

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

SURVEY NOTES

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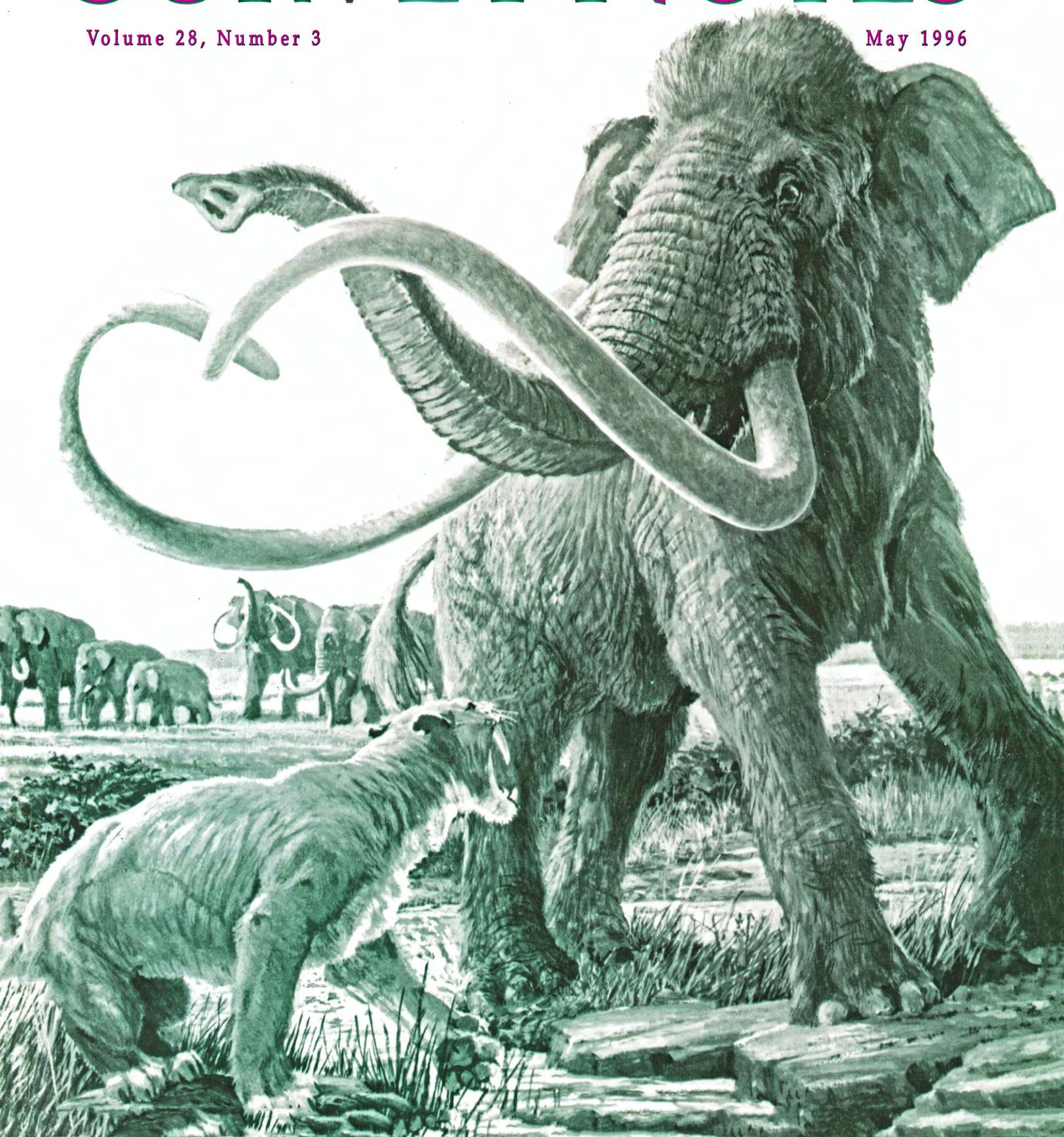


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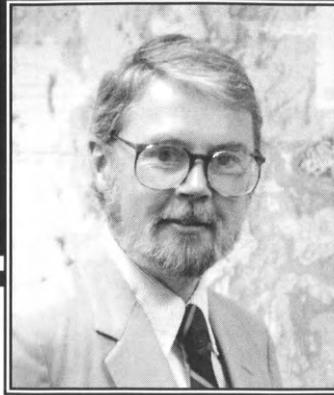
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The Director's Perspective

by M. Lee Allison

UGS' Sample Library

Two big changes are coming for the UGS Sample Library, the state's repository for cores and cuttings from thousands of Utah wells. First, a new, dedicated core warehouse will be constructed at the Utah Dept. of Natural Resources (DNR) office campus in northwest Salt Lake City where the UGS is relocating in May, 1996. Second, legislative approval for creation of a trust fund allows us to now accept donations for the long-term improvement and maintenance of the Sample Library.

The new core warehouse will be designed and built in fiscal year 1997. In addition to the core presently stored in the Sample Library, it will also contain laboratory and sample preparation space currently housed in the UGS offices and at the Division of State History. An interest-free loan from the DNR Warehouse Internal Service Fund for construction of the core warehouse will be repaid with the money currently spent on

rent for the present Sample Library building. The new building will be completely paid off in about 18 years.

By its proximity to the UGS the new warehouse will increase staff efficiency and usage of the samples. We are designing it to allow for expansion to handle additional samples received in the future. Improved core layout space will make research and training classes easier and more effective.

With the funds secure for construction of the new Sample Library core warehouse, the UGS will now be soliciting contributions to the Sample Library Trust Fund. The Fund was authorized by the State Legislature in the 1996 session and will be managed by the State Treasurer. It is the intent of the UGS to use interest earned on the Fund's principal to increase and improve services of the Sample Library. Under unusual circumstances the UGS Board may authorize dipping into the Fund's principal. Other state geological surveys have been very successful at raising funds to help underwrite their sample library operations. Utah can now try to emulate them.

Cover: Artist's interpretation of the Huntington mammoth (*Mammuthus columbi*), prepared for National Geographic Magazine. The artwork was produced prior to the recovery of the jaw and teeth of the extinct giant predator, *Arctodus simus*, the short-faced bear from the Huntington Canyon site. The saber tooth cat shown in this illustration is artist's license. Such cats were contemporaneous with the mammoth and bear in Utah, but none were found at the Huntington site. By permission of National Geographic Society.

Survey Notes is published three times yearly by Utah Geological Survey, 1594 W. North Temple, Suite 3410, Salt Lake City, Utah 84114-6100: (801) 537-3321. 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. Reproduction is encouraged with recognition of source.

Investigating Environmental Change in the Deserts of Western Utah

by David B. Madsen

The Utah Geological Survey (UGS) is currently involved in a multi-year project investigating long-term environmental change in the Bonneville Basin of western Utah and eastern Nevada. With funding from the Department of Defense Legacy program and additional support from the Bureau of Land Management and the environmental management directorate at Hill Air Force Base, the Paleontological and Paleoecology Program at UGS is using small animal paleontology and preserved

plant macrofossils to define the continuing evolution of plant and animal communities in Utah's western deserts.

One of the primary responsibilities of land-holding

agencies such as the Bureau of Land Management, Trust Lands Administration, and the U.S. Forest Service is to manage resources under their control in such a way that they can be both used to serve present needs and preserved for future generations. Numerous ecological studies suggest, however, that individual physical and biotic resources are interrelated and that they must be managed together to insure the continued health of these communities. Such a holistic approach to land management has

*There is no one
"correct" ecosystem
in any one place . . .*



Limber pine needles in a fossil woodrat midden collected along the margin of the Great Salt Lake Desert.

come to be known as "ecosystem management" and it is now an integral part of the management strategy of virtually every major land-holding agency. The Department of Defense (DOD) controls much of the land within the Bonneville Basin. As one of the largest land-holding agencies in the Federal Government, DOD has adopted ecosystem management strategies to insure both long-term environmental stability and the continued availability of realistic training conditions on lands under its jurisdiction.

Initially, ecosystem management strategies were geared



Jay Quade (University of Arizona) and Donald Grayson (University of Washington) collect woodrat fecal pellets from the Homestead Cave deposits for radiocarbon dating.

toward identifying the constituent parts of an ecosystem and, once identified, managing them in a static fashion to preserve them for the future. Terms such as "sustainable yield" were widely used as labels for the kind of approach which sees an

ecosystem as a fixed, unchanging set of plants, animals, and physical conditions. Much of this management strategy was due to early short-term studies which focused

primarily on mapping the distribution of plants and animals through space. With the advent of longer term studies, however, it has become increasingly clear that ecosystems are not static communities, but consist of a changing mosaic of plants and animals that continually respond to modifications in such factors as climate, fire frequency, and surrounding biota. Many plant species, such as single-leaf pinyon, are relatively recent additions to current communities, and as they migrated into their present positions they modified the relationships between existing plants and animals. In short, what land-holding agencies are managing is change, not the status quo, and many land managers now realize that to properly manage resources they must understand the nature and rate of that change and clarify long-term environmental trends. To this end, environmental management personnel at Hill Air Force Base and Dugway Proving Grounds, with the help of the Paleontology and Paleocology Program, have embarked on a multi-year project to collect detailed environmental records from unique cave resources on their lands.

The dry, stratified caves of the western Utah deserts provide extraordinary source data for an interdisciplinary project focusing on changes in small animal populations

and corresponding vegetational changes during the late Quaternary (50,000 years). Initial work in the general area suggests that many limestone caves created by Pleistocene Lake Bonneville were occupied by raptors and other carnivores immediately after the lake receded ~14 thousand years ago. People began to occupy many of these same caves by 10 ka, but the intermittent cultural use was not usually sufficient to dislodge the raptors. It did, however, produce a highly stratified depositional record which allows change through time to be readily identified. These dry caves share two additional features which make them particularly useful as paleontological laboratories. First, since they are dry, they are also home to woodrats, whose fossilized packrat nests (often called middens) provide clues to surrounding vegetation spanning the past 50,000 years or longer. Combined with floral remains brought to the caves by later human occupants, the plant record produced by these fossil nests provide the necessary background against which the small mammal record can be examined. Second, many of these western Utah mountain ranges are completely isolated within the vast expanse of the flat salt desert. As a result, faunal records from these

ranges provide a test of biogeographical theories of change in isolated animal populations. Examination of such theories is important in understanding rates of extinction and in developing

ways of dealing with endangered species.

Small mammal fauna and plant macrofossil records provide valuable proxy data for paleoclimatic change because they can be identified to the species level (thereby allow-

[Environmental managers] are faced with the difficult task of separating natural trends from those induced by modern development.

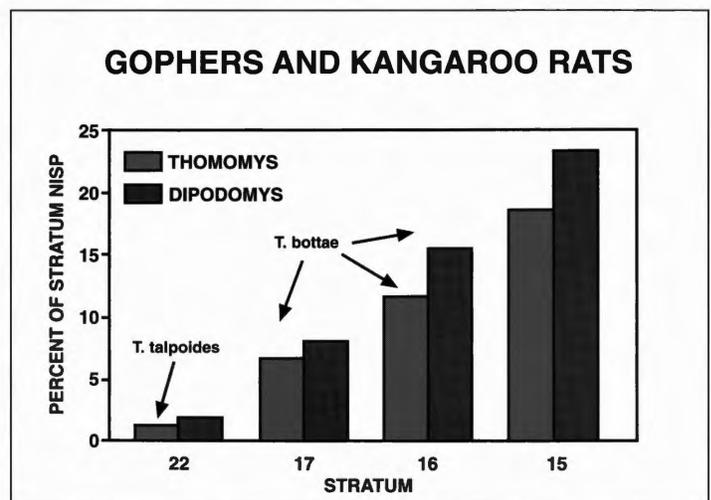
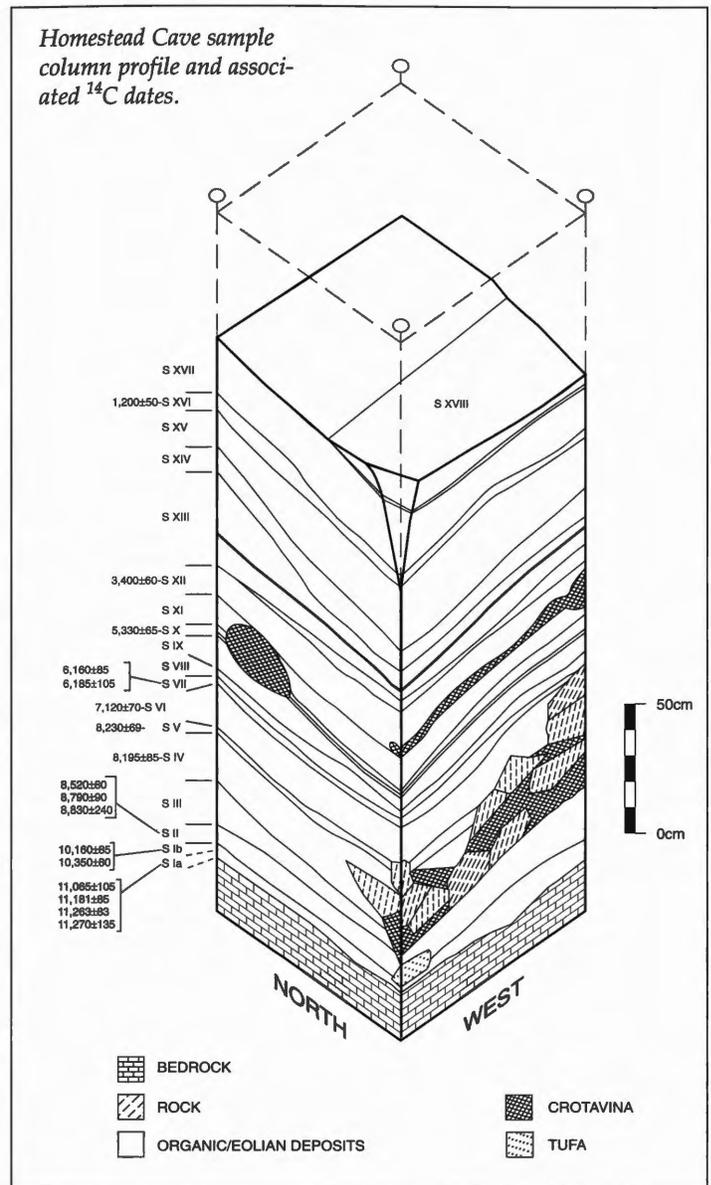


Fish bones from the lower deposits of Homestead Cave represent the largest sample of Lake Bonneville fish yet recovered.

ing the identification of specific temperature and precipitation requirements) and because they can be recovered in samples large enough to offset factors of chance in the discovery process. Other paleoenvironmental records, such as pollen sequences, lake-level fluctuations, and megafaunal remains are available for the area, but are too generalized to allow the reconstruction of historical native habitats and the changes those habitats have undergone. Moreover, with the exception of isostatic rebound associated with the shrinking of Lake Bonneville, tectonic and geomorphic change has been limited and any changes in floral and faunal records can be attributed directly to climatic events.

Small animal paleontology has focused on the recovery of a 1 x 1-meter sample column from Homestead Cave on the north end of the Lakeside Mountains, directly west of the Great Salt Lake. The 3-meter-deep column was excavated by separately removing 18 depositional units, then screening and sorting the recovered materials. Although only the lower third of the column had been analyzed by the end of 1995, the column appears to contain more than 2.5 million small animal bones; virtually all of them derived from owls and other raptors hunting within 3-5 kilometers of the cave. More than 40 taxa of birds, including an array of waterfowl, and 20 of small mammals have been identified from the lowest deposits. These also contain an assemblage of eight species of fresh-water fish, including the Bonneville Cutthroat and Bear Lake Cisco. Many of the small mammal species are currently restricted to much higher elevations in the mountains of western Utah. These early deposits are securely dated to 11,200 radiocarbon years ago and represent a period when Lake Bonneville was rapidly drying and eventually became too saline to support fish populations. By 10 ka, the lake was near its present size and climatic conditions were similar to those of today, although slightly cooler. Local plant and animal communities, however, were somewhat different. Many of the desert species, such as rabbitbrush and the kangaroo rat, became prominent around the cave, but other species which are not currently found in low-elevation habitats, such as hackberry, continued as part of the mixed plant community.

Plant macrofossils have been recovered from an array of more than 100 woodrat middens collected from locations around the margin of the northern Bonneville Basin. Nearly 50 of these middens have been dated and have radiocarbon ages ranging from a few hundred years to more than 50,000 years ago. Only a portion of the planned analysis is completed and initial work has focused on the transition from the Pleistocene to Holocene, about 15-8 ka. Prior to 13 ka, much of the western Bonneville Basin was covered by cold montane steppe, dominated by sagebrush. Temperatures were ~12°C lower than at present. Between 13 and 10.8 ka, limber pine forests were widespread at low elevations with summer temperatures ~6°C cooler than



Change in the numbers of several small mammal species in the lower deposits of Homestead Cave.



David Madsen (Utah Geological Survey) and David Rhode (Desert Research Institute - Reno) collect woodrat middens from the western Bonneville Basin south of Wendover, Utah.

now. Several middens dating to this period also contain the bones of fresh-water fish probably derived from Lake Bonneville. These low-elevation limber pine woodlands began to retreat upslope after about 11 ka and were replaced by sagebrush and shadscale. By 7 ka, single-leaf pinyon pines had migrated into portions of the region, and what we now recognize as the pinyon-juniper ecosystem started to develop. Other components, such as *Ephedra* (commonly known as Mormon tea) continued to be added at later dates and some species such as pinyon pine continued to expand their range.

Together these data suggest Bonneville Basin vegetational patterns are representative of the changing mosaic that is characteristic of most ecosystems. Some species, such as limber pines, were eliminated from the mix, while others such as pinyon pine and Mormon tea were added, and yet others maintained relatively stable populations. Animal communities show the same kind of changing mosaic, with some species being eliminated and others being introduced. Some, such as the bushy tailed woodrat, were even locally extirpated by 8 ka, remained absent for 4-5,000 years, and then returned about 3-4 ka. Our work suggests a protracted decline of Lake Bonneville at the end of the glacial interval spanning a period of 2-3,000 years, with the lake continuing to be as high as the Stansbury level until after ~12.5 ka. The Homestead Cave fishes appear to represent a massive die-off in response to a salinity crisis about 11.2 ka.

This research remains in progress and, at present, we remain unsure about what, when, and how other ecosystem changes may have occurred in the Bonneville Basin between about 7 ka and the present. What is clear, however, is that at any one time, ecosystems in the basin were uniquely different from earlier and later ecosystems. It is

After a modest education in Utah's public schools, David Madsen attended the University of Utah where he majored in anthropology and geology. These twin interests continued through graduate school at the Universities of Utah and Missouri, and led, in 1973, to a position as Utah's first State Archaeologist. During his twenty-year tenure in that position he developed a series of research programs focusing on the paleoecology and human prehistory of the Great Basin and, eventually, on comparative work in similar interior basins of central China. Dr. Madsen now serves as the manager of the Utah Geological Survey's Paleontology and Paleocology Program where he is trying to define patterns of environmental change in Utah's Bonneville Basin. He and his wife, Evelyn Seelinger, like to spend their rare off-hours raising blue-ribbon vegetables.



evident that individual plant and animal species in western Utah have reacted independently to changes in their surrounding physical and biological environment, and that the concept of these species acting as fixed "sets" is a product of our rather limited temporal perspective. Environmental managers of Department of Defense lands now recognize that each plant and animal community is both dynamic and unique, and that there is no one "correct" ecosystem in any one place they must protect and preserve. Rather, they are faced with the much more difficult task of separating natural trends from those induced by modern development. As this project is completed, we hope to make that task slightly easier by identifying long-term patterns of environmental change.

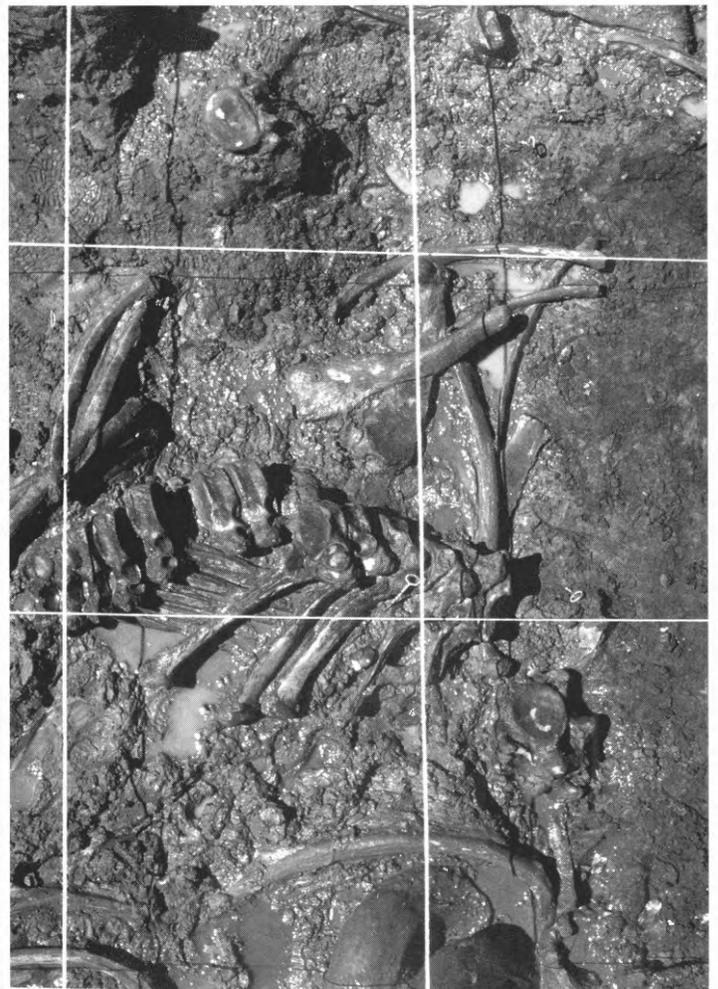
Utah's Wildlife in the Ice Age

by David D. Gillette

Utah has not always been home to humankind. Before Utah was a state, before Europeans claimed the New World as theirs, before Lake Bonneville dwindled to remnants that we call the Great Salt Lake and Utah Lake, before the first Native Americans trekked to the New Continent, the American West was home to a diverse and exotic suite of animals. Early in the Tertiary Period, not long after dinosaurs became extinct, mammals began a long and colorful evolution in North and South America. By late Tertiary time, two million years ago, our continent was occupied by camels, mastodons, horses, ground sloths, armadillos, saber tooth cats, giant wolves, giant beavers, giant bears, and many other exotic animals. The landscape from a distance looked more like today's Africa than modern North America.

By the late Tertiary, glacial conditions in high latitudes intensified. Enormous quantities of water were bound up by the glaciers, and sea levels fluctuated with each short-lived glacial episode. About 1,600,000 years ago, the first mammoths emigrated to North America from Asia during one of the low stands of sea level. That event marks the arbitrarily defined beginning of the Pleistocene Epoch of the Quaternary Period. The Ice Age was in full swing. Mammoths spread throughout North America, adjusting to the native fauna, which included mastodons, their distant cousins. Like most of the other Ice Age animals, mammoths became isolated from their Eurasian ancestors in the Pleistocene. Mammoths evolved for more than 1.5 million years in North America, adjusting to the fluctuating conditions of the Ice Age. With each cycle of glaciation and deglaciation, habitats were disrupted first, then stabilized, and then disrupted again with renewed glaciation.

Each time the glaciers formed, they coalesced into enormous sheets of ice over central and eastern Canada, eventually pushing southward. These ice sheets, or continental glaciers, were as thick as two miles. They often moved so rapidly that they crushed standing forests. At one site in Wisconsin, a low-elevation forest was crushed by the mountain of ice that overran the landscape; in a matter of



Part of the Huntington Canyon mammoth skeleton as it was exposed during excavation, with 1-meter grid. The vertebral column is clearly shown in the middle of the photo. Ribs and the upside down lower jaws are visible on the left. The bones were in a saturated clay horizon that protected them from decay.

only a few years (or perhaps, months) the elevation changed from only a few hundred feet above sea level (the elevation of the forest) to perhaps 10,000 feet at the top of the glacier, as high as the Wasatch Plateau today. Effects in the West were similar, but more localized. Glaciers waxed and waned in the mountain valleys, and fresh-water lakes filled the adjoining basins. In Utah, Big and Little Cottonwood Canyons, and many others, were gouged by glaciers hundreds of feet thick. Glacial Lake Bonneville received the waters from spring and summer melt from the glaciers. Lake Bonneville grew, submerging vast tracts of low-elevation habitat. The vast intermountain basin we know today as the Great Basin was filled with fresh water. Terrestrial vertebrates were restricted to the shorelines of that glacial lake. Habitats suitable for mammoths, mastodons, camels, horses, and muskoxen were restricted to the margins of lakes and the periphery of mountain glaciers. Large ungulates that for generations had migrated with the seasons had to move along shorelines rather than across valleys.

Climatic effects during the Ice Age became drastic by the end of the Pleistocene. Populations of animals and plants that lived in Canada were pushed southward thousands of miles. Intermountain valleys in the West became home to forests, rather than the deserts we have today. Between glacial episodes, forests retreated to higher elevations and desert vegetation returned, only to be replaced with the next glacial episode. Especially during the latter part of the Ice Age, animals and plants that lived in northern Utah left a wonderful legacy of their history. With each fluctuation of the climate, some old species returned, and some new ones appeared. Some of those animals have been preserved as fossils in sediments deposited during their existence. This paleontological record allows us to chart a faunal history for northern Utah during the Ice Age that reflects climatic fluctuations brought about by the waxing and waning of glaciers, the rise and fall of glacial lakes such as Lake Bonneville, and modifications of vegetation zones. This fossil record, especially of the past 30,000 years of the Ice Age in Utah, expands every year with new and important discoveries.

Gradually through the Ice Age, the fauna became familiar. There was a net loss of diversity: extinction took a heavy toll, ultimately removing mastodons, mammoths, camels, horses, ground sloths, giant bears, giant wolves, giant beavers, muskoxen, giant bison, and many other species. The history of emigrations, population expansions and ad-



The author photographing the mammoth excavation at Huntington Canyon.

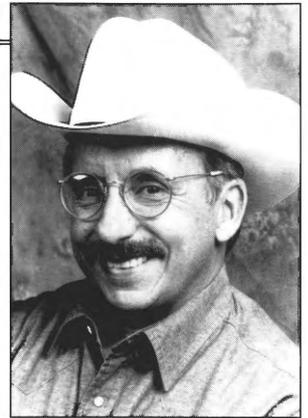
justments, and ultimate extinction or survival of these Pleistocene animals are only broadly understood. We debate ultimate causes, seeking to understand broad patterns of evolutionary history of the Ice Age biota. We seek to more clearly understand the origins of the modern biota from this Pleistocene heritage, and the patterns of survival that this rich paleontological history can provide. Theories that seek to explain the Pleistocene extinction fall into two categories. According to "Pleistocene Overkill Theory," the large animals in the Americas were killed off in a veritable blitzkrieg by early humans who entered North America from Asia. The "Climate Theory" holds that rapidly fluctuating climatic changes proved too demanding to populations of large ungulates, which became extinct for their failure to adjust; predators such as the short-face bear and saber tooth cats lost their natural prey and met extinction as well. These theories provide

working hypotheses that can be tested by modern application of stratigraphy and biochronology from radiometric dates. Each new fossil site holds potential clues that add to the knowledge of these original Utah wildlife species.

New discoveries of fossil vertebrates in northern Utah include several of the extinct megafauna. A nearly complete skeleton of the Columbian mammoth, *Mammuthus columbi*, was discovered by construction crews in Huntington Canyon, between Fairview and Huntington, in 1988. Our office (State Paleontologist, then in the Division of State History) conducted the excavation and study of that skeleton, associated plant fossils, an associated cheekbone with teeth of the giant short-faced bear *Arctodus simus*, and sev-



Lower jaw of a large ungulate, probably a muskox, as it was discovered at Bear Lake during a low stand of lake level.



David D. Gillette, Ph.D., has been the State Paleontologist of Utah since 1988. His research interests focus on Ice Age animals and dinosaurs. His first major contribution to the study of Ice Age fossils was a comprehensive review of the bones, classification, and way of life of giant relatives of armadillos called "glyptodonts" that were about the same shape and size as a Volkswagen "beetle." A highlight of his career was the excavation of the complete skeleton of the Columbian mammoth from Huntington Canyon between Fairview and Huntington, Utah.

Before coming to Utah, Dave was Curator of Paleontology at the New Mexico Museum of Natural History, and before taught at Southern Methodist University (Department of Geology), College of Idaho (Biology Department), Sul Ross State University in Texas (Geology); and Bryn Mawr College in Pennsylvania (Geology). Dave is the statewide advisor for the Utah Friends of Paleontology, and a member of several professional societies including the Utah Geological Association. His wife, Janet, also a paleontologist, is currently the collections manager of the paleontology collections at the Utah Museum of Natural History. His daughter, Jennifer, is about to enter graduate school in biology at Southwest Louisiana State University. For fun Dave enjoys hiking, reading, and playing with Togo, his blind Huskie.

eral human artifacts.

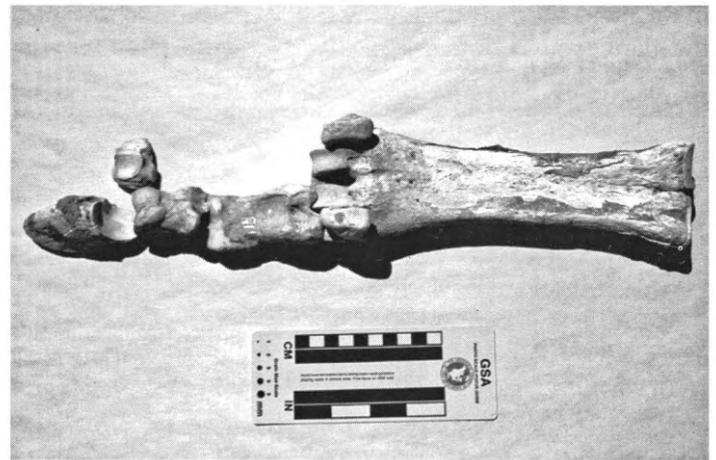
The mammoth died at a record-high elevation (9,000 feet) for the species, which is generally regarded as a plains animal. The age of this old bull was roughly 65 years, based on comparisons of dental wear in modern elephants. The Huntington mammoth was also one of the last mammoths to live in North America; the best radiocarbon date of roughly 11,220 ¹⁴C years before present represents the very end of mammoth existence in the Americas. The bones were so perfectly preserved by the bog conditions that they retained proteins; these original organic compounds will be analyzed for genetic information, diet, and disease by colleagues at other institutions.

The mammoth discovery was all the more spectacular for the preservation of a set of boluses, or round mats of partially digested vegetation from its intestinal tract, giving direct evidence of the old bull's last meal: more than half was fir needles, a decidedly poor diet for an elephant. The cause of death remains undetermined. Casts of the mammoth skeleton are on display at the University of Utah Museum of Natural History and the College of Eastern Utah's Prehistoric Museum in Price, and in several other museums around the world.

The Huntington Canyon short-faced bear found at the site is around 400 years younger than the mammoth. Dated at roughly 10,800 ¹⁴C years before present, this individual was one of the last of the Pleistocene megafauna in North America, perhaps even the last generation. If this difference in age between the mammoth skeleton and the cheekbone and teeth of the bear is correct, it is possible that the bear had fed on the frozen carcass of the mammoth, like wolves do today in the Arctic on mammoths that are at least 10,000 years old. A groove in one of the mammoth's foot bones perfectly matches the huge canine

tooth of this giant bear, half again as large as modern grizzlies. Whether the groove was made by the same individual bear remains a mystery, but it is possible that the bear fed on the carcass and died at the same place.

Two other mammoth sites were discovered in 1995. One was at Bear Lake, where the complete lower jaw of a baby



Partial leg of the muskox skeleton excavated from the site of the new Huntsman Chemical Building on the campus of the University of Utah.

mammoth was found in association with bones of a large ungulate, probably a muskoxen. The baby was only about a year old, its small teeth and jaws in marked contrast to the huge grinders of the Huntington specimen. From a site near Logan, construction workers discovered the complete tusk of an adult mammoth, about 7 feet long and nearly a foot in diameter where it fit into the tooth socket. This tusk has an unusually tight curve of almost 180°. This tusk is on display in the Geology Department at Utah State University.



Little Dell dam under construction. The Pleistocene fossils found at the construction site were in the middle of the valley, just upstream from the dam.

Muskoxen, today restricted to the high latitudes of Canada, Alaska, and Siberia, were once abundant in Utah. Two new sites have produced partial skulls of these exotic ungulates. One is from a gravel pit near the Kennecott Copper Mine west of Salt Lake City, the other from the construction site of the new Huntsman Building on campus at the University of Utah. Both were from shoreline deposits of Lake Bonneville, roughly 18,000 years old. These and other records of muskoxen in Utah seem to indicate the presence of frigid conditions in northern Utah in the not-so-distant past. However, a partial skeleton of the giant ground sloth, *Megalonyx jeffersoni*, named for our

third President who was the first scientist to describe ground sloth bones in North America, was discovered near Provo in 1992 in a Lake Bonneville shoreline deposit. This ugly, plant-eating giant, weighing probably two tons and standing 10 feet tall at the shoulder, came from ancestors that were tropical. Halfway between the Arctic and the tropics, Utah's megafauna in the Pleistocene is perplexing and exotic indeed.

Other recent discoveries of Ice Age animals in northern Utah include camels and horses from a site near the Kennecott Copper Mine, on the east flank of the Oquirrh Mountains; and horses, mastodon, and other smaller animals at the Little Dell Reservoir in East Canyon a few miles east of Salt Lake City. The Kennecott site might be early Pleistocene in age, rather than late Pleistocene like all other Ice Age sites in northern Utah. Both sites have small rodents whose fossil jaws and teeth are a permanent record of their past existence. Because rodents evolved rapidly during the Pleistocene, their fossil remains can be used to establish approximate stratigraphic position; they are among the best index fossils we have for deciphering Pleistocene stratigraphic positions.

Confirmed records of Utah's Ice Age residents now number several dozen vertebrates, and the list is slowly growing. With each new discovery, we have the prospect of adding more details to the picture, and eventually of expanding our rudimentary understanding of the animals and people who came before us. The past is our prologue.

Survey News

The Utah Geological Survey is part of a consortium headed by TerraTek that was just awarded a contract from DOE for our proposal "Advanced Fracture Modeling in the Uinta Basin for Optimized Primary and Secondary Recovery". Craig Morgan is UGS project manager. University of Utah, University of California Berkeley, and a consulting company are other partners.

As a footnote to Dave Madsen's article, the UGS has a new contract in place with Hill Air Force Base to conduct a paleoecology study with Dr. Dave as the principle investigator. The three-year contract will extend

their work on paleoenvironments and ancient lifestyles from Camels Back Cave on the Dugway Proving Grounds. Study of the cave indicates evidence of human occupation for at least 8,000 years.

Bill Lund, Deputy Director until May when he opens the UGS Cedar City office, has another easy out. He has been asked to do a trenching study in the Gobi Desert (southern Mongolia - not southern Utah) to ascertain faulting ages. The project is under the auspices of the U.S. Geological Survey and the Mongolian Academy of Science.

The new issue of Petroleum News is ready. The newsletter is a summary of events and milestones in the various petroleum-related projects of the UGS, as well as pertinent information on Utah's oil industry. It can be found at the UGS home page <http://utstdpwww.state.ut.us/~ugs/> under Petroleum News.

The 1997 SME Annual Meeting and Exhibit will be held February 24-27 in Denver, Colorado. The program will focus on the global practice, science, and technology of finding, obtaining, and processing minerals for the community of man. Contact: SME, PO Box 625002, Littleton, CO 80162-5002.



The Rockhounder

Gypsum sand near Knolls, Tooele County

by Christine M. Wilkerson

Geologic information: Gypsum sand dunes are widespread on the eastern margin of the Great Salt Lake Desert. Gypsum dune sand can be collected near Knolls in Tooele County. Sand-size gypsum (calcium sulfate with water) crystals form in the top layer of the moist, salty clay that forms the desert floor. As the clay dries, the gypsum crystals are blown by the wind into dunes. These dunes also contain many oolites: small, rounded grains of calcium carbonate layered around a tiny brine shrimp fecal pellet or mineral fragment. These oolites formed in the Great Salt Lake approximately 9,400 to 9,700 years ago when the lake was larger and its shoreline was located in the Knolls area at an elevation of about 4,230 feet.

How to get there: Travel approximately 78 miles west of Salt Lake City

on Interstate 80 until you reach the Knolls exit. Exit and turn south (left) onto the frontage road to Knolls. Travel about 1.5 to 2 miles. Sand dunes are located on both sides of the road.

Where to collect: Gypsum sand dunes are adjacent to the road and easily accessible in this area. Use a plastic bag or a bucket to collect the sand. Be careful not to disturb the vegetation that stabilizes the dunes.

Useful maps: Bonneville Salt Flats 1:100,000-scale topographic map, Knolls 7.5-minute topographic map, and a Utah highway map. Topographic maps can be obtained from the Utah Geological Survey, 1594 W. North Temple, Salt Lake City, UT 84114-6100, (801) 537-3321.

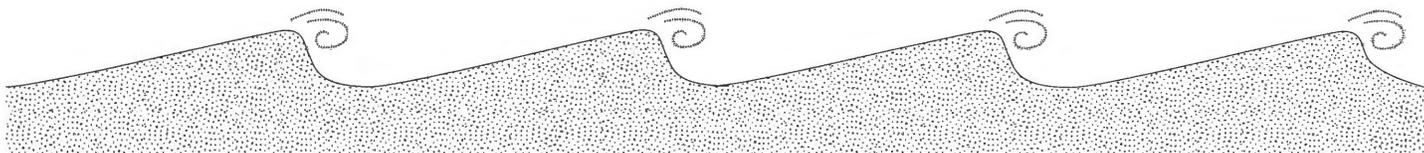
Land ownership: Bureau of Land

Management (BLM) public lands.

BLM collecting rules: The casual rockhound or collector may take small amounts of petrified wood, fossils, gemstones, and rocks from unrestricted federal lands in Utah without obtaining a special permit if collection is for personal, non-commercial purposes. Collection in large quantities or for commercial purposes requires a permit, lease, or license from the BLM.

Miscellaneous: A hat and water are recommended. Glasses will protect your eyes from wind-blown sand. Watch out for broken bottles and shotgun shells. Please carry out your trash. Have fun collecting!

For information on where to collect oolitic sand, see "The Rockhounder", Survey Notes v. 28 no. 2.



"Glad You Asked"

by Rebecca Hylland

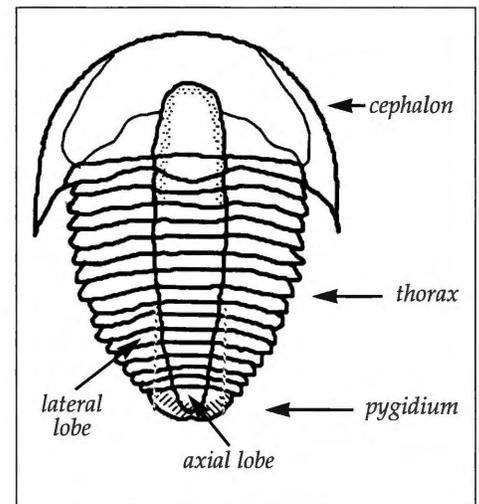
Trilobites and the Cambrian Environment of Utah

Trilobites. The very name conjures up images from "B" science-fiction movies of bug-eyed, wiggly-legged, insect-like creatures that eat New York. Two questions we commonly receive are "what are trilobites and where are they found in Utah?" Trilobites are members of the phylum Arthropoda (jointed-foot animals). Arthropods have segmented bodies and appendages covered by an exoskeleton which provides support and protection for muscles and organs. Living Arthropods include insects, spiders, scorpions, ticks, crabs, lobsters, barnacles, and centipedes. Trilobites belong to an extinct class of marine organisms called Trilobita. This name refers to the three-part (trilobes) latitudinal and longitudinal shape of a trilobite's exoskeleton. The latitudinal lobes consist of the cephalon (head), segmented thorax (body), and pygidium (tail); the longitudinal lobes consist of two lateral lobes (on each side of the body) and an axial lobe (central back area of the exoskeleton).

More than 500 different trilobite species have been found across Utah, in a broken band of Cambrian Period (570 to 500 million years old) limestones, siltstones, and shales that trends northeast-southwest across the western part of the state. During the Early Cambrian (about 570 to 540 million years ago), western Utah was covered by a shallow sea. Slow-mov-

ing rivers flowing across the sandy lowlands of eastern Utah deposited sediment into the sea. The heavier sediment (mostly sand) was deposited near the shoreline and metamorphosed through time into quartzite. The lighter sediments (mostly silt) were deposited farther out into the sea, and through time lithified into siltstone and shale. The deepest part of the sea was an ideal environment for the precipitation of calcium carbonate, which lithified to limestone.

Regional subsidence during the Middle and Late Cambrian (about 540 to 500 million years ago), caused the sea's shoreline to migrate eastward across Utah, allowing the deposition of a fairly complete sequence of Cambrian sediment in western Utah. Utah was located near the equator during the Cambrian, so the water temperature was warm. The combination of warm, shallow water and nutrient-rich silt allowed several marine genera to thrive. The most common and diverse of these were trilobites, which occupied several different marine environments. Most trilobite species were bottom dwellers that crawled over sand and mud. Some of them could curl up like modern pill bugs. Other trilobites burrowed into bottom sand and mud using their shovel-shaped cephalons. These crawling and burrowing trilobites were either scavengers, or they ingested mud and silt, digesting the organic material



Main divisions of a trilobite exoskeleton (from Wilson, 1995).

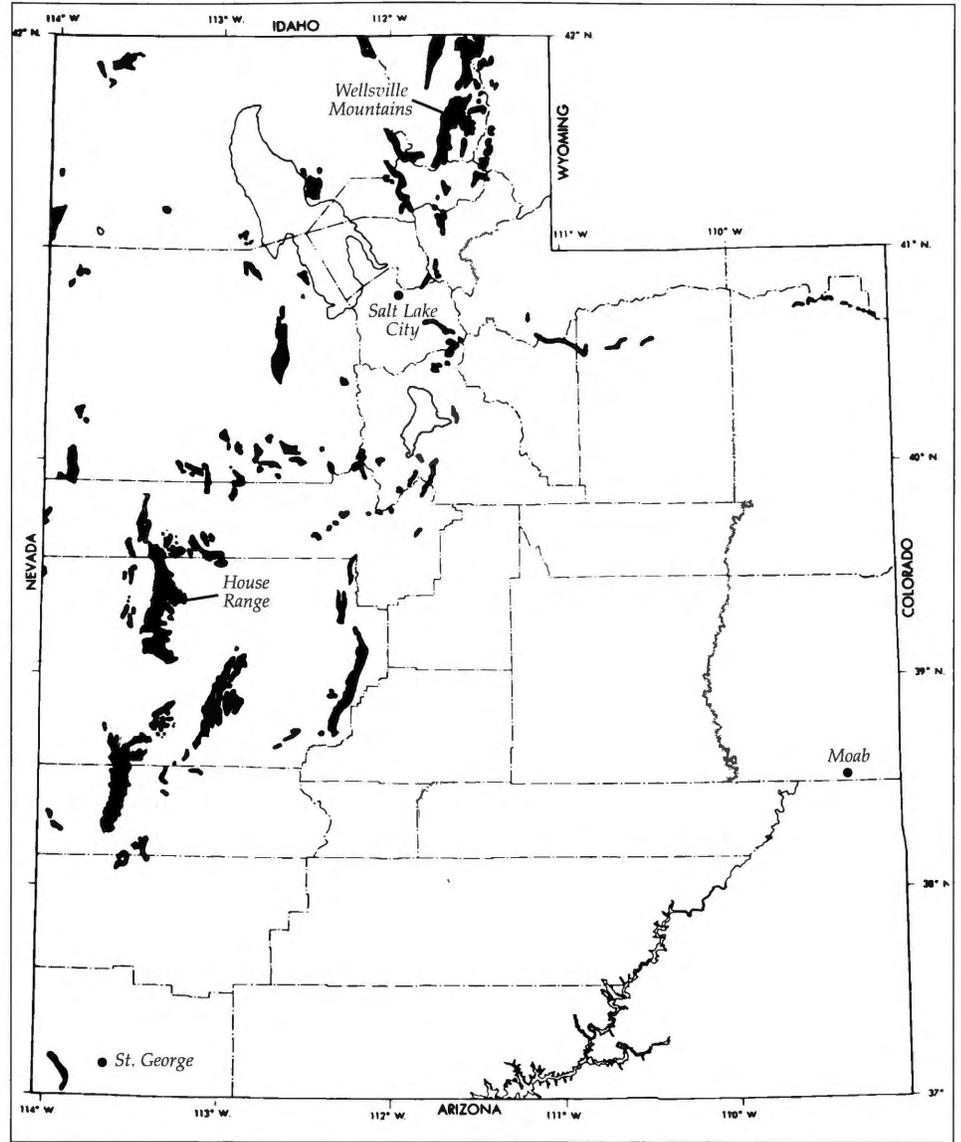
contained in it like modern-day worms (annelids). Some trilobites lived in shallow burrows where they could keep their heads near the surface of the sand or mud, and grab passing prey. Fossil evidence suggests some trilobites were capable of swimming. The bodies of swimming trilobites are narrower and the eyes are closer to the sides of the cephalon, than those of bottom-dwelling trilobites. Swimming trilobites may have been predators, or they may have been "filter-feeders" using special appendages to remove nutrients from the surrounding water. The smallest trilobites were plankton-like and lived close to the water surface.

Trilobites are probably the most com-

mon fossils collected in Utah, many world-class specimens from this state reside in museums throughout the world. In Utah, trilobites can be found at several localities. The Wheeler Amphitheater in the House Range, Millard County is one of the more well-known collecting areas. Most of the trilobites in this area come from the Middle Cambrian formation called the Wheeler Shale. The Wheeler Shale contains interbeds of shaley limestone, mudstone, and thin platy limestone. Another trilobite-bearing unit that directly overlies the Wheeler Shale in the central part of the House Range is the Marjum Formation. This formation consists of thin-bedded, fine-grained, silty limestone with interbeds of shale and mudstone. Also located in the central part of the House Range is a fossiliferous limestone called the Weeks Formation, that crops out in North Canyon near Notch Peak. The Weeks Formation overlies (is younger than) the Marjum Formation and also contains trilobites. Another trilobite-bearing unit is the Spence Shale Member of the Langston Formation in the Wellsville Mountains, Box Elder County. Here, trilobites can be found in Miner's Hollow, Dry Canyon, and the area between Antimony and Hanson Canyons. "A Collector's Guide to Rock, Mineral and Fossil Localities in Utah" by James R. Wilson provides detailed descriptions on trilobite fossil localities. This book is available from the Utah Geological Survey Bookstore.

Selected References

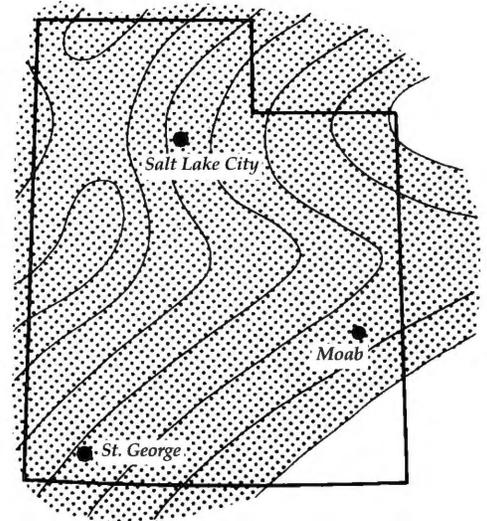
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- Gunther, L. F., Gunther, V. G., and Gunther, G., 1994, Some Middle Cambrian fossils of Utah, *in* Special issue on Utah: Utah Geological Survey Public Information Series 26, p. 59-62.
- Hintze, L. F. , 1988, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 7, p. 14-19.



General location of Cambrian rocks in Utah (modified from Stokes, 1986).

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Wilson, J. R., 1995, A collector's guide to rock, mineral and fossil localities in Utah: Utah Geological Survey Miscellaneous Publication 95-4, p. 65-104.



Generalized map of Utah during Cambrian time. The shaded area represents the sea that covered Utah. The contour lines represent the eastward shallowing of this sea (modified from Stokes, 1986).

GEOLOGIC HAZARDS: *How much risk is acceptable?*

by M. Lee Allison

The following was modified from a keynote address to the 31st Annual Engineering Geology & Geotechnical Engineering Conference, held at Utah State University, March 29-31, 1995.

Introduction

Utah is currently undergoing unprecedented economic and population growth. We are seeing pressures to develop lands that were previously avoided in part because of geologic hazards. When evaluating these lands for development, geologists and engineers have to ask ourselves a question: "How much risk is acceptable in dealing with geologic hazards?" This question has no simple answer that everyone can agree on, but geological and engineering professionals, and society in general, have to address the issue. Are we ignoring dangers to lives and property, or are we spending too much time and money trying to ensure safety?

My goal is to list the questions and identify the decisions that we as geologists and engineers have to deal with in our jobs every day. Homebuyers, business people, developers, planners, local politicians, and our other clients will be able to make more informed, and thus more prudent, decisions if they understand the risks they are accepting.

The Problem

A Utah judge allowed a lawsuit to go forward recently where owners of a home destroyed by the Springdale landslide in the 1992 St. George earthquake were suing their insurance company. The homeowners assumed that a "comprehensive" policy covered geologic hazards, but the insurance company asserts geologic hazards were not covered. This is probably not an unusual belief of many homeowners. Most homeowners' insurance does not cover geologic hazards; such coverage must be bought separately. Earthquake and flood insurance is usually available where needed but, in general, insurance is not commonly used to lower risks from geologic hazards.

Geologic hazards are becoming more expensive wherever



Home destroyed by the Springdale landslide of September 2, 1992. Parts of this landslide were recognized as actively moving as early as 1975. More than 10,000 ancient and active landslides have been identified in Utah so far.

they occur in the world. The 1994 Northridge earthquake caused \$10-15 billion damage and the Kobe, Japan, earthquake in 1995 may cost over \$100 billion. As a society we are becoming more urbanized and thus more concentrated and vulnerable to geologic hazards. As we develop areas we had previously avoided, we will see an increasing cost from geologic hazards.

Geologic hazards include landslides, problem soils, flooding, debris flows, rock falls, and earthquake-generated phenomena such as ground shaking, surface faulting, and liquefaction. Geologic hazards are identified and characterized by geoscientists and engineers, but the simple existence of a hazard does not create a risk. Society creates a risk by placing people and structures in a position to be affected by a hazard and then by not properly reducing or acknowledging the hazard. In these cases, society must make conscious decisions about how much risk is acceptable.



Scarp of the Wasatch fault crossing urban Salt Lake Valley. The scarp can be seen as a gently curving line accentuated by shadows from left to right just above the center of the photo. More than 85 percent of Utah's population lives within 10 miles of the Wasatch fault.

Just by the way we as scientists and engineers design and conduct our geotechnical studies we inherently build in a level of risk that is commonly passed along to our customers, whether they are developers, consumers, or governments. When we recommend an assessment for a potential building site, what level of study do we propose? For instance, do we always trench a site to look for faults? Normally we don't. This is usually done only if we have previous information that a fault trace is already known or suspected to be present. And how active must the fault be before we worry about it? To address landslide stability do we drill to find the slide surface, perform soil tests, date the time of last movement, and measure pore pressure? Generally we don't because it's too expensive and not specifically required by local ordinances.

Policy makers and our customers may think risk is purely a technical issue. Our recommendations to our clients and customers that they can build are based on a level of risk that we implicitly accept, but often do not clearly identify or quantify.

So, society often does not know what risks it is accepting. When a local government issues a building permit, the developer builds, the customer moves in, and they all usually unknowingly accept risks. Often local governments do not have the expertise to question the work of the geoscientists and engineers. When the "experts" say the projects can be built, the permit is issued. The issuance of a permit conveys to the developer and the consumer an assumption that the site is safe because government approved the project. Throughout the country and around the world we see the consequences of these misperceptions.

Society is unlikely to fully take actions to define levels of acceptable risk and responsibly deal with geologic hazards until it recognizes the problem and consequences. But determining levels of acceptable risk must be a conscious

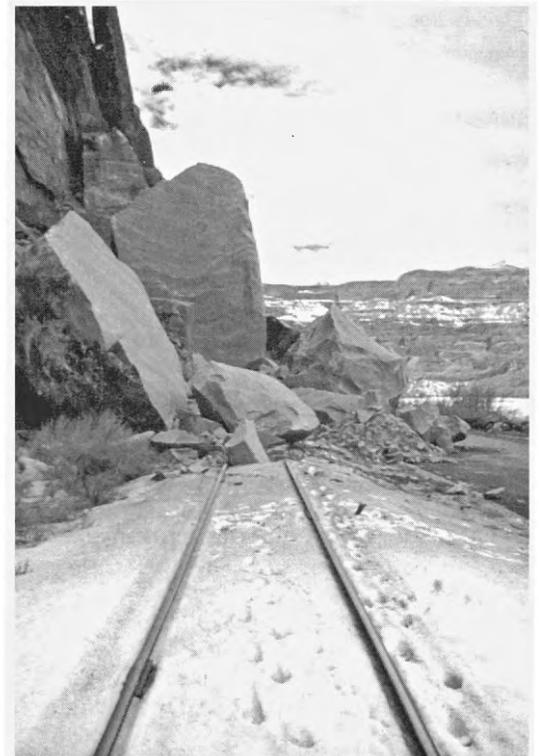
societal decision.

Examples of present practice in Utah

There is no uniform standard for assessing different geologic hazards, which may be confusing to many but allows flexibility. Addressing each hazard in a different way may be the best way to handle them.

Earthquake ground shaking - In Utah, the most strict seismic requirements (minimum) are in seismic zone 3 of the Uniform Building Code (UBC), which encompasses much of the Wasatch Front. The UBC requirements are based on the severity of ground shaking expected to occur on average every 475 years. This is a national standard which has unique consequences in Utah where large earthquakes are less common than in areas such as California. The ground shaking expected at any given location in the 475-year time period is substantially less than what we will actually experience during the biggest earthquakes we expect in Utah. Along the Wasatch Front, ground shaking from a magnitude 7.5 earthquake is more similar to a 2,500-year event and far exceeds UBC seismic zone 3 minimum requirements.

Liquefaction - Many valley areas of the Wasatch Front are susceptible to liquefaction during an earthquake because of old lake deposits, made up largely of unconsolidated sandy sediments and containing shallow ground water. Liquefaction potential is ranked from low to high depending on soil and ground-water conditions and the probability of ground shaking strong enough to cause liquefaction. Exposure times and probabilities used to prepare liquefaction potential maps are different from those used in assessing ground-shaking hazards.



Rock fall closed this rail line. Utah's steep cliffs contribute to this hazard. While areas of rock-fall potential can be identified, it is nearly impossible to predict where a specific rock fall may occur.



Debris flows occur when sudden runoff from rainfall or snowmelt carries large amounts of mud, rocks, and debris down canyons and deposits them at canyon mouths. Development along mountain fronts often does not consider this hazard.

Flooding - In Utah this common hazard along streams is dealt with through the National Flood Insurance Program. Local entities must implement the standards in the program for home or business owners to get flood insurance. Community flood-control measures are commonly government-funded. Costs for most other geologic hazards reduction measures are borne by the private sector.

Surface faulting - Along Utah's most active fault, the Wasatch fault which ruptures at any given location on average every 2,000 years, local governments require buildings be set back and not "straddle" the fault. Requirements are usually less strict for less active faults.

Debris flows - Mostly government-funded debris basins are built at canyon mouths to contain debris flows, but assessment of the actual risk (likelihood and magnitude of future debris flows) is difficult. In some canyons, very large debris flows may be 1,000-year events.

Rock falls - We generally disclose the existence of the hazard, although even this often is not done. Locally, landscaping measures are used to catch rocks and protect structures.

Landslides - The usual method is to perform qualitative studies to assess stability and recommend set-back distances or other hazard-reduction measures. Detailed quantitative analyses, however, are seldom performed.

How do we assess the hazard?

What is the probability of occurrence: how often should we expect a hazard to occur? A couple came into the Utah Geological Survey recently looking for information on landslides. Their real-estate agent had shown them a house built on a "100-year landslide" that had moved about 10 years ago. Their conclusion? They had 90 years

to go before it moved again! They were ready to buy and move in because they would not be around when the landslide reactivated. In this case it was clear that they and their real-estate agent were confusing landslides with floods, almost everyone having heard of "100-year floods." But even then, they did not understand what that meant.

Each hazard should be treated separately. One-hundred-year floods are likely localized, whereas a 500-year earthquake will affect large areas. Large debris flows may be 1,000-year events, whereas landslides can occur at any time when the conditions are right. A uniform 100-year recurrence risk level for all hazards, for example, is unrealistic and dangerous. It would mean for instance, that all of Utah would qualify as UBC seismic zone 1, meaning little or no seismic resistance would be incorporated into buildings. The consequences (severity) of the hazard must be considered in defining what recurrence level is used.

How severe can these hazards be? The Northridge earthquake of January, 1994 surprised many building owners with the severity of damage. Building codes are designed to save lives but not necessarily to save the building or contents. As a result, large numbers of buildings that continued standing after the Northridge earthquake had to be torn down and replaced because of significant structural damage.

Few people understand the risk inherent in building only to the minimum codes. When the public learned the impact of the life-safety philosophy after Hurricane Hugo in Florida, they demanded a change to strengthen and better enforce building codes. We need to be up front with consumers about the goals of our codes and requirements. The expense of hazard-reduction measures is as variable as the severity of the hazards themselves. Structural measures can be taken to help a building withstand liquefaction or debris-flow impact, but these measures generally do not reduce damage from a landslide or fault rupture.

Cost of assessing a hazard may be higher than the value of the property. At what point do hazard or risk studies in effect become a 'taking' of the property? What is the balance between ensuring safety and accepting risks? For example, to fully analyze a landslide may cost more than the value of the land or of the proposed development. So, do we allow the development to take place anyway because it is too costly to assess the risk? If so, who assumes the risk for future landslides?

Reliability and accuracy of technical information - In some cases, even comprehensive and thorough study may not solve the problem or yield a conclusive answer. We need to ask, "Is further study practical or useful?" If not, then let's not do it. That may mean, however, that we will need to either reject the project outright or accept a higher level of risk if we proceed.

How much risk is acceptable?

To answer this we must first ask: What does the public expect?

My perception is that members of the public see endless regulations, permits, and hearings in order to be allowed to develop and build. They are bombarded with so many concerns in the building process, from energy conservation to impact fees, that geologic hazards can be easily ignored or overlooked until something bad happens. They see high taxes to pay for planning departments, inspectors, and engineers. They pay consultants to perform studies. As a result, they believe that the rules will protect them. Because of this, many homebuyers do not even consider geologic hazards and aren't aware of the risks because they think that government has taken care of such things in the permitting process.

What are the responsibilities of government? Let me give you an example of a potential problem. Approximately 165 lots are being sold on an old landslide near Cedar City where as many as 165 septic tanks could be placed in the old slide. The developer has publicly stated that since the local government permitted the project, the government has assumed the risk. If a lot owner has a problem in the future, the developer has told them to see the government. It is unlikely that the local government permitting this development agrees that they assumed the risk for future landslide problems.

Who determines the level of risk?

Right now, everybody involved in geologic hazards, from those of us who first identify them, through the developer, the local government permitting authority, and the consumer, sets some of the risk. Unfortunately, the risks are rarely stated clearly and many of those in the process do not realize what those risks are and who is accepting them.

What is our goal? Is it protecting life safety or do we also want to reduce property damage? A good example of this was brought up earlier regarding building codes. The primary concept of building codes is to protect life safety, with less emphasis on non-life-threatening building damage. The extraordinarily high costs of recent natural disasters in this country have sparked serious discussions at the national level to rethink the strategy of our building codes, to reduce the level of damage to buildings. Still, minimum standards in most building codes and ordinances are designed only to protect lives.

What if an individual takes on the risks? If someone wants to build in a debris-flow area, for example, knowing the risk, should that be allowed? The problem is that if a debris flow occurs, we have a rescue cost. Also, the original



Flooding along the Jordan River at the north end of Utah Lake.

owner may accept the risk but what about subsequent owners who assume that the government permitting process is protecting them? There may be other societal costs for repairing or replacing roads and other government services. In this case, we have allowed society to accept some of the risk and the associated costs for the benefit of an individual.

All of us are sensitive to litigation. The Cedar City situation described above is ripe for lawsuits if the landslide reactivates. Local government was informed more than a decade ago that the landslide existed but permitted the development anyway. What is its responsibility? As a government agency, is it immune? What level of geotechnical study was performed? How much information has the developer provided the buyers of lots? Is the developer's declaration of "no responsibility" legitimate?

How can we deal with hazards?

Do we ignore them and accept the risk (let the "buyer beware")? We are moving away from this concept because we live in an increasingly complex society with higher societal costs of geologic hazards.

Disclosure in real-estate transactions - Many real-estate agents favor disclosure because it helps protect them and their clients selling properties from litigation from disgruntled buyers later. Hazard disclosure in Utah is voluntary, so there are no guarantees that future buyers will know the risks they are accepting.

Insurance - In a market-driven situation, the cost of insurance would reflect the actual risk. Then, if you want to live in a hazardous location you will understand the risk through the amount of the insurance premium you pay. By building better and reducing the risk or choosing another location, you could reduce your costs. The insurance industry may be moving in this direction following devastating losses due to major disasters. Alternatively, the insurance industry may convince the federal government to subsidize risk by financially backing them for big losses.

State mandates - In Utah, the state defers to local government to deal with hazards. However, most local governments do not have the technical staff to evaluate them. The Utah Geological Survey therefore offers to review hazard reports, submitted by developers, to ensure that they are adequate and complete.

Local government geologic-hazards ordinances - Many Wasatch Front cities and counties are doing reasonably well. Many have ordinances and are implementing them. Enforcement is an ongoing concern due to pressures from those who may be enamored of short-term profit and economic growth regardless of risks generated.

A federal program exists in the National Flood Insurance Program - The federal government stepped in to deal with floods and is thinking of creating a National All-Hazards Insurance program. This is because the federal government usually ends up paying for a big part of disaster costs.

Conclusions

There is a level of acceptable risk implicit in much of what geologists and engineers do and recommend regarding geologic hazards. We need to be aware of what we are doing, why we are doing it, and the level of risk we are accepting through our work. We must clearly communicate it to our clients and customers. We as professionals are to some degree setting the levels of acceptable risk that really should be debated and set by society as a whole.

Many parties, including geologists and engineers, play a part in setting levels of acceptable risk. However, because local governments ultimately control development through the permitting process, I believe they ultimately have the most influence in making these decisions. Geologists and engineers must be available to help define the risk and "coach" decision-makers regarding acceptable levels. We must make the risk level clear in our reports so that everyone involved can make informed decisions.

Global Type Locality for Cambrian-Ordovician Boundary May be Defined in Western Utah

by James F. Miller

Southwest Missouri State University

The boundary between the Cambrian and Ordovician Periods of earth history was defined in Wales in 1879, but by the end of this year it may be redefined in Millard County, Utah. The International Working Group on the Cambrian-Ordovician Boundary, a research committee of the International Union of Geological Sciences, has grappled with redefining this boundary since 1974. The Working Group is considering three areas for the new reference standard (stratotype) section for this boundary: Newfoundland, China, and a section in the northeastern Wah Wah Mountains in Utah's Great Basin. Voting on these sections will occur this year, and because the other two sections were rejected in previous votes, the Utah section is likely to be approved.

The boundary horizon is within the House Limestone in a section that was measured originally by Lehi Hintze (BYU emeritus Professor of Geology). The horizon being considered is younger than the traditional boundary used in North America but is equivalent to the boundary recognized in Europe. Fossils used to correlate this boundary around the world include trilobites, brachiopods, and conodonts, with the latter group being most useful. Raymond Ethington (University of Missouri-Columbia) and I identified nearly 18,000 conodonts from 62 samples taken through 102 meters of strata exposed in this section. Limestone conodont samples yielded geochemical (carbon isotope) data that reflect global changes in ancient seawater chemistry. Insoluble residues from these

samples aid in correlating global fluctuations of sea level.

Locating the global reference section for the Cambrian-Ordovician boundary in Millard County is entirely logical because Cambrian and Ordovician strata and fossils are so well known here. Middle Cambrian shales and trilobites at Antelope Springs in the House Range are a famous example, and Lower to Middle Ordovician strata near Ibex and Fossil Mountain are known to geologists all over the world. Two field trips visited these exposures during an international symposium on the Ordovician held in June 1995 at Las Vegas. The Lower Ordovician rocks in this area are regarded as the standard reference section for North America.



Teacher's Corner

By Martha Hayden and Sandy Eldredge

Dinosaur Teaching Kits Now Available at the UGS

The Dinosaur Teaching Kit advertised in a previous issue of Survey Notes as available through the Utah State Historical Society, will be available instead from the Utah Geological Survey (UGS) at the new Department of Natural Resources complex, located at 1594 W. North Temple in Salt Lake City. The kit consists of authentic and cast specimens, slides, publications, and other teaching aids. Kits may be reserved in advance by calling Martha Hayden at (801)537-3311. They must be picked up in person and require a \$25.00 refundable deposit.

The Utah Friends of Paleontology (UFOP) is an organization sponsored by the State Paleontologist that may be of interest to teachers. UFOP is a statewide non-profit volunteer organization dedicated to preserving Utah's fossil record through public education and volunteer support of sponsoring institutions. There are currently four local chapters throughout the state, sponsored by the following institutions: the Utah Geological Survey, Salt Lake City; Brigham Young University Earth Science Museum, Provo; College of Eastern Utah Prehistoric Museum, Price; and the Utah Field House of Natural History State Park, Vernal. Certification classes train

UFOP members to assist paleontologists with dinosaur digs, preparation projects, and public outreach programs.

Geologic Workshop for Teachers of 3rd, 5th, and 9th Grades

Investigate Geological Processes that Shape Landforms workshop for 3rd-grade teachers includes a packet of 26 activities matching the new science core curriculum, background materials, a set of 20 slides, activity materials, and a geologist and a 3rd-grade teacher as instructors.

Plate Tectonics workshop for 5th-grade teachers includes a packet of 21 activities matching the new science core curriculum, background materials, a set of 20 slides, activity materials, and a geologist and a 5th-grade teacher as instructors.

Geologic Systems workshop is not yet available, but may be advertised as early as this fall. A team composed of two geologists (from the UGS and the University of Utah), an Education Specialist, and four 9th-grade teachers, is currently developing activities matching the 9th-grade "Earth Systems" course.

Workshops can be catered to your needs. For further information, contact Deedee O'Brien at the Earthquake Education Services office in the University of Utah Seismograph Stations (705 W.C. Browning Building, Salt Lake City, UT 84112, 801-581-6201). Or contact Sandy Eldredge, UGS, at 801-537-3328.



New Publications of the UGS

Large mine permits and plants in Utah, by R.L. Bon,
4 p., 1 pl., 1:750,000, 4/96 (an excellent resource
map to locate operating mines state-wide)
PI-33\$2.70

The radon-hazard potential map of Utah by B.D.
Black, 12 p., 1 pl., 1:1,000,000, 1993 (reprint of a
very useful map for seeing geologic-based radon
patterns) Map 149\$3.50

Geologic map of the Agate quadrangle, Grand
County, Utah by G.C. Willis, H.H. Doelling, and
M.L. Ross, 34 p., 2 pl., 1:24,000, 1996
Map 168\$7.75

Geologic map of the northern Wasatch Front, Utah
compiled by F.D. Davis, 2 pl., 1:100,000, 1985
(reprint of the known geologic data for the area
from middle Cache Valley to Washington Terrace)
Map 53A\$5.00

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