensions of the monument. The BLM recently used the new maps to discuss geologic issues at public input meetings held in Utah, Arizona, California, and Washington D.C.



Teacher's Corner

by Sandy Eldredge

Announcement

Field Trips for Credit

In September , the Utah Geological Association is celebrating the millennium with four field trips to Utah's parks and monuments. Teachers are invited to attend one or two days at a reduced cost, and receive inservice credit upon completing assignments.

- **Moab area ...... Sept. 15 (Friday) and/or Sept. 16 (Saturday)**
- **Wasatch Front ... Sept. 15 (Friday) and/or Sept. 16 (Saturday)**
- **Vernal area ..... Sept. 22 (Friday) and/or Sept. 23 (Saturday)**
- **St. George area .. Sept. 22 (Friday) and/or Sept. 23 (Saturday)**

Check your Resourse Portfolio in February for more information and registration details.

Geological Features and Processes in Utah

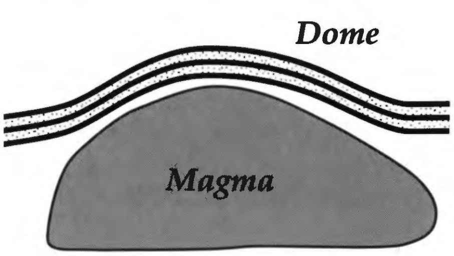
Part I: Mountains (continued)

Dome Mountains

This is the second in a series on Utah's geological features and processes. Geological features constitute anything from major landforms such as mountains or plateaus, to ripple marks or glacial striations on a rock. The geological processes, such as volcanic eruptions, earthquakes, erosion, and deposition are what create or change geological features.

Background: Mountains are major geological features on the surface of the Earth. Depending on what geological processes created these landforms, mountains can be classified as different types: volcanic, dome, fold, and fault block. Utah has all four types.

Dome Mountains are formed from hot molten material (magma) rising from the Earth's mantle into the crust that pushes overlying sedimentary rock layers upward to form a "dome" shape. Unlike a volcano, the magma typically does not reach the Earth's surface. Instead, the magma cools underneath the surface and forms the core of the mountains. Dome mountains in Utah include Navajo Mountain and the La Sal, Abajo, and Henry Mountains in the southeastern part of the state.



Activity (for 3rd grade)

Materials for pairs of students: tube of toothpaste, one large index card, pencil, dried grass, scissors.

Procedures: Punch a small, pencil-size hole in the index card. Cover the surface of the card with finely cut dried grass to represent rock layers and the surface of the earth. Have one student hold the index card while the other student places the tube of toothpaste under the hole and slowly squeezes until the grass is pushed up into a small dome over the squeezed toothpaste (alternate method - take the cap off the tube of toothpaste, drill a hole in the cap, place the index card hole over the neck of the toothpaste tube, and place the cap back on so the card is fastened between the cap and the tube).

Results/discussion: What does the toothpaste represent? *Magma.* What could happen inside the earth that would create the same effect? *Magma can squeeze and move like the toothpaste.* What does the grass represent? *Rock layers and the surface of the Earth.* How is this landform different from a volcano? *The magma does not erupt onto the surface of the earth.*

Some of this information was taken from a 3rd-grade Utah Core teaching packet called *Investigate Geological Processes that Shape Landforms - Earthquakes, Volcanoes, Erosion, Deposition.* For information on this packet and accompanying workshops, call Sandy Eldredge (UGS) at 801-537-3325 or Paula Wilson (Earthquake Education Services) at 801-585-5613.

More information on coal, oil, and gas can be found at www.ugs.ut.us under "Energy and Minerals"

Energy News

Central Utah Coal Resources Still Substantial

The coal industry has been a vital part of Utah's economy since the 1870s, and today provides Utah residents with many good-paying jobs while fueling some of the nation's lowest electricity rates.

Coal mining has mainly been concentrated in Carbon, Emery, and Sevier Counties. Residents there, as well as local and state government officials, are keenly interested in the future of this important industry. A recent report by UGS scientists further defines the potential for maintaining the coal mining industry in central Utah. This report, the first in a series of studies covering Utah's two producing coalfields, the Book Cliffs and Wasatch Plateau fields, examines the coal resources in the northern half of the Wasatch Plateau coalfield, an area that accounted for 64 percent of the state's coal production in 1998.

The study found that 129 years of mining had removed, or made unminable, only 30 percent of the original 5.4 billion tons of minable coal. Thus, 3.8 billion tons of coal remain for future mining in coalbeds that are at least four feet thick and under less than 3,000 feet of cover. The study documents that past mining removed the thicker, more easily reached portions of the coalbeds, and that the percentage of the in-ground coal actually recovered is between 30 and 36 percent.

Future efforts will encounter more difficult conditions, however. Even though improved technology has increased extraction capabilities in recent years, future mining in many areas will involve reaching generally thinner and deeper coalbeds. Of the remaining resource, 28 percent is in beds that are 4 to 6 feet thick, thinner than the coals currently being mined. In addition, coal mining is subject to increasingly stringent environmental restrictions which will further limit the amount of coal available for future mining.

While it is impossible to predict the impact of changes in technology or market conditions on future coal mining, the study projects how much longer, under current practices, mining could extend into the next century. The shallow, thick, low-cost resources will be exhausted in about half a century at current extraction rates, the study concludes, while deeper, thinner, and more costly coal resources will be available beyond that time but in smaller quantities and at a higher price.

The UGS's study was a cooperative project with the U.S. Geological Survey, which provided funding and information in the National Coal Resources Data System. The study used data from more than 600 drill holes and measured sections along with a Geographic Information System to produce maps showing the spatial distribution and thickness of individual coalbeds from which the resources were estimated. The published study, entitled "The Available Coal Resources for the Nine 7.5-Minute Quadrangles in the Northern Wasatch Plateau Coalfield, Carbon and Emery Counties, Utah," is available at the Natural Resources Map & Bookstore at 1594 West North Temple, Salt Lake City, Utah, at a cost of $9.

UGS Wins Grant to Study Increasing Oil Production in Paradox Basin

The Paradox Basin, which extends from Utah into portions of Colorado and Arizona, contains more than 75 small oil fields, each capable of producing 2 to 10 million barrels of oil. But variations in the reservoirs of these fields prevent recovery of up to 75 percent of that resource using conventional extraction methods.

A new 5-year study, entitled "Heterogeneous Shallow-Shelf Carbonate Buildups in the Blanding Sub-Basin of the Paradox Basin, Utah and Colorado: Targets for Increased Oil Production and Reserves Using Horizontal Drilling Techniques," will evaluate methods to extract as much as another 50 million barrels of oil from existing wells in the basin. Funding for the project will come from the U.S. Department of Energy, the Utah Geological Survey, the Colorado Geological Survey, and private industry.

DOE Secretary Bill Richardson said, "The oil industry in the United States is increasingly an industry of smaller companies, many of which are family-owned businesses. These companies account for nearly half the oil produced in the lower 48 states. Our support will help them develop and deploy technologies that otherwise would probably never make it into the oil field, certainly not on a widespread basis. Our hope is that these projects will show hundreds of other

....continued on page 11

Complete copies of Survey Notes back to August 1995 can be found on our website at www.ugs.ut.us under "Newsletters"

Survey News

Personnel Matters

Tom Chidsey, Mark Milligan, and **Grant Willis** are incoming officers with the Utah Geological Association (UGA). Chidsey is president, Milligan is secretary, and Willis is program chairman for the millennium year. **Jeff Quick** was elected Councilor of The Society for Organic Petrology.

Michele Hoskins left us for an accounting position with the Division of Parks and Recreation. **John Hanson, Alexa DuBois,** and **Bill Black** left the UGS to pursue other interests.

John Porcher has joined the Paleontology group after doing contract mapping for the U.S. Forest Service – welcome aboard!

Eric Pierson, an intern in the "Schools to Careers Exploration Program" at West High School, spent last autumn at the UGS assisting the Geologic Extension Service and the Paleontology Section with field work, fossil preparation, map making, and photograph cataloging.

Field Reviews, Field Trips, & Conferences

UGS geologists led field trips for the Association of Engineering Geologists (AEG) 42nd annual meeting in Salt Lake City; the Utah Geological Association 1999 Field Symposium; the Dixie Geological Society visit to the Silver Reef mining district, Washington County; the Weber State University's Geoscience Department; and for geologic mapping field review of the Center Creek quadrangle in Wasatch County.

Tom Chidsey and **Craig Morgan** presented papers and poster sessions at the American Association of Petroleum Geologists (AAPG) Rocky Mountain Section meeting in Bozeman, Montana. **Kevin McClure** and Chidsey were co-authors on Morgan's poster presentation. Morgan presented a poster session, as well as a paper co-authored by Chidsey, at the Department of Energy-sponsored 1999 Oil & Gas Conference in Dallas, Texas. In addition, work on the Paradox project was summarized in an article Chidsey co-authored in *"Oil & Gas Journal,"* and Morgan wrote an article about the Bluebell project for the National Petroleum Technology Office's newsletter.

Francis Ashland, Charlie Bishop, Gary Christenson, Rich Giraud, Mike Lowe, Barry Solomon, and **Janae Wallace** co-authored or presented papers at the AEG annual meeting. Giraud also gave a presentation to the Utah Floodplain Management Association Annual Conference.

Bill Black, Hugh Hurlow, Janine Jarva, Jim Kirkland, Mike Lowe, Jeff Quick, Dave Tabet, and **Janae Wallace** co-authored or presented papers at the annual meeting of the Geological Society of America in Denver.

Jim Kirkland co-authored an abstract presented at the VII International Symposium on Mesozoic Terrestrial Ecosystems in Buenos Aires, Argentina, and a paper presented at the Society of Vertebrate Paleontology annual meeting in Denver. He also co-authored a paper accepted for publication in *Cretaceous Research.*

David Madsen was an invited lecturer at the College of Environment and Resource Sciences, Lanzhou University, Gansu, China. Privately, he also organized and directed a Smithsonian Institution workshop on North Asian-North American connections relating to the peopling of the Americas; participated in the "Pronghorn Perspectives" symposium of the Rocky Mountain Anthropology Conference in Glenwood Springs, Colorado, and was the invited speaker at the "Clovis and Beyond: A Peopling of the Americas" conference in Santa Fe, New Mexico.

Several UGS staff helped organize the Utah Geographic Information Council annual meeting at Snowbird where **Alison Corey** and **Mike Lowe** presented a poster session.

Staff also helped organize the annual meeting of The Society of Organic Petrology at Snowbird. **Jeff Quick** was a featured presenter at the meeting. **Dave Tabet** led a two-day post-meeting field trip to the Uinta Basin.

Miscellaneous

The UGS Sample Library donated oil and core samples from the Paradox Basin for display at the Dan O'Laurie Canyon Country Museum in Moab. **Tom Chidsey** and the Geologic Extension Service helped in gathering items of interest for the permanent display, which examines the discovery and production of oil in that area of southeastern Utah.

Security and business issues determined that The Natural Resources Map & Bookstore will return to weekday-only hours. Present hours are now Monday through Friday, 7:30 a.m to 5 pm.

"Glad You Asked"

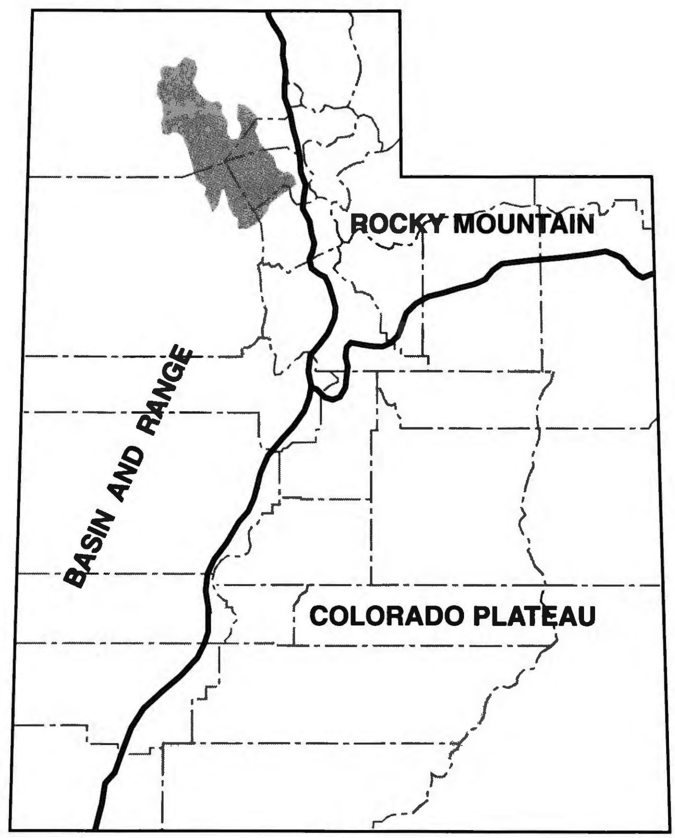
Mark R. Milligan

"How was Utah's topography formed?"

Answers to this question are as numerous as the landforms found across Utah. However, some cursory geologic history and broad generalizations serve as a good starting point for interpreting Utah's world-famous topography and scenery.

Based on characteristic landforms, geologists and geographers have subdivided the United States into areas called physiographic provinces. Features that distinguish each province result from the area's unique geology, including prominent rock types, history and type of deformation (including crustal-scale forces of compression and extension), and erosional characteristics. Utah contains parts of three major physiographic provinces: the Colorado Plateau, Basin and Range, and Rocky Mountains.

The three provinces meet near the center of the state, with the Basin and Range Province extending across western Utah, the Colorado Plateau across southeastern Utah, and the Rocky Mountains across northeastern Utah. Where to draw the line between the Colorado Plateau and Basin and Range is subject to debate. Between the two provinces lies an area that displays characteristics of both, and some geologists would make this area a distinct, fourth physiographic province called the Basin and Range - Colorado Plateau Transition. The same holds true for the area between the Rocky Mountains and Basin and Range provinces. Additionally, each major province can be further divided into sub-provinces. Here, however, we will keep things "simple" and stick to highlights of the three major provinces.



Basin and Range Province

Steep, narrow, north-trending mountain ranges separated by wide, flat, sediment-filled valleys characterize the topography of the Basin and Range Province. The ranges started taking shape when the previously deformed Precambrian (over 570 million years old) and Paleozoic (570 to 240 million years old) rocks were slowly uplifted and broken into huge fault blocks by extensional stresses that continue to stretch the earth's crust. Sediments shed from the ranges are slowly filling the intervening wide, flat basins. Many of the basins have been further modified by shorelines and sediments of lakes that intermittently cover the valley floors. The most notable of these was Lake Bonneville, which reached its deepest level about 15,000 years ago when it flooded basins across western Utah.

Colorado Plateau Province

In contrast with the Basin and Range Province, a thick sequence of largely undeformed, nearly flat-lying sedimentary rocks characterize the Colorado Plateau province. Erosion sculpts the flat-lying layers into picturesque buttes, mesas, and deep, narrow canyons.

For hundreds of millions of years sediments have intermittently accumulated in and around seas, rivers, swamps, and deserts that once covered parts of what is now the Colorado Plateau. Starting about 10 million years ago the entire Colorado Plateau slowly but persistently began to rise, in places reaching elevations of more than 10,000 feet (3,000 meters) above sea level. Miraculously it did so with very little deformation of its rock layers. With uplift, the erosive power of water took over to sculpt the buttes, mesas, and deep canyons that expose and dissect this "layer cake" of sedimentary rock.

Of course, exceptions to this layer-cake geology do exist. For example, igneous rocks that cooled from once-rising magma form the core of the Henry, La Sal, and Abajo Mountains, and several wrinkles or folds, such as the San Rafael Swell and Waterpocket Fold, can also be found as exceptions to the rule of flat-lying beds.

Rocky Mountains Province

High mountains carved by streams and glaciers characterize the topography of the Rocky Mountains province. The Utah portion of this province includes two major mountain ranges, the north-south-trending Wasatch and east-west-trending Uintas. Both ranges have cores of very old Precambrian rocks, some over 2.6 billion years old, that have been altered by multiple cycles of mountain building and burial.

Uplift of the modern Wasatch Range only began within the past 12 to 17 million years. However, during the Cretaceous Period (138 to 66 million years ago), compressional forces in the earth's crust began to form mountains by stacking or thrusting up large sheets of rock in an area that included what is now the northeasternmost part of Utah, including the northern Wasatch Range. This thrust belt was then heavily eroded. About 38 to 24 million years ago large bodies of magma intruded parts of what is now the Wasatch Range. These granitic intrusions, eroded thrust sheets, and the older sedimentary rocks form the uplifted Wasatch Range as it is seen today.

The Uinta Mountains were first uplifted approximately 60 to 65 million years ago when compressional forces created a buckle in the earth's crust, called an anticline. The mountains formed by this east-west-trending anticline were subsequently eroded back down, but began to rise again about 15 million years ago to their present elevations of over 13,000 feet above sea level.

The Rocky Mountains province is further characterized by sharp ridge lines, U-shaped valleys, glacial lakes, and piles of debris (called moraines) created during the Pleistocene (within the last 1.6 million years) by mountain glaciers.

This is, of course, a most cursory overview of the geologic events that formed the topography of Utah's three physiographic provinces. Numerous anomalies and variations give color and detail to the big picture outlined here.

Energy News continued from page 8....

small companies ways to keep their wells flowing."

The management and technical team, headed by UGS's Thomas C. Chidsey, Jr., will include Seeley Oil Company of Salt Lake City, the Colorado Geological Survey, and Eby Petrography & Consulting, Inc. They will conduct a geologic and reservoir characterization study of the Ismay and Desert Creek zones of the 300 million-year-old Paradox Formation. The goal will be to determine if horizontal drilling techniques can increase well productivity from thin, untested intervals of reservoir rock. Cherokee field in San Juan County will be a target for a detailed case study.

In addition, the project will be guided by a technical advisory board of industry partners who are currently operators of fields in the basin, and a stake-holders board of representatives from governments of Utah and Colorado, the Ute Mountain Ute Indian Tribe, and the U.S. Bureau of Indian Affairs.

The Rockhounder continued from page 13....

Useful maps: Jessies Twist 1:24,000-scale topographic map, San Rafael Desert 1:100,000-scale topographic map, Utah Atlas and Gazetteer, and a Utah highway map. Topographic maps can be obtained from the Natural Resources Map & Bookstore, 1594 W. North Temple, Salt Lake City, UT, 801-537-3320 or 1-888-UTAH MAP.

Land ownership and collecting rules: The described collecting location is on Bureau of Land Management (BLM) public lands. If collection is for personal, non-commercial purposes, the casual collector may take small amounts of invertebrate fossils, petrified wood, gemstones, and rocks from unrestricted federal lands in Utah without obtaining a special permit. Collection in large quantities or for commercial purposes requires a permit, lease, or license from the BLM.

Precautions, miscellaneous: With little vegetation or shade, in summer this area can get hot enough for the devil; always carry plenty of water, and use sunscreen. Please carry out your trash. Have fun and enjoy the fossils, but be sure to leave plenty for others.

New Utah Minerals

by Carl Ege

Utahite, $Cu_5Zn_3(Te^{6+}O_4)_4(OH)_8 \cdot 7H_2O$

Utahite is a hydrated copper-zinc-tellurate hydroxide found on the dump of the Centennial Eureka mine in the Tintic mining district in Juab County. The mineral is found isolated or in groups as elongate crystals in small vugs with drusy quartz. Individual crystals are up to 0.3 mm long, prismatic, and are subhedral to euhedral. Utahite is pale blue in individual crystals or blue-green in aggregates. Utahite has a vitreous to pearly luster and a pale blue streak. X-ray studies reveal a triclinic symmetry. Utahite is nonfluorescent under ultraviolet light and is brittle with an uneven fracture. The mineral has a hardness of 4-5 and a density of 5.34 g/cm^3.

Utahite is found in association with cesbronite and other Cu-Zn-Te-bearing secondary minerals on quartz. Utahite is named for the state where the Centennial Eureka mine is located.

Headframe of the Centennial Eureka mine. The minerals Utalite and Juabite were found on this mine's dump.

Juabite, $Cu_5(Te^{6+}O_4)_2(As^{5+}O_4)_2 \cdot 3H_2O$

Juabite is a copper-tellurate-arsenate hydrate found on the dump of the Centennial Eureka mine in the Tintic mining district in Juab County. The mineral is found isolated or in groups as elongate crystals on drusy quartz. Cystalline masses average 0.2 - 0.3 mm in size and are subhedral to euhedral. Juabite is emerald green, has a vitreous to adamantine luster, and a pale green streak. Individual juabite crystals are transparent, but juabite masses are translucent. X-ray study results reveal a triclinic symmetry. Juabite is nonfluorescent under ultraviolet light and is brittle with an uneven to subconchoidal fracture. The mineral has a hardness of 3-4 and a density of 4.59g/cm^3.

Juabite is found in association with enargite, beudantite, and an unidentified lead-rich form of arsenobismite. Juabite is named for the county within the state of Utah where the Centennial Eureka mine is located.

Blatonite, $UO_2CO_3 \cdot H_2O$

Blatonite is a uranyl carbonate monohydrate found in gypsum seams within the Triassic Shinarump Conglomerate at the Jomac mine, San Juan County. The mineral occurs as subparallel fibers up to 1 mm long and 0.1 mm wide. Blatonite is canary-yellow, has a white streak, silky luster, and is translucent. X-ray study reveals a hexagonal or trigonal symmetry. Blatonite fluoresces strongly under ultraviolet light and is flexible with an uneven fracture. The mineral has a hardness of 2-3 and a density of 4.02 g/cm^3.

Blatonite is found in association with boltwoodite, coconinoite, metazeunerite, rutherfordine, azurite, malachite, carbonate-cyanotrichite, brochantite, and smithsonite. Blatonite is named for N. Blaton of the University of Leuven, Belgium.

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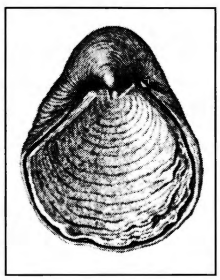
The Rockhounder

by Mark R. Milligan

Devil's Toenails in the Mancos Shale, Emery County

Geologic information: In the 1660s a Dane named Nicolaus Steno made a startling observation: tonguestones, fossils then believed to be the tongues of snakes or dragons, were identical to the teeth of modern sharks. Through this observation and others, Steno came to the realization that rocks had not always been solid, but had hardened around these shark's teeth and other shells. With this insight Steno developed some of geology's fundamental laws. While fossils that look like dragon tongues may exist at this rockhounder site, they are not easily found. However, fossils that look like devil's toenails are fairly abundant.



Pycnodonte newberyii - heavy shelled oysters commonly known as Devil's Toenails. This fossil was originally identified as Gryphaea newberyii. However, the genus Gryphaea is found in rocks older than the Mancos Shale. Penny for scale.

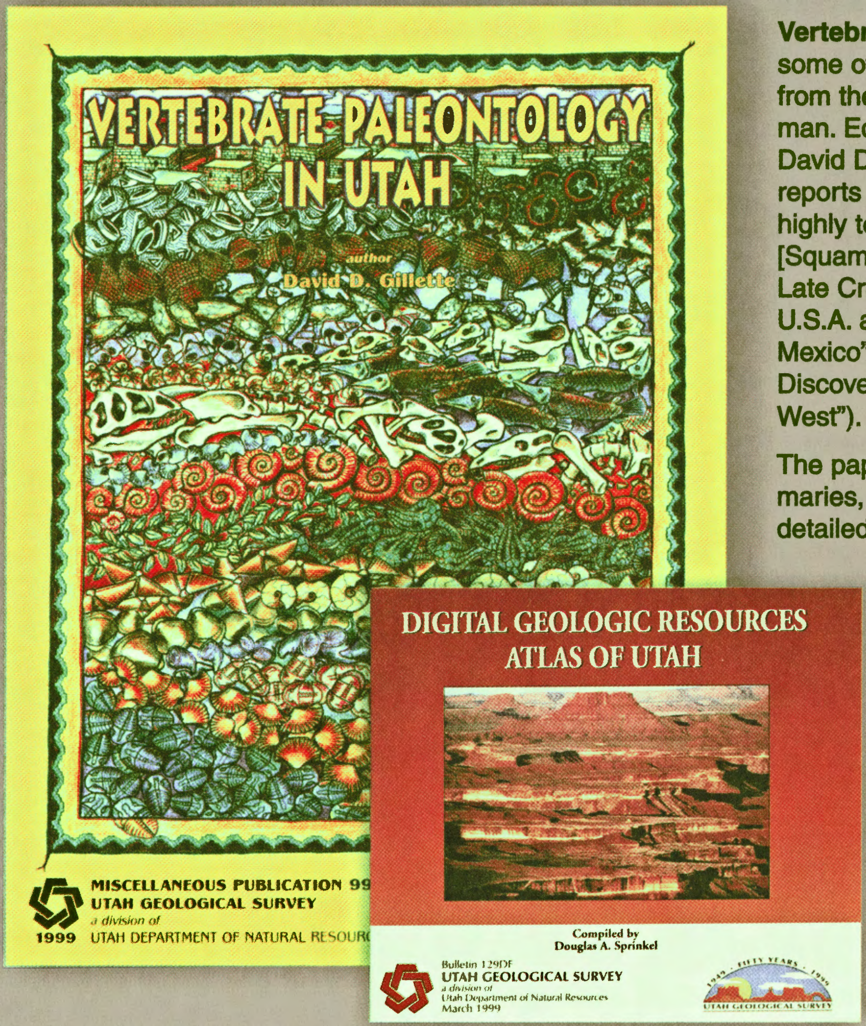
Much of eastern Utah was once covered by the Mancos sea. On the muddy floor of this sea lived a heavy shelled oyster called *Pycnodonte newberyii* (originally it was called *Gryphaea newberryi).* Some 85 million years later this muddy floor has turned into the rocks of the Mancos Shale, with fossils that include this type of oyster shell, commonly called Devil's Toenails.

While this may be a good place to collect Devil's Toenails, it is not the only place they are found. Scotsmen wore a similar variety of Devil's Toenails *(Gryphaea arcuata)* as amulets thought to alleviate joint pains. Englishmen pulverized these fossils, mixed them with whey, and employed the concoction as cattle medicine. Perhaps Utah's indigenous people had their own ingenious recipes for this part of the devil's anatomy. Maybe you can come up with your own magical use for these fossils. Better yet, maybe you can be a Nicolaus Steno of the twenty-first century and develop a revolutionary geologic theory through insights gleaned from *Pycnodonte newberyii.*

How to get there: This site is located in Emery County about 10 miles southwest of Green River, Utah. From Green River, take I-70 west about 11 miles to State Route 24 (exit 147). On State Route 24 travel south (towards Hanksville) 3.5 miles, then turn left (northeast) on an old paved road. Although paved, this road (old State Route 24) is no longer maintained by the county, so proceed with caution. Drive 4 miles and you will find a low-lying rocky outcrop on both sides of the road. If you drive under the power lines leading to the communication towers, you've gone several hundred yards too far.

Where to collect: Specimens erode from the outcrop and are easily collected from the gullies immediately adjacent to the road's shoulder.

....continued on page 11



Vertebrate Paleontology in Utah covers some of the experiences of vertebrate life from the age of fishes to the appearance of man. Edited by former State Paleontologist David D. Gillette, the publication has 52 reports in 542 pages that range from the highly technical ("Polyglyphanodontinae [Squamata: Teiidae] from the Medial and Late Cretaceous: New Taxa from Utah, U.S.A. and Baja California Del Norte, Mexico") to the more accessible ("The First Discoveries of Dinosaurs in the American West").

The papers "vary in content from summaries, or 'state-of-knowledge' treatments, to detailed contributions that describe new species," notes Gillete in his introduction to the volume. "The science of vertebrate paleontology in Utah is robust and intense. It has grown prodigiously in the past decade, and promises to continue to grow indefinitely. This research benefits everyone in the state through Utah's museums and educational institutions — which are the direct beneficiaries."

The soft-cover publication is available for $29.95.

The Digital Geologic Resources Atlas of Utah contains over 600 megabytes of ArcView® shape files gleaned from geologic resource data that have been collected for more than 50 years by the Utah Geological Survey, U.S. Geological Survey, U.S. Bureau of Mines, and the Bureau of Land Management. Among the layers are:

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This CD-ROM is ideal for government agencies and mineral and energy exploration companies. This is the first of several new digital products of the UGS and comes with ArcExplorer 1.1®. Available for $49.95.

These products and more are available at the Natural Resources Map & Bookstore, 1594 West North Temple, Salt Lake City (www.maps.state.ut.us).

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M-12 Geologic map of Cache County, Utah, by J.S. Williams, approx. scale 1:125,000, 1958 (part of Bulletin 64), 1-55791-410-9

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SS-11 Engineering implications and geology Hall of Justice excavation, Salt Lake City, Utah, by J.C. Osmond, W.P. Hewitt, and R. Van Horn, 1965, 35 p., 1-55791-130-4

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