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

SURVEY NOTES

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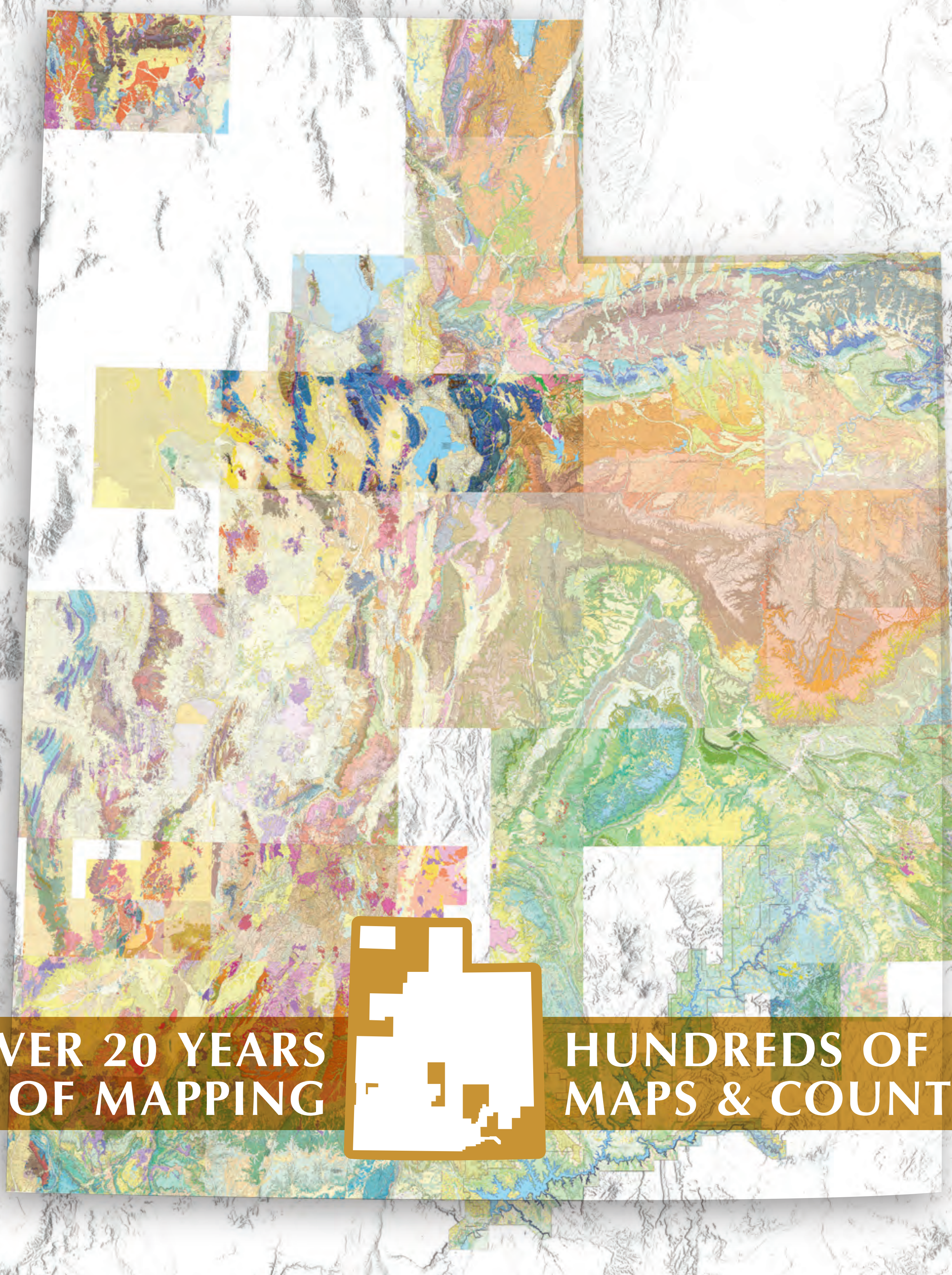

OVER 20 YEARS OF MAPPING

HUNDREDS OF MAPS & COUNTING

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Design | *Nikki Simon*

Cover | *Map of Utah showing all completed geologic mapping in 30' x 60' series.*

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THE DIRECTOR'S PERSPECTIVE

by Richard G. Allis

The Utah Department of Natural Resources (DNR) celebrates its 50th anniversary during 2016. In 1966 the Utah Geological and Mineralogical Survey (UGMS, as we were then called) was part of the State School of Mines and Mineral Industries at the University of Utah, and it was not until 1973 that the UGMS was transferred to the DNR. The early history of the UGMS from 1964 to 1975 is recorded in the *Quarterly Review*, the predecessor of *Survey Notes*, and these newsletters make interesting reading (go to http://geology.utah.gov/map-pub/survey-notes/past_survey_notes/). Some articles in the *Quarterly Review* could have been written today, having such timely topics as the importance of geological commodities to Utah's economic development, being aware of geologic hazards when planning for growth, and discussion about whether the State would be a better manager than the federal government of its resource potential. One notable change of UGMS responsibilities from 50 years ago compared to the UGS today was its early focus on Great Salt Lake. In 1965, the UGMS in partnership with the U.S. Geological Survey planned to produce 47 new quadrangle maps of the bathymetry of the lake. An article in the November 1965 *Quarterly Review* titled "The Great Salt Lake Navy" described the UGMS as having a fleet of three amphibious "ducks" (essentially 6 x 6 army trucks with a hull and a propeller), a motor dory, and a flagship vessel that was a 42-foot, 16-ton, dual jet-engine boat appropriately named the G.K. Gilbert. The ducks were not well suited to the lake, being heavy and slow, and frequently were "mired in the lake ooze and sand." Even the G.K. Gilbert had problems, requiring redesign and facelifts in 1968, 1972, and 1978 to make it faster and more suitable for the research required on the lake. By the mid-1970s, the UGS had installed a 12-foot tower in the middle of Great Salt Lake for continuous monitoring of meteorological and hydrological conditions, published navigational charts of the lake, studied the salt crust beneath the lake's north arm, and had been sampling and analyzing the brine chemistry four times a year since 1966. The February 1980 issue of *Survey Notes* records the end of the UGS fleet on Great Salt Lake. Ownership of the G.K. Gilbert was transferred to the DNR Division of Parks and Recreation in 1979, and the subsequent fate of the boat is not known. Although the UGS now has no vessels, it is still active on the lake, monitoring brine chemistry and less frequently the salt deposits. The UGS now maintains the sampling and water analysis program as a sub-contract to the DNR Division of Forestry, Fire and State Lands. The most recent release of water chemistry data, which includes all the historic sample data, can be found at http://files.geology.utah.gov/databases/index.htm—see Great Salt Lake brine chemistry database. As future alterations to the railroad causeway, separating the north and south arms of the lake, are considered and implemented, this database will be an important record of salinity, which can function as a tool to understand and interpret past salinity changes and help in predicting future lake responses.

MAPPING

UTAH'S GEOLOGY

BY **GRANT WILLIS**

In the 1980s geologic mapping was in serious decline—of much concern to oil and gas companies, geologic hazards geologists, and many others. The U.S. Geological Survey (USGS), long the bastion of geologic mapping, had suffered several major budget cuts; many senior mappers retired and younger mappers were laid off—few were ever replaced. Accurate, detailed geologic maps that meet modern standards are essential for land-use, resource-development, and geologic-hazard planning. Some states, recognizing the large negative impact a lack of up-to-date geologic maps could have on their economies, stepped in and created their own mapping programs—Utah created one of the first. In addition, many state geologists, industry leaders, and others lobbied Congress to fund new geologic mapping. The result was the National Cooperative Geologic Mapping Program, with three parts: FEDMAP—USGS, STATEMAP—state geological surveys, and EDMAP—students and their professors. Now, 23 years later, the results are impressive. Nearly every state and many universities have participated, and the act is reapproved with nearly unanimous support every 10 years. In Utah, this 50:50-match program has funded 168 geologic maps covering about 75 percent of the state (7.5' and 30' x 60' quadrangles and GIS databases).

Soon after STATEMAP started, Utah's State (geologic) Mapping Advisory Committee (SMAC) recognized that Utah has a unique situation—over 90 percent of our population and growth is concentrated in two areas: the Wasatch Front area and southwest Utah. Of course, these high-growth areas, with their hazard, resource, water, and other geology-related issues, have great need for up-to-date geologic maps. But if all mapping was in these growth areas, then the rest of the state, with equally pressing economic-resource and land-management issues, would go without modern mapping for decades. SMAC found a compromise—half of the budget would fund detailed (1:24,000 scale) mapping in high-growth areas; the other half would map large rural areas at intermediate detail (1:62,500 to 1:100,000 scale). While not suitable for geologic-hazard technical studies, the intermediate-scale maps meet most resource, recreational, and land-management needs. Now, two decades later, the benefits are clear. We just passed a major milepost in which 75 percent of the state is now covered by intermediate-scale geologic maps. These maps are produced in printed (plot-on-demand) and digital (GIS-geographic information system) formats and are purchased and downloaded by individuals, small companies, large corporations, professors, students, and many government agencies. Perhaps of greatest use, these maps are posted on an interactive web page (http://geology.utah.gov/apps/intgeomap/) in which the user can quickly view and zoom into hundreds of maps at several scales. Linked GIS data from the 30' x 60' series provides a detailed description of the geologic unit. With the addition of our latest 30' x 60' map, the Ogden quadrangle, we now have a continuous strip of intermediate-scale maps from St. George to Logan, plus much of the Uinta Basin, Colorado Plateau, and western Utah. In these areas, with the click of a mouse you can get a description of the geology of your neighborhood, work site, research area, or favorite hiking area.

This *Survey Notes* issue features two of our recent 30' x 60' quadrangle maps. The Ogden article tells how some of its complex geology was deciphered, and about the contributions of the new map. The Markagunt gravity slide article adds another chapter to one of the most fascinating geologic discoveries in Utah in several decades—the world's largest known land-based landslide. This story was unraveled through probing investigations conducted during the Panguitch 30' x 60' quadrangle mapping project.

THE TOPOGRAPHIC QUADRANGLE SERIES

Up until the early 1960s, the first step in detailed geologic mapping was usually to make your own topographic base map, which could squander half of your field time before you even drew a geologic line! Fortunately, we now have quality USGS topographic maps on which we build our geologic maps. The USGS produced crude topographic maps of most of the state as early as the 1880s, but it soon shifted to the "series" concept—standard quadrangles at standard scales with standard features (quadrangles follow lines of latitude and longitude and are not rectangles). The first reasonably accurate topographic maps were the 30' x 30' series (1:125,000 scale) produced from the 1890s to early 1920s. Following World War II, partially driven by the Cold War, they went on a topographic mapping blitzkrieg! Over the next 40 years they produced almost 2,000 Utah topographic maps, first mainly in the 15' (1:62,500) and 1° x 2° (1:250,000) series, but gradually shifting to the 7.5' (1:24,000) series.

The 7.5' series is now the base for most modern detailed geologic mapping. Utah is divided into 1,512 7.5' quadrangles (plus a thin sliver of 40 more along the Nevada border); each is about 58 square miles (2 square miles larger near Arizona/smaller near Idaho). Geologic maps have been completed for about 40 percent of these (the first batch in 1952). Unfortunately, we struggle to keep up—methods and expectations have changed so much that fewer than half meet modern standards. Our primary regional maps are done in the 30' x 60' series (about 1,850 square miles each); about 34 of 46 quadrangles have a reasonable geologic map, with a few more covered by older "temporary" maps. Today, with nearly all map assembly being done on computers, we can map at any scale appropriate for the area of interest. We also include as much detail as possible even if at "normal" scale the map looks too busy (yes—many map users zoom in far beyond the intended scale!).

In an ironic twist, we have now almost come full circle—just like in the old days, we now often make our own topographic base maps! But now we use USGS digital files of topographic map components, including a ground elevation model. In a matter of minutes we can create a customized topographic map of any area at any scale, with elevation contours at any spacing—in a way, the concept of "scale" has almost become obsolete. Base maps continue to improve—we eagerly await LiDAR (laser-sourced) ground control for our next base maps, which will allow production of even better geologic maps (but, unfortunately, make old maps seem even less accurate).

THE NEW OGDEN 30' X 60' GEOLOGIC MAP
COMPLEX GEOLOGY IN ONE SYNOPTIC MAP

BY JON K. KING

The Ogden 30' x 60' geologic map area extends from Ogden, Utah, to Evanston, Wyoming, and includes the growing Wasatch Front and Ogden and Morgan Valleys. The quadrangle is a popular all-seasons recreational area with scenic vistas, skiing, snowmobiling, boating, fishing, hiking, biking, camping, second homes, and more. The area is economically important because the Bear, Weber, and Ogden Rivers, which drain the area and are impounded in several reservoirs in the quadrangle, supply water to the Wasatch Front. The area is also economically and geologically important because of gas and oil fields on the east margin of the map area, and because of more mundane resources like the cement plant near Devils Slide and numerous sand and gravel pits.

A 30' x 60' geologic map is useful for recognizing large-scale structural geologic patterns of faults and folds, thickness changes in rock units, unconformities, where rock units are exposed and may be located in the subsurface, and what areas are more susceptible to geologic hazards, at least in a gross way (for example, landslides in the Norwood Formation). On the new Ogden map, like some other geologic quadrangles, valuable rock units are mapped separately from other units; for example, the Nugget and Twin Creek Formations which are gas and oil reservoirs, the Phosphoria Formation which contains potential phosphate resources, and specific Twin Creek Formation members (subunits) which contain material for cement and aggregate.

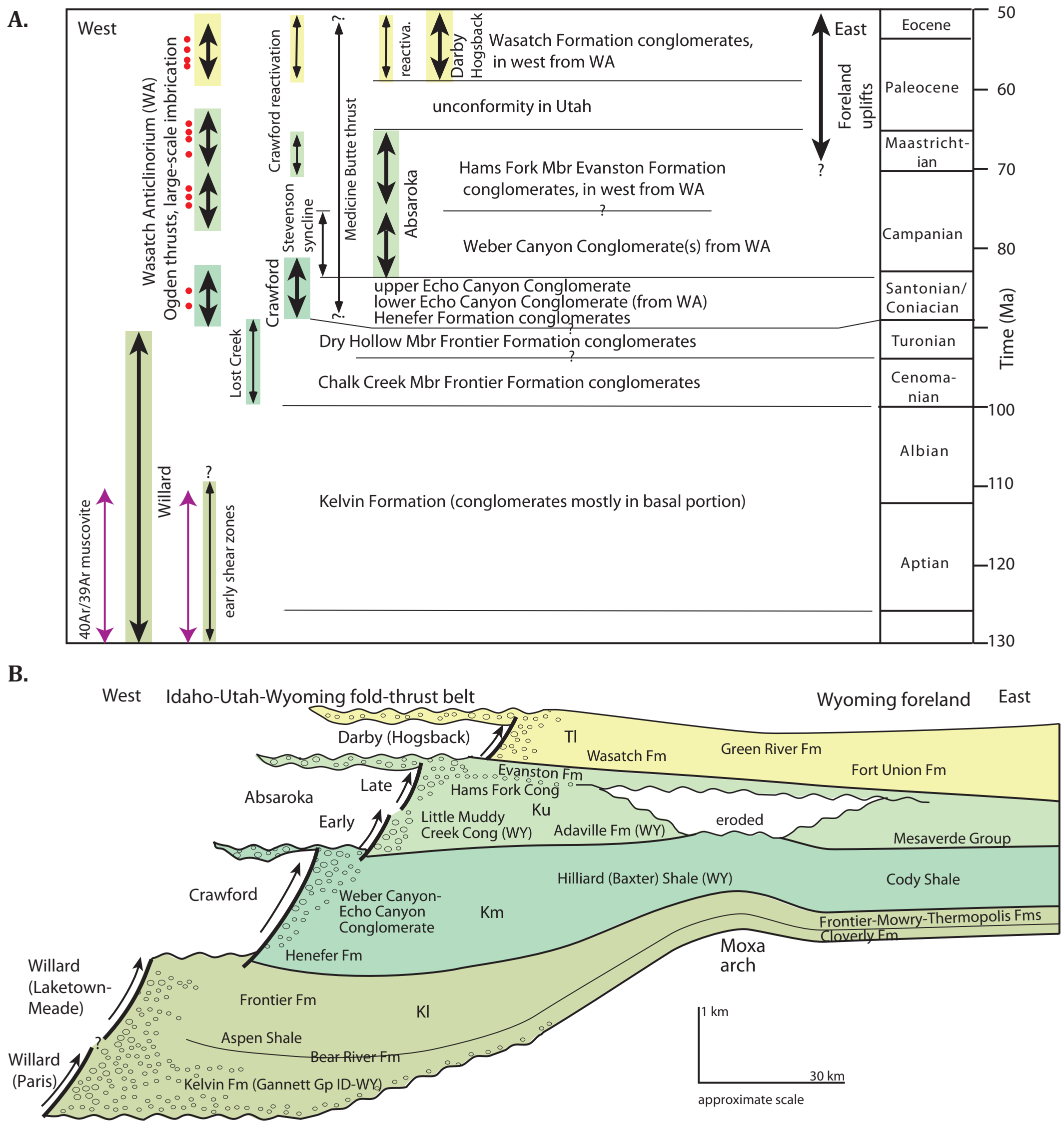
This map will be released as a geographic information system (GIS) product with supporting materials that include map unit descriptions, an index to detailed geologic mapping that was simplified to make the Ogden map (both with references cited), an explanation of line and point symbols on the map, multiple bedrock lithologic columns and correlation charts, and a correlation chart for Quaternary surficial deposits. This is the first attempt to systematically map the surficial deposits in the Ogden quadrangle, including the glacial deposits in the northern Wasatch Range, on Durst Mountain, and in the southern Bear River and Monte Cristo Ranges, and to map sinkholes (karst). On previous maps, surficial deposits were mapped inconsistently—one mapper decided some deposits were too thin to show, while another mapped similar deposits. Our new Ogden map has about 90 surficial-deposit units and about 180 bedrock units, with map-unit descriptions and references in excess of 100 pages.

Why map the Ogden 30' x 60' quadrangle? Specifically, to replace less detailed geologic mapping that is over 30 years old and does not reflect geologic knowledge generated during the late 1970s and early 1980s energy boom. The new Ogden map fills a hole between similar 30' x 60' geologic maps to the north (Logan), south (Salt Lake City), and east (Kemmerer and Evanston, Wyoming). Fortunately for Utah, Jim Coogan, who had mapped similar terrain for his Ph.D., was available to map most of the quadrangle and, as a bonus, had access to energy-boom data.

Geologically, the Ogden map area has a unique combination of rocks and deformation packed into a single 30' x 60' quadrangle. The rocks can be divided into the following groups: (1) deformed and

Trappers Loop road area with Strawberry Bowl on right, Strawberry Peak on right center skyline, and deformed and metamorphosed middle Precambrian rocks (Farmington Canyon Complex) on left. Glacial deposits, landslides, and Norwood Formation in mid-ground and foreground. Photograph by Ken Krahulec.

metamorphosed middle Precambrian (~1.7 billion years old) crystalline rocks of the Wasatch Range, (2) miles-thick latest Precambrian metasedimentary rocks in the northwest part of the map area, (3) marine Paleozoic mostly carbonate sedimentary rocks exposed in the west half of the map area that thin to the east, (4) mostly marine Mesozoic sedimentary rocks that are exposed in the central part of the map area, (5) mostly non-marine late Mesozoic (Cretaceous) conglomeratic sedimentary rocks in the central part of the quadrangle that cover the older rock packages, (6) non-marine early Cenozoic (early Tertiary) sedimentary rocks in the central and east parts of the quadrangle that cover older rocks, and (7) later Cenozoic non-marine sedimentary rocks and surficial deposits in valleys scattered across the map area. The Cretaceous and early Tertiary rocks were deposited when the first four rock groups were deformed into a fold and thrust-fault (or overthrust) belt that is part of the Cordilleran mountain chain that spans western North America from Alaska to Mexico. The folding and thrusting created the complex geology in the western and central parts of the Ogden 30' x 60' map area, including thrust-stacking of Precambrian rocks, and the gas and oil fields near the Utah-Wyoming border. Typically, in the Idaho-Utah-Wyoming area the numerous thrust faults get younger to the east, but the timing is more complicated in the Ogden map area. Huge alluvial fans that are now Cretaceous conglomeratic rocks were shed off the mountains built during the folding and thrusting (a mountain-building event is known as an orogeny). Smaller early Tertiary alluvial fans (now sedimentary rocks) were shed from mountain remnants during waning stages of the orogeny and are conglomeratic in the central part of the map area. Later Cenozoic rocks and surficial deposits are in valleys that formed during normal faulting. As demonstrated by normal faults that break the ground surface (form scarps), more recent (Quaternary) faulting has occurred in at least a dozen roughly north-south trending valleys throughout the map area, and may present a serious earthquake risk.



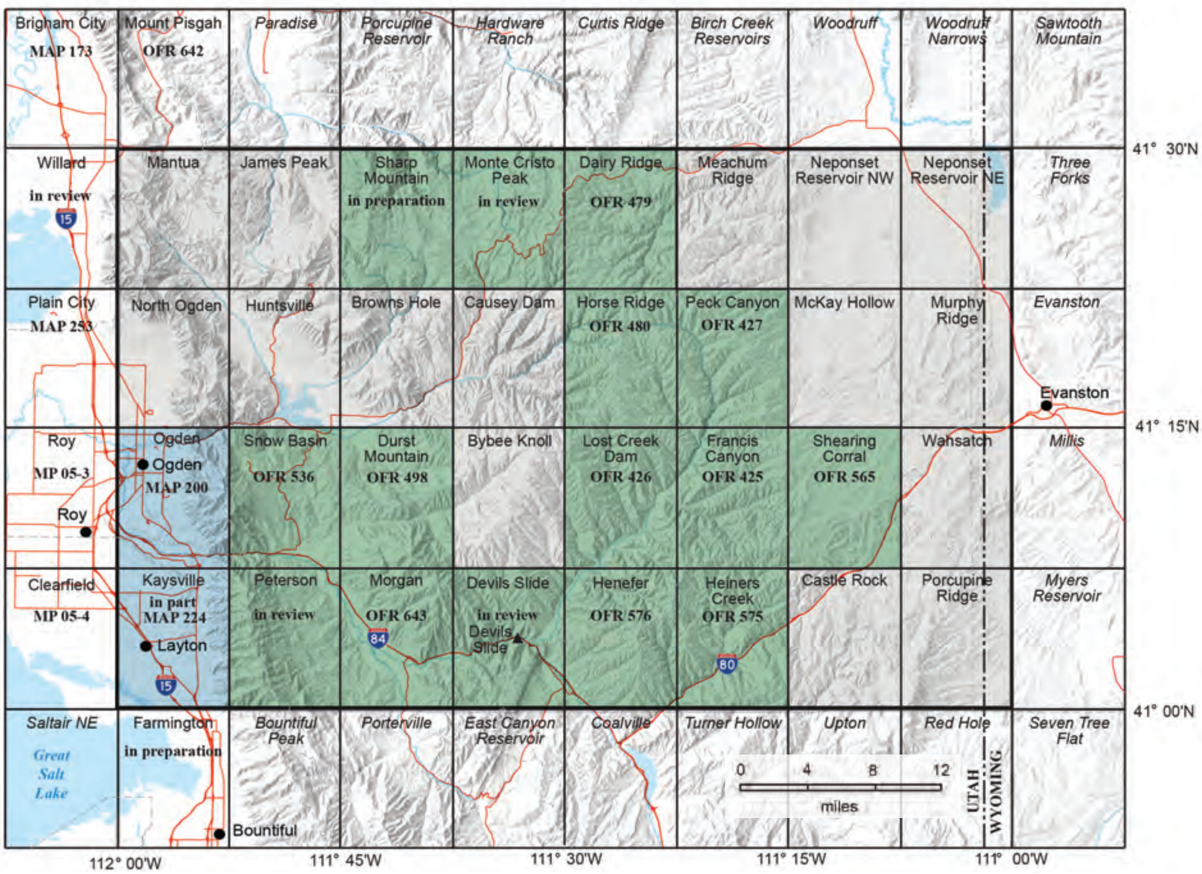
History of thrusting in the Idaho-Utah-Wyoming fold-thrust belt (modified from previous work). (A) Ages of thrusting and fossil pollen in conglomerates from the Ogden project. Fission-track ages (red dots) and $^{40}Ar/^{39}Ar$ ages (red lines with arrows) from previous work. (B) Thicknesses and names of strata related to major thrusts in Utah and southwest Wyoming. Note that conglomeratic intervals (ellipses) are east and west of associated thrusts. Lower Cretaceous strata (Kl) are thickest in the foredeep associated with the Willard (Paris, Laketown-Meade) thrusts. Middle Cretaceous strata (Km) record movement on the Crawford thrust and regional subsidence, indicated by thick shales. Upper Cretaceous strata (Ku) record two episodes of movement on the Absaroka thrusts, with uplift of and erosion over the Moxa arch. Lower Tertiary strata (Tl) record movement on the Darby (Hogsback) thrust.

As a major contribution to the geology of Utah, this is the first regional map of the Utah-Idaho-Wyoming fold and thrust belt to use extensive fossil pollen data (palynology), removing the earlier speculation and assumptions about non-marine Cretaceous and Tertiary synorogenic (deposited during orogeny) rocks. Through our painstaking mapping of angular unconformities, our sampling for and analysis of fossil pollen by Gerry Waanders, and previous work by the U.S. Geological Survey and Chevron on fossil pollen, we now know the outcrop patterns and geologic ages of the numerous synorogenic conglomerates (and thrust deformations) in the Ogden map area. These conglomerates were dated by identification of the age-specific fossil pollen they contain, with previous isotopic and fission-track dating providing age control in uplifted areas. With previous studies and our own work, these conglomerates have been tied to specific thrust sheets by being on or near the thrust sheets, and by rock types in the conglomerate clasts being from formations on the related thrust sheet.

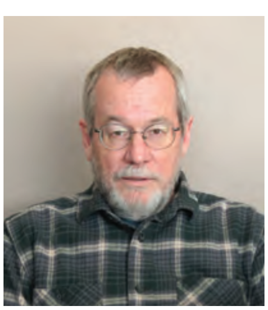
As with many geologic maps, the references cited in the supporting materials for the new Ogden map can be as important as the map itself for people who want more detailed geologic information. Specifically during the Ogden project, the UGS has or will publish detailed geologic maps for nearly half of the 32 7.5-minute quadrangles within the 30' x 60' quadrangle. These detailed maps show Quaternary deposits that were removed from the 30' x 60' map to better show the bedrock geology.

The Ogden 30' x 60' geologic map and many of the detailed 7.5-minute quadrangle geologic maps were partially funded through U.S. Geological Survey STATEMAP award numbers 96HQAG01521, 97HQAG01797, 98HQAG2067, 00HQAG109, 03HQAG0096, 04HQAG0040, G10AC00386, and G11AC20249.

The Ogden 30' x 60' geologic map is expected to be released later this year. Please check the UGS website (geology.utah.gov) for a notice of availability.



Index to detailed geologic mapping of the Ogden 30' x 60' quadrangle, with U.S. Geological Survey 7.5-minute quadrangle names. Green areas are mapping completed for this project. Blue areas are other mapping in project area. All Maps, Miscellaneous Publications (MP), and Open-File Reports (OFR) shown have detailed Quaternary mapping and are published by the Utah Geological Survey.



ABOUT THE AUTHOR

Jon King has been a geologist in the Geologic Mapping Program at the Utah Geological Survey since 1992. He is a co-author on the Ogden 30' x 60' geologic map, 14 detailed geologic maps within the quadrangle, and 2 detailed geologic maps adjacent to the quadrangle. Prior to 1992, Jon worked for the Wyoming State Geological Survey for seven years investigating industrial minerals, construction materials, uranium, thorium, rare earth elements, and even gold, and generating about 30 publications.

UPDATE ON THE MARKAGUNT GRAVITY SLIDE

UTAH'S LARGEST LANDSLIDE JUST GOT BIGGER—A LOT BIGGER

BY ROBERT F. BIEK[1], DAVID B. HACKER[2], AND PETER D. ROWLEY[3]

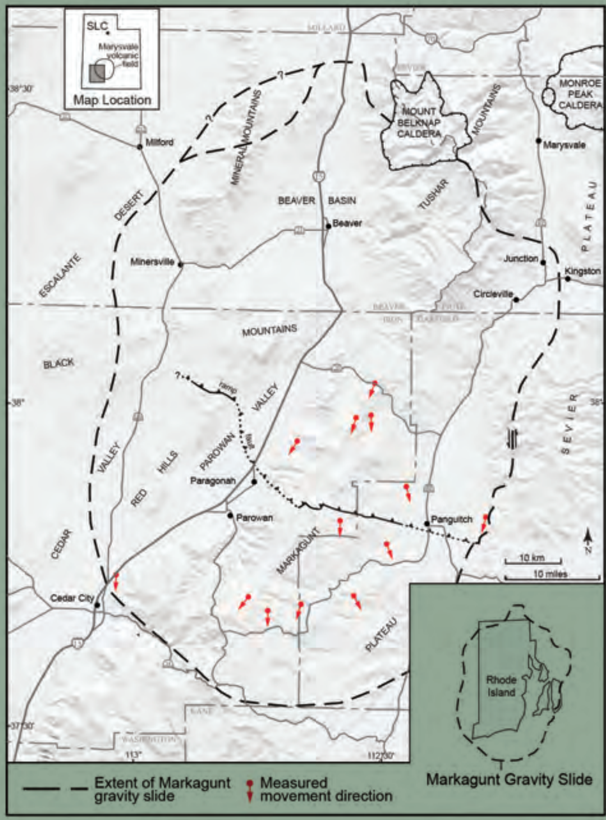
In the May 2013 issue of *Survey Notes*, we introduced the Markagunt Megabreccia, the eroded remains of a 21- to 22-million-year-old landslide that blankets the Markagunt Plateau northeast of Cedar City. At that time, we understood this enigmatic deposit to be Utah's largest landslide, which we thought was about 500 square miles in extent—considerably larger than all of Salt Lake Valley and a bit more than three-times the size of Utah Lake.

Since then, new geologic mapping between Cedar City and Beaver shows that this landslide is much, much larger. We call it the Markagunt gravity slide (gravity slides are a special class of extremely large landslides).

We summarized this new discovery in the November 2014 issue of *Geology*. At about the same time, we also published a field guide, sharing the history of its discovery and 17 exceptionally instructive exposures, in *Geology of Utah's Far South*, Utah Geological Association Publication 43. In both reports, we hypothesized its size to be about 1,300 square miles. Ongoing research in 2014 and 2015 enabled us to identify the eastern flanking fault, which bounds the east margin of the gravity slide near the western edge of the Sevier Plateau, and the western flanking fault, which bounds the west margin in the central Black Mountains. Additional exposures of deformed rocks in the southern and western Tushar Mountains, eastern Black Mountains, and Mineral Mountains further expands the known extent of rocks involved in this gigantic landslide.

In fact, we now estimate the Markagunt gravity slide is at least 2,000 square miles in extent and thus similar in size to the newly redefined 2,000-square-mile Heart Mountain gravity slide in northwestern Wyoming; both now vie for the title of Earth's largest known terrestrial landslide (larger submarine landslides are known in ocean basins and former submarine basins on Mars). Additionally, the discovery in 2015 of intensely deformed rocks in the nearby southern Sevier Plateau shows that those volcanic rocks also moved catastrophically, likely as a large (at least 500 square miles) gravity slide somewhat older than the Markagunt gravity slide. The ultimate slide plane of both landslide masses is a gently south-tilted volcaniclastic unit of incompetent (greasy) tuffaceous mudstone and sandstone beneath the volcanic rocks.

The Markagunt gravity slide consists of Miocene and Oligocene (about 20 to 30 million years old) volcanic mudflow deposits, lava flows, and volcaniclastic sedimentary rocks derived from the Marysvale volcanic field, and intertonguing ash-flow tuffs mostly derived from the Indian Peak and Caliente caldera complexes (located near the present-day Utah-Nevada border). A basal slip surface with striations, grooves, and distinctive fractures, a basal zone of crushed and sheared rock and associated clastic dikes, and pulverized rock (ultracataclasite) and friction-generated melt rock (pseudotachylyte) on shear planes and in dikes emanating from these shear planes provide strong evidence of catastrophic emplacement from the north as part of a gigantic landslide. This is the first reported occurrence of landslide-generated pseudotachylyte in North America and is among only a handful of examples known throughout the world.



Extent of the Markagunt gravity slide, now understood to be one of the largest terrestrial landslides known on Earth. The slide resulted from catastrophic collapse of the southwestern part of the Marysvale volcanic field about 21 to 22 million years ago. The ramp fault is where the slide mass moved up and over the former land surface. Insets show size of slide in relation to the state of Rhode Island and location with respect to the Marysvale volcanic field.

From its breakaway zone in the southern Tushar Mountains to the southern limit of its debris-avalanche deposits near Cedar Breaks National Monument, the Markagunt gravity slide is nearly 65 miles long and locally at least 40 miles wide. We document southward transport of at least 20 miles over the former early Miocene land surface, and suggest that this movement was extremely rapid, possibly approaching speeds of 200 miles per hour. We suggest that the slide represents catastrophic gravitationally induced collapse of the southwestern part of the Marysvale volcanic field.

The Markagunt gravity slide exhibits the full range of structural features commonly seen in modern landslides, including compression and resultant thrust faulting in the gravity slide's toe area, simple translational movement of the main body of the slide, and extensional faulting in the upper parts (breakaway zone) of the slide. These facts, coupled with its gigantic size, illustrate why the gravity slide remained undiscovered for so long and why early interpretations were incomplete and oft-times apparently conflicting. In addition, basin-range tectonism that eventually created the present topography followed the gravity slide to add confusion to the age of gravity-slide structures.

Understanding the Markagunt gravity slide is important because it opens the door to re-evaluation of other large volcanic centers that may conceal exceptionally large, as-yet unrecognized landslides. It represents a new class of low-frequency but high-impact hazards associated with catastrophic collapse of large volcanic fields containing multiple volcanoes, and it serves as an analog to better understand these rare, extreme events. Magmatic doming and resultant lateral spreading of modern volcanic fields—which precedes catastrophic collapse and is known in many places around the world, including the Big Island of Hawaii, Mount Etna in Sicily, and the Canary Islands—could have important implications for hazard assessment of potential gigantic landslide events from collapsing volcanic fields.

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[2]*Kent State University*
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ENERGY NEWS

Some impacts of low oil prices on Utah

BY **DAVID E. TABET**

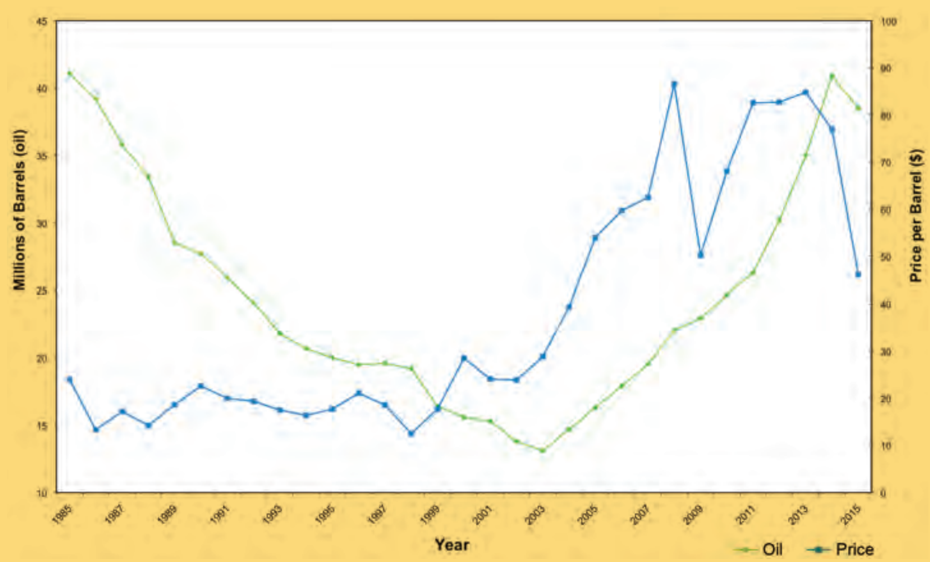
For the past year or so Utah drivers have been enjoying low gasoline prices at the pump as a result of the dramatically lower price paid per barrel of oil (1 barrel = 42 gallons). While the average driver and the transportation sector of the Utah economy may be benefiting from lower oil prices, those benefits are coming at the expense of the oil-producing sector, whose revenues and profits have fallen. Utah, as the 11th largest oil-producing state in the U.S., will have some negative impacts to its economy as a result of the current low prices paid per barrel of oil.

Because oil is an internationally traded commodity, Utah oil prices are affected by changes in the world market. Utah oil prices dropped from about $86 per barrel in July 2014 to about $33 per barrel in January 2015. Over the past 30 years, the trend of Utah's oil prices has fluctuated, trading in a mostly flat range from 1985 to 1998, and since 1999 on a generally upward, but volatile, trend. Besides the 40 percent drop in the average annual oil price per barrel in 2015, there have only been three other times in the past 30 years when the average annual oil price has dropped by more than 30 percent from the previous year: 1986 (44 percent drop), 1998 (32 percent drop), and 2009 (42 percent drop) when there was a major economic recession. The 2015 drop in Utah's average annual oil price harkens back to the 44 percent oil price drop in 1986 when, like today, Saudi Arabia sought to regain market share by increasing production to lower prices and drive higher-cost suppliers, such as those in Utah with difficult-to-handle waxy crude, from the market.

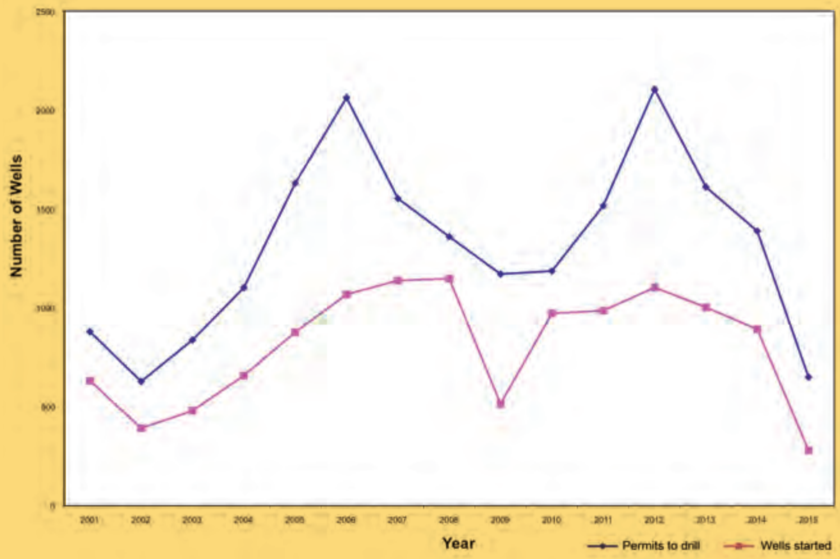
Although full-year numbers are not yet in for 2015, it appears that Utah, as one of the higher-cost petroleum-producing states, will see its oil production fall from 40.9 million barrels in 2014 to 38.5 million barrels in 2015, or about a 6 percent decrease. This production decline will result from a dramatic drop in drilling activity in the state. The annual rig count for Utah is forecast to plunge from an average of 25 operating rigs in 2014 to a projected annual average of about 8 rigs for 2015. In a similar fashion, applications to drill and well starts (spuds) for 2015 in Utah are expected to be at low levels not seen since 2002.

Economically, this recent decline in petroleum exploration and production activities significantly affects the gross value of Utah's produced oil and gas. The value of oil and gas production is anticipated to drop from $5.6 billion in 2014 to about $3.0 billion in 2015. The decrease in petroleum exploration and production activity over a year's period ending March 2015 led to a loss of 791 energy-related jobs in Duchesne and Uintah Counties according to recently released statistics from the Utah Department of Workforce Services, and petroleum development activity in Utah has decreased further since that time. In addition to lower income tax revenues from laid-off petroleum and service-company workers, Utah's General Fund will likely lose about $38 million in severance tax revenue related to oil and gas, since these taxes are estimated to decline from over $89 million in 2014 to about $51 million in 2015. The State of Utah will also see its 48 percent share of oil and gas royalties from petroleum production on federal lands in Utah shrink by another $50 million. The royalties collected for energy production from federal lands in Utah by the U.S. Office of Natural Resources Revenue and returned to the state will decrease from over $167 million in 2014 to an estimated $116 million for 2015. The State of Utah also collects a 0.2 percent conservation fee on the net production value of oil and gas produced from state and private lands to help with public education about oil and gas and to plug orphaned and abandoned petroleum wells. In 2014 about 20.4 million barrels of oil and 177.6 billion cubic feet of natural gas were produced from state and fee lands with an estimated value of $2.5 billion that would generate about $5 million for the conservation fund. For 2015, the conservation fee collections will likely be reduced 40 percent to about $3 million.

This reduction of over $85 million in petroleum-related revenue to the State of Utah from 2014 to 2015 only amounts to a 1.3 percent drop in overall state revenue, but certain



Utah average annual oil price per barrel and production from 1985 through 2015 (2015 full-year data are estimated). Sources: UGS files and Utah Division of Oil, Gas, and Mining.



Annual permits to drill and wells started (spudded) from 2001 through 2015 (2015 full-year data are estimated). Source: Utah Division of Oil, Gas, and Mining.

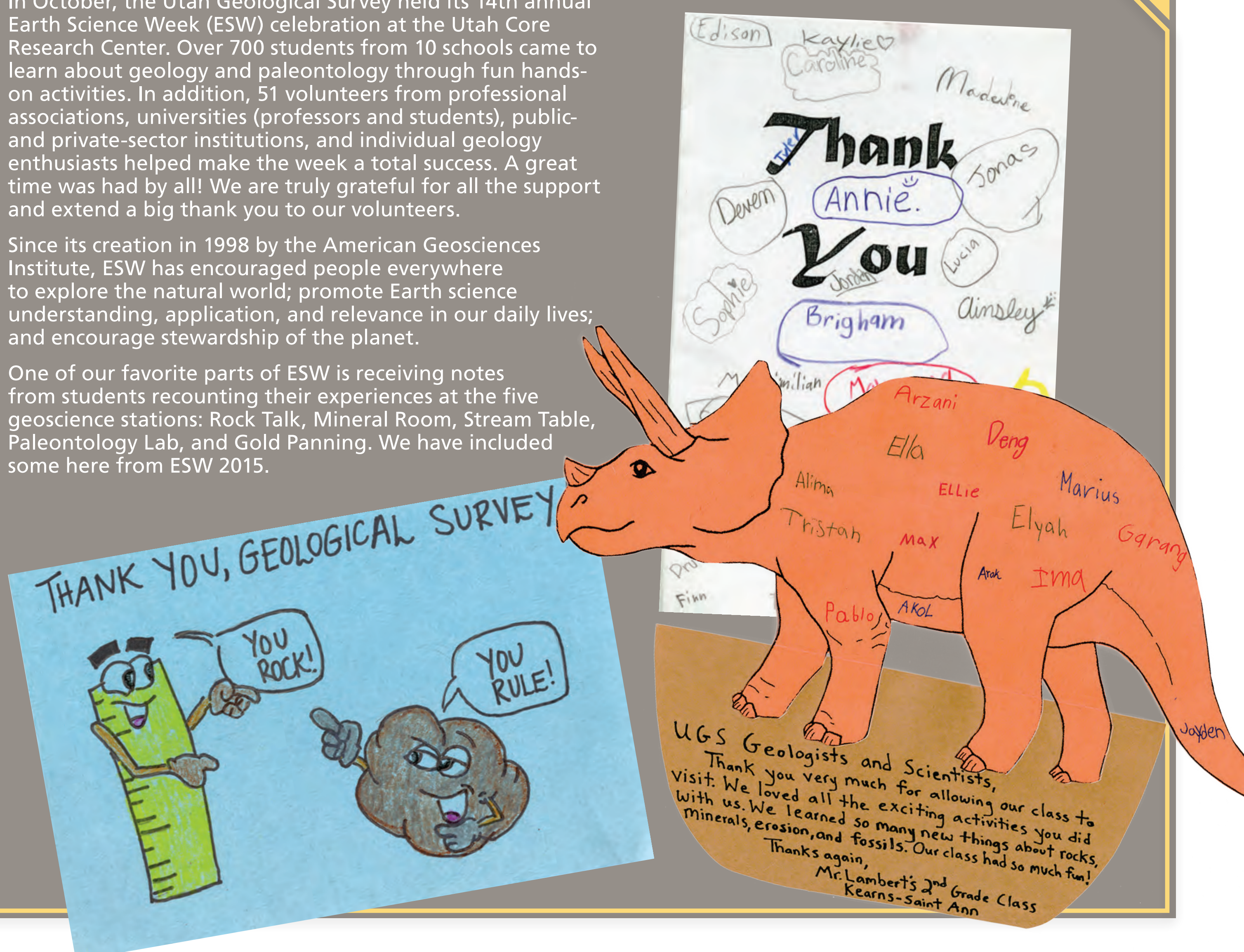
parts of state government and several county governments will be more severely affected than others. Since it is difficult to predict when oil prices and industry activity will pick up in the future, these impacts could continue for several more years. At the time of writing, many financial forecasters are predicting a slow, gradual increase in oil prices through 2016 to an average annual Utah price of about $31 per barrel from around $39 per barrel in 2015. Hopefully growth in other sectors of Utah's economy will benefit from lower oil prices and offset losses in revenue and employment in Utah's petroleum sector that have been caused by the plunge in oil prices, activity, and ultimately production.

TEACHER'S CORNER

In October, the Utah Geological Survey held its 14th annual Earth Science Week (ESW) celebration at the Utah Core Research Center. Over 700 students from 10 schools came to learn about geology and paleontology through fun hands-on activities. In addition, 51 volunteers from professional associations, universities (professors and students), public- and private-sector institutions, and individual geology enthusiasts helped make the week a total success. A great time was had by all! We are truly grateful for all the support and extend a big thank you to our volunteers.

Since its creation in 1998 by the American Geosciences Institute, ESW has encouraged people everywhere to explore the natural world; promote Earth science understanding, application, and relevance in our daily lives; and encourage stewardship of the planet.

One of our favorite parts of ESW is receiving notes from students recounting their experiences at the five geoscience stations: Rock Talk, Mineral Room, Stream Table, Paleontology Lab, and Gold Panning. We have included some here from ESW 2015.



GLAD YOU ASKED

WHY ARE THERE SO MANY NATURAL ARCHES IN UTAH?

BY LANCE WEAVER

Utah's Colorado Plateau is home to the densest concentrations of natural arches found anywhere in the world. Arches National Park alone claims to be home to over 2,000 documented natural sandstone arches with diameters of at least 3 feet. At least 800 significant arches have been photographed and identified elsewhere in the state and thousands of others are estimated to exist. Six of the world's fifteen largest known natural arches are found in Utah. Such impressive statistics often give rise to the question, "What is it about Utah and the Colorado Plateau that makes natural arches so prevalent?"

CLIMATE AND SUBSTRATE MATERIAL Natural arches form in a variety of rock types such as limestone, shale, granite, or even basalt. However, in Utah, sandstone is the most common geological substrate for their formation. Several of Utah's sandstone bedrock units meet the favorable conditions of being strong enough to support the weight of large natural arches, yet soft enough to be easily eroded by the natural processes of wind, water, and gravity. The region's semiarid climate also plays an important role in forming and maintaining the needed exposures of these sandstone units. Because of sandstone's unique permeability and porosity (the ability of water to flow through its pore spaces), a climate that is too wet tends to destroy sandstone's ability to form cliffs by allowing groundwater to leach out too much of the mineral cement that holds the sand grains together. On the other hand, a climate that

Oblique aerial view of the parallel joint pattern formed in the Entrada Sandstone near Arches National Park in southeastern Utah. The axis of the Moab Valley anticline runs along the left side of the image. GoogleEarth imagery ©2015 Google Inc., Landsat. Used with permission.

is too dry will not sustain the perennial streams responsible for the effective development of cliffs and canyons where arches most often form.

REGIONAL, PARALLEL JOINT SYSTEMS Arch formation in Utah is also facilitated by an abundance of regional, parallel joint systems or sequences of bedrock fractures. These joint systems tend to be located on the flanks of broad, gently sloping uplifts or folds. Many of the arches found in iconic places such as Arches, Capitol Reef, Canyonlands, and Zion National Parks, for instance, formed along deeply eroded fracture systems bordering folds created during compressional tectonic events. In some areas, such as Arches National Park, subsurface salt migration played a role in creating these elongated domed structures. In other areas, such as Zion National Park, more recent extensional tectonics played a role in enlarging preexisting joint systems. Over time, these joints and fractures become exposed at the surface and erode into a network of canyons and rock fins ideal for the formation of arches.

Joint systems can also form independent of regional fold or fault zones. In many parts of Utah, arches form along joints that develop parallel to the walls of deep canyons. As streams carve canyons into the bedrock, lateral pressure is removed, allowing the bedrock to fracture as it relaxes and expands into the newly created space. Expansion of ice in these fractures greatly accelerates this process. In many of Utah's sandstone alcoves, "sheeting" of the rock is evidence of this slow relaxing and expansion of rock once under great pressure.

ENTRENCHED MEANDERS Utah is also unique in its abundance of entrenched river systems, which often form spectacular natural bridges. A natural bridge is a subtype of natural arch that is primarily water-formed and often spans a waterway such as a stream. Many of Utah's natural bridges, such as those found at Natural Bridges National Monument, were formed as the gentle uplift of the Colorado Plateau caused the region's rivers and streams to become entrenched in deep canyons, while maintaining their original meandering courses. As these entrenched meanders deepened and widened over time, erosion and undercutting of the canyon walls on the outside of meander bends eventually allowed the river to break through, rerouting the river to flow along the shorter course under the newly formed natural bridge. Rainbow Bridge near Lake Powell, Coyote Natural Bridge, and the three large bridges at Natural Bridges National Monument are a few of Utah's best examples of this type of arch.

Arches form because the shape is nature's most effective geometry for holding up overlying strata. The semicircular shape of an arch is actually the most effective load-bearing form in nature because of the manner in which it distributes the compressional stresses and eliminates the extensional stresses in the surrounding rock. It is the shape that most effectively follows nature's rule of getting the best natural stability with the least amount of effort.

The Natural Arch and Bridge Society defines a natural arch as "a rock exposure that has a hole completely through it formed by the natural, selective erosion of rock, leaving a relatively intact frame." In a colloquial sense, a natural arch is often defined more loosely as a rock formation composed of a curved or vaulted rock structure which supports its own weight without necessarily being a free-standing bridge.

IRREGULARITIES IN CEMENTATION Variability in the mineral cements of many of Utah's exposed sandstone layers is another important factor in the formation of arches in the state. Small arches and alcoves tend to be more common in regions where groundwater movement and other processes have created abundant irregularities in the hardness of the supporting sedimentary units. These regions of poorly cemented sand or variable hardness can be created as the sandstone is being deposited and cemented or by post-depositional processes, such as mineral leaching, surface evaporation, or groundwater movement. When a sandstone layer is exposed, irregularly cemented areas often differentially erode in ways more likely to create arches and alcoves. In Utah these types of irregularities in cementation are responsible for hundreds of small arches and windows in places like Goblin Valley and Snow Canyon State Parks.

It is the various combinations of these arch-forming components which have made Utah's Colorado Plateau region one of the world's densest concentrations of arches.

Rainbow Bridge, near Lake Powell in southern Utah, is an example of an arch formed in an entrenched meander within the Navajo Sandstone.

Kolob Arch, in Zion National Park, is an example of an arch formed along parallel joint systems in the Navajo Sandstone. Photo courtesy of the National Park Service.

GeoSights

Smoky Mountain, Kane County

BY MARSHALL ROBINSON

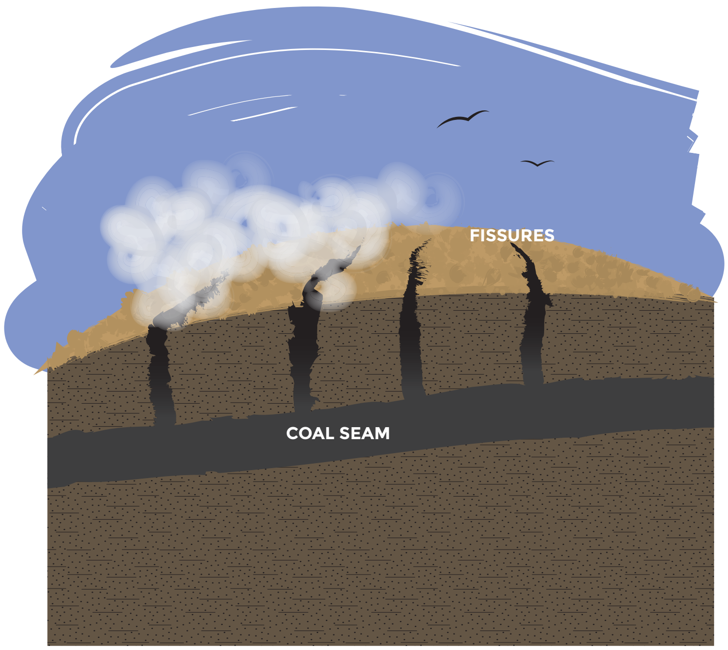
Nobody denies southern Utah can be blazing hot. An area north of western Lake Powell is even dotted with heat-related place names: Warm Creek, Burning Hills, Smoky Hollow, and Blackburn Canyon to name a few. These place names actually signify underlying heat sources that have nothing to do with the air temperature. One place has actually been burning hot for hundreds and maybe even thousands of years. Atop the appropriately named Smoky Mountain, you will find… no flames whatsoever. A bit anticlimactic yes, but there truly is a fire (known as the Big Smokey Fire), although it is burning (or at least smoldering) underground. Large fissures or cracks in the ground feed oxygen to this underground fire. Expectations may be high to see the gaseous fumes from this fire venting from the cracks, but realize this is only possible when temperatures are near or below freezing. The extra time required to bundle up for cold temperatures shouldn't dissuade your visit though, as you will be rewarded with a scene similar to a volcanic area such as Yellowstone National Park. However, an underground coal seam (or seams), rather than a volcanic hotspot, fuels the fire beneath Smoky Mountain.

Smoky Mountain's numerous coal seams are interbedded among 1,000 feet of Cretaceous-aged mudstone and sandstone known as the Straight Cliffs Formation. The Straight Cliffs Formation was deposited approximately 80 to 90 million years ago when the area was encroached upon by a fluctuating body of water called the Western Interior Seaway. The fluctuating sea level caused deposition of the alternating layers of mudstone, sandstone, and coal you find in the cliffs and ledges of Smoky Mountain. A thick layer of sandstone dominates the uppermost cliffs of Smoky Mountain and overlies a poor foundation of soft mudstone.

In the area of the Big Smokey Fire, numerous long fissures, or ground cracks, run parallel to the cliff edge. The cracks near the cliff are likely due to the erosional undermining of the cliff's mudstone base. Other cracks developed as the underlying coal seams burned out and reduced to ash, leaving little to no support for the overlying sandstone. These cracks eventually propagate to the surface, allowing additional oxygen to reach the fire, so it is unlikely that a lack of oxygen will naturally lead to the fire's demise.

You may be wondering, "How did this fire start in the first place?" Spontaneous combustion or a lightning-sparked wildfire are the two probable candidates. Coal is susceptible to spontaneous combustion due to its ability to self-heat in the presence of oxygen and moisture coupled with minimal ventilation for cooling. In the case of a lightning-sparked wildfire, hot embers may fall into preexisting fissures, igniting any exposed coal. Once coal

View to the northeast of a fuming ground fissure atop Smoky Mountain. Photo: David Rankin (used with permission).



The existing fissures atop Smoky Mountain slowly grow as the underlying coal seams continue to burn and reduce to ash. The scenery is ever changing, as this ongoing process will undoubtedly create new fissures as time progresses.

begins burning, it often burns until there is none left, or the oxygen source is cut off.

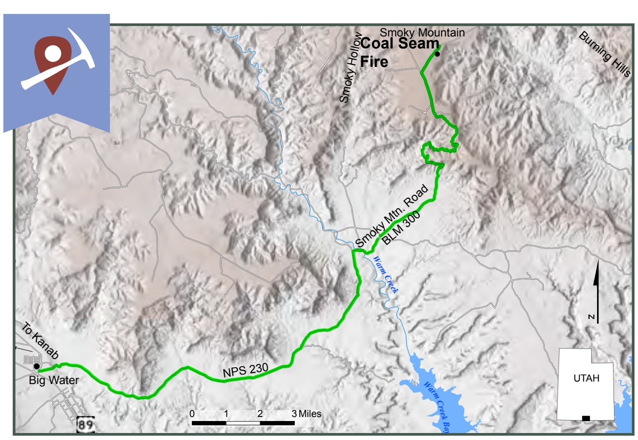
On two separate attempts (1967 and 1968), the U.S. Bureau of Mines tried to extinguish the Big Smokey Fire with water and other fire retardants to no avail. Additionally, bulldozers and excavators filled the cracks with rocks and dirt hoping to smother it; however, the unyielding coal fire continues to smolder to this day. A visit to the site today reveals these human disturbances as many of the fissures are mounded over with boulders and crushed rock. As proof that the fire still burns, new cracks have since propagated to the surface since the '67–'68 extinguishing attempts. Because this coal fire is a naturally occurring phenomenon, it will likely continue to smolder until the coal is gone as this location is now part of Grand Staircase–Escalante National Monument, which preserves the land within its boundaries for non-destructive scientific studies.

Underground fires may seem like an anomaly local to Smoky Mountain, but there are actually thousands of these blazes burning uncontrolled throughout the world. China is home to a majority of coal seam fires with an estimated 20 to 200 million tons of coal burned each year. Utah has had eleven uncontrolled coal seam fires concentrated in Kane, Emery, and Carbon Counties. Between 1958 and 1976, the U.S. Bureau of Mines attempted to smother eight of Utah's active coal seam fires at an inflation-adjusted cost of over $4.1 million. The Zion Fire, located between Mt. Carmel Junction and the eastern entrance to Zion National Park, was successfully extinguished, but the remaining seven actively burn today.

ON A SIDE NOTE

Coal is not the only fuel for underground fires; natural gas fires also burn in a few places across the planet. For example, the "Door to Hell" in central Turkmenistan is a blaze that began as an exploratory oil well in 1971. Drilling operations encountered natural gas, which subsequently destabilized the land and caused the drill rig and camp to be swallowed up by a 66-foot-deep crater approximately the size of two basketball courts. Estimating the noxious fumes would burn off in a couple weeks, the escaping natural gas was ignited. As it goes with many estimates, it was wrong, and the fire still burns 44 years later.

HOW TO GET THERE



The cracks and fissures atop Smoky Mountain are located approximately 245 miles south of Salt Lake City. From Kanab, drive east on U.S. Highway 89 for approximately 57 miles to Big Water. Turn left (north) onto Ethan Allen Road for 0.3 miles and turn right (east) onto National Park Service (NPS) Road 230. Continue for 12.7 miles and make a slight right to stay on NPS 230. After this junction, NPS 230 is also known as Smoky Mountain Road. Continue for 1 mile and stay left to stay on Smoky Mountain Road (also known as Bureau of Land Management [BLM] Road 300). Stay on Smoky Mountain Road for the next 7.6 miles as it winds up 1,000 feet of elevation to the top of Smoky Mountain. As the road levels out at the top of the climb, continue past the viewpoint pullout for an additional 1.4 miles to an unmarked road on the right. Turn at this unmarked road and continue for 0.6 miles to another junction on the right. Turn at this junction and continue for 0.2 miles to where you will park. Upon exploring the vicinity, you will see the numerous ground fissures. Remember though—if it is smoke you are looking for, then you will need to visit on a very cold day.

Note: A high-clearance vehicle is advisable for travel in the Smoky Mountain area. Also, NPS 230 and Smoky Mountain Road (BLM 330) are generally impassible during and shortly after wet weather conditions and cross numerous washes that can be subject to flash floods. Please research weather and road conditions before planning a trip. A helpful website that provides road conditions for Grand Staircase–Escalante National Monument is www.nps.gov/glca/learn/news/road-conditions.htm. Also, be advised that web-based mapping services as well as paper maps/atlases from various sources tend to disagree as to what names are given to the roads to Smoky Mountain, so please research your route thoroughly before starting your journey.

SURVEY NEWS

NEW UGS CEDAR CITY OFFICE

The Utah Department of Natural Resources (DNR) opened its new Southwest Regional Complex in Cedar City with an official ribbon cutting ceremony in September. The new complex houses employees from four DNR divisions, including the Utah Geological Survey. "Building a permanent regional office reaffirms our commitment to Iron County and the entire southwest region of Utah," said DNR Executive Director Mike Styler. "By centralizing our services at one facility, we increase convenience for the public, save money long-term, and improve functionality and collaboration between our divisions and regional partners." The new Cedar City office is located at 646 North Main Street.

BILL LUND retired in September after 36 years with the UGS, including 7 years as Deputy Director and 18 years as Senior Scientist and Southern Utah Regional Office Manager. Bill began his career with the UGS in what is now the Geologic Hazards Program, concentrating on engineering geology investigations. He then worked on some of the first paleoseismic investigations and research in Utah, and became one of the foremost experts on seismic hazards in the Intermountain West. He started the UGS Paleoseismology of Utah publication series in 1991 containing paleoseismic investigation research reports from Utah projects, and continues as editor. Bill received the 2009 Utah Governor's Medal for Science and Technology, along with numerous other awards and honors for his work. Bill's varied knowledge and strong commitment to investigating hazards will be missed.

KIMM HARTY retired in January after 31 years with the UGS, including nearly 20 years as Deputy Director. Kimm began her career with the UGS in what is now the Geologic Hazards Program, where she concentrated on investigating, mapping, and reporting on landslides. Kimm later became the UGS' first technical reviewer, and first manager of the Geologic Information and Outreach Program. Highlights of Kimm's career while Deputy Director include overseeing the construction of the on-campus Utah Core Research Center in 1998, and serving as UGS Acting Director for 15 months (1999–2000). She was named DNR Manager of the Year in 2006. Last December, at the annual DNR Employee Awards Ceremony, Kimm received a Distinguished Service Award in recognition of her outstanding career. Despite these accomplishments, Kimm always insisted that her greatest legacy was to finally get water coolers installed at the UGS!

DIANNE DAVIS retired in January after 15 years with the State of Utah. Dianne spent the first seven years of her career with Fleet Operations and the last eight years with the UGS, as the Administrative Assistant to both divisions. Dianne is looking forward to spending her time between her elderly mother, grandkids and family, and doing some traveling.

IN MEMORIAM

Don R. Mabey, former UGS Deputy Director, passed away on October 10, 2015, in Salt Lake City. Don's career included working for the U.S. Geological Survey (1951–80) and the UGS (1982–86). He received the U.S. Department of the Interior's Superior Performance Award in 1958 and 1961, Meritorious Service Award in 1970, and Distinguished Service Award in 1979 "in recognition of his outstanding contributions to solid-Earth geophysics and the exceptional leadership he provided scientific research programs." Before he was UGS Deputy Director, Don managed the Applied Geology Program (now the Geologic Hazards Program). In retirement he provided technical expertise and inspiration to Earth Science Education, a small not-for-profit that teaches Utah teachers about local Earth science. He is survived by his wife, Genevieve Atwood, former UGS Director and State Geologist.

2015 Lehi Hintze Award | DOUG SPRINKEL

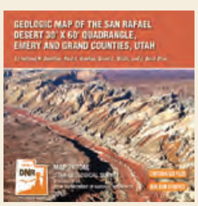
The Utah Geological Association (UGA) and the Utah Geological Survey (UGS) presented the 2015 Lehi Hintze Award to Douglas A. Sprinkel, for his outstanding contributions to Utah geology. Doug's geologic contributions over his 40-year career include (1) petroleum exploration, (2) management, mapping, and conducting studies with the UGS, (3) volunteer activities for the UGA, American Association of Petroleum Geologists (AAPG), and other organizations, and (4) geologic maps and publications about the geology of Utah based on his research.

In his 10 years with Placid Oil Company, Doug was both an exploration geologist and manager (District Geologist in Salt Lake City). His work in the central Utah thrust belt greatly added to the understanding of this geologically complex region. Since joining the UGS in 1986, Doug has served as Geologic Hazards Program Manager, UGS Deputy Director, and presently is a Senior Geologist in the Geologic Mapping Program. Doug has published 71 technical papers or articles on Utah geology, 40 for which he was the senior author. He also has published 15 geologic maps of Utah, with another 6 in press or preparation. His current principal projects are geologic mapping in the Uinta Mountains-Uinta Basin and a regional stratigraphic study to correlate Middle Jurassic marine to fluvial formations in Utah and surrounding states.

Doug served as UGA President in 1984–85 and was the editor/co-editor of five UGA guidebooks, including senior editor of the popular UGA guidebooks *Geology of Utah Parks and Monuments* and *Road, Trail, and Lake Guides to Utah's Parks and Monuments*; he is currently the lead editor for UGA's online journal *Geology of the Intermountain West*. He has led/co-led nearly 20 field trips for the UGA, AAPG, universities, middle and high school earth science teachers, and the UGS using Utah geology to educate both the current and future generation of geologists. Finally, Doug has provided technical expertise for geologic displays for the Utah Field House and Museum of Natural History in Vernal, for Ashley National Forest, and for the Uinta-Flaming Gorge National Scenic Byway.

Named for the first recipient, the late Dr. Lehi F. Hintze of Brigham Young University, the Lehi Hintze Award was established in 2003 by the UGA and UGS to recognize outstanding contributions to the understanding of Utah geology. When Dr. Hintze accepted that first award, he stated, "There are two geologists that I have the greatest respect for their contributions to Utah geology. The first is Hellmut Doelling (retired UGS geologist and second winner of the Lehi Hintze Award), and the other is Doug Sprinkel."

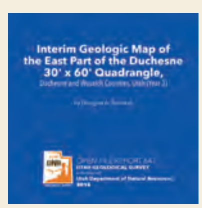
NEW PUBLICATIONS



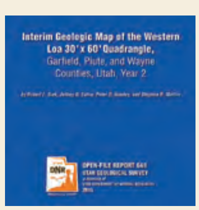
Geologic map of the San Rafael Desert 30' x 60' quadrangle, Emery and Grand Counties, Utah, by Hellmut H. Doelling, Paul A. Kuehne, Grant C. Willis, and J. Buck Ehler, DVD (15 p., 2 pl. [contains GIS data]), scale 1:62,500, ISBN 978-1-55791-888-8, **Map 267DM..................$24.95**

Geologic map of the Goshen quadrangle, Utah and Juab Counties, Utah, by Adam P. McKean, Barry J. Solomon, and Stefan M. Kirby, CD (16 p., 2 pl. [contains GIS data]), scale 1:24,000, ISBN 978-1-55791-915-1, **Map 272DM....................$24.95**

Proceedings volume, Basin and Range Province Seismic Hazards Summit III, edited by William R. Lund, DVD (7 technical sessions [47 presentations], 14 posters), ISBN 978-1-55791-916-8, **Miscellaneous Publication 15-5.....$19.95**



Interim geologic map of the east part of the Duchesne 30' x 60' quadrangle, Duchesne and Wasatch Counties, Utah (year 3), by Douglas A. Sprinkel, CD (18 p., 1 pl.), **Open-File Report 647......................$14.95**



Interim geologic map of the western Loa 30' x 60' quadrangle, Garfield, Piute, and Wayne Counties, Utah, (year 2), by Robert F. Biek, Jeffrey G. Eaton, Peter D. Rowley, and Stephen R. Mattox, CD (20 p., 2 pl.), **Open-File Report 648.......................$14.95**

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