SURVEY NOTES

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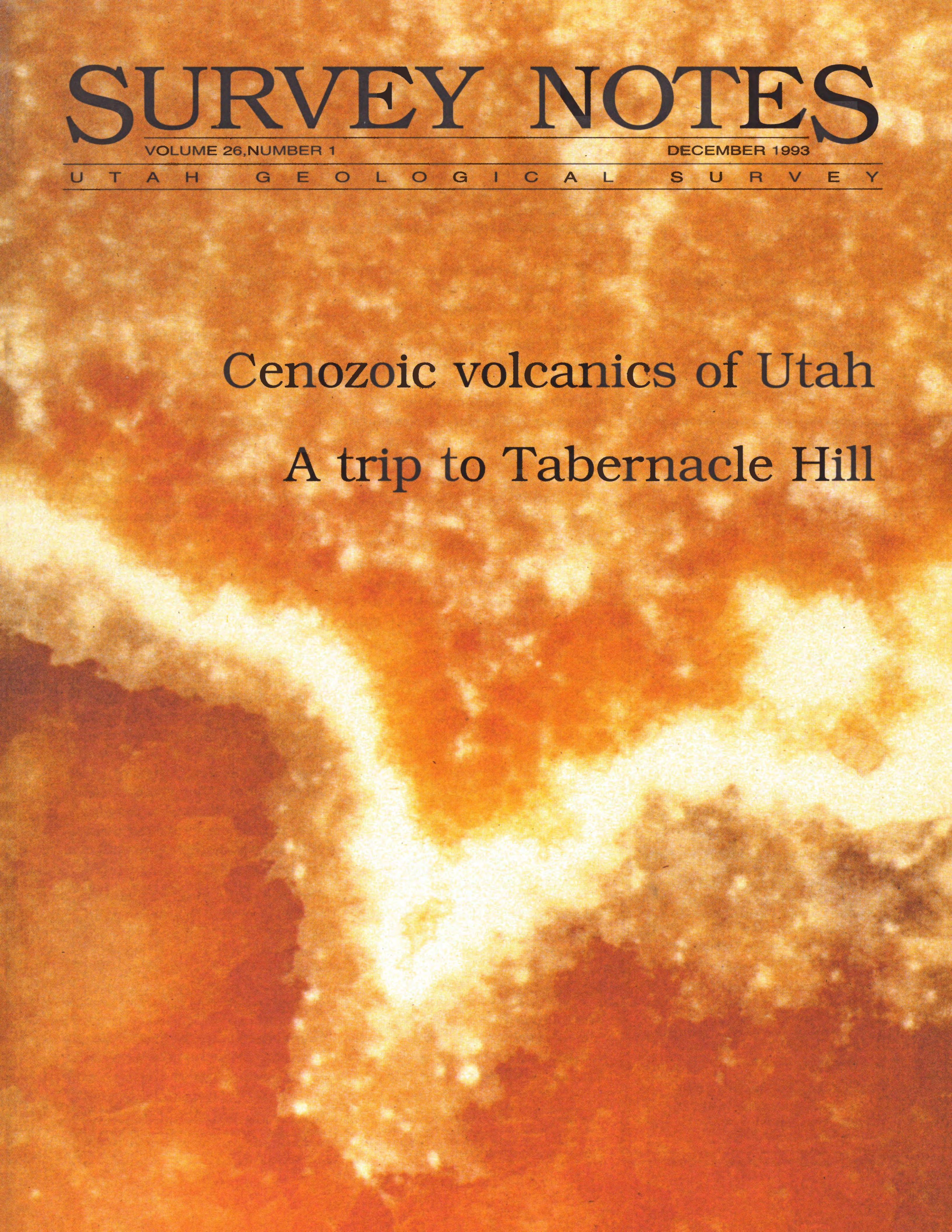
UTAH GEOLOGICAL SURVEY



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Cover photo: A polished onyx marble slab. Raw material for the slab was quarried from a calcite vein deposit near Nephi, Utah. Photo by Bryce Tripp.

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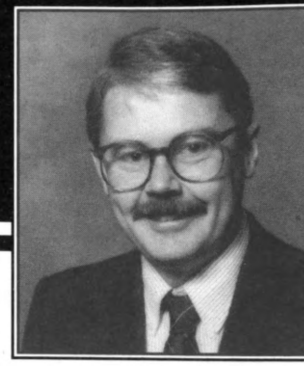


The UGS launched a major new initiative recently with the creation of a Geologic Extension Service. We blatantly copied the name for the very successful and important Agricultural Extension Service which has played such a critical role in the nation's farming communities. The Geologic Extension Service (GES) is intended to carry out a comparable mission with Utah's energy and mineral industries, homeowners, local officials, teachers, and tourists.

The GES is largely created out of various elements that already existed in the UGS. Veteran UGS geologist Kimm Harty has been tapped to direct the GES and establish its goals and agenda. Staff for the GES mostly comes from the former Information Section at the UGS. The UGS library, because of its increasing role as a resource to industry, researchers, and the public, is part of the GES as well. Additional staff may be moved into the GES as we continue to refine its goals and duties.

One of our primary goals is to be a one-stop source for geoscience information in Utah. For highly specialized questions the GES staff may refer inquiries to particular UGS scientists. Even if we don't have the information or the expert in-house, we will help find the right source and people for you.

A second goal of the change is an increased effort to get out to our customers and make sure they (you) know what information or help is available, not only from the UGS but other sources as well. Our goal is to make the GES as visible and as helpful as its agricultural namesake.

The UGS bookstore will soon be carrying all of the geologic quadrangles published for Utah, not just the ones published by us. We are also arranging for the UGS bookstore to carry complete USGS topographic map coverage and other selected products for the state.

And last, but definitely not least, is the new public-access computer system. Now set up in the UGS library is a powerful personal computer with CD-ROM reader. We have loaded a variety of UGS and other databases and an extensive library of local, regional, and national topographic, geological, and geophysical information. One of our databases, INTEGRAL, lists every oil and gas well ever drilled in Utah (over 10,000) with a variety of information on each one of them. The computer runs Windows software and is available to the public during normal working hours.

Our next step is to set up Internet and an electronic bulletin board so you can dial in from anywhere in the world and have access to the UGS's vast array of information. That system should be operational within a few months.

These are exciting changes for us. We hope they provide better service to you, our customers.

Survey Notes is published three times yearly by Utah Geological Survey, 2363 South Foothill Drive, Salt Lake City, Utah 84109-1491: (801) 467-7970. 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.

Cenozoic volcanic history and landforms of Utah

by Miriam Bugden

Utah's topographic profile includes red sandstone monoliths, deeply eroded river gorges, stone arches, panoramic mountains, an enormous salt-water lake, and often overlooked volcanos. Surprised? Few of us associate Utah with explosive clouds of volcanic ash or molten lava. But throughout geologic time volcanos have marred our landscape adding new land to old as they forged distinct patterns on the terrain.

Several prominent Utah landforms remind us of times when volcanic activity ejected steaming rubble and lava over the land. Big Rock Candy Mountain (Piute County) formed between 32 and 22 million years ago when Oligocene- and Miocene-aged volcanic flows and debris (Bullion Canyon Volcanics) spewed from mammoth stratovolcanos in the Tushar Mountains and on the Sevier Plateau. The rounded hills of the Awapa Plateau (Piute, Wayne, and Garfield Counties) were molded when volcanic debris ferociously coursed down the slopes of ancient volcanos or was carried aloft in winds, and ultimately settled into nearby lowlands. Unique vistas of the Black Rock Desert of west-central Utah, the southwestern High Plateaus, and terraces surrounding Washington County's St. George basin resulted from black, erosion-resistant volcanic rocks that began flowing over southwestern Utah between 8 and 6 million years ago.

For billions of years erosion has also shaped Utah's landscape. Landforms and flows from geologically old volcanics have been modified, recycled, and obscured by constant erosion. Only Utah's most visible volcanic features, those from eruptions in the last 45 million years, are discussed in this paper.

PROPERTIES OF VOLCANIC MATERIALS. Volcanic materials are ejected onto the earth's surface as flowing lava, as turbulently discharged debris called pyroclastics (ash, dust, bombs, and boulders), and as gases and vapors. Before reaching the earth's surface, lava is called magma. Magma originates deep in the earth's crust or migrates up into the crust from the underlying mantle. The chemical composition of magma, along with the temperature, pressure, and related gases, determines the ease with which a lava will flow and what type of landform will evolve.

Volcanic rocks are classified and divided according to the amount of silica present (figure 2). Volcanics with high or moderate levels of silica are called acidic or intermediate-composition lava. Their flows tend to be thick and gummy. Volcanic gases, which can induce extremely violent explosions of high-temperature rock and ash often accompany acidic and intermediate-composition

While studying for a Bachelor of Science degree in Geology at the University of Utah, Miriam Bugden worked as a curator of the rocks and mineral collection for the Department of Geology and Geophysics. She conducted structural geology field work in the Talkeetna Mountains of Alaska, and base and precious metal exploration in Colorado, Utah, and South Dakota for Duval Corporation. After graduation, she spent a second, extended field season as a mineral exploration geologist with Duval Corporation. She also worked for Classic Mining company conducting library research on oil and gas prospects. Getty Oil Company - Minerals Division employed her to perform reconnaissance work on the Mercur, Utah gold prospect.

In 1983, she came to work for the Utah Geological and Mineral Survey as a geotechnician for the State Geologist. In 1988, she began working as an Information Geologist for the Survey.

lava. The rocks that form when these lavas cool range in composition from rhyolite to dacite to andesite. Associated landforms include domes, plugs, stratovolcanos, calderas, and widespread sheets of ash and welded tuff.

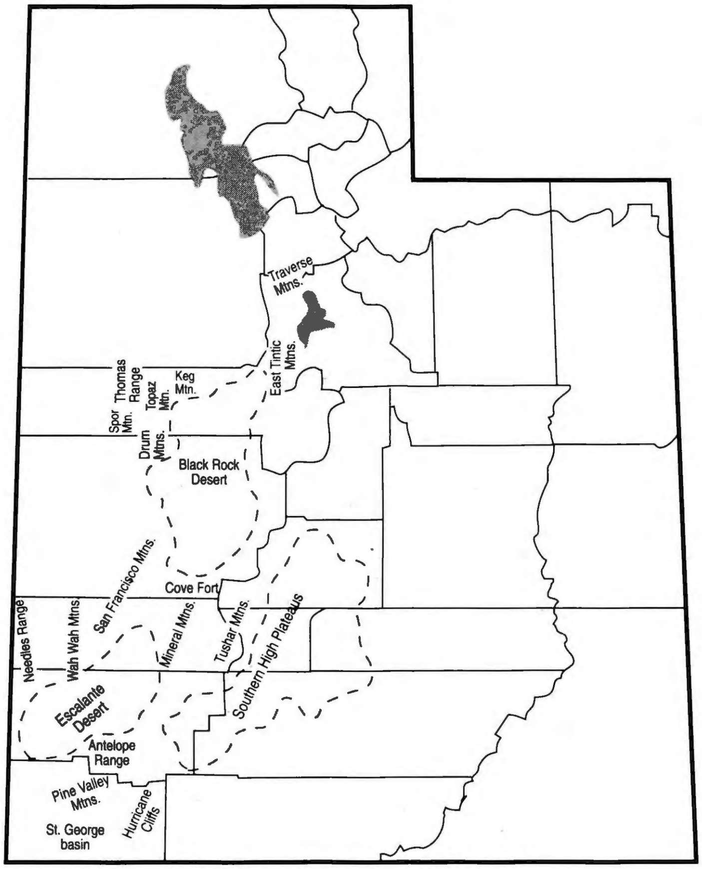


Figure 1. Approximate locations of select Utah geologic features. Modified from Hintze, 1988.

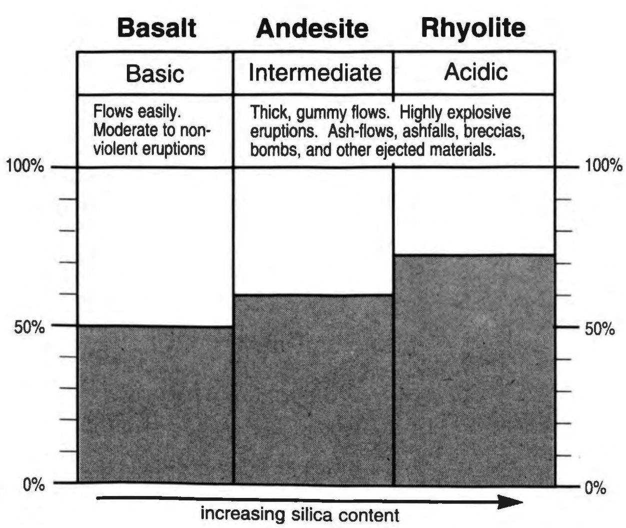


Figure 2. Approximate amounts of quartz in common volcanic lavas. Chart by Christine Wilkerson.

Low-silica volcanic materials are referred to as basic or ultrabasic. Rocks that form from these lavas are basalts (or nephelinites if they are ultrabasic). Relatively high in iron and manganese, these lavas are typically more fluid and have less violent eruptions than their more acidic counterparts. Basalts flow more readily than rhyolites, therefore, they typically roll away from their vents before accumulating into mammoth landforms. Basaltic eruptions form flood basalts (flat rivers and sheets of basalt that are often seen as plateau caprocks), cinder cones, and shield volcanos.

CENOZOIC VOLCANIC HISTORY OF UTAH. How, when, and why did volcanos form in Utah? Since plate tectonic studies began in the 1960s, scientists have attempted to relate the dynamics of the earth's crustal movements to volcanic activity. Broadly speaking, acidic- to intermediate-composition volcanism is associated with compressional forces in a continental plate. Basic or ultrabasic volcanism is typically associated with extensional forces. However, there are many exceptions and considerable work must be completed before the complexities of these relationships are understood.

Compressional forces and related volcanism are briefly discussed below, and extensional forces and related volcanic patterns are discussed in the Middle Miocene To Quaternary Volcanism section.

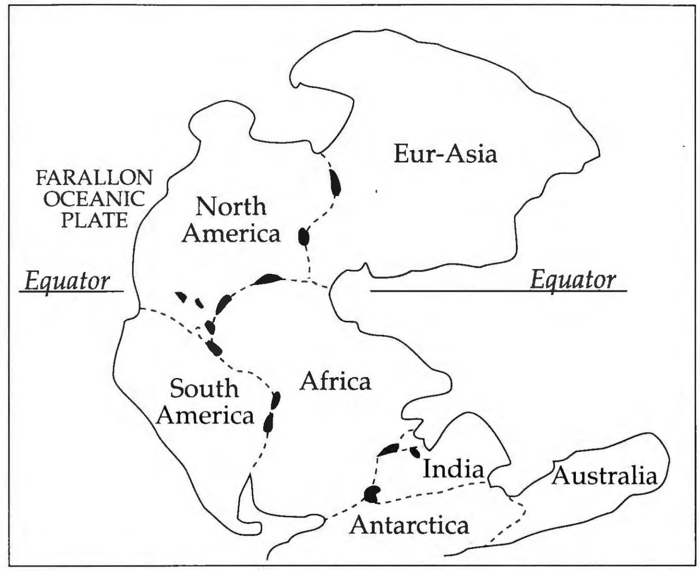
Time Divisions & Select Volcanic Events from Utah's Cenozoic History

Era	*Period*	*Epoch*	*Millions of years*	*Select Volcanic Events*
CENOZOIC	Quaternary	Holocene		Ice Spring Basalt - Black Rock Desert
			.01	Diamond Valley cinder cones and flows - Washingtom County
		Pleistocene		Pryor Knoll, Lone Tree Mtn., Pine Spring Knoll, Co-op Knoll cinder cones - Southwest of High Plateaus
			1.6	
	Tertiary	Pliocene		St. George basin basalts
			5	
		Miocene		Awapa Plateau basalts Thomas Range rhyolite Topaz Mountain rhyolite Mt. Belknap caldera forms - Tushar Mtns. Big John caldera forms - Tushar Mnts. Monroe Peak caldera forms - Sevier Plateau
			24	
		Oligocene		Indian Peak caldera forms - Utah/Nevada border Needles Range rhyolite Big Rock Candy Mnt. - Tushar Mtns. Dugway Valley cauldron forms Thomas caldera forms - Juab County
			38	
		Eocene		
			55	
		Paleocene		
			66	
MESOZOIC (partial)	Cretaceous (partial)			

Figure 3. Divisions of Cenozoic time & select volcanic events. (from Hansen, 1991).

EOCENE TO EARLY MIOCENE VOLCANISM - 45 TO 20 MILLION YEARS AGO. About 200 million years ago, the North American continental plate began separating from a mega-continent called Pangea (figure 4a). As it pulled away from its eastern neighbor, the western edge of the North American plate abutted against, and rode up and over, the heavier Farallon oceanic plate (figure 4b). Contrasting densities forced the oceanic plate to sink down toward the torrid interior of the earth. Elevated pressures and temperatures melted the thick slab of rock that once defined the ocean floor. The hot magma eventually reached the earth's surface as volcanic activity.

Figure 4a. Two hundred million years ago, the earth's lands began separating from an immense landmass called Pangea. The North American continent drifted away from the African and Eur-Asian continents on the east and collided with the dense Farallon oceanic plate on the west.



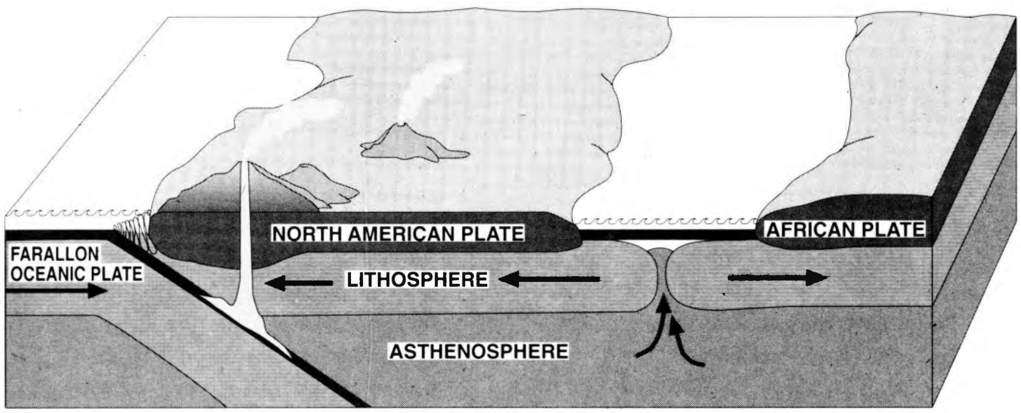


Figure 4b (left). As the dense oceanic plate sank beneath the continental crust, buoyant gases and fluids from the melting oceanic plate rose, invading cracks, faults, and broken zones in the thickened continental crust. The continental slab domed, creating a broad-scale uplift which, in turn, generated more breaks that served as conduits for rising gases and magma. This is thought to be the driving force behind the intermediate-composition volcanics that dominated western Utah and Nevada during early to middle Cenozoic time.

Viscous rhyolite and andesite plugs and domes emerged in western North America while other materials tumultuously erupted into the atmosphere. Beginning slowly in Eocene time (about 45 million years ago), gaining momentum and lasting until about 25 million years ago (when eruption rates began to diminish until about 17 million years ago), copious amounts of gas, steam, dust, boulders, and molten rocks roared from craters and fissures throughout western North America. Thick clouds of volcanic dust obstructed the sun's rays for extended periods of time, eventually settling over a diversity of climates, elevations, and flora.

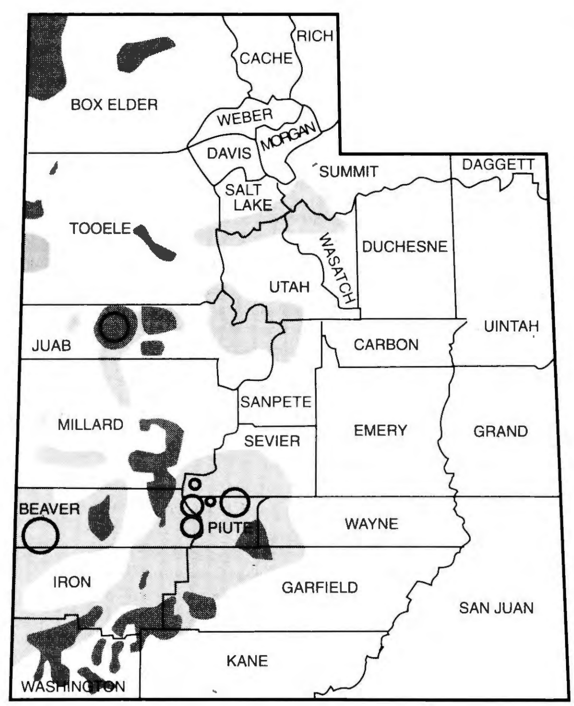
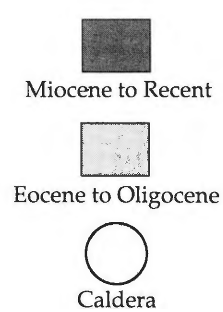


Figure 5 (left). Approximate locations of Cenozoic volcanic rocks in Utah. Circles mark the approximate outlines of calderas. Illustration by Doug Sprinkel.



Many volcanos that were active in Utah in this period were composite volcanos, or stratovolcanos, similar to the modern Cascade Range of the Pacific Northwest. Ancestors to Utah's ranges like the Tushar, the Wah Wah, the East Tintic, and the San Francisco-Shauntie Hills formed as towering mountains of alternating layers of ash, cinders (uncemented, glassy, and porous fragments spit from volcanic vents), blocks, and lava flows. Gummy intermediate-composition volcanic ejecta and gases blistered the land. Rhyolitic domes (similar to the one that developed on Mount St. Helens after the violent 1980 eruption) swelled, and showers of rock dust and bombs were catapulted from scattered volcanic vents.

As ash and volcanic debris continued spewing into the atmosphere, new volcanic features began appearing in western Utah and eastern Nevada during middle Oligocene time. Volcanic vents began collapsing, forming immense, roughly circular depressions. These landforms are called calderas and they often have diameters that are many times larger than the size of the original vent. Numerous calderas formed in Utah during this time (figure 5). The Thomas-Keg-Drum Mountain caldera formed between 39 and 38 million years ago; the Indian Peak caldera collapsed between 29 and 27 million years ago; the Sevier and Piute Counties' Monroe Peak caldera subsided about 23 million years ago; the Red Hills caldera subsided about 19 million years ago; and the Mount Belknap caldera subsided about 19 million years ago. Unlike Oregon's famous Crater Lake caldera, erosion and burial have since altered the walls of these ancient Utah landforms and most are nearly indistinguishable today.

It is difficult to imagine what Utah looked like from early- to middle-Cenozoic time. Many clues and "fingerprints" of prior climates and environments were buried by immense thicknesses of volcanic materials. The profusion of flora and primative mammals is conveyed soley by the geologic record. The image of a volcanic-ravaged land is far from a description of that of modern Utah. What changed?

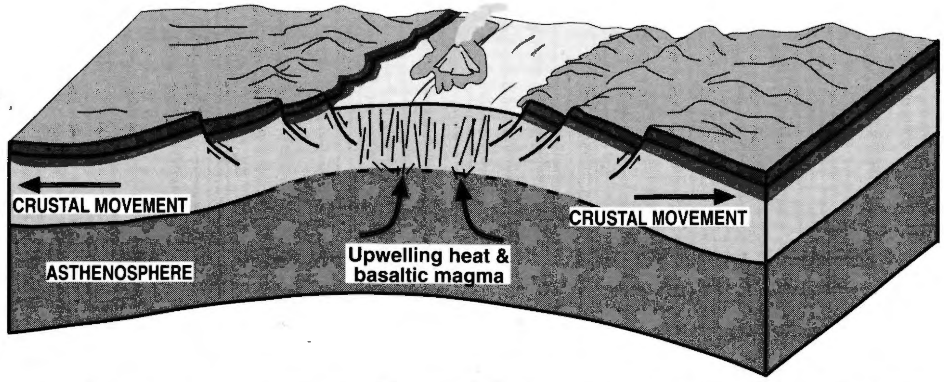


Figure 6. Extension, or relaxation of the crust, is often associated with a change in mode and chemistry of eruptions. During middle Cenozoic time, the mode and composition of volcanic eruptions in western North America shifted from explosive, predominantly intermediate-composition materials to less volatile rhyolitic and basaltic-composition materials.

MIDDLE MIOCENE TO QUATERNARY VOLCANISM - 17 MILLION YEARS AGO TO PRESENT. Almost as abrupt as the onslaught of Cenozoic volcanism, the mode and chemistry of the regional volcanics dramatically changed about 17 million years ago. Intermediate and acidic-composition volcanics gave way to eruptions of bimodal rhyolitic and basaltic composition lavas. Frequency of eruptions and the volume of materials vented diminished at approximately the same time. These changes roughly coincided with a modification in plate tectonic activity that occurred during middle Cenozoic time.

About 29 million years ago, a portion of the Farallon oceanic plate terminated its journey beneath the central part of North America (today, remnants of the Farallon plate are continuing to sink beneath the North American Continent off the coasts of the Pacific Northwest and Central America). The forces exerted upon the crustal plates changed and a transform fault (the San Andreas) developed along the western edge of North America. As the compressional forces eased, the North American continental crust relaxed and began to spread. As the crust elongated, it thinned and bowed upward.

Like juice through cracks in the crust of a hot fruit pie, dark magma from the asthenosphere (the zone below the crust where temperatures and pressures are high enough that stresses are met with flexible responses instead of breaking and shattering) moved up through splintered zones of the crust until it oozed onto western lands as scorching basalt flows and rhyolite domes (figure 6). Thick acidic and intermediate-composition magmas continued forming plugs, domes, and generating ashfalls but were less numerous than before. Basalt, heavy with iron and manganese, and thick plugs of acidic rhyolite dominated the volcanic scene. Although several theories are employed to explain why these two chemically contrary rock types emerged, it remains an enigma.

UTAH'S PROMINENT VOLCANIC LANDFORMS. Although volcanism occurred in Utah throughout most of Cenozoic time, the best preserved volcanic landforms are those that formed during middle Miocene through Quaternary time. Relics of these events are well preserved and endure as significant elements of Utah's modern landscape. Since they are prominent, the features resulting from events during the most recent part of Utah's history are highlighted in this section. Older remnants are mentioned wherever obvious, however, this discussion is not an all-inclusive list of volcanic landforms in Utah.

Northern Utah. The onset of Cenozoic volcanism in the northern part of western North America most likely began in the north and swept southward. Northern Utah's Eocene to early Miocene volcanic record is sparse as subsequent faulting and erosion has obscured much of the volcanics. Only intermittent outcrops of the older Cenozoic volcanics are visible in northern Utah and those seldom form striking landforms. In Summit County, 35 to 32 million-year-old rhyolitic and andesitic flows and breccias outcrop as the Keetley Volcanics. Also in southern Salt Lake County's Traverse Mountains, rhyolite flows and plugs are 32 million years old and latite flows and lahars are considered to be even older.

Between 16 and 14 million years ago, fissures in Washington, Oregon, and Idaho began glowing with sheet after sheet of basaltic and rhyolitic flows and plugs. Dark, iron- and manganese-rich flood basalts inundated the broad northern plains and quickly solidified to form a stark, dense veneer to the north and west of Utah. Although most of these flows occurred in the Columbia River Plateau and the Snake River Plain, Utah's extension of these sheets includes the 12 to 11 million-year-old extrusive rocks in southern Box Elder and northern Tooele Counties' Silver Island Mountains.

Other occurrences of recent volcanism in northern Utah include the Wildcat Hills of Box Elder County which display bimodal basalt, rhyolite, and welded tuff. Black Mountain, located north of Rozel Point on the shores of the Great Salt Lake, is a prominence of basalt with distinct shoreline deposits of ancient Lake Bonneville.

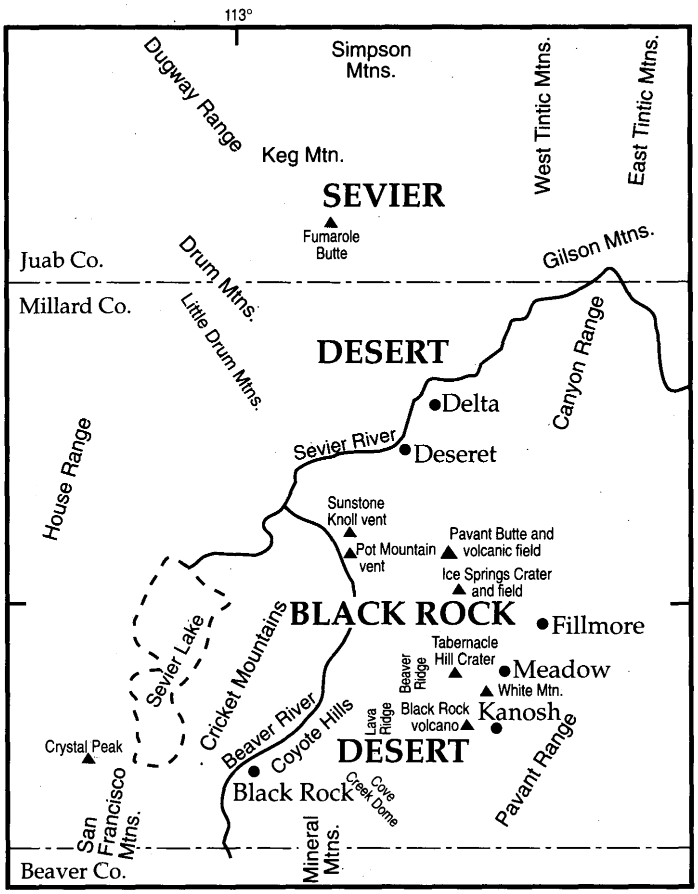


Figure 7. Geographic features of the Sevier and Black Rock Deserts. Modified from Oviatt, 1991.

Spor, Topaz, Thomas, Keg, and Drum Mountains. Spor, Topaz, Thomas, Keg, and Drum Mountains are familiar, celebrated Utah landmarks and recreational havens. Some of the oldest Tertiary volcanic rocks in the Thomas Range include 41 to 38 million-year-old ash flows, agglomerates, and lava flows. The Thomas Range lies within the perimeter of a middle Cenozoic-age caldera that collapsed about 39 million years ago when the Mt. Laird Tuff erupted from vents in the northern Drum Mountains.

About 21 million years ago, tuff, breccia, and topaz-bearing rhyolite flows began masking the older volcanics in the area. Rhyolites and beryllium-rich tuff of the Spor Mountain Formation (21 million years old) erupted, followed by the Topaz Mountain rhyolite and tuff (between 7 and 6 million years ago). Topaz, garnet, and beryl are among the interesting minerals found in the Thomas Range. The youngest eruptions in this area are predominantly rhyolitic rocks that range from 8 to 5 million years old.

Black Rock Desert. The Black Rock Desert basin, sporadically interrupted by dark- and light-colored hills, buttes, and knolls stretches across Beaver and Millard Counties. Early to middle Cenozoic history is difficult to decipher as crustal stretching has formed sediment-filled valleys, obliterating many clues to past environments and climates. One of the most prominent Utah relics from early Cenozoic volcanism are the rocks of Crystal Peak, a whitish-gray mound rising from the desert floor of Millard County. Crystal Peak is a compact (welded) accumulation of 34 to 33 million-year-old volcanic ash called the Tunnel Spring Tuff. Volcanic ash includes dust-sized to larger materials that explode into the air or sweep along the ground at high speeds as dense clouds. When they accumulate in thick layers, ash particles are welded together by the intense heat and weight of overlying materials, forming a rock called a

Figure 8. Black Rock volcano, eastern Millard County, is visible from Interstate Highway 15. The level terraces on the sides of the volcano are beach sands deposited by Lake Bonneville.

tuff. The Tunnel Spring Tuff was most likely erupted from a site located east of Crystal Peak.

The Black Rock Desert hosts prominent Utah sites like Fumarole Butte, Pavant Butte, and Black Rock volcano that suggest an active volcanic backdrop to an arid Utah scene. An extreme climate; contrasting rock colors, textures, and chemistries; and topographic diversity hint at the complex conditions that formed these lands.

The terrain, named for its stark, black appearance, resulted from late Cenozoic volcanism. Along with prominent basaltic flows and landforms, rhyolite domes and plugs are also present, fueling the enigma of bimodal volcanism. A prominent example is the youngest rhyolite in Utah, the White Mountain rhyolite dome, which is located south of the youngest basalt flow in Utah, the Ice Springs basalt.

A 400,000-year-old rhyolite dome, topped with glassy pumice, forms White Mountain (black volcanic glass can also be found on the mountain). The youngest basalt flow in Utah, only 600 years old, is located in Black Rock Desert's Ice Springs volcanic field. This field's eruptive history began less than 4,000 years ago as cinder and spatter vented to the surface forming four cone-shaped hills. Named the Crescent, the Miter, the Terrace, and the Pocket the cones in the Ice Springs field are built of red and black cinder that has been quarried and used as gravel and ornamental stone.

The Black Rock volcano, a large spatter and cinder cone, erupted dark, mafic basalt flows between 1 million and 600,000 years ago. Basaltic rocks accumulated, forming Beaver Ridge during the same interval (about 900,000 years ago). The Pavant volcanic field at the northern end of the desert has dark 128,000 to 75,000-year-old volcanic rocks that display necks, small lava tubes, pressure ridges, pahoehoe textures, and columnar jointing (roughly hexagonal shrinkage cracks from cooling basaltic rocks). "Sugarloaf," or Pavant Butte is a 750-foot-high cone-shaped mound (tuff cone) that formed when dense volcanic dust and ash erupted into sands and clays of the large Pleistocene-age Lake Bonneville.

Also included in this geologically young volcanic hub is the Tabernacle eruptive center. Named for its uncanny likeness to the Salt Lake Mormon Tabernacle, the Tabernacle Hill tuff cone and surrounding basalts are about 14 miles southwest of Fillmore, Utah. The center is not only unique in its profile, but possesses an eruptive history that is atypical for Utah. Between 15,000 and 14,000 years ago, ash and basalts issued from vents in the valley floor and splashed into the waters of Lake Bonneville. Cool waters quenched the smoldering basalts, forcing them to contract and curl, forming pillow basalts similar to those on ocean floors.

Figure 9. A modern-day recreation area, Utah's Tushar Mountains were once huge stratovolcanos similar to the Cascade Range along the northwestern coast of the United States. Photo courtesy of Bryce Tripp.

Cove Fort. Southeast of the Black Rock Desert near the town of Cove Fort, 0.7 to 0.5-million-year-old basalts erupted during Utah's

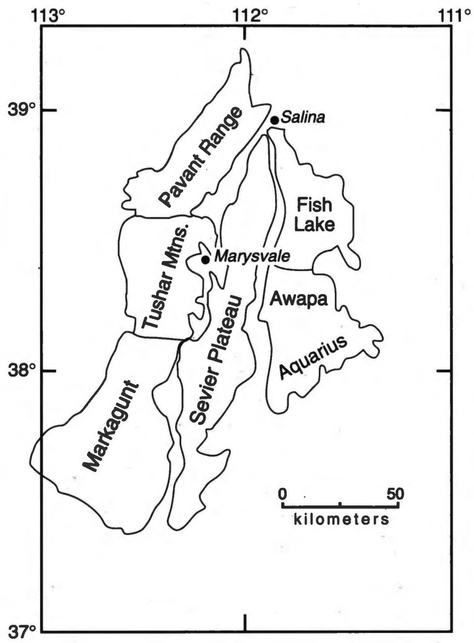


Figure 10 (left). Approximate locations of Utah's High Plateaus. Modified from Rowley and others, 1979.

Figure 11 (above). A dense pile of Cenozoic intrusive and extrusive rocks describe southwestern Utah's magnificent Pine Valley Mountains.

Pleistocene ice age. Unusually high ground-water temperatures (greater than 194°F), coupled with gas emissions and locally altered rocks, have contributed to this area's designation as a "Known Geothermal Resource Area" (KGRA). Like Cove Fort, many of Utah's KGRAs are located close to once-active volcanic centers. Some theories speculate that these elevated water temperatures are directly related to volcanic activities or buried, cooling intrusive bodies.

Marysvale Area. Many volcanos that were active during early Cenozoic times were composite volcanos, or stratovolcanos, similar to the modern Cascade Range of the Pacific Northwest. Stratovolcanos are towering mountains of alternating layers of ash, cinders (uncemented, glassy, and porous fragments spit from volcanic vents), blocks, and lava flows. Utah's Tushar Mountains and Sevier Plateau were the site of immense stratovolcanos that began forming in Oligocene time. Gummy, intermediate-composition volcanic ejecta and gases blistered the land. Rhyolitic domes swelled and showers of rock dust and bombs were catapulted from scattered volcanic vents. In the Tushar Mountains, the Big John caldera collapsed about 22 million years ago when the Delano Peak Tuff Member of the Bullion Canyon Volcanics was erupted, and the Mount Belknap caldera collapsed about 19 million years ago in response to eruption of the Joe Lott Tuff Member of the Mount Belknap Volcanics.

Although present, volcanic activity in the Marysvale area was not prolific after the middle of the Miocene. A few Miocene basalt flows can be found in the area, but their volumes pale in comparison to the sizable volcanic piles of earlier times (the Bullion Canyon Volcanics are 3,300 feet thick in places in the Tushar Mountains). Thick, steep-sided mounds of rhyolite swelled into volcanic vents about 18 million years ago.

Southern High Plateaus. From Oligocene to early Miocene, when the vents and volcanos of the Tushar Mountains and Sevier Plateau were most productive, gargantuan piles of volcanic debris shed off the stratovolcanos' slopes. Flowing magmas, exploding gases, ash flows and falls, and steaming ground water often initiated other catastrophic events. Large-scale rock avalanches drove torrents of water-saturated materials down the slopes of volcanos. Gargantuan piles of debris accumulated in nearby, low-lying areas. One catchment area included lands that we know as the Awapa Plateau, portions of the Fish Lake Plateau, Thousand Lake Mountain, and the Markagunt and Aquarius Plateaus. Uplifted at a later time, these prominent Utah plateaus are imbued with layers of rubble that originated as ash flows, ashfalls, lahars (mudflows generated by volcanic activity), and breccias.

Many of these layers are now capped with younger basalts. Lava flows, cinder cones, and "necks" (the eroded, hardened central vents of volcanos) sit on top of older volcanics. On the Awapa Plateau, these predominantly basaltic rocks range in age from 16 million years old to about 5 million years old.

Southwest of the plateaus on Cedar Mountain, geologically recent cinder cones (dated between Pleistocene to recent) include: Pryor Knoll, Lone Tree Mountain, Pine Spring Knoll, and Co-op Knoll. These cinder cones form distinct profiles that rise several hundred feet above the plateau on which they sit.

Southwestern Utah. Significant volumes of Cenozoic volcanism began in southwestern Utah and eastern Nevada about 33 million years ago. A series of volcanic vents, located on the Utah-Nevada border, spewed

Figure 12. A volcanic cone north of Snow Canyon State Park, Washington County, represents a not-so-distant age when hot basalts flowed from vents in the earth.

acidic and intermediate-composition magma, ash, and lapilli over approximately 13,000 square miles. Referred to as the Indian Peak caldera complex, this area is considered to be the source for a thick sequence of volcanic rocks called the Needles Range Group. The Indian Peak caldera collapsed between 29 and 27 million years ago. Faulting and erosion, however, have erased the landforms from this explosive period of the earth's past.

Although the frequency and volume of eruptions waned in early Miocene time, eruptions did not entirely disappear. West of Washington County's Bull Valley Mountains, the Caliente caldera complex activated about 24 million years ago and lasted until about 18 million years ago. Rhyolitic ash flows and andesitic lavas extruded from vents in Nevada's Caliente complex, accumulated in low regions surrounding the area, later to be buried in the basins of the Escalante Desert or uplifted and exposed in the nearby mountains.

After a lull in volcanic activity, deposits of southwestern Oligocene-Miocene tuffs, lahars, breccias (rubble), flows, ashfalls, and rhyolite domes were veiled with fabrics of new eruptions. Southwestern Utah's late Cenozoic volcanic blankets included a variety of extrusive rocks but the majority were basalts. Between 6 and 5 million years ago, basalts began flowing from vents surrounding the Pine Valley Mountains and the St. George basin and covered the plateaus east of the Hurricane Cliffs. Similar eruptions continued intermittently into Quaternary time. Lands that were at one time topographically low captured basalt flows enabling them to resist erosion. Adjacent, unprotected highlands were deeply carved by streams. Now standing high in relief as plateaus, this type of feature is called inverted topography.

Some of the youngest flows in southwest Utah emanated from vents north of St. George in Washington County. As thick lava flowed from vents, nearly weightless basaltic froth (scoria) exploded into the air and accumulated as conical-shaped hills or cinder cones. Two young, prominent cones, between 20,000 and 1,000 years old, command the skyline about ten miles north of St. George.

Basalts in southern Utah display fascinating textures and landforms (figure 12). In addition to cinder cones, the well-preserved flows often appear as frozen lava falls cascading over underlying rocks as they rolled onto lower terraces. Inspection of the basalts shows both "ropy", sinuous and rough, broken surfaces. The smooth, snake-like, wrinkled, textures are called pahoehoe (pronounced "pa-hoy-hoy"). They are typical of basalts that flow easily. The jagged aa (pronounced "ah ah") textures represent a more sluggish lava that moves forward as broken, blocky tongues.

Utah's southwestern volcanic terrain extends from recent basalt flows in the St. George basin northward into the Bull Valley and Pine Valley Mountains where middle- to late-Cenozoic rhyolite plugs and ash-fall tuffs (and intrusions) contributed to immense piles of early Cenozoic volcanics. Further north in Iron County, flows and domes of the Silver Peak Rhyolite were emplaced between 9 and 8 million years ago in the Antelope Range. Northeastward in Garfield and Iron Counties, late Cenozoic basalts cap and preserve some of Utah's unique and most scenic plateaus. Further to the north, volcanic activity resumed in areas where older volcanics had once been plentiful.

CONCLUSION. This brief synopsis of Utah's Cenozoic volcanic activity is, by no means, all inclusive. Utah's scenic lands are a melting pot of environments and climates of times gone by. Only a small chapter in the story of Utah's evolution, the most recent volcanic events played a critical role in shaping the profile of our state. Cenozoic volcanics provided Utah with a dramatic geologic record, striking landforms, a wealth of metallic and non-metallic economic resources, unique rock hounding opportunities, geothermal energy, and vast recreational assets.

It is important to remember that Utah's vigorous volcanic past suggests the potential for a volcanic future. Although volcanic and seismic activity can go hand in hand, volcanic threats are not as imminent as Utah's earthquake hazards or as potentially destructive. Active, but dormant, volcanos do exist in Utah, however, and are capable of altering wildlife and human habitats by polluting water supplies and destroying grazing pastures and farmlands. Whether located in Utah or in nearby states, volcano-generated molten flows and ashfalls may play a role in Utah's next geologic chapter.

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Amoco's advanced drilling technology retrieves a deep core from Lake Bonneville sediments, Davis County

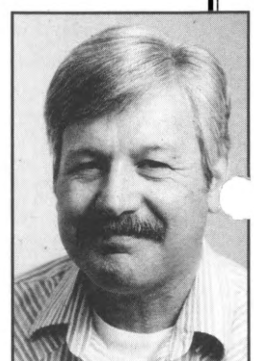
by Douglas A. Sprinkel

The Utah Geological Survey (UGS) recently received a donated core taken from a test well (Kremco #1) drilled in northern Davis County (see p.11). The Kremco #1 well penetrated nearly 650 feet (200 m) of Lake Bonneville and older Quaternary sediments. Although the UGS Sample Library routinely receives donated core and cuttings from companies, this core is unique because it was cut with a state-of-the-art advanced drilling system developed by Amoco Production Company and fabricated by Kremco.

The well location was selected because of its proximity to Kremco's facility in the Freeport Center in northern Davis County. Amoco conducted the operation in order to test the rig's system functions and to make any necessary adjustments before the rig was moved to another location for additional tests. Drilling crews from Nabors-Loffland operated the rig while engineers from Amoco's Tulsa Research Center oversaw the operations. Although Amoco planned only to core between 500 to 1,000 feet (150 - 305 m) and with core recovery only a secondary concern at this stage of testing, Amoco realized that any core recovered would be of value to geologists in Utah. Thus, looking for a place to donate the core, Amoco contacted Dr. Donald Fiesinger at the Utah State University Geology Department who contacted the Utah Geological Survey.

The core from the Kremco #1 well was of interest to us because it might yield data on Lake Bonneville and possibly pre-Lake Bonneville sediments. Stratigraphic information gained from the core could improve our understanding of sedimentation in Lake Bonneville, particularly the Weber River delta, and provide a more complete three-dimensional view. We also hoped that the Kremco #1 core might contain volcanic ash so that critical isotopic ages of lake sediments could be obtained. The preserved sediment record and any datable material in the core could offer scientists additional data on Quaternary tectonic processes, perhaps including rates of tectonic subsidence along the Wasatch fault in Weber and Davis Counties.

This article briefly describes the Kremco #1 core and the advanced drilling system used to retrieve it, but does not attempt to relate the core to the Lake Bonneville stratigraphic framework (McCoy, 1987; Oviatt and others, 1987). The intention is to provide a level of information on the core so interested scientists may assess its potential usefulness to their research.



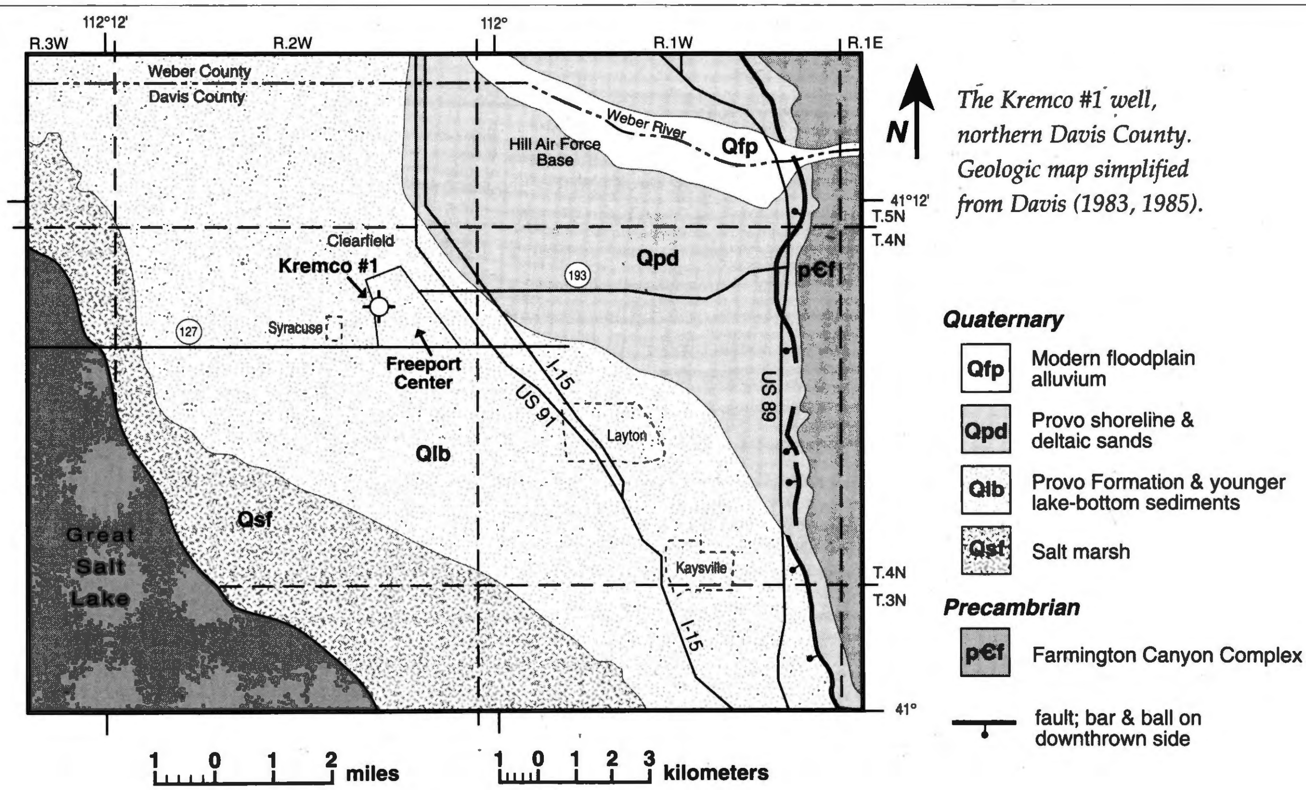
Doug Sprinkel received his BS (1975) and MS (1977) in geology from Utah State University. Doug was employed by Placid Oil Company from 1976 to 1986 where he directed a frontier exploration program that encompassed the western United States. His work at Placid also included geologic projects that evaluated the petroleum resources of parts of Alaska, Canada, Mexico, and Turkey. Doug has been employed by the Utah Geological Survey since 1986 where he served as Senior Geologist of the Applied Geology Program and Deputy Director. Doug is currently Staff Scientist and is conducting stratigraphic, structural, and petroleum studies in Utah's thrust belt and Basin and Range Province. He also manages the UGS Computer Resource group.

AMOCO SHADS PROJECT. Significant technological advances in petroleum land-based drilling operations and on-site geologic evaluation methods are not common. As technological improvements and lower costs of personal computer hardware and software continue, many petroleum engineers and geologists use these tools for gathering, transmitting, and analyzing drilling and geologic data in the field and office. Amoco Production Company has utilized advanced computer technology to develop a high-speed drilling system that improves and automates coring and on-site core evaluation. The Amoco SHADS (Stratigraphic High-Speed Advanced Drilling System) is truly revolutionary because it integrates computerized drilling systems and on-site geologic evaluation modules to cut, retrieve, and quantitatively analyze up to 14,000 feet (4,300 m) of core. The rig with its advanced drilling system is a development of Amoco Production's Tulsa Research Center.

Operator	Amoco
Contractor	Kremco
Well Name	Kremco #1
Approximate Location	NW¼SE¼NW¼ section 11, T. 4 N. R. 2 W. Salt Lake Base Line & Meridian
Approximate Latitude-Longitude	Latitude 41.10° Longitude 112.03°
County	Davis
State	Utah
Approximate Ground Elevation	4370 feet (1332 m)
Approximate KB Elevation	4378 feet (1337 m)
Total Depth (TD)	649.73 feet (198 m)
Casing Size	5-1/2 inches (14 cm)
Casing Depth	116 feet (35 m)

Table 1. Well information

Coring for the entire length of a hole is desirable because core can provide geologists with a complete record of the subsurface stratigraphy, and can enable them to more accurately describe the rocks and interpret depositional environments. In addition, petrophysical properties like porosity, permeability, bulk density, etc., can be measured directly from the core. But the method used to retrieve the core may determine the cost effectiveness of coring a deep hole. Rigs are generally designed to recover the core barrel either by a wire-line retrieval method (leaving the drill pipe and core barrel in place while pulling out the inner barrel and core) or by pulling all of the drill pipe out of the hole. The Amoco rig uses a wire-line retrieval method and, for this paper, continuous-coring technology or continuous core infers the wire-line retrieval method. The mining industry has traditionally used continuous-coring technology to evaluate properties and



The Kremco #1 well, northern Davis County. Geologic map simplified from Davis (1983, 1985).

The rig, fabricated by Kremco of northern Utah, can drill or core to 14,000 feet (4,300 m). The rig floor is 25 feet (5 m) above the ground and the stand of drill pipe in the monkey boards is approximately 60 feet (18 m).

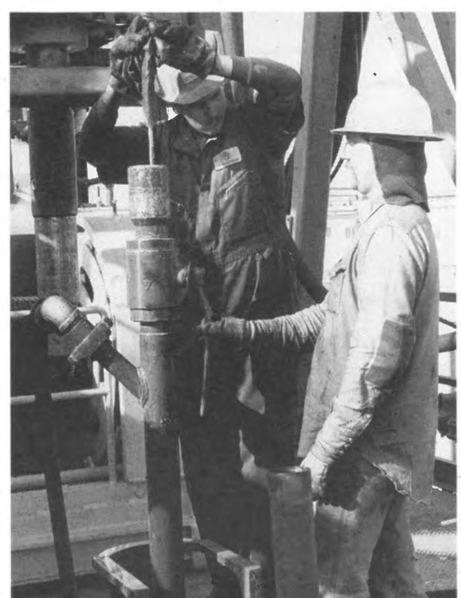
prospective areas. The petroleum industry, on the other hand, generally has not used continuous-coring technology which made retrieving core from several consecutive coring runs an expensive part of evaluating deep stratigraphic horizons. Instead, the petroleum industry relies on sophisticated down-hole geophysical logging tools to indirectly measure petrophysical properties of the stratigraphic section. SHADS was developed to obtain real-time subsurface stratigraphic data from remote locations by cutting a cost-effective continuous core in basins where little or no subsurface stratigraphic data are available. SHADS integrates state-of-the-art technology in nearly every aspect of the coring operation from the driller's console and the mud-monitoring system to pipe and core handling.

Through SHADS, Amoco not only developed an innovative drilling system, but also developed an innovative approach to frontier exploration by applying the concept of "inverse logging." Conventional exploration uses downhole geophysical logging tools. The "inverse logging" concept employs direct descriptions (lithology, texture, grain size, color, etc.) and petrophysical measurements (porosity, permeability, bulk density, shear and compressional wave velocities, etc.) of continuous core using on-site geological and geophysical evaluation modules to conduct a quick core analysis. Core analysis is a common practice in the petroleum industry, but conventional laboratory methods may take weeks or months. The advantage of SHADS is that the core, retrieved from deep and geologically unknown basins, immediately undergoes on-site descriptive and quantitative petrophysical analysis. All of the coring parameters, as well as the descriptive and petrophysical analysis, can be transmitted via satellite from the drill site to Amoco's offices. The information provided by the SHADS geologic modules is, therefore, available to Amoco's explorationists while the rig is still coring. This approach should produce an enhanced understanding of an area or basin in a relatively short period of time. In turn, this will help assess an area's potential and reduce exploration risk.

THE KREMCO #1 WELL

Well History. Amoco began the Kremco #1 well in Kremco's parking lot, drilled to 116 feet (35 m) with a tri-cone rock bit, and cased to surface with 5½ inch (14 cm) casing. The well was drilled-out below the surface casing with a tri-cone bit for an additional 40 feet (12 m) before coring commenced. Amoco originally planned to take a continuous 2½ inch (6 cm) core from 156 feet (48 m) to at least 500 feet (150 m) and possibly as deep as 1,000 feet (300 m) if additional coring was warranted to test the rig systems. Coring was begun at 156 feet (48 m) but was terminated at 350 feet (107 m) because of hole problems. The well was deepened, using a conventional tri-cone bit, to about 580 feet (177 m) before coring was resumed. The Kremco #1 well was completed at the end of the continuous run to a total depth of 649.73 feet (198 m) and abandoned by plugging the hole with cement. Thus, the well has an upper and lower drilled interval, as well as an upper and lower cored interval (table 2). Approximately 41 percent of the hole was cored. The upper cored interval was intermittently cut over a period of several days. The lower cored interval was cut during a 36-hour continuous run.

Kremco Core. Operational procedures for the cored intervals consisted of coring for about 20 feet (6 m), retrieving the inner barrel with a wire line (figure 3), and dropping a new inner barrel to continue coring another 20 feet (6m). The retrieved inner barrel was laid down and the core was forced out with pressurized water. The core was lithologically described, measured, and placed in core boxes for transport to the UGS Sample Library. Coring proceeded smoothly, even though we were not achieving full recovery on each coring run because much of the unconsolidated, fine-grained sand was



The drilling crew retrieves the inner barrel after a 20-foot (6 m) coring run.

being washed out during coring. Determining the position of recovered core for each core interval was estimated by locating the base of the core from the bottom of the core barrel and noting the depth of pump pressure changes. Recovery for the upper cored interval was only about 17 percent, whereas recovery in the lower cored interval was about 60 percent, probably because the sediments were more indurated with calcium carbonate.

Lithology and Probable Depositional Environment. The Kremco #1 well started in mud and silt of the Provo Formation and younger lake-bottom sediments of the Bonneville Alloformation (Davis, 1983, 1985; McCoy, 1987; Oviatt and others, 1987). The upper cored interval (table 2) lithologically consists of a mostly gray, fining-upward sequence overlying mostly pink to orange, laminated beds of sand and silt. The base of the fining-upward sequence is at a depth of 242 feet (74 m) and consists of a quartzite pebble gravel. It grades upward to a medium-grained sand, to silt, and mud. The quartzite pebble gravel probably correlates to the Sunset aquifer described by Feth and others (1966) in the Weber Delta District. Below 242 feet (74 m), the section consists of fine-grained to very fine-grained sand and silt which is well sorted and thinly bedded to laminated. The lithologies in the upper cored interval suggest a lacustrine depositional environment.

The inner barrel containing the core is laid on the pipe racks. The core is forced out with water onto a core tray where it can be measured and described.

Interval	Interval (ft)	Interval Thickness (ft)	Percent of Total Depth	Core Recovery (ft)	Percent Interval Core Recovery
Upper Drilled	0.00 to 156.00	156.00	24%		
Upper Cored	156.00 to 348.60	192.60	30%	33.10	17%
Lower Drilled	348.60 to 577.90	229.30	35%		
Lower Cored	577.90 to 649.73	71.83	11%	42.82	60%
Total Drilled		385.30	59%		
Total Cored		264.43	41%	75.93	29%
Total Hole		649.73	100%	75.93	12%

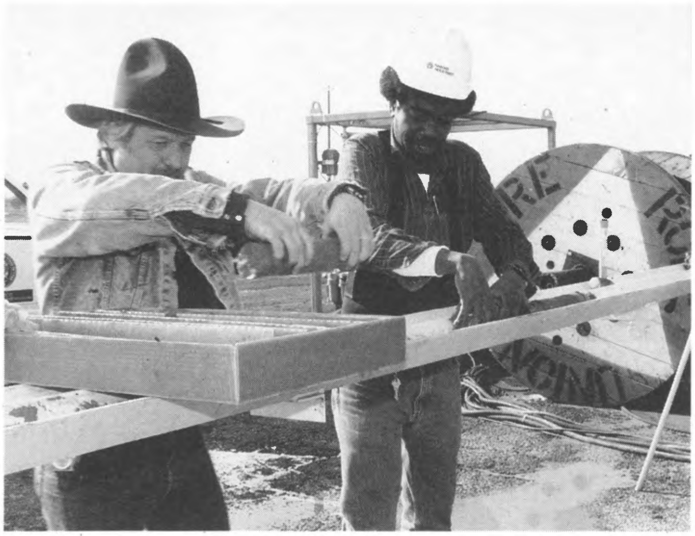
Table 2. Well Summary

The lower cored interval (table 2) lithologically consists of sand and silt beds that are gray to brown near the top of the interval, intercalated with beds that are mottled orange-pink-light gray. The mottled beds are resting on a cobble and pebble gravel at the bottom of the interval. The sand and silt section is dominated by sand that is moderately to well sorted, with fine to very fine grains. The descending stratigraphic sequence begins with a sand, rich in gastropods and roots, overlying a moderately indurated sand with some roots (caliche? zone), which rests on a basal friable sand barren of fossils or roots. The stratigraphic sequence is apparently repeated within the sand and silt section, probably indicating a fluctuating lake level. The depositional environment of these sediments is interpreted as marginal lacustrine to fluvial-eolian.

The bottom of the lower cored interval consists of a cobble and pebble gravel of mostly quartzite clasts with some schist and possibly gneiss clasts. The clasts are subangular to subrounded and moderately sorted. The cobble and pebble gravel probably correlates to the Delta aquifer described by Feth and others (1966) in the Weber Delta District. The gravel suggests a fluvial depositional environment.

Datable Material. The UGS hoped the core would contain ash beds, fossils, wood, or any other material that might yield an age of the sediments. A cursory inspection of the upper cored interval found no fossils or woody material; however, two possible ash beds were noted in the laminated beds (table 3) at depths of 282 feet (86 m) and 298 feet (91 m). These ash beds are thin, dark gray, and vitreous. Although the beds are probably ash, they could possibly be reworked carbonaceous material.

A cursory inspection of the lower cored interval found zones of gastropod shells and roots (table 3). Whole



The core is placed in core boxes after its length is measured, depth recorded, and lithology described.

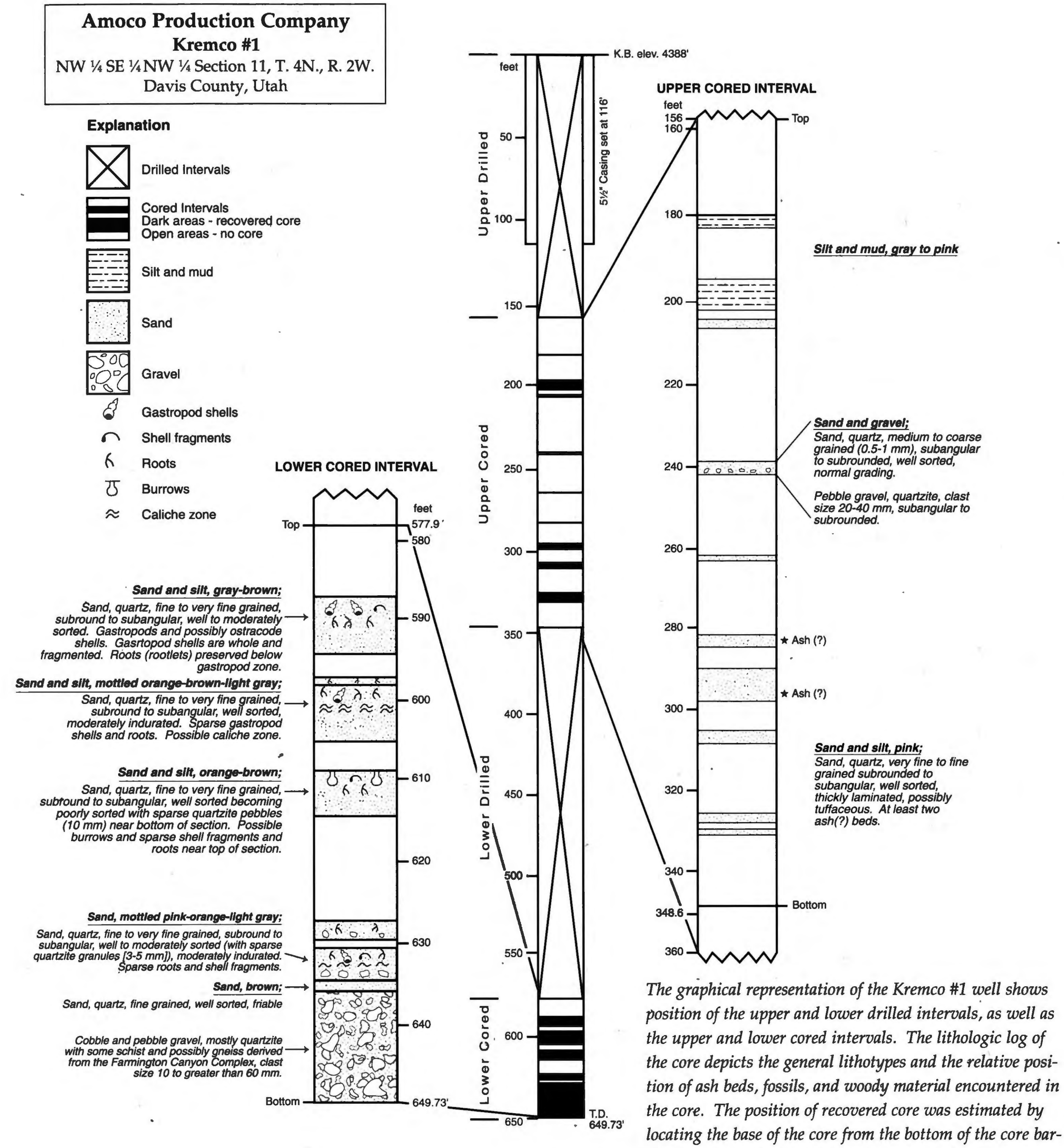
and fragmented gastropod shells were found in thin, discrete zones within the lower cored interval, but were more abundant near the top at a depth of 587 feet (179 m). Root zones generally underlie the gastropod zones and were more abundant and preserved over a thicker interval. The roots (probably better described as rootlets) were of uniform size, vertically to obliquely cut the sediments, and were more carbonized near the bottom of the interval.

CONCLUSIONS. The Kremco #1 core contains no obvious evidence of earthquake-related activity, however, it shows distinctive lithologic variations from which depositional environments may be interpreted. The core also contains fossils, woody material, and probable ash beds that could constrain the age of the sediments. A closer examination of the core would provide a more detailed lithologic description and may possibly yield additional ash or fossil beds. Detailed lithologic descriptions and well-constrained ages of the Kremco core would more accurately place the sediments within the Lake Bonneville stratigraphic framework (McCoy, 1987; Oviatt and others, 1987). Comparison with this and other Great Salt Lake cores (Feth and others, 1966; McCoy, 1987) may enable scientists to make inferences regarding Quaternary paleoclimates and basin tectonics.

ACKNOWLEDGMENTS. This information would not be available without Amoco Production Company's generosity in retrieving and donating the core. They also provided Utah Geological Survey personnel with a unique opportunity to view a state-of-the-art drilling system. I would particularly like to thank the engineers at Amoco's Tulsa Research Center who were on location: Kirby L. Edwards, Scott B. Randolph, and David J. Bode. Their main goal was to get the rig and its advanced drilling systems operational, thus their cooperation and support during coring is gratefully acknowledged. I would also like to acknowledge Bruce Howell (Tonto) and Jerome Dietz (Nabors-Loffland) for the expertise in recovering as much core as we got, considering the material we were coring. Thanks go to Fran Craigle (Utah Department of Natural Resources) and Dick Murphy (who recently retired as Public Affairs Representative for Amoco's Tulsa Research Center) for coordinating the positive public relations received during coring operation, and to Fran (again) for providing some of the photographs used in this article. A special thanks go to Ed Yeates, KSL-TV for his typically outstanding reporting of scientific events in Utah. Finally, I am grateful to Robert L. Blackett (UGS), Gary E. Christenson (UGS), Scott B. Randolph (Amoco), and Anne Marie Dumas (Amoco Production Company) for reviewing the manuscript. Their comments and suggestions significantly improved it.

Depth (feet)	Material	Thickness	Remarks
282.3	Ash(?) bed	0.5-1 mm	Dark gray, vitreous, possible reworked carbon
297.74	Ash(?) bed	0.5-1 mm	Dark gray, vitreous, possible reworked carbon
586.9 - 587.4	Gastropod, ostracode(?)	0.5 ft	Whole and abundant fossils near top of interval
587.4 - 591.2	Roots	3.8 ft	Abundant in top 3.1 ft of interval
597.4 - 597.8	Roots, gastropods	0.4 ft	Abundant roots and some whole gastropods
601.0 - 605.5	Roots	4.5 ft	Sparse
630.3 - 631.2	Roots, gastropods	0.9 ft	Sparse shell fragments and roots

Table 3. Summary of datable material noted from cursory inspection of the core from the Kremco #1.



The graphical representation of the Kremco #1 well shows position of the upper and lower drilled intervals, as well as the upper and lower cored intervals. The lithologic log of the core depicts the general lithotypes and the relative position of ash beds, fossils, and woody material encountered in the core. The position of recovered core was estimated by locating the base of the core from the bottom of the core barrel and noting the depth of pump pressure changes.

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Marketing the UGS' wealth of information

by Werner Haidenthaller

For some time the Utah Geological Survey (UGS) has recognized the need to make potential users more aware of the vast resources of information available through UGS publications and maps. Geologic research provides little benefit unless the results of this research are publicly known and put to use. Recently, major steps have been taken to gain public exposure for the informational products available from the UGS.

Annually, the UGS publishes on average 15-20 formal printed publications and maps and countless other "open-file" reports. Currently, over 900 products are available. These are sold at prices which allow the UGS to recoup printing or photocopying costs. The $70-80,000 annual sales proceeds are used to produce newly released studies and maps, and to reprint popular items which have sold out. Demand for our geologic information is as varied as the information available, ranging from local, state, and federal agencies to libraries and universities around the country to energy and mineral extraction industries to bookstores and tourist-oriented outlets.

Recognizing that many potential users are still unaware of the information available from the UGS, we have begun aggressive efforts to gain public exposure for these products of our work. Components of this marketing plan include:

- implementation of a computerized sales and inventory control system to track publication sales and perform market research to identify gaps in our distribution
- development of additional distribution outlets for UGS maps and publications
- remodeling of the UGS' sales room to make it "user friendly," to help customers search for the information they need
- use of various media resources, including industry and trade publications, to make potential users more aware of our products
- utilization of exhibits and booths at society conventions and industry trade shows to showcase the wealth of available information

Our computerized sales and inventory control system is already providing us with interesting and valuable information. The system not only keeps track of our finances, but provides us with feedback concerning our customers, their needs, and the sales of our products. The following is a summary of the UGS' top sellers in the last few months.

PUB #	TITLE
Map 92	Postcard geologic map of Utah *
MP S	Geology of Utah *
M 20	Relief map of Utah*
PI 14	Geologic resources of San Juan County *
M 68	Energy resources map of Utah
PI 17	Utah stone brochure *
C 63	Rockhound guide to fossil & mineral localities*
MP 92-1	Geologic tours of northern Utah *
MP 88-2	Geology of Antelope Island State Park *
MP 91-3	Soils as a tool for applied Quaternary geology

** Denotes a publication or map appropriate for a non-technical audience.*

We have suspected for some time that a large segment of the general population is interested in non-technical geologic information. In the last several years the UGS has begun to produce a variety of publications geared toward this audience. The above list illustrates the demand for these types of products. All but two of the UGS' top ten sellers are non-technical publications.

One of the UGS' best selling publications is Dr. W.L. Stokes book, "The Geology of Utah." Since its initial printing in 1987, almost 9,000 copies have been sold. This 317 page volume has been touted by many as being the most comprehensive, yet understandable source of information on the general geology of Utah. An article in the July '91 issue of "Geotimes" recommended it as a "fine book ... on the geology of Utah, well written by (an) outstanding geologist who has made tremendous contributions to the story." Southern Utah's tourist industry has discovered that this book is just what the tourists are looking for. It gives an in-depth explanation of the unique geology, which is the prime component of that area's incredible scenery.

The Stokes book provides a broad and general understanding of Utah's geology, but the UGS also carries a variety of non-technical publications specific to particular areas of interest. Several brochures are available which summarize the geology and resources of individual counties. Geologic maps and booklets are available for several of Utah's National and State parks. We also have a variety of resources designed to help earth science teachers explain Utah's geology. Non-technical information about Utah's earthquake and other geologic hazards is also available.

Many rockhounds have discovered the UGS as a source of information about the state's mineral and semi-precious stone resources. Our "Rockhound Guide to Mineral and Fossil Localities in Utah" sold out in the first few years. After photocopies were sold for years thereafter, we decided last year to reprint the guide. A new and more extensive rockhound guide is in progress.

Another of the UGS' most popular non-technical publications is "Geologic Tours of Northern Utah" by Sue Morgan. This 98 page compilation leads the reader through the diverse geology and scenic beauty of northern Utah. A brief introduction to basic geologic principles and a time scale acquaint the amateur geologist with the rocks, after which the reader is guided through eight scenic drives and two hikes.

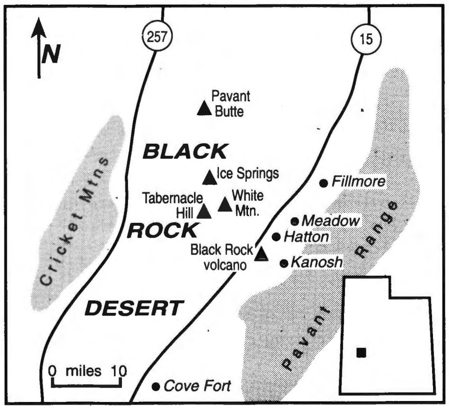
Although the UGS continues its tradition of producing in-depth technical reports of geologic research, a substantial effort is also being made to address the informational needs of the lay public. The UGS plans to begin acting as a distribution outlet for the U.S. Geological Survey's publications and maps. We welcome feedback concerning these informational needs, and encourage you to come and see what information is already available.

A trip to Tabernacle Hill in the Black Rock Desert

by Sandra N. Eldredge

Black Rock Desert .... sounds like an inferno, a place better to avoid than to visit. Actually, it was an inferno just this morning - in geologic time (kind of like dog years, but, well, you get the idea). Volcanos erupted, spewing fiery ash and fragments into the air; red hot lava poured over the land, and in some areas flowed into lake waters, enveloping the region with clouds of steam ... Yikes! What's going on here?? We better relocate to the present.

The aptly named Black Rock Desert provides a fascinating view of Utah's active volcanic past from as recently as 600 years ago to about 2 million years ago. The name "black rock," of course, implies lots of black basalt. **Basalt** is a magnesium- and iron-rich volcanic rock that solidifies from lava (molten magma that has reached the earth's surface through a volcanic vent). The black basalt contrasts with the wind-swept, brown grass in the desert.



The Black Rock Desert encompasses an area roughly 35 miles wide and 25 miles long in west-central Utah. It is bounded by the Cricket Mountains on the west and the Pavant Range on the east (see map). This part of Utah has been undergoing stretching and subsequent faulting of the earth's crust during the past 20 million years. Volcanic activity has ensued along some of the faults. A few volcanic events were contemporaneous with Lake Bonneville - a large glacial lake that covered much of western Utah, including the Black Rock Desert - between about 30,000 and 12,000 years ago.

Parts of the Black Rock Desert are geologically unique; one such area, known as Tabernacle Hill, has been designated as an Area of Critical Environmental Concern (ACEC) due to the special geologic features present. The Richfield District of the Bureau of Land Management (BLM) is developing a recreation management plan for Tabernacle Hill "... to protect the significant scientific, educational, and recreational values that occur in the area."[1] The plan involves withdrawing 3,512 acres from all mining activities. Mining claims in the ACEC have been declared invalid, but one mining claimant is appealing that decision. The BLM's plan to develop and maintain interpretive trails at Tabernacle Hill is contingent on the court's final ruling.

Sandy Eldredge first joined the UGS in 1982 to staff the Utah Geologic Work Group assessing potential sites in southern Utah for a high-level nuclear-waste repository. For the past five years, she has been a UGS Information Geologist. Sandy received a bachelor's degree in geology and anthropology from Skidmore College, and a teaching certificate from Weber State University. She taught high school before coming to UGS and continues to instruct courses for teachers.

What's so significant about tame-looking Tabernacle Hill you ask? Driving on I-15 in any direction from the Fillmore, Meadow, and Hatton areas, several volcanic hills can be seen rising above the broad expanse of Lake Bonneville's former floor. From the north to the south, you will

Aerial view of Tabernacle Hill from the south. The smooth, light-colored hills are the tuff cone, or ring, rising 80 to 120 feet above the surrounding basalt flow. Tabernacle Hill is the most prominent segment of the cone (the northern portion). The collapsed flat-floored crater contains two dark-colored cinder cones.

see the large mass of Pavant Butte, the black rocks of the Ice Springs volcanic center, the brown mounds of Tabernacle Hill, the small white hill of White Mountain, and the stark outline of Black Rock volcano. The smooth, low, rounded profile of Tabernacle Hill doesn't appear impressive (unless, when looking at the highest ridge from the north, you see the similarity to the roof of the Salt Lake Tabernacle), and from a distance, the basalt flow surrounding Tabernacle Hill isn't as noticeable as the rugged black rocks near Ice Springs. But wait, let your imagination unfurl, for Tabernacle Hill was once a volcano that erupted into Lake Bonneville - creating a volcanic island.

The Tabernacle Hill basalt flowed into Lake Bonneville about 14,300 years ago. The eruption occurred after the lake had receded from its highest level of 5,090 feet to about 4,740 feet in elevation (known as the Provo level). Lava issued from fissures and surged along the lake bottom to create a now distinct circular basalt flow. On the outer margins of the flow, where hot, fluid lava broke through the hardening lava crust, squeezing out like toothpaste, pillow structures formed. **Pillow structures** result when hot lava spurts out from the front edge of a subaqueous lava flow and cools rapidly in the cold water, curling into globular blobs that geologists think resemble pillows (remember we're using our imaginations). Often a concentric pattern of numerous tightly fitting "pillows" is evident in the hardened basalt.

The final outburst at Tabernacle Hill transpired when volcanic vents opened along faults* in the basalt flow, allowing lake water to come in contact with hot magma and instantaneously flash to steam (called a "phreatic", or steam-blast eruption). Billowing steam, black plumes of basaltic ash, and hardened lava droplets were explosively ejected into the air. This explosive eruption created Tabernacle Hill's **tuff cone** (a low-rimmed ring composed of cemented volcanic ash and cinder) that rose above the lake waters. Within the encircling tuff cone, two **cinder cones** (built from uncemented particles and clots of congealed lava that blasted into the air and fell around the vents to form the cones) formed above water. The volcanic ash from this volatile upheaval was widely distributed by winds and lake currents. Eventually the ash settled to the bottom of Lake Bonneville and was preserved as a distinctive dark band between layers of light-colored lake sediments.

A closer look at Tabernacle Hill promises an intriguing adventure. The desert can look forbidding - that rugged black rock glistening in the hot sun, so be prepared; in the words of a 1947 guidebook:

> Lava is hard; its edges often sharp. It will cut shoes very badly, or one may slip on a glassy surface with painful results. Do not wear low slippers, nor any kind of foot covering with sharp heels. Choose the oldest, strongest, flattest and sturdiest lace shoes you possess, or better yet, go with the modern climbing boot, suitable for rough usage. Don't wander away from companions, as the surface is deeply gullied, and to one unfamiliar, all will shortly look alike and one is lost.[2]

OK, got your boots? Got your companions? (Of course, water would also be good to bring along).

Tabernacle Hill is 12 miles southwest of Fillmore. From Fillmore, travel west on Utah Highway 100 until you cross a canal 2.5 miles from town. In the banks of the canal, black volcanic ash is interbedded with white, deep-water Lake Bonneville sediments (called marl). The basaltic ash layer is about 4 inches thick here and is actually from the Pavant Butte eruption, which took place 12 miles to the northwest. Pavant Butte was another volcano that erupted into Lake Bonneville, prior to Tabernacle Hill's existence. Tabernacle Hill ash is also black and basaltic (basaltic ash is unusual; volcanic ash is typically lighter colored and rhyolitic or andesitic in composition). These basaltic ashes within the lake sediments are important stratigraphic markers that provide valuable clues to the history of Lake Bonneville. And conversely, Lake Bonneville's sedimentary history provides clues to the timing of the volcanic events.

** The faults cut the basalt flow, and therefore are younger than 14,300 years. The vents that appeared along the faults could have surfaced at the same time, or after, the faults ruptured. In any event, because there is displacement along these faults, earthquakes most certainly accompanied the faulting. Let your imagination work on that one ... earthquakes, seiches (waves generated by an earthquake) in Lake Boneveille, possible simultaneous volcanic turbulence ....*

Pressure ridge in the Tabernacle Hill basalt flow. Note prominent crack extending along the crest.

Continue westward along the main paved road toward the Ice Springs volcanic field; the road turns to gravel at mile 9.8. Just before the Ice Springs cinder pit (the cinder is used for light-weight aggregate and as decorative stone material), take the road's left fork and drive around the south end of the Ice Springs basalt flow. Note the blocky and jagged character of this basalt (called "aa" lava). The sharp projections and fresh black appearance are evidence of the young age - about 600 years old - of the basalt. Compare this with the more weathered, older basalt (about 13,700 years old) at Tabernacle Hill.

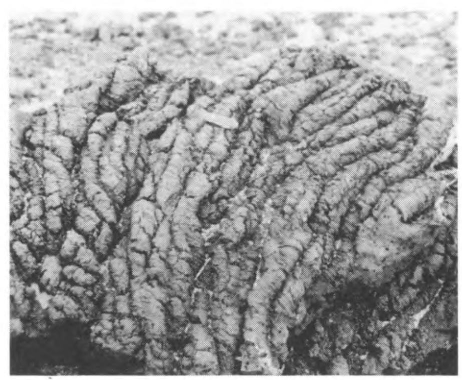
Approximately 3 miles from the cinder pit, turn left (south) on a dirt road that leads toward Tabernacle Hill. After traveling 1/2 mile, turn right (west) on a gravel road, and then immediately turn left (south) on an unimproved dirt road that starts your bumpy ride up and over the north end of the Tabernacle Hill basalt flow.

Along the outer edge of the basalt flow, caliche whitens the underside of basalt boulders in some places. Caliche is typically calcium carbonate that forms as the result of solution and precipitation of soluble minerals by rain and ground water. After bouncing along for 1/2 mile, you will pass the remnant of a small tuff cone to the west, and then cross a fault scarp that cuts the basalt flow where the road drops down to the west. The tuff cone erupted along this fault.

Some basalt surfaces in this area exhibit six-sided, polygonal crack patterns (the simplest pattern to relieve uniform stress when liquid material, for example mud or lava, dries, hardens, and shrinks). Also visible are large longitudinal cracks along the crest of pressure ridges. **Pressure ridges** result when the surface of a lava flow cools and forms a crust on top of underlying, still-flowing lava. The congealing crust is uplifted into elongate ridges, either due to the movement of the underlying lava, or because the lava stalls at a barrier and exerts an upward force while seeking a way around the barrier.

The road continues to the volcano's central area, which is semi-encircled by the tuff cone. The **tuff** consists of cemented cinder and ash; it is of basaltic composition and contains blocks of basalt. The tuff is partially altered to yellow-colored palagonite (hydrothermally altered basaltic glass). The chemical alteration was probably caused by hot water trapped within the tuff. Unaltered tuff is gray to black in color. The tuff contains small pieces of green and red, fine-grained sediments (these may have originally been silt and sand deposited by a pre-Bonneville lake), which were brought to the surface with other material during the eruption and baked by the high temperatures. Two 80- to 100-foot-high, red, brown, and black cinder cones are located near the center of the crater.

Adventurous visitors will want to park their vehicles and hike around on the surrounding basalt flow.



Pahoehoe lava (right) and aa lava (below).

Entering a lava tube.

Although Tabernacle Hill's flow is the smallest in the Black Rock Desert, covering an area of only 7.5 square miles, you cannot help but see the myriad pressure ridges, cracks of varying depths and widths (don't forget your companions), and both pahoehoe and aa lava. **Pahoehoe** (pa-hoey-hoey) is hot, fluid, gas-rich lava, which can flow quickly across the ground surface. Pahoehoe is an Hawaiian term meaning "satin-like," referring to pahoehoe lava's typically smooth, satiny appearance. Also known as ropey lava, it commonly cools into twisted, ropey wrinkles. **Aa** (ah-ah) lava is cooler and moves more slowly (less than 5 feet/minute); it is more viscous, so the dissolved gases cannot escape as readily. Often aa lava moves as a wall of tumbling blocks, and the resulting hardened surface is rough and jagged, with sharp projections (aa can be the expletive uttered when walking on this basalt in bare feet). At Tabernacle Hill, you can observe how pahoehoe lava changed into aa lava with distance from the vent.

You may also discover caves, called lava tubes. **Lava tubes** are hollow spaces, often tunnel-shaped, beneath the surface of a basalt flow. The tubes are formed by the withdrawal of molten lava from beneath a hardened lava crust. Lava tubes of varying sizes and degrees of collapse are found in the Tabernacle Hill basalt flow; some are large enough to walk through with plenty of room to spare. Depending on your luck, you may find hanging calcite stalactites, soda straws (tubular stalactites), lava stalactites that formed on the walls and roof by the dripping of molten lava, or bat guano (yes, bat guano - deposits in some lava tubes were once mined as a source of fertilizer). DO NOT touch the stalactites or soda straws; they are scarce, very delicate and easily destroyed.

To approach the east side of the basalt flow, backtrack north to the gravel road at the northern edge of the basalt flow and then proceed about 2 miles southeast to White Mountain. White Mountain (the covering of white gypsum sand gives it its name) contains the youngest rhyolite in Utah - 400,000 years old. You need to drive around the east and south sides of White Mountain; this will include executing a sharp right turn around a gypsum pit that is excavated from dunes on the east side of White Mountain. An alternate route to White Mountain is from the town of Meadow - go west on Center Street off of Utah Highway 133; after traveling 4.5 miles you will reach the same gypsum pit - take the road's left fork just before the pit. Once on the south side of White Mountain, cross a playa (which is impassable if wet) and white gypsum sand. This eastward approach allows you to easily see the high walls of basalt that mark the Tabernacle Hill flow's outer margin. Envision the Provo shoreline of Lake Bonneville at the upper edge of the basalt flow. The outer rim of the basalt flow is at a uniform elevation of 4,740 feet, which is also the Provo level.

Traveling south along the east side of the basalt flow, look for Lake Bonneville shoreline indicators: pillow structures, wave-rounded boulders, and basalt encrusted with tufa. **Tufa** is calcium carbonate or silica deposited from solution in the lake water. It tends to be yellower in color than caliche. The pillow structures are common on the steep flanks of the flow and have a glassy texture on their outer surfaces with coarser-grained interiors.

From the south side of the basalt flow, you may choose to explore the crater area via a jeep trail, or you may want to investigate other interesting areas in the Black Rock Desert. Contact the Bureau of Land Management in Fillmore for maps and information.

Useful maps include:
- Bureau of Land Management, 1988, Recreation and vehicle guide to Warm Springs Resource Area, scale 1" = 4 miles.
- U.S. Geological Survey, 1980, Richfield 30 x 60 minute quadrangle map, metric scale 1:100,000.

Reminder: bring boots, companions, water, and please stay on the roads with your vehicles. Do not touch stalactites or soda straws, so that future visitors may also enjoy these wonders.

Footnotes

1. *Horsburgh, C.A., 1982, Mining claim validity examination for the unpatented mining claims within the Tabernacle Hill protective withdrawal: U.S. Bureau of Land Management.*
2. *Beckwith, Frank, 1947, Trips to points of interest in Millard and nearby: Springville, Utah, Art City Publishing Company.*

Public Inquiries

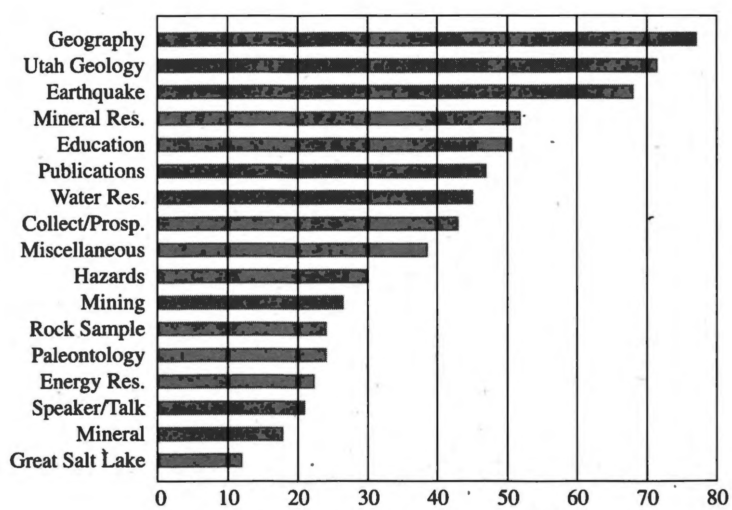
The Geologic Extension Service

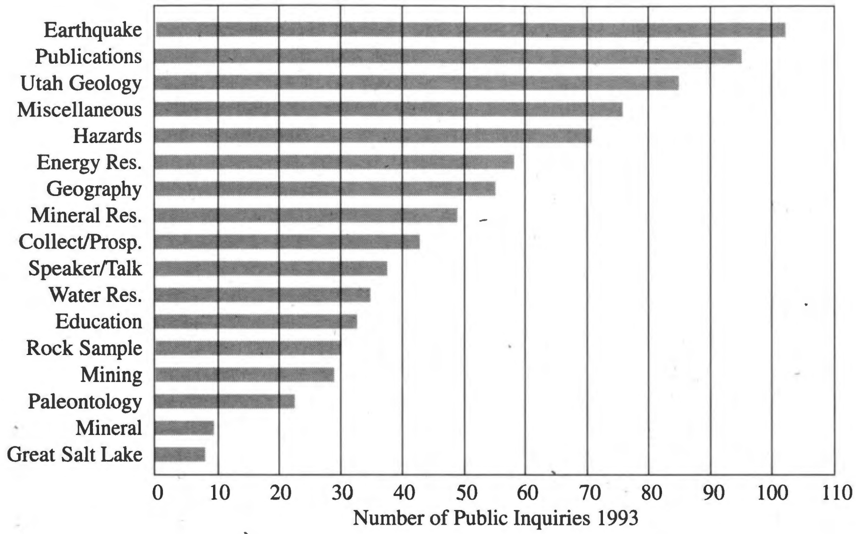
Answering public inquiries is an important function of the Utah Geological Survey (UGS). By providing this service, the UGS helps Utahns and others better understand Utah's geology, geologic hazards, and economic opportunities. Throughout the year the UGS answers numerous questions from the general public, teachers, industry representatives, and from federal, state, and local officials. Most of those inquiries are handled by the UGS Geologic Extention Service consisting of two geologists and a geotechnician. They are the technical staff that the public first encounters when letters, callers, and "walk-in" customers do not ask for a specific person within the UGS. This group responded to almost 700 inquiries from October 1991 through September 1992, and 830 from September to October 1993.

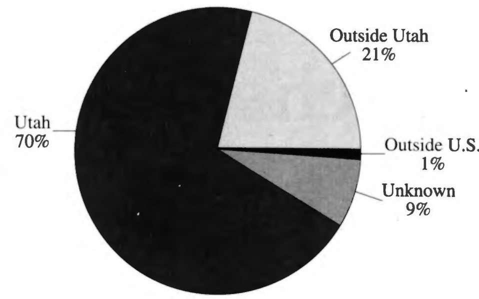
Public inquiries vary widely in subject matter and technical content. The first inquiry of the day might be a letter from an elementary school student asking for a rock sample to complete a science project, the next might be from an out-of-state investor looking for pumice deposits suitable for stonewashing jeans, then possibly a home-owner requesting general earthquake information, followed by a newspaper reporter searching for the elevation of Kings Peak. When an inquiry needs additional specialized information, the caller is referred to a UGS expert or to the appropriate federal, state, or local government agency.

Each inquiry received by the Extension Service is entered into a computer database in which the following information is recorded: date of inquiry, the type of question, and the inquirer's location (state or country). The graphs display the number

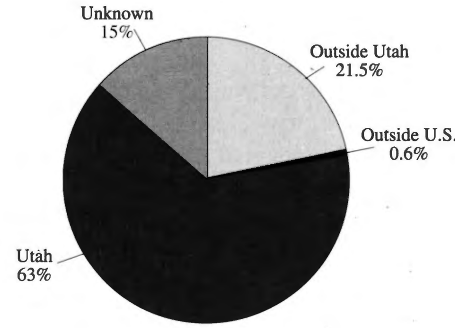
Category / Keyword	Explanation (if necessary)
Geography	elevations / locations / names
Utah Geology	various aspects
Earthquake	includes fault information
Mineral Resources	
Education	educational materials
Publications	publication availability
Water Resources	
Collecting / Prospecting	mineral collecting locations and recreational prospecting
Miscellaneous	all other requests
Hazards	other than earthquakes
Mining	includes specific mining district information
Rock Sample	rock sample from Utah
Paleontology	fossil information
Energy Resources	
Speaker / Talk	need UGS speaker or UGS staff member to give talk
Mineral	a mineral's characteristics or properties
Great Salt Lake	







October 1991 to October 1992



October 1992 to October 1993

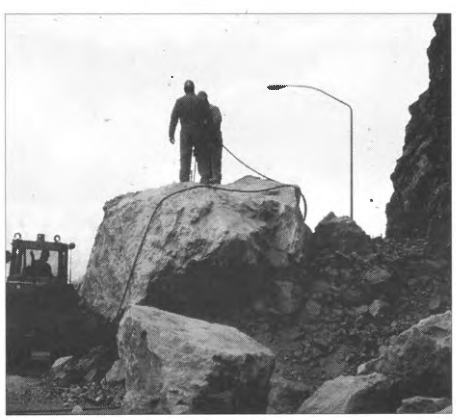
and type of questions answered for the last two years.

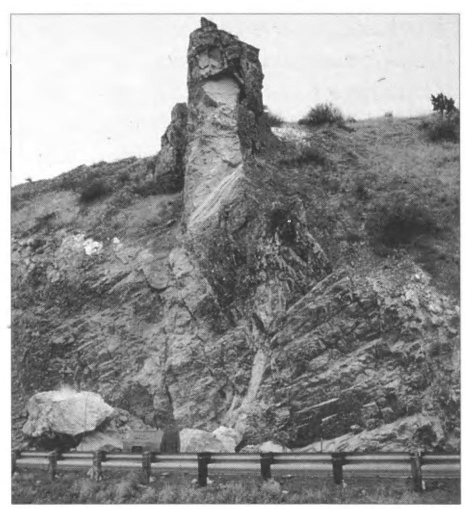
Although most of the inquiries received during this period were from Utahns, over 20 percent were from out of state, including some from other countries: Germany (Utah geology), Finland (collecting-prospecting), Canada (Utah geology), and England (mineral resources). The pie charts show a breakdown of this geographic distribution.

As part of its duties, the UGS Geologic Extension Service also conducts teacher field trips, prepares information for geologic displays and road signs, and compiles non-technical geologic information for a variety of publications. By ascertaining the types of information most frequently requested by the public, the group can prepare non-technical brochures and flyers on those subjects. This goal has been partially accomplished by producing the following publications (not a complete listing): Earthquake fault maps of portions of Weber, Davis, Salt Lake, and Utah Counties; Earthquake hazards and safety in Utah; Geologic resources booklets for Salt Lake, Summit, Box Elder, and San Juan Counties; The geology of Snow Canyon State Park, Washington County, Utah; Geology and scenery of the central Wasatch Range; Gold prospecting in Utah; Rockhound guide to selected rock and mineral localities in Utah; and a series of flyers on mineral fuels, industrial minerals, and gemstones. Future projects include a Utah geologic history fact sheet, a homebuyer's guide to geologic hazards, and the geology of Utah's state parks and travel regions.

Big boulder blocks byway

On November 29,1993, a boulder of Mississippian Lodgepole Limestone roughly as large as a dump truck fell more than 40 feet (12 meters) from a fractured bedrock pinnacle on the north side of Interstate Highway 84 onto the road just east of Morgan, Utah. No injuries occurred but the boulder buckled asphalt and blocked one westbound lane of I-15, a major east-west thoroughfare in northern Utah. The boulder was blown into rubble with explosives by the Utah Department of Transportation and hauled away on December 1, 1993.





Removal of the rock was complicated by the presence of a high-pressure natural-gas pipeline beneath the road. The highly fractured pinnacle may continue to present a rock-fall hazard.

Teacher's Corner

by Sandy Eldredge and Carolyn Olsen

Tours

Classes are welcome to tour the Utah Geological Survey Sample Library, located in Salt Lake City at 4060 South 500 West, #4. The library contains geologic cuttings and core, oil samples, and fossils from Utah. Explore the senses of touch, taste (within reason), and sight with a microscope; or experiment with a supervised hardness test and hydrochloric acid test on rocks and minerals. See the fascinating variety of oils with different colors and different viscosities. Learn about oil drilling and observe the difference between cores and cuttings. View drill cores from mineral, geothermal, and Great Salt Lake wells; don't miss the unusual and beautiful salt core from the Paradox basin. Examine fossils, samples of tar sands and salt crystals. To arrange a memorable tour, contact Carolyn Olsen at the Sample Library, (801) 266-3512.

Educational Products.

The U.S. Geological Survey offers several excellent items to help teachers inform students about how geology, hydrology and other earth sciences affect them, their communities, the nation, and the world. Recent products include a series of colorful posters on water resources; a booklet on helping children learn geography; and a multimedia, interactive computer system called GeoMedia. GeoMedia is designed to help teach middle school children (grades 4 to 6) about the hydrologic cycle , earthquakes, and maps. To obtain a copy of GeoMedia, write to: Project Chief, GeoMedia Educational System, U.S. Geological Survey, 801 National Center, Reston, VA, 22092.

Contact the U. S. Geological Survey in Salt Lake City for other products. Of particular interest to Utahns is "What Do Maps Show?" - a packet of maps, a teaching poster, lesson plans, and activities focusing on the Salt Lake Valley. The materials are appropriate for upper elementary and junior high school classes. Teachers may pick pick up single copies from: U.S. Geological Survey, Earth Science Information Center, 8105 Federal Building, Salt Lake City, UT, 84138, (801) 539-5652.

Superb minerals, mining and energy educational materials for educators of primary and secondary students are available from the National Energy Foundation, 5160 Wiley Post Way, Suite 200, Salt Lake City, UT, 84116, (801) 539-1406.

Survey News

Michael Leavitt, the Governor of Utah, presented his prestigious Governor's Medal for Science and Technology to UGS staff for two years in a row. **Lehi Hintze** received the medal for 1992 and **Hellmut Doelling** was awarded the medal for 1993. The two UGS scientists were honored for the quality and vast quantity of their geologic mapping, as well as for promoting and encouraging mappers. Doctors Hintze and Doelling have published numerous books and papers on various aspects of Utah's geologic history, perhaps the most well-known being Lehi's *Geologic History of Utah* and Hellmut's three massive monographs on Utah coal.

Survey News (continued)

New DOE Project Brings Utah Total To $13 Million

The UGS has received funding from the U.S. Department of Energy for a $1.7 million project to improve oil field production techniques. The UGS heads a multidisciplinary team to develop three-dimensional petroleum reservoir models based on outcrops of the Ferron Sandstone in central Utah. The models will be applied to oil and gas fields throughout the world.

Amoco, Mobil and British Petroleum oil companies, University of Utah, Utah State University, Brigham Young University and prominent industry consultants are participants in the project. The three oil companies will provide nearly $1 million of the project cost with the remainder coming mostly from DOE.

"This is the third DOE contract Utah has received in 12 months," says State Geologist M. Lee Allison. "We now have over $13 million government-industry projects working to rebuild Utah's oil and gas industry through better and more efficient technologies."

The UGS heads two other cooperative research projects being conducted in the Uinta and Paradox basins of eastern and southeastern Utah. All three projects are designed to increase oil and gas production from existing fields.

"These projects have the potential to recover hundreds of millions of barrels of oil that would otherwise be left behind," says Allison. "We're especially pleased with the industry-university-state-federal cooperation. This third contract award illustrated our success in putting together complex projects that have tremendous potential to benefit Utah's economy."

UGS AAPG Presentation Winners

The Energy Minerals Division Best Poster Award for the recent 1993 AAPG-Rocky Mountain Section meeting went to Brigitte Hucka for her paper titled "Cleat and Joint Patterns in Some Cretaceous Coal Sequences in Utah and Their Regional Implications."

The Energy Minerals Division President's Certificate of Excellence in Presentation of a Poster (established to recognize the runner-up) went to Charles Bishop for his paper titled, "Geology and Methane Content of the Book Cliffs Coal Field."

Brigitte will receive a mineral desk set with an engraved plaque and Charlie will receive the President's Certificate of Excellence.

In the Division of Environmental Geoscience, Wally Gwynn's poster presentation titled, "Saline Waters Produced from Oil Fields in the Uinta and Paradox Basins, Utah" came in second. Unfortunately, only the first-place winner receives an award.

The Steve Champlin Memorial award for Best Poster (the Best Poster Award for the entire convention including all AAPG divisions) went to Carol Tripp (Bryce's wife) for her paper entitled, "A Hydrocarbon Exploration Model for the Beta Member of the Permian Kaibab Formation, with Emphasis on the Potential for Hydrodynamically Displaced Oil, in East-Central Utah." This project was funded by a UGS Mineral Lease Grant and has been published as a UGS Contract Report (see new publications of the UGS.

Kimm Harty has been named Chief Technical Reviewer for the UGS and supervisor of the Geologic Extension Services (formerly the Information Section). Kimm joined the Applied Geology Program at the UGS in 1984 after completing her master's degree at the University of Alberta, Canada. The main focus of Kimm's work at the UGS has been the study and mapping of Utah's geologic hazards. Kimm has produced statewide hazard maps depicting landslides, shallow ground water, and floods, and has performed numerous geologic-hazards investigations throughout Utah.

Award-Winning Book

The guidebook for the Uinta Basin Symposium, sponsored last year by UGS, received the 1992 Best Guidebook award from the Geoscience Information Society. Tom Chidsey, Jr. was co-editor. The award was presented at the national GSA meeting in Boston. Congratulations are due to everyone who was involved in the book.

Dan Burke has accepted a new position as Director of Museum Services with the Department of Community & Economic Development. This is a great opportunity for Dan and we wish him well.

Vicky Clarke is the new graphic artist in Editorial. She previously worked for Ivy Food and Deseret Book Company, and applies her years of experience to this issue of Survey Notes.

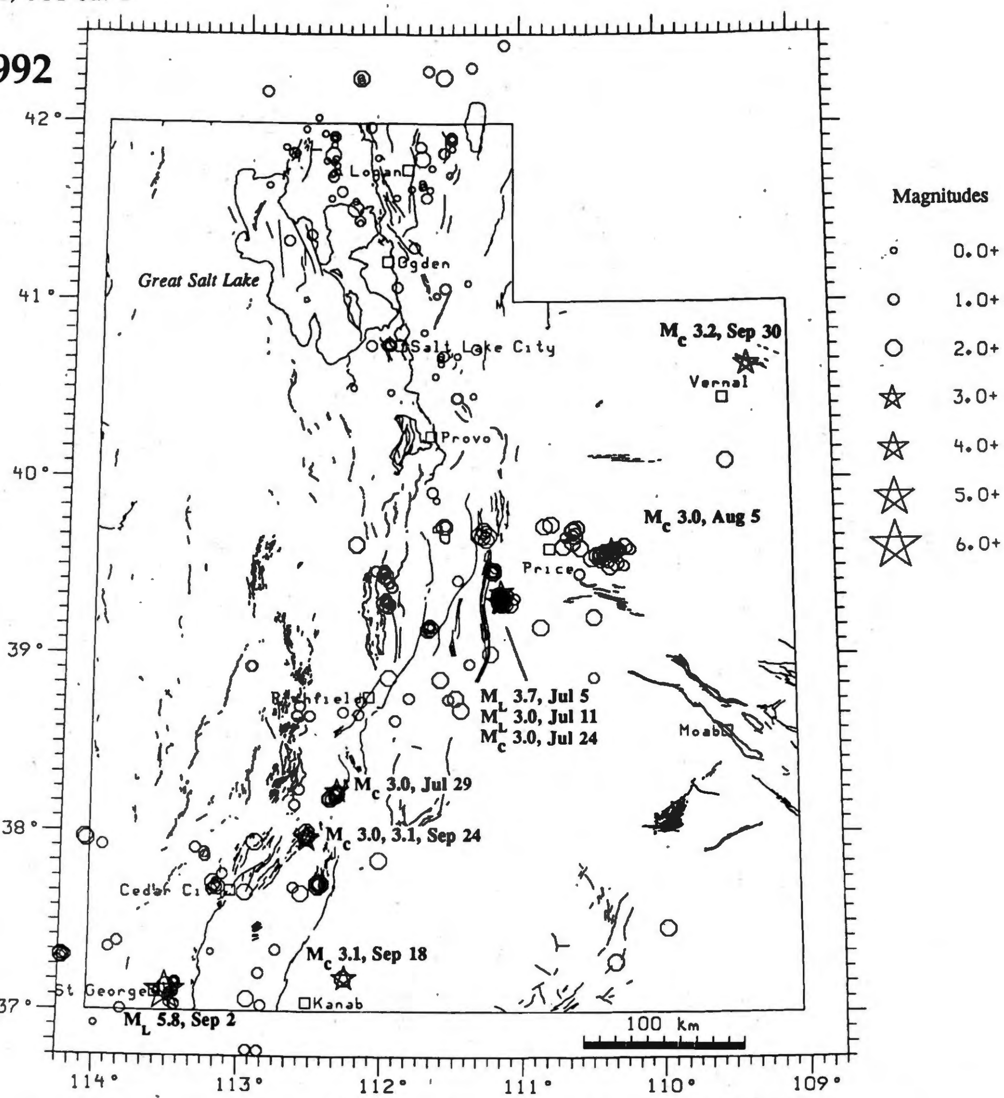
Michele Hoskins begins this month as the secretary for the Economic and Mapping Sections.

Earthquake activity in the Utah region

by Susan J. Nava

University of Utah Seismograph Stations, Department of Geology and Geophysics
Salt Lake City, UT 84112-1183 (801) 581-6274

July 1 - September 30, 1992



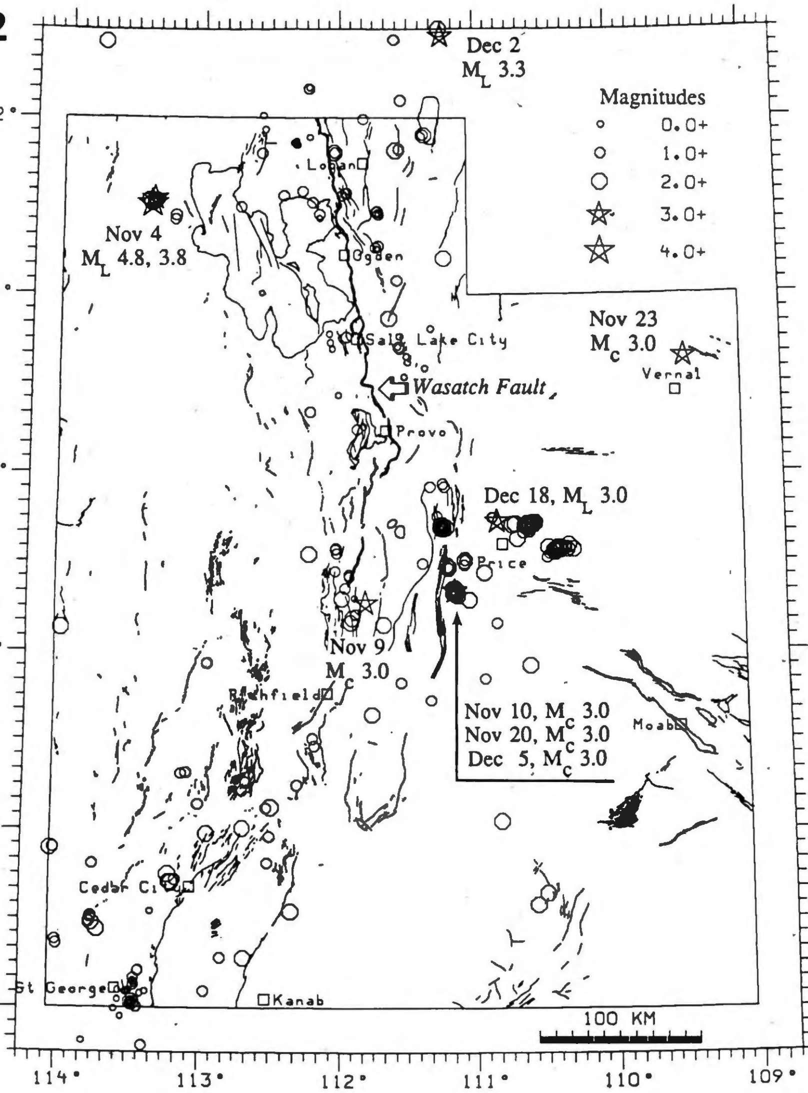
During the three month period July 1 through September 30, 1992, the University of Utah Seismograph Stations located 357 earthquakes in the Utah region with one in the magnitude 5 range, nine in the magnitude 3 range, and 135 in the magnitude 2 range. Earthquakes of 3.0 or larger are plotted as stars and specifically labeled on the epicenter map. Magnitude indicated here is either local magnitude, M_L, or coda magnitude, M_C. All times are local times, which was Mountain Daylight Time.

St. George: A damaging earthquake (M_L 5.8) occurred 5 miles southeast of St.. George, Utah, on September 2, 1992. The earthquake was felt throughout most of southwestern Utah, northwestern Arizona, and southeastern Nevada. The shock was the largest in the Utah region since 1975 and the largest in the St. George area since 1902. The earthquake caused damage in communities within about 35 miles of its epicenter and triggered a massive, destructive landslide near Springdale, Utah, 30 miles to the northeast. Preliminary seismological data indicate that the earthquake originated at a depth of 9 miles (15 km) and was caused by dominantly normal faulting on a north-south-trending fault, possibly a subsurface extension of the Hurricane fault. The main shock was followed by remarkably few aftershocks (only 16 locatable) during the report period. Additional information is available in "The St. George (Washington County), Utah, Earthquake of September 2, 1992," Preliminary Earthquake Report., University of Utah Seismograph Stations, 1992. A detailed summary will be published by the Utah Geological Survey during 1993.

Significant shocks:

M_L 5.8	September 2	4:26 a.m.	5 miles SE of St. George; widely felt (see above)
M_C 2.7	September 10	12:42 a.m.	4 miles NE of Washington; felt in St. George
M_C 1.0	September 23	11:19 p.m.	1 mile NE of Washington; felt in St. George
Book Cliffs/Price (coal-mining related):			
M_L 3.7	July 5	6:22 p.m.	9 miles NW of Orangeville
M_L 3.0	July 11	7:23 a.m.	8 miles NW of Orangeville
M_C 3.0	July 24	9:01 a.m.	10 miles W of Huntington
General vicinity of Cedar City:			
M_C 3.0	July 29	7:54 p.m.	5 miles NW of Circleville
M_C 3.0	September 24	4:02 a.m.	11 miles NW of Panguitch
M_C 3.1	September 24	8:35 a.m.	12 miles NW of Panguitch
Northeast of Kanab:			
M_C 3.1	September 18	8:45 p.m.	18 miles NE of Kanab
Northeast of Vernal:			
M_C 3.2	September 30	9:35 a.m.	16 miles NNE of Vernal

October 1 - December 31, 1992



During the period October 1 through December 31, 1993 the University of Utah Seismograph Stations located 347 earthquakes within the Utah region. The total includes one earthquake in the magnitude 4 range, eight in the magnitude 3 range, and 146 in the magnitude 2 range. Magnitudes of 3.0 or larger are plotted as stars and specifically labeled on the epicenter map. There were six earthquakes reported felt during this period. (Magnitude indicated here is either local magnitude, M_L, or coda magnitude, M_C. All times are local time, which was Mountain Daylight Time from October 1 to 24, and Mountain Standard Time for the remainder).

St. George: Aftershocks continued to occur in the vicinity of the September 2, 1992, St. George (M_L 5.8) earthquake. Thirty-three aftershocks, ranging in magnitude from 0.3 to 2.2, were located.

Book Cliffs/Price (coal-mining related): Five clusters of earthquakes (magnitude 1.3 to 3.3) make up 50% of the shocks occurring in Utah during this period. These clusters are located: (a) near Sunnyside and East Carbon (southeast of Price); (b) in the vicinity of Soldier Canyon (northeast of Price); (c) northwest of Orangeville (southwest of Price); (d) near Hiawatha (southwest of Price); and (e) southwest of Scofield (northwest of Price).

Terrace Mountain, West Desert: An M_L 4.8 earthquake occurred November 4 under the Great Salt Lake Desert, south of Terrace Mountain and 29 miles east-northeast of Lucin. The shock was felt throughout northern Utah, eastern Nevada, and southeastern Idaho; no locatable foreshocks. Nine locatable aftershocks occurred during the 101 minutes following the main shock. The largest was M_L 3.8 located 31 miles east-northeast of Lucin. Prior earthquakes in this general region include a magnitude 4.8 shock in 1987, 25 miles to the southeast of the Terrace Mountain earthquake, and a magnitude 4.7 shock in 1970, located 26 miles to the northwest of the Terrace Mountain earthquake.

M_L 3.0	November 23	11:36 a.m.	14 NNE of Vernal
M_L 2.6	November 28	11:01 p.m.	13 miles SSE of Morgan; felt in Bountiful, eastern Salt Lake Valley, Emigration Canyon
M_L 2.7	December 21	10:34 p.m.	12 miles ENE of North Logan; felt in Cache County
M_L 2.5	October 12	5:04 a.m.	4 miles E of Fielding; felt in Fielding
M_L 3.0	November 9	11:11 a.m.	4 miles NNE of Fayette
ML 3.3	December 2	5:59 p.m.	6 miles NNE of Bennington, ID

New Publications of the UGS

Map Series

Provisional geologic map of the Gold Hill quadrangle, Tooele County, Utah, by J.P. Robinson with a plate of the mines, prospects and workings of the Gold Hill quadrangle, by H.M. Messenger, H.H. Doelling, B.T. Tripp, and M.E. Jensen; 19 p., 3 pl., 1:24,000, 1993, Map 140 .... **$6.00**

Provisional geologic map of the Smithfield quadrangle, Cache County, Utah, by M. Lowe and C.L Galloway, 18 p., 2 p., 1:24,000, 1993, Map 143 .... **$6.00**

Geologic map of the Patterson Pass quadrangle, Box Elder County, Utah and Elko County, Nevada, by D.M. Miller, A.P. Lush, and J.D. Schneyer, 20 p., 2 pl., 1:24,000, 1993, Map 144..**$5.00**

Geologic map of the Crater Island NW quadrangle, Box Elder County, Utah, by D.M. Miller, 13 p., 2 pl., 1:24,000, 1993, Map 145 .... **$5.00**

Geologic map of the Blue Mountain quadrangle, Beaver County, Utah, by C.L. Weaver and L.F Hintze, 17 p., 2 pl., 1:24,000, 1993, Map 146 .... **$6.00**

Geologic map of the Smelter Knolls West quadrangle, Millard County, Utah, by L.F. Hintze and C.G. Oviatt, 21 p., 2 pl., 1:24,000, 1993, Map 148 .... **$6.00**

The radon-hazard-potential map of Utah, by B.D. Black, 12 p., 1 pl., 1:1,000,000, 1993, Map 149 .... **$3.50**

Special Study

Soil and rock causing engineering problems in Utah, by W.E. Mulvey, 23 p., 2 pl., 1:500,000, 1992, Special Study 80 .... **$9.00**

Public Information Series

Geologic resources of San Juan County, Utah, by S.N. Eldredge, 30 p., 1992, PI-14 .... **$2.50**

Geologic postcard of Snow Canyon State Park, Washington County, Utah, by Miriam Bugden, 1992, PI-15 .... **$0.25**

Antelope Island State Park, Davis County, Utah, 1 pl., 1″=3200′ PI-16, Sept 1993 .... **$1.00**

Utah stone, by B.T. Tripp, color flyer, 1993, PI-17 ..**$0.25**

Radon-hazard potential in the Sandy-Draper area, Salt Lake County, Utah, by B.J. Solomon, 1 p., Sept 1993, PI-18 .... **Free**

Utah's geologic history, by C. M. Wilkerson, 4 p., 1993, PI-19 .... **Free**

Miscellaneous Publication

Stratigraphic and lithologic analysis of the Claron Formation in southwestern Utah, by W.J Taylor, 52 p., April 1993, MP-93-1 .... **$6.00**

The Markagunt megabreccia: large Miocene gravity slides mantling the northern Markagunt Plateau, southwestern Utah, by J.J. Anderson, 37 p., April 1993, MP-93-2 .... **$5.00**

The geology and production history of the uranium deposits in the White Canyon mining district, San Juan County, Utah, by W.L. Chenoweth, 26 p., 1pl., approx. 1:125,000, April 1993, MP-93-3 .... **$6.00**

Damage potential index mapping for Salt Lake Valley, Utah, by S.M. Adan and K.M. Rollins, 64 p., April 1993, MP-93-4 .... **$6.00**

Characterization of argillic alteration and K/Ar dating of illite at the Mercur gold mine, Utah: further evidence for a Mesozoic age of gold mineralization, by P.N. Wilson and W.T. Parry, 26 p., April 1993, MP-93-5 .... **$5.00**

Tectonic evolution of the Uinta Mountains: palinspastic restoration of a structural cross section along long itude 109°15′, Utah, by D.S. Stone, 19 p., 3 pl., 1:19,55 and 1:97,500, 1993, MP-93-8 .... **$6.00**

Report of Investigation

Debris-flood and debris-flow hazard from Lone Pine Canyon near Centerville, Davis County, Utah, by W.E. Mulvey, 40 p., March 1993, Report of Investigation 223 .... **$3.50**

Open-File Report

A series of open-file reports is available depicting the landslides on each 30' x 60' quadrangle (46 for full coverage of Utah) at a scale of 1:100,000. Price for each sheet is **$3.50**

Interim geologic map of the Picture Rock Hills, Juab County, Utah, by M.A. Shubat, 78 p., 2 pl., 1:24,000, February 1993, OFR-270 .... **$8.00**

Utah Geologic Mapping Program, in partnership with the National Geologic Mapping Program-long-range plans and objectives, by UGS staff, 52 p., March 1993, OFR-284 .... **$4.50**

Interim geologic map of the Big Bend quadrangle, Grand County, Utah by H.H Doelling and M.L. Ross, 116 p., 2 pl., 1:24,000, July 1993, OFR-285 .... **$14.00**

Interim geologic map of the Agate quadrangle, Grand County, Utah, by G.C. Willis, H.H. Doelling, and M.L. Ross, 130 p., 2 pl., 1:24,000, July 1993, OFR-286 .... **$14.00**

Interim geologic map of the Moab 30′ x 60′ quad rangle, Grand County, Utah, by H.H. Doelling, 16 p., 1 pl., 1:100,000, July 1993, OFR-287 .... **$3.50**

Guide to authors of geologic maps and text booklets of the Utah Geological Survey, 105 p., July 1993, OFR-288 .... **$8.50**

Stratigraphic and time-stratigraphic cross sections of Phanerozoic rocks, western Uinta Mountains through the San Pitch Mountains-Wasatch Plateau to western San Rafael Swell, Utah by D.A. Sprinkel, 64 p., 2 pl., 1:500,000, Oct. 1991 (revised to June 1993), OFR-214 .... **$9.00**

Quaternary geologic maps of Tooele Valley and the West Desert Hazardous Industry Area, Tooele County, Utah, by B.J. Solomon, 48 p., 20 pl., 1:24,000, August 1993, OFR-296 ....
$3.85 for text, $1.50 each plate; $30.00 for pkg.

Interim geologic map of the Hildale quadrangle, Washington and Kane Counties, Utah and Mohave County, Arizona, by E.G. Sable, 39 p., 2 pl., 1:24,000, August 1993, OFR-298 .... **$6.00**

Interim geologic map of the Standardville quadrangle, Carbon County, Utah, by R.E. Carroll, 1 pl., 1:24,000, Sept 1993, OFR-299 .... **$2.00**

Preliminary policies and development plan for the Utah Geological Survey component of the Utah Strong-Motion Instrumentation Program, by S.S. Olig and G.E. Christenson, 15 p. + 26 p. appendix, Sept. 1993, OFR- 302 .... **$3.50**

Interim geologic map of the Fairview quadrangle, Sanpete County, Utah, by N.R. Jensen, 2 pl., 1:24,000, Sept. 1993, OFR-300 .... **$4.00**

Interim geologic map of the Steele Butte quadrangle, Garfield County, Utah, by W.W. Whitlock, 1 pl., 1:24,000, Sept. 1993, OFR-301 .... **$2.00**

Contract Report

Sedimentology of the Precambrian Big Cottonwood Formation, Big Cottonwood Canyon, central Utah, by M.A. Chan, 41 p., February 1993, CR-93-1 .... **$3.30**

Interim geologic map of the Wellsville quadrangle, Cache County, Utah, by K.S. Barker and S.W. Barker, 17 p., 2 pl., 1:24,000, April 1993, CR-93-2 .... **$4.50**

Characteristics of debris flows in central Utah,1983, by E.W. Lips, 66 p., April 1993, CR-93-3 .... **$5.50**

Radiocarbon and thermoluminescence dating of Wasatch faulting events, Garner Canyon, Utah, by T.W. Stafford, Jr., 15 p., May 1993, CR-93-4 .... **$2.00**

Petrologic and geochronologic studies in the Farmington Canyon Complex, Wasatch Mountains and Antelope Island, Utah by D. Barnett, J.R. Bowman, and H.A. Smith, 34 p., 1 pl., 1:50,000 July 1993, CR-93-5 .... **$4.50**

A hydrocarbon exploration model for the Beta Member of the Permian Kaibab Formation, with emphasis on the potential for hydrodynamically displaced oil, in east-central Utah, by C.N. Tripp, 16 p. + 104 p. appendix, 12 pl., 1:500,000, August 1993 CR-93-6 .... **$25.00**

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Meetings and calls for papers

February 14 • Association of Exploration Geochemists, Annual General Meeting, in conjunction with the SME Convention, 1:00 - 2:00 pm, Dona Ana Room, Albuquerque, NM (A. Clendenan, Business Manager, AEG, P.O. Box48270, Bentall Centre, Vancouver, BC V7X 1A1, Canada, (604) 685-4767.

February 14-17 • Integrating Mining and The Environment, SME Annual Meeting and Exhibit, Albuquerque, New Mexico. Contact: Meetings Dept., SME, P.O. Box 625002, Littleton, CO. 80162, (303) 973-9550, Fax (303) 979-3461.

February 22-25, 1994 • U. S. Geological Survey, 9th V. E. McKelvey Forum on Mineral Resources, Tucson Convention Center, Tucson, Arizona. The forum will feature: Geology and mineral deposit studies of the southwestern U.S. and Latin America; Mineral resource assessments and land use planning; Minerals resource-related environmental studies; Field trips in southeastern Arizona. Contact: Warren C. Day, U.S. Geological Survey, Box 25046, MS 905, Denver Federal Center, Denver CO 80025, (303) 236-5568, Fax (303) 236-5603.

March 27-31 • Seventh Annual Symposium on the application of Geophysics to Engineering and Environmental Problems (SAGEEP), Boston, Massachusetts. Contact: EEGS, Mark Cramer, P.O. Box 4475, Englewood, CO 80112, (303) 771-6101.

April 1 • Abstract deadline for submission of abstracts concerning all aspects of ore deposits of the Cordillera and related geological topics, for the April 1995 symposium entitled *Geology and Ore Deposits of the American Cordillera* to be held in Reno, Nevada. Contact: Geological Society of Nevada, P.O. Box 12021, Reno, NV 89510, (702) 323-4569, Fax (702) 784-1766.

May 4-6 • Geological Society of America Rocky Mountain Section Meeting, Durango, CO. Abstract due January 14. Submit complete abstracts to Jack A. Ellingson, Dept. of Geology, Fort Lewis College, Durango, CO 81301. Contact: Jack A. Ellingson, Technical Program Chairman, Geology Dept., Fort Lewis College, Durango, CO 81301, (303) 247-2744.

May 13-18 • GAC-MAC Annual Meeting, and MDD-GAC short course on alteration processes, Waterloo. Contact: G. Roberts, Waterloo '94, Dept. Of Earth Science, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada, (519)885-1211, Fax (519) 746-7484. Short course info contact: D. R. Lentz, GSC, P.O. Box 50, Bathurst, New Brunswick E2A 3Z1, Canada, (506) 546-2070, Fax (506) 546-3994.

June 15-20 • GSA Penrose Conference - Fractured Unlithified Aquitards: Origins and Transport Processes, Racine, Wisconsin. Contact: John A Cherry, Waterloo Center for Groundwater Research, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada, (519) 888-4516, ext. 2892.

July 10-14 • Earthquake Engineering Fifth U.S. National Conference, Chicago, Illinois. Contact: Claudia Cook, Newmark Civil Engineering Laboratory, University of Illinois, 205 N. Mathews, Urbana, IL 61801-2397, (217) 333-0498.

October 2-7 • Association of Engineering Geologists Annual Meeting, Williamsburg, Virginia. Contact: AEG, Suite 2D, 323 Boston Post Road, Sudbury, Massachusetts 01776, (508) 443-4639.

October 24-27 • Geological Society of America Annual Meeting, Seattle, Washington. Contact: Vanessa George, 3300 Penrose Place, Boulder, CO 80301, (303) 447-1133.

NEW

Beginning January 18, UGS will be the outlet for U.S. Geological Survey topographic maps (hiking maps with the most detail) as the USGS moves into smaller quarters.

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