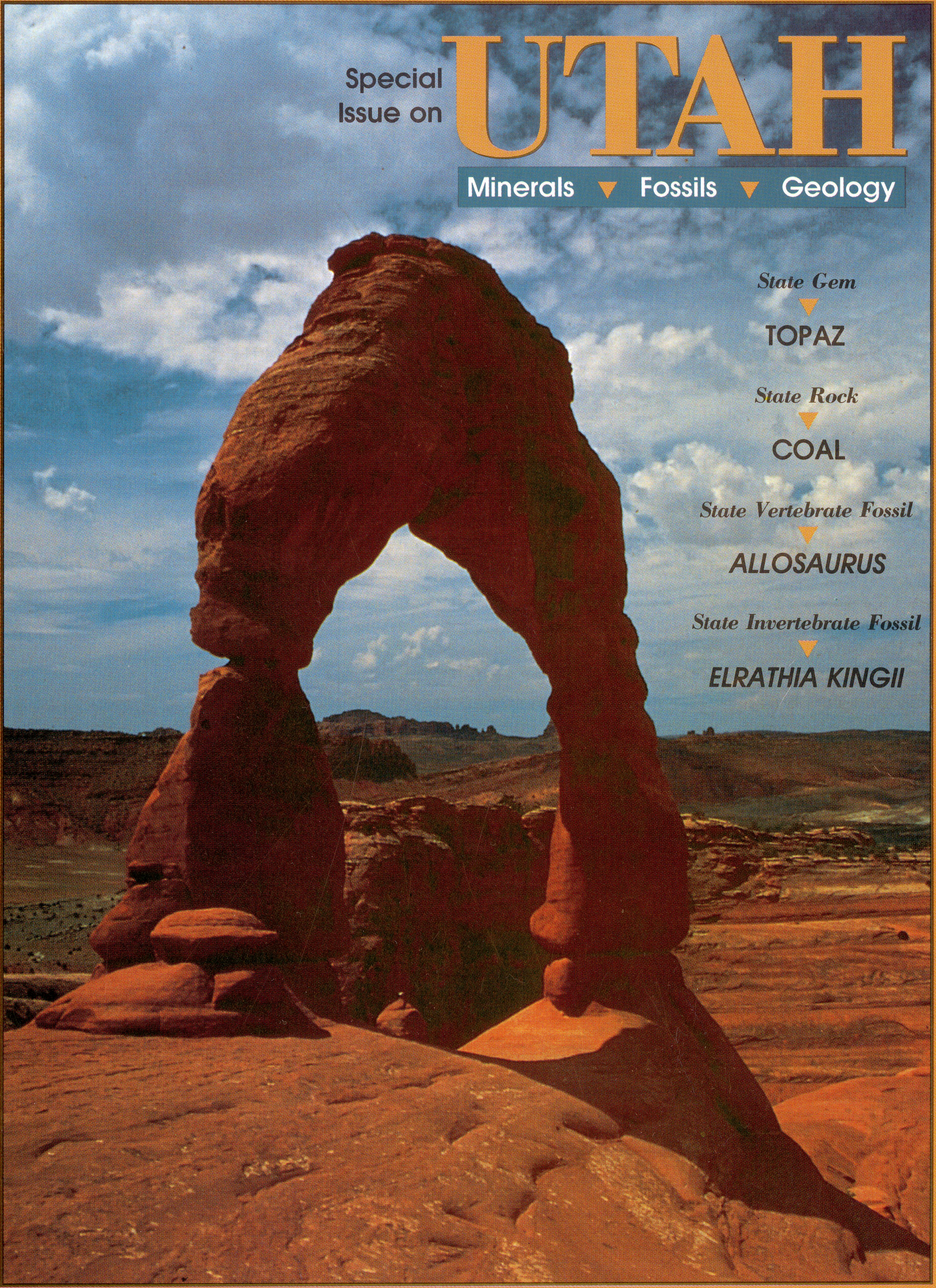
Special Issue on

UTAH

Minerals ▼ Fossils ▼ Geology



State Gem

▼

TOPAZ

State Rock

▼

COAL

State Vertebrate Fossil

▼

ALLOSAURUS

State Invertebrate Fossil

▼

ELRATHIA KINGII

Photo: Delicate Arch, Arches National Park. Photo by Frank Jensen, courtesy Utah Travel Council, Salt Lake City.

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ACKNOWLEDGMENT

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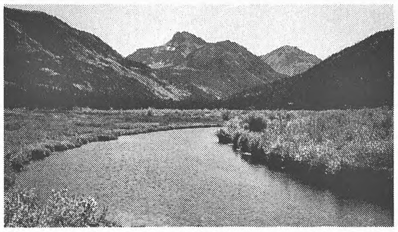
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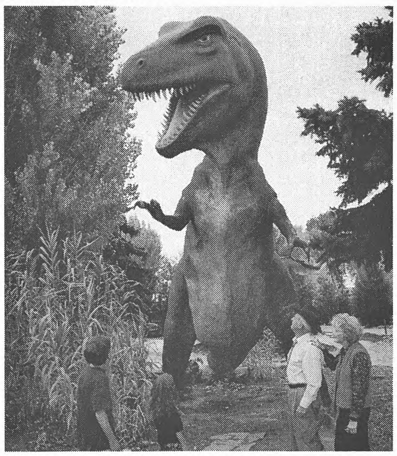
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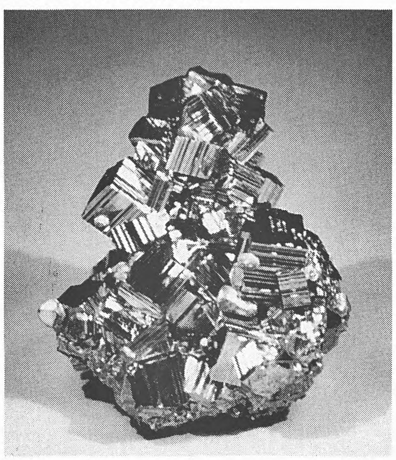
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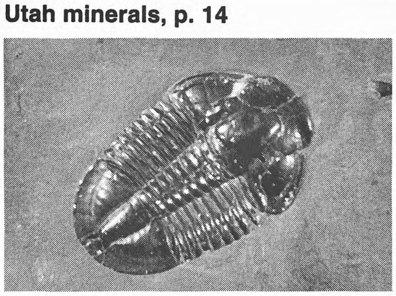
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This publication is a reprint of *Rocks & Minerals,* volume 68, number 6, November/December 1993

Figure 1. The canyonlands of Utah's Colorado Plateau are characterized by horizontal layers of sedimentary rock, chiefly of Mesozoic age, deeply dissected by the Colorado River. Photo by Laurel Casjens.

The Geology of Utah
A RÉSUMÉ

FRANK DECOURTEN
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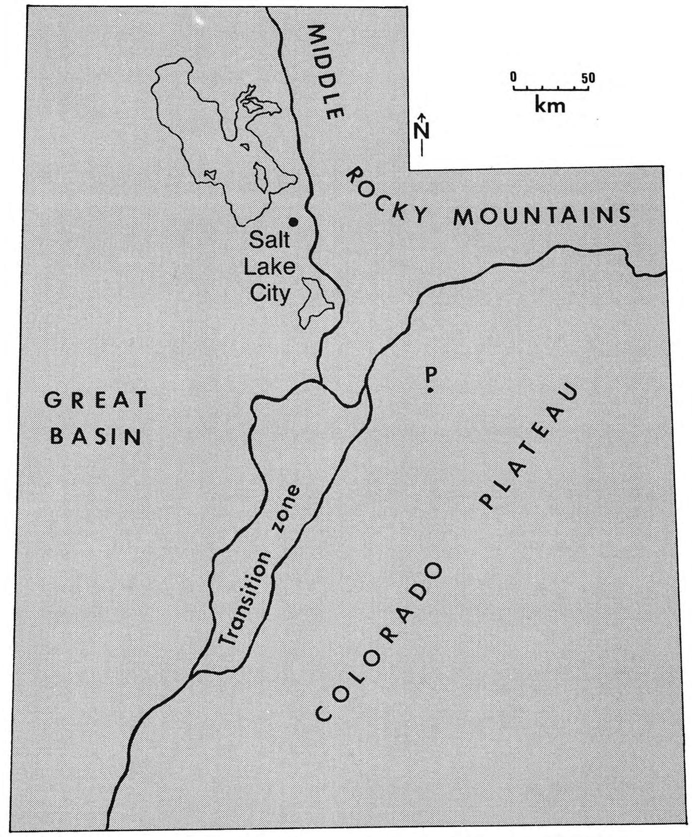

Figure 2. **The geological provinces of Utah.**

For everyone interested in rocks, minerals, and fossils, Utah is an inviting place, where every new outcrop is an exciting adventure and every bend in the trail promises new opportunities for discovery.

IN 1847 WHEN BRIGHAM YOUNG crossed the Wasatch Mountains of Utah with his band of weary pioneers, it is said that he gazed across the Salt Lake Valley and exclaimed, "This is the place!" No one knows exactly how much attention Young was paying to the geological character of his new home, but certainly no one familiar with the geology of the Beehive State would dispute the statement. When it comes to diversity of geological phenomena, magnificence of scenery, and richness of natural heritage, few states can surpass Utah. This is a land of wonder and beauty that offers endless opportunities for collecting and studying rocks, fossils, and minerals.

Utah: A Geological Wonderland

For well over a century, geologists have converged on Utah to examine the bold rock exposures that document a fascinating tale of geological evolution. There are several reasons why Utah is so alluring to those interested in anything geological. Nearly three-fourths of the state's 85,000 square miles are desertlike in character. Consequently, the minimal plant cover and relatively thin soils do little to conceal the vast bedrock exposures. Most of Utah is also sparsely populated, with about 80 percent of its 1.7 million inhabitants living along the foothills of the Wasatch Mountains in north-central Utah. The other 20 percent are scattered around scenic rural Utah in delightful towns and villages. Therefore, Utah geology is only sporadically concealed by asphalt and concrete.

In addition, most land in Utah is in the public domain, with the Bureau of Land Management alone holding over 23 million acres; additional large tracts of land are managed by the National Park Service, U.S. Forest Service, Division of State Lands and Forestry, and other public agen-

In addition to the famous trilobite beds of the House Range area, there are scores of other localities in the Great Basin where Paleozoic brachiopods, crinoids, corals, cephalopods, bryozoa, and mollusks can be found in dazzling abundance.

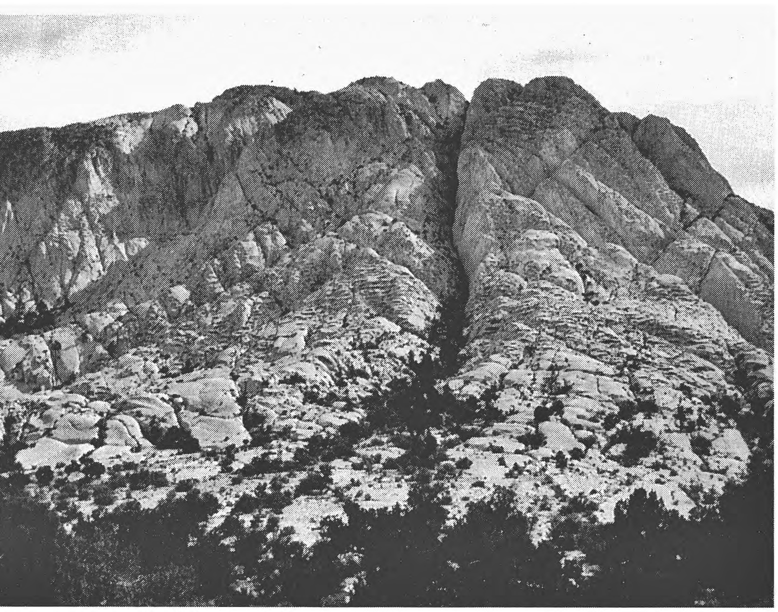

Figure 3. **Crystal Peak, in the Great Basin of western Utah, is composed entirely of volcanic ash erupted about 33 million years ago, during the Oligocene Epoch. Such rocks record explosive volcanic events and are widespread in the Great Basin province. Photo by F. DeCourten.**

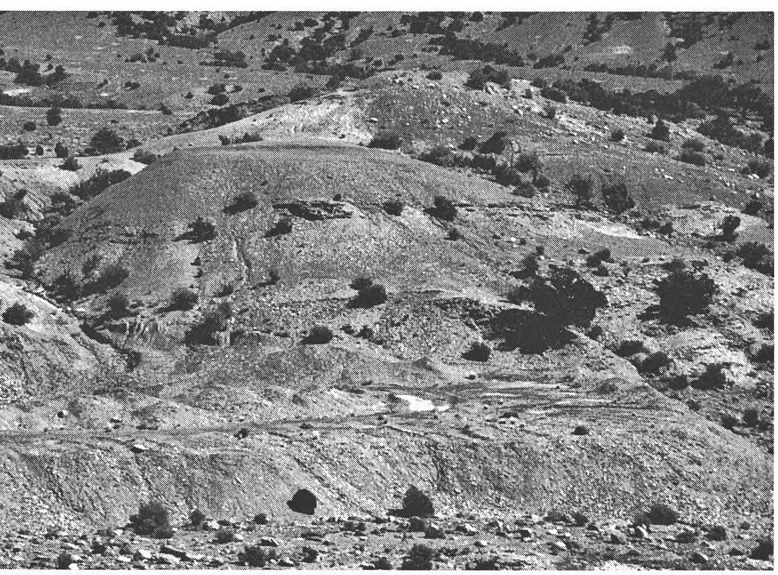

Figure 4. **Exposures of middle Cambrian shale and limestone in the House Range area of western Utah. These strata produce millions of specimens of trilobites and associated fossils that inhabited the shallow sea floor of western Utah during the Paleozoic Era. Photo by F. DeCourten.**

cies. Because of this, fewer "No Trespassing" signs are posted in Utah than in most other states. For everyone interested in rocks, minerals, and fossils, Utah is an inviting place, where every new outcrop is an exciting adventure and every bend in the trail promises new opportunities for discovery.

The Geological Provinces of Utah

The geological diversity of Utah stems primarily from the fact that three great geological provinces meet near the center of the state: the Great Basin of western Utah, the Colorado Plateau in the southeast, and the Middle Rocky Mountains in the northeast. Each of these provinces has a distinctive geologic fabric and unique geological history. Visiting the three regions is like exploring three different worlds. Together, they provide magnificent examples of nearly every fundamental geological process. It is no surprise that the list of fossils, rocks, and minerals that can be collected in Utah is indeed a long one.

The Great Basin

The Great Basin of western Utah is a corrugated land characterized by linear, north-south–trending mountain ranges that are separated by intervening valleys. The pleated nature of this landscape is the result of widespread and intense normal faulting that, beginning about 20 million years ago, fractured the rock sequence into a series of elevated mountain blocks and down-faulted valley basins. The valleys are underlain largely by unconsolidated alluvium, up to (and in places exceeding) 10,000 feet in thickness, shed from the adjacent mountains. Where water is available, or has been developed from the subsurface, the soils are fertile enough to permit successful agriculture, but this is a limited industry in western Utah because of the arid desertlike climate.

The level floors of many of the basins in western Utah were once submerged under the fresh water of Lake Bonneville, an Ice Age lake that reached its maximum stage of development about 16,000 years ago. At that time, it covered approximately 20,000 square miles to a maximum depth of about 1,000 feet. The lake began its rapid decline about 14,500 years ago with the catastrophic Bonneville Flood, which sent more than 1 thousand cubic miles of water surging northward across southern Idaho into the Snake River system. By about 12,000 years ago, the increasingly warm and dry climate had reduced Lake Bonneville to a relatively small saline remnant, the predecessor of the modern Great Salt Lake. As the water of Lake Bonneville became progressively more saline during the later stages of its decline, a variety of salts were deposited on the old floor to form the famous Bonneville Salt Flats.

The bedrock exposed in the mountains of the Great Basin is dominated by marine sedimentary rocks of Paleozoic age (570-245 million years old) and middle to late Cenozoic volcanic rocks (about 40 to 6 million years old). The Paleozoic marine strata consist primarily of limestone and dolomite interbedded with thinner sequences of sandstone and shale. The thickness of the Paleozoic strata is impressive: In the House Range, for example, the Cambrian rocks alone are over 10,000 feet thick and rise about the valley floor along the western face as an immense wall of gray limestone. The cumulative thickness of the Paleozoic section in Utah's Great Basin locally exceeds 60,000 feet, representing the mud, silt, and sand that accumulated on the shallow floor of a tropical sea that submerged the region for some 400 million years.

Many units of this succession of rock layers are richly fossiliferous, demonstrating that this ancient sea floor was populated by a diverse array of marine invertebrate creatures. In addition to the famous trilobite beds of the House Range area, there are scores of other localities in the Great Basin where Paleozoic brachiopods, crinoids, corals, cephalopods, bryozoa, and mollusks can be found in dazzling abundance.

In many of the mountains of Utah's Great Basin, the thick sequence of Paleozoic limestone is capped by middle to late Cenozoic volcanic rocks of diverse compositions and textures. In some mountain systems, such as the Needles Range in southwestern Utah or the Thomas Range 110 miles southwest of Salt Lake City, the volcanic rocks comprise the entire mountain block. Between the Cenozoic volcanic rocks and the underlying Paleozoic sediments, a major unconformity, representing most or all of the Mesozoic Era, is usually present. The volcanic sequences consist chiefly of numerous fragmental or "ashy" layers, such as tuffs, agglomerates, and ash flows. The composition of the Cenozoic volcanic rocks is generally intermediate to silicic, and most of them are described as rhyolites, dacites, or latites. Less-common flows are typically composed of andesites or basalts.

The pyroclastic rocks document a long period of violent volcanic explosions that distributed great volumes of ash across broad areas of western Utah and eastern Nevada. It has been estimated, for example, that 2,500 cubic miles of ash were discharged during the late Oligocene (33-26 million years ago) over approximately 10,000 square miles of southwestern Utah. By comparison, the eruption of Mount St. Helens in 1980 produced only 1-2 cubic miles of ash. About 15 million years ago, the character of volcanic activity in western Utah shifted somewhat to produce a "bimodal" record consisting of rhyolite and basalt couplets. This latter style of volcanic activity continued until very recent times; the dark lava flows of the Black Rock Desert west of Fillmore and the cinder cones north of Saint George represent basaltic eruptions as young as a few thousand years.

The volcanic rocks of the Great Basin are fascinating targets of investigation for mineral and rock collectors. Many of the tuffs are crystal-rich, containing quartz, biotite, hornblende, and other crystals within a matrix of fused ash. In some places, the ash-flow tuffs and rhyolite flows yield gem-quality crystals of such minerals as red beryl and topaz, the official Utah state gemstone. In addition, the volcanic rocks, along with their intrusive equivalents, have played an important role in the widespread mineralization characteristic of western Utah. More than one-hundred metal-producing mining districts have been established in Utah; most of these are located in the western part of the state. Even today, old mining areas such as the Frisco district, Gold Hill, Ophir, and Tintic district are wonderful locations for mineral collectors to explore.

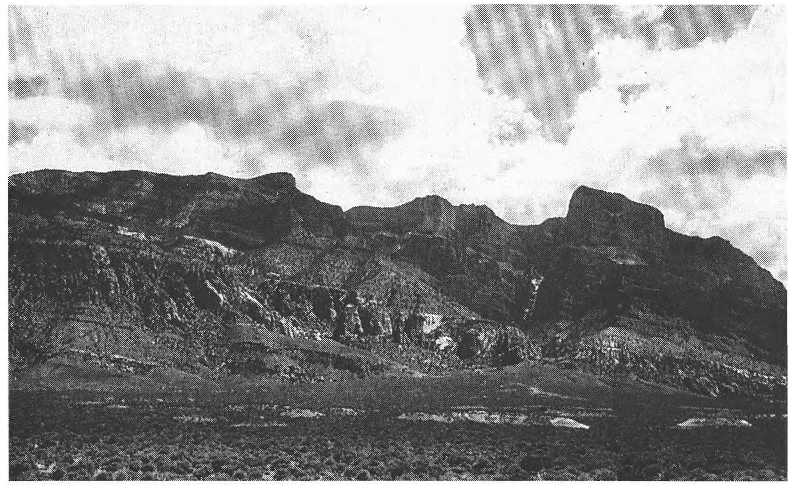

Figure 5. **Notch Peak, in the central House Range of western Utah. The sheer face of the mountain front exposes thousands of feet of early Paleozoic limestone. Photo by F. DeCourten.**

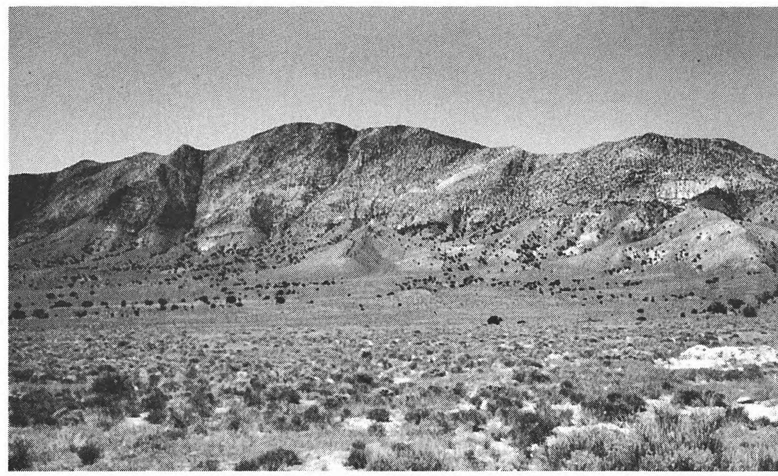

Figure 6. **The Thomas Range in the Great Basin is composed almost entirely of Cenozoic volcanic rocks that locally contain abundant topaz crystals. Photo by Frank DeCourten.**

In some places, the ash-flow tuffs and rhyolite flows yield gem-quality crystals of such minerals as red beryl and topaz, the official Utah state gemstone.

The scenic Colorado Plateau of Utah is home to five national parks, three national monuments, and many other parcels managed by the state park system.

Figure 7. **The La Sal Mountains near Moab are one of three main centers of Cenozoic igneous activity in Utah's Colorado Plateau. These mountains consist of igneous rock formed from magma emplaced at shallow depths about 29 million years ago. Photo by Laurel Casjens.**

Figure 8. **Exposures of the Paleocene-Eocene Claron Formation at Bryce Canyon National Park. This area is one of five scenic national parks located in the Colorado Plateau of southeastern Utah. Photo by F. DeCourten**

The Colorado Plateau

It is hard to imagine a landscape more different from the Great Basin than that of southeastern Utah. Here, sweeping expanses of bare red rock—rising in tablelands, mesas, and buttes—define a generally horizontal landscape. This majestic land is part of the Colorado Plateau province, named for its tablelike character and for the river system that has dissected it into labyrinthine canyonlands. The scenic Colorado Plateau of Utah is home to five national parks, three national monuments, and many other parcels managed by the state park system. The scenery of this region, coupled with its geological setting and cultural history, combine to create an almost mystical captivation for the millions of visitors drawn to the Colorado Plateau each year.

The horizontal appearance of Colorado Plateau vistas is an expression of the geological stability of the region. There are few faults to disrupt the continuity of the horizontal rock layers. In places, however, the strata of the Colorado Plateau are gently warped into broad folds, such as the San Rafael Swell south of Price or the Waterpocket Fold near Capitol Reef National Monument. But, there is no hint of the intense faulting that characterizes the corrugated terrain of the Great Basin.

Most of the rocks exposed in the grand vistas of the Colorado Plateau are of Mesozoic age (i.e., desposited 245–66 million years ago). Recall that rocks of this age are extremely scarce in the Great Basin. The red-rock canyons of southeastern Utah comprise a sedimentary wonderland: Sandstone, mudstone, and shale dominate the exposures everywhere. These sediments were, for the most part, deposited in nonmarine environments, such as streams, lakes, dunes, or floodplains. The massive dune-deposited sandstones are particularly characteristic of the Colorado Plateau, forming the towering walls of Zion National Park and the lofty rims that surround Canyonlands National Park.

Mesozoic seas occasionally penetrated into southeastern Utah to form the dark gray shale and near-shore sandstones of, for example, the Book Cliffs between Price and Green River. These marine strata contain many good fossils of ammonites, clams, oysters, and sporadically other inhabitants of the ancient seas. During the Cretaceous Period of the late Mesozoic Era, swampy coastal plains developed along the edge of a seaway in central Utah. Numerous layers of coal were deposited in these ancient swamps, and today these form the foundation of the local mining economy in places like Carbon County.

In addition to coal, southeastern Utah is famous for the rich uranium ores found in the river-deposited sandstones of early and middle Mesozoic age. These uranium deposits were mined extensively in the late 1950s and early 1960s,

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producing both substantial mineral wealth and part of the fascinating folklore of southeastern Utah. The mesas and canyons of the Colorado Plateau are still dotted with old uranium claims, and many abandoned workings can be encountered in the back country. The uranium minerals are often associated with secondary sulfate, carbonate, and sulfide minerals. Good specimens of a variety of minerals can still be found in some of the old mining areas.

Any review of the geology of Utah's Colorado Plateau would be incomplete without some mention of the most captivating fossils of all—the dinosaurs. Dinosaur remains in Utah occur in several different rock units, but the most famous is the Morrison Formation of late Jurassic age (about 150 million years old). This colorful sequence of lavender and gray mudstone, tan sandstone, and reddish siltstone has produced thousands of dinosaur bones from numerous localities in Utah, Colorado, and Wyoming. In Utah, the Cleveland-Lloyd quarry and Dinosaur National Monument are two sites with a truly spectacular abundance of dinosaur fossils. The Cleveland-Lloyd quarry is located about 25 miles south of Price and has a small interpretive center managed by the Bureau of Land Management. Dinosaur National Monument is situated in the Uinta Basin, along the northern periphery of the Colorado Plateau; the National Park Service operates an extremely informative visitor center here. Elsewhere in the Colorado Plateau, dozens of other sites have produced dinosaur bones from the Morrison Formation. This interesting rock unit has certainly earned its reputation as the "great dinosaur graveyard of the West." Although dinosaur fossils (even bone fragments) cannot be collected without appropriate permits, finding them adds the thrill of discovery to any trip into the Mesozoic wonderland of southeastern Utah.

Igneous rocks are not widespread in southeast Utah, but are concentrated in three main clusters of isolated mountain peaks. The Henry Mountains near Hanksville, the La Sal Mountains near Moab, and the Abajo Mountains at Monticello are all composed of numerous bodies of Cenozoic igneous rock emplaced as magma at relatively shallow depths between 20 and 30 million years ago. The highest of the igneous peaks in the Colorado Plateau is Mount Peale in the La Sal Mountains, which rises above the red-rock panorama to an elevation of 12,721 feet. The other igneous mountains are nearly as high, and they all provide exquisite alpine scenery in stark contrast to the surrounding desert landscapes.

The igneous rocks in these mountain systems are varied in texture and composition, but many are strikingly porphyritic, exhibiting large hornblende or plagioclase crystals set into a fine-grained groundmass. There has been some limited mineralization in and around the igneous mountains of the Colorado Plateau, but only minor amounts of precious or base metals have been produced in the region.

The Henry Mountains are particularly fascinating from the geological perspective because of the many excellent exposures that reveal the relationships between the several intrusions and the deformed and altered sedimentary rocks through which they rose. It was in the Henry Mountains that G. K. Gilbert studied the hemispherical intrusions known as laccoliths in the late 1800s and formulated a theory for their origin involving the emplacement of magma in the relatively shallow subsurface. The Henry Mountains and the other igneous peaks are easily accessible via graded roads that lead to numerous campgrounds in the luxuriant conifer forests nestled among the high peaks.

Thus, the Great Basin of western Utah and the Colorado Plateau of southeast Utah are indeed two different worlds. Paleozoic limestone, trilobite fossils, volcanic rocks, gem-quality crystals, gold and silver, and intense faulting characterize the Great Basin. In the Colorado Plateau, none of these phenomena prevail; instead, the visitor most often encounters Mesozoic sandstone, dinosaur fossils, coal and uranium, and relatively undisturbed rock layers.

These profound differences between the Great Basin and Colorado Plateau reflect their radically different geologic histories: The Great Basin represents a dominantly oceanic history, whereas the Colorado Plateau experienced a chiefly continental history and erosion while the Paleozoic seas submerged western Utah. Later, during the Mesozoic Era, the older sea floor of western Utah was elevated to become dry land exposed to the agents of erosion, thus accounting for the general scarcity of deposits of this age within the Great Basin. This was the time when great amounts of sand, silt, and mud were washed or blown by the wind into a low interior basin in eastern Utah.

During the Cenozoic Era, the Great Basin was ablaze with volcanic activity as the crust began to stretch and rupture into a series of fault-block mountains and valleys. The Colorado Plateau experienced little of this Cenozoic may-

The Morrison Formation has earned its reputation as the "great dinosaur graveyard of the West."

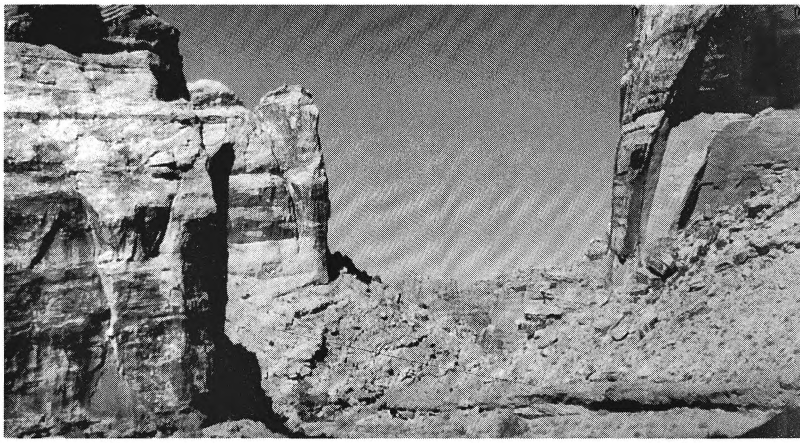

Figure 9. **Twisting canyons bordered by towering walls of Mesozoic sandstone offer numerous opportunities to explore the magnificent back country of the Colorado Plateau.**

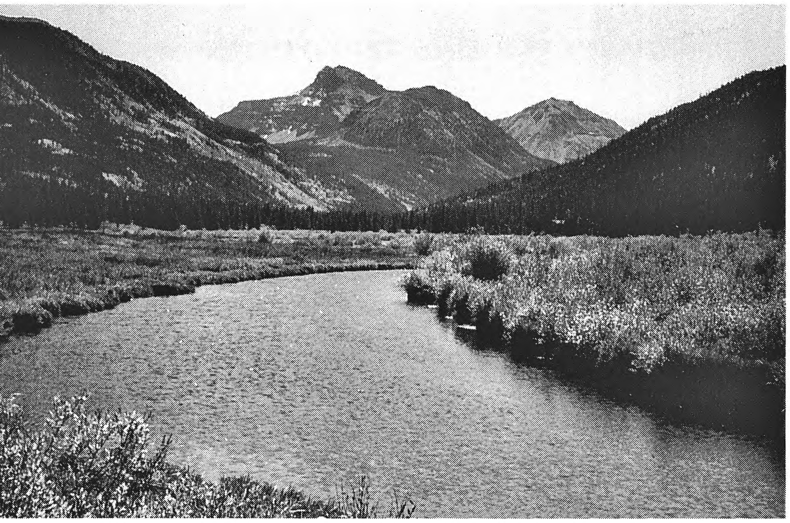

Figure 10. **The scenic peaks of the high Uinta Mountains typify the landscapes of the Middle Rocky Mountains in northeastern Utah. These peaks above Christmas Meadows are composed of late Precambrian sandstone and siltstone. Photo by Laurel Casjens.**

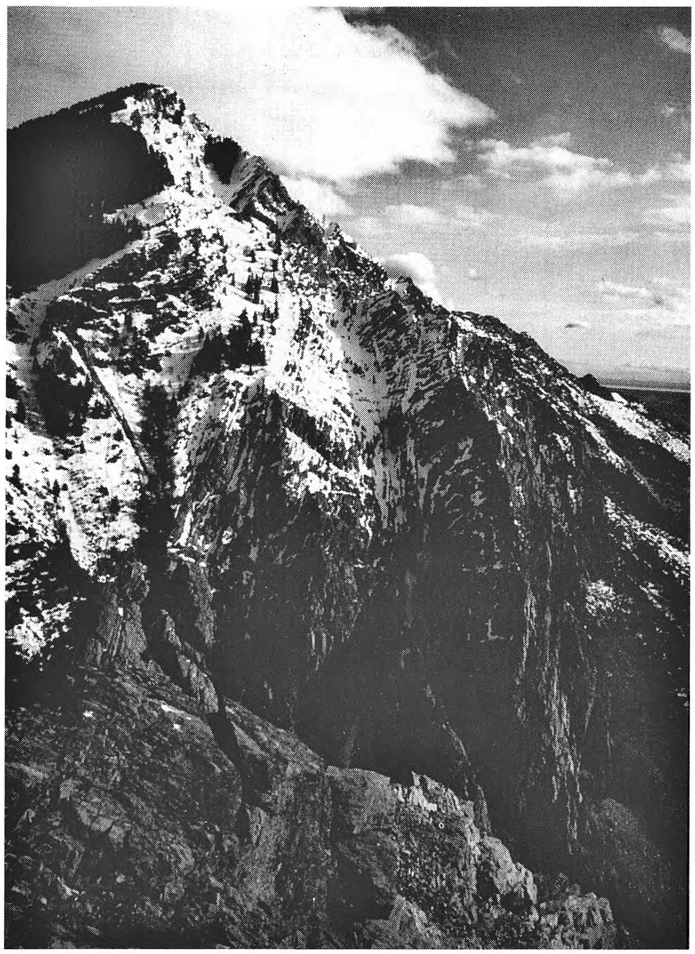

Figure 11. **The rugged Wasatch Mountains near Willard provide excellent exposures of some of Utah's oldest rocks. The vertical grain of the rocks in the middle slope results from the high-angle foliation and rock cleavage of nearly 3-billion-year-old gneiss and schist. These highly metamorphosed basement rocks are overlain by Cambrian sandstone (dark forested cap). Photo by Laurel Casjens.**

hem, merely rising as a stable block that the Colorado River system has now sculpted into a superb network of breathtaking canyons.

The Middle Rocky Mountains

The geologic setting and physiographic character of the northeastern corner of Utah contrasts sharply with anything encountered in the Great Basin or Colorado Plateau. This is a region of high mountains, consisting of two principal elements: the east-west-trending Uinta Mountains just south of the Wyoming-Utah state line and the north-south-aligned Wasatch Mountains, the geological backbone of the state. These mountain systems, and the lowlands that immediately surround them, are classified as part of the Middle Rocky Mountains province. This is a beautiful corner of Utah, with summits rising as high as 13,528 feet at Kings Peak in the Uinta Mountains, the highest point in the state. At such elevations, great expanses of ragged rock sculpted by Pleistocene glaciers rise above timberline. Below the bare peaks, hundreds of sparkling lakes are surrounded by lush forests that thrive under the cool alpine climate. The Middle Rocky Mountains are an extremely important watershed for Utah, serving as the recharge area for most of the major rivers in this otherwise arid region.

Unlike the Colorado Plateau and the Great Basin, the Middle Rocky Mountains province of Utah lacks any general geological uniformity. In fact, it is difficult to imagine two adjacent mountain ranges so utterly dissimilar in their overall geological structures and characteristics. The right-angle intersection of the Uinta and Wasatch mountains is only the initial hint of their great differences.

The Uinta Mountains are, broadly speaking, of relatively simple geological structure. The core of this east-west promontory is composed of a thick and monotonous sequence of late Precambrian sandstone, shale, and mudstone. These strata are arched into a broad upward fold and have been driven as a huge deformed wedge northward over younger rocks along a thrust fault system that extends parallel to their north flank. This uplift occurred mainly during the Laramide Orogeny, a period of widespread mountain-building that affected the Rocky Mountain region about 40–60 million years ago. Younger sedimentary rocks, of both Paleozoic and Mesozoic age, have been eroded from the axis of the Uinta arch and are now exposed in the flanking lowlands. Except for some small dikes cutting the older rock units, there are few igneous rocks in the Uinta Mountains.

In spite of the enduring legends of "lost" gold mines in the Uinta Mountains, no significant mineralization is known. The only fossils that can be collected from the region are the marine forms—chiefly corals and brachiopods—within the flanking Paleozoic strata.

It appears that the early history of the Uinta Mountains involved a period of continental fragmentation that began about 800 million years ago. A late Precambrian "supercontinent'' was rifted into several smaller pieces that became the cores of the continents we know today. In the Utah region, a deep, east-west–trending trough developed as part of this rifting process. Over the ensuing 100 million years, the linear depression was filled with granular sediment washed into it by rivers. After the beginning of the Paleozoic Era (570 million years ago), layers of limestone and other sedimentary rocks were deposited over the top of this filled trough.

Throughout most of the Mesozoic Era, additional layers of sediment accumulated on top of the Paleozoic sequence. Then, near the beginning of the Cenozoic Era (66 million years ago), the buried trough was compressed and "closed" by forces related to the Laramide Orogeny. The rock layers that filled the trough, and the younger material deposited above them, were folded upward and driven out of the compressed trough along the north-flank thrust fault. Erosion subsequently removed the cover of Paleozoic and Mesozoic strata from the top of the arched and thrusted mass, revealing the core of late Precambrian sedimentary rocks. So, the Uinta Mountains represent the scar of a Precambrian rifting event: A linear fracture that developed 800 million years ago was subsequently filled with sediment and then closed and elevated by relatively recent compression.

Whereas geological simplicity is the hallmark of the Uinta Mountains, the Wasatch Mountains are composed of a complex and heterogenous mixture of rock types and geological structures. Included in the tortured tangle of stone in the Wasatch are Utah's oldest rocks, the intensely metamorphosed gneiss and schist, more than 3 billion years old, exposed in the foothills between Farmington and Brigham City. In addition, there are extensive exposures of both billion-year-old sandstones reminiscent of the Uinta Mountain core and Paleozoic sedimentary rocks similar to those in the Great Basin. In the central part of the Wasatch Mountains, contorted layers of red rocks of Mesozoic age are widespread; and except for its strong deformation, this portion of the range resembles the Colorado Plateau. Cenozoic igneous rocks of both volcanic and plutonic origin are concentrated in a linear zone that extends across the Wasatch Mountains 20 miles south of Salt Lake City.

Utah's famous ski resorts are located in and around peaks where the granitic rocks and the older strata into which they were emplaced 20-30 million years ago are exposed. Interactions between the older Paleozoic limestones and the Cenozoic igneous rock have led to the development of several orebodies that spawned a period of intense silver, lead, and zinc mining during the late 1800s. The modern Wasatch ski resorts of Snowbird, Alta, Park City, and Deer Valley are built on, or close to, the sites of the raucous nineteenth-century mining camps.

The Wasatch Mountains were elevated over the last 18 million years by displacement along the Wasatch Fault system, an extensive and segmented zone of normal faults that trends north-south along the base of the steep western escarpment of the range. Thirty-six thousand feet of cumulative displacement along this fault system has lifted a dozen peaks in the central Wasatch Mountains to elevations exceeding 11,000 feet. The Wasatch block was tilted to the east as it rose to give the mountains their characteristic asymmetry: a sheer western face and a gentle eastern slope. The Wasatch Fault system remains active and gives rise to hundreds of earthquakes each year, demonstrating that the mountains are still rising and that the evolution of this portion of the Middle Rocky Mountains is still progressing.

Although the Wasatch Fault system is the most prominent geologic structure of the Wasatch Mountains, it is certainly not the only source of deformation of the rock assemblage. Internally, the Wasatch Mountains are contorted by a sometimes bewildering pattern of folds and thrust faults. The forces that produced these compressional features are thought to have been active in earlier periods of mountain-building that began in the late Mesozoic Era and continued into the early part of the Cenozoic Era.

The effects of each deformational event have been superimposed upon earlier faults and folds, making it difficult to unscramble the exact timing of each period of disturbance. So chaotic is the pattern of bedrock geology in the Wasatch Mountains that hikes up two adjacent canyons can often lead one into completely dissimilar geological realms. There are no easy answers to the question of when and how the Wasatch Mountains developed. Indeed, they are the product of a long series of complex geological events that occurred over billions of years. The sharp contrast between the complexity of the Wasatch Mountains and the simplicity of the Uinta Mountains in terms of their rocks, structures, and geological history is nothing short of astonishing.

The modern Wasatch ski resorts are built on, or close to, the sites of the raucous nineteenth-century mining camps.

Despite the profound differences in bedrock geology, however, the Uinta and Wasatch mountains do share one common feature. Both ranges were extensively sculpted by glaciers during several Ice Age glaciations. During the cold intervals of the Pleistocene Epoch, great tongues of ice extended down the canyons from source areas in the upper basins. In the Wasatch Mountains, a roughly 500-foot-thick mass of ice plugged the mouth of Little Cottonwood Canyon about 24,000 years ago and extended all the way up to Albion Basin above the ski town of Alta. By about 12,000 years ago, the ice had receded about halfway up the canyon as the climate became warmer. After withdrawal of the glacier, a classic U-shaped canyon, lined and bordered by bouldery glacial deposits, was left as evidence of the glaciation.

Similarly, many canyons in the Uinta Mountains, and elsewhere in the Wasatch, exhibit comparable evidence of recent glaciation. In the higher regions of both mountain ranges, the alpine landscapes are characterized by a rugged topography of sharp ridges, jagged spires, and hanging valleys. Thus, the glaciers added the finishing touches to the Wasatch and Uinta landscapes and created similar landforms from utterly different geological substrates.

Summary

Utah is a splendid geological paradise. Located in a spectacular part of western North America, Utah has been situated at the geological crossroads of the continent for an immense span of time. Billions of years ago, Utah was involved in the piecemeal assembly of the embryonic core of our continent. The ancient metamorphic rocks in the northern Wasatch Mountains are evidence of this early phase of geological evolution. The geology of the Uinta Mountains suggests that later, near the end of Precambrian time, Utah was strategically located along a zone of continental rifting. As Paleozoic time began, tropical seas encroached from the west to a position (during most of this time) in central Utah. The dominance of Paleozoic marine strata in the Great Basin, coupled with their general absence or reduced thickness in the Colorado Plateau, record these conditions.

In the Mesozoic Era, while the rivers washed sediments into the interior basin to the east, the Great Basin was elevated and eroded to produce the prevalent gap separating the Paleozoic and Cenozoic rock assemblages. During this time, dinosaurs romped on the Colorado Plateau, shallow continental seas came and went, coal swamps developed, and dune fields arose. The varied sedimentary record of the Mesozoic Era in the Colorado Plateau is a fabulous chronicle of change in land and life over 180 million years.

During the Cenozoic Era, the Great Basin was torn by myriad faults while a great volcanic rampage began. Meanwhile, in the Colorado Plateau and Middle Rocky Mountains, gentle uplift began to elevate the plateaus, mesas, and mountains. The Colorado River began to cut through the thick stack of rising rock layers, carrying away immense quantities of sand and silt. In the Great Basin, erosion of the mountain ranges produced debris that accumulated in the intervening valleys. Finally, during the Ice Age, glaciers in the Middle Rocky Mountains sculpted the lofty ramparts, while lakes expanded and contracted in rhythm with the climatic oscillations in the lower terrain in the Great Basin.

This remarkable series of events, recorded in the geological framework of Utah, is not duplicated anywhere else in the world. Every cliff face, every roadcut, and every outcrop offers fascinating opportunities to investigate a vast history of geologic change recorded in rocks, minerals, and fossils. For anyone interested in earth phenomena, Utah's landscapes are irresistible. A lifetime of adventure and intrigue awaits all who explore them.

REFERENCES

Baars, D. L. 1983. *The Colorado Plateau: A geologic history.* Albuquerque: University of New Mexico Press.

Best, M. G., and J. D. Keith. 1983. Mid-Tertiary history of the central Pioche-Marysvale igneous belt, southwestern Utah. In *Geologic excursions in volcanology: Eastern Snake River Plain* (Idaho) and southwestern Utah, ed. by K. D. Gurgel, 35–55. Utah Geological and Mineral Survey special studies 61.

Bryant, B. 1988. *Geology of the Farmington Canyon Complex, Wasatch Mountains, Utah.* U. S. Geological Survey professional paper 1476.

Bullock, K. C. 1981. *Minerals and mineral localities of Utah.* Utah Geological and Mineral Survey bulletin 117.

Chidsey, T. C., Jr., ed. 1991. *Geology of east-central Utah.* Utah Geological Association publication 19, 1991 Field Symposium.

DeCourten, F. L. 1987. Precambrian metamorphic rocks of the Devil's Gate–Weber Canyon area, northern Utah. In *Rocky Mountain section of the Geological Society of America, Geological Society of America centennial field guide,* vol. 2, ed. by S. S. Bues, 243–46.

Hamblin, W. K. 1987. Late Cenozoic volcanism in the St. George Basin, Utah. In *Rocky Mountain section of the Geological Society of America, Geological Society of America centennial field guide,* vol. 2, ed. by S. S. Bues, 291–94.

Hintze, L. F. 1987. Exceptionally fossiliferous Lower Ordovician strata in the Ibex area, western Millard County, Utah. In *Rocky Mountain section of the Geological Society of America, Geological Society of America centennial field guide,* vol. 2, ed. by S. S. Bues, 261–64.

———. 1988. *The geologic history of Utah.* Brigham Young University geology studies special publication 7.

Hintze, L. F., and R. A. Robinson. 1987. The House Range, western Utah: Cambrian mecca. In *Rocky Mountain section of the Geological Society of America, Geological Society of America centennial field guide,* vol. 2, ed. by S. S. Bues, 257–60.

Peterson, F., and C. Turner-Peterson. 1989. *Geology of the Colorado Plateau: 28th International Geological Congress field trip guidebook T130.* Washington, D.C.: American Geophysical Union.

Rigby, J. K. 1976. *Field guide to the northern Colorado Plateau.* Dubuque: Kendall/Hunt Publishing Company.

———. 1977. *Field guide to the southern Colorado Plateau.* Dubuque: Kendall/Hunt Publishing Company.

———. 1987. Stratigraphy and structure of the San Rafael Reef, Utah: A major monocline of the Colorado Plateau. In *Rocky Mountain section of the Geological Society of America, Geological Society of America centennial field guide,* vol. 2, ed. by S. S. Bues, 269–74.

Rigby, J. K., M. P. Russon, and R. E. Carroll. 1987. The Book Cliffs Cretaceous section. In *Rocky Mountain section of the Geological Society of America, Geological Society of America centennial field guide,* vol. 2, ed. by S. S. Bues, 251-56.

Smith, G. I., L. Benson, and D. R. Currey. 1989. *Quaternary geology of the Great Basin: 28th International Geological Congress, field trip guidebook T117.* Washington, D.C.: American Geophysical Union.

Stokes, W. L. 1986. *Geology of Utah.* Utah Museum of Natural History occasional papers no. 6. Salt Lake City. □

Utah!

VISITOR INFORMATION

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Salt Lake City, Utah 84106-3313
Photos courtesy Utah Travel Council
unless otherwise noted

Utah Information

U.S. Geological Survey, Rm. 8105, Federal Bldg., 125 S. State St., Salt Lake City, UT 84138. Utah topographic maps and small Utah mineral exhibit on display in Lobby.

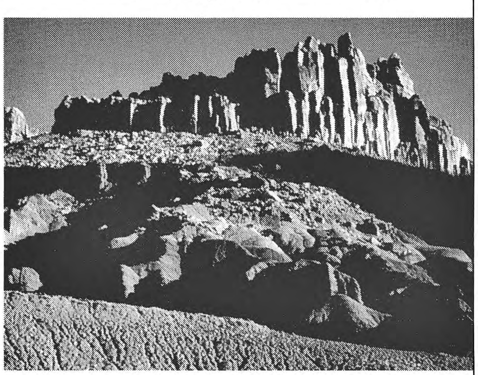
Utah Geological Survey, 2363 S. Foothill Dr., Salt Lake City, UT 84109. Utah-related professional papers, miscellaneous publications, public information series, and collecting guides. Utah mineral exhibit, organized by county, on display in foyer.

Utah State Historical Society, 300 Rio Grande, Salt Lake City, UT 84101. Official state agency for archaeology and paleontology; site of the Utah State Historical Museum and the photographic archives.

Utah Tourism and Recreation Information Center, Utah Travel Council, Council Hall/Capital Hill, Salt Lake City, UT 84114-7420; 801/538-1030, fax 801/538-1399.

Utah Gem, Mineral, and Prospecting Clubs

Beehive Rock & Gem Club (Ogden), P.O. Box 1011, Ogden, UT 84402.



Capitol Reef National Park; Tom Till photo.

Cache Geological & Archaeological Society (Logan), P.O. Box 441, Logan, UT 84321.

Color Country Gem & Mineral Society (Panguitch), P.O. Box 769, Panguitch, UT 84759.

Golden Spike Gem & Mineral Society (Ogden), 1354 31st Street, Ogden, UT 84403.

Dinosaur Gardens, Vernal; Evan Hall photo, courtesy Dinosaurland.

Mineral Collectors of Utah (Salt Lake City), c/o Phil Richardson, 1599 E. Evergreen Ln., Salt Lake City, UT 84106-3313.

Moab Points & Pebbles (Moab), P.O. Box 625, Moab, UT 84532.

Northern Utah Prospectors Association (Ogden); call for information: Chester Miles 801/775-3141.

Timpanogos Gem & Mineral Society (Provo), P.O. Box 65, Provo, UT 84601-0065.

Arches National Park.

Tooele Gem & Mineral Society (Tooele), P.O. Box 348, Tooele, UT 84074-0348.

Utah Federation of Gem & Mineralogic Societies (Salt Lake City), 1223 N. 1500 W., Salt Lake City, UT 84116.

Utah Gold Prospectors Club (Salt Lake City), c/o Frank Powell (editor), 2639 W. 7080 S., West Jordan, UT 84084.

Wasatch Gem Society (Salt Lake City), P.O. Box 26491, Salt Lake City, UT 84126-0491.

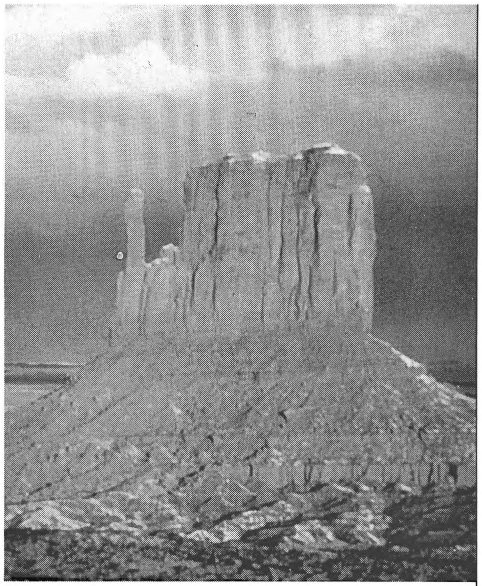
Wasatch Rock & Mineral Club (Brigham City), P.O. Box 152, Brigham City, UT 84302.

Utah Collections and Displays

Brigham Young University Earth Science Museum, 1683 N. Canyon Rd., Provo, UT 84602; 801/378-3680. Fossil exhibits.

College of Eastern Utah Prehistoric Museum, 155 E. Main St., Price, UT 84501; 801/637-5060. Archaeological, dinosaur, and fossil exhibits; features a Huntington mammoth.

Dixie College, Science Building, 225 S. 700 E. St., George, UT 84770. Mineral, rock, and fossil displays in halls of the science building; open year round when school is in session.



Monument Valley; Tom Till photo.

Edge of the Cedars, Anasazi Museum State Park, Blanding, Utah; 801/678-2238. Archaeological exhibits.

Emery Museum of Natural History, 96 N. 100 E., Castle Dale, UT 84513; 801/381-5252. Dinosaur and fossil exhibits.

Fremont Indian State Park and Museum, Clear Creek Canyon, 24 miles southwest of Richfield, Utah; 801/527-4631. Archaeological exhibits.

Great Basin Museum, 328 W. 100 N., Delta, UT 84624; 801/864-5013. Fossil, mineral, and mining exhibits; features Cambrian trilobites from the Wheeler Shale.

John Hutchings Museum of Natural History, 685 N. Center St., Lehi, UT 84043; 801/768-8710. Archaeological, fossil, mineral, and seashell exhibits, highlighted by state's largest public display of minerals from Bingham, Mercur, Park City, and Tintic district.

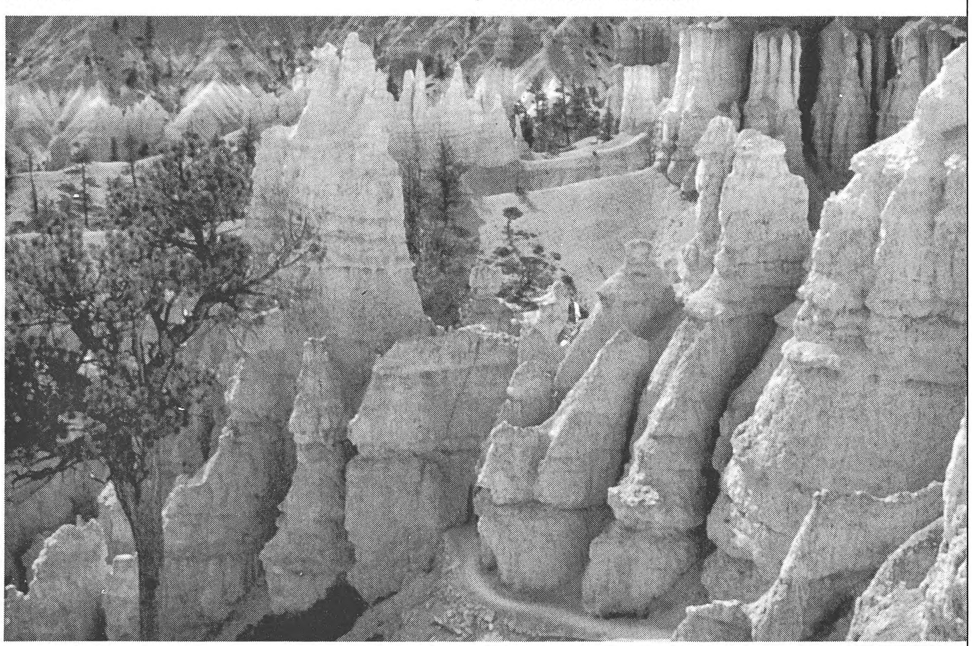
Park City Museum, 528 Main St., Park City, UT 84060; 801/649-6104. Small mining museum in historical section of downtown area; Park City visitor information, 1-800/453-1360.

Tintic Mining Museum, Top Floor, City Hall, 241 W. Main St., Eureka, UT 84628; 801/433-6842. Mining and mineral exhibits of the Tintic district, Juab County, Utah.

Tooele Valley Railroad Museum, Vine and Broadway, Tooele, UT 84074; 801/882-2836. Mining displays scattered among railroad exhibits.

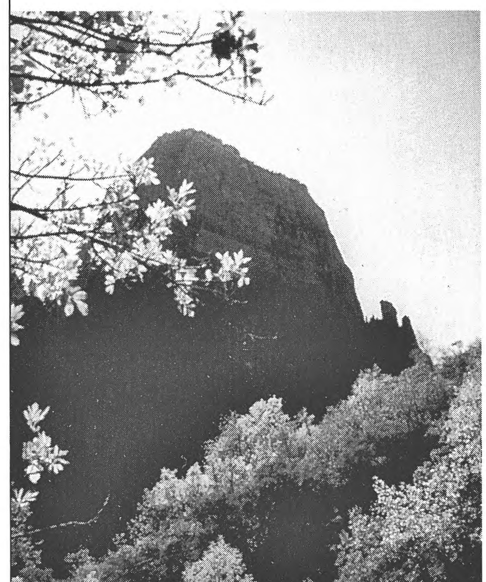
Union Station Natural History Museum, 2501 Wall Ave., Ogden, UT 84401; 801/629-8444. Small display of fossils and minerals.

Utah Field House of Natural History State Park and Dinosaur Gardens, 235 E. Main St., Vernal, UT 84078; 801/789-3799. Located in Vernal, Utah, self-proclaimed capital of "Dinosaurland," this museum has a mixture of dinosaur, fossil, mineral, and fluorescent-rock displays, plus fourteen life-sized fiberglass replicas of dinosaurs and prehistoric mammals in the museum's outdoor Dinosaur Garden.



Queen's Garden, Bryce Canyon National Park; John Telford photo.

Utah Museum of Natural History, University of Utah, Salt Lake City, UT 84112; 801/581-4303. Housed within the George Thomas Building on Presidents' Circle, the museum is home to an excellent collection of minerals on display in the Norton Hall of Minerals and four full-skeletal mounts arranged in interactive dioramas. Descriptive audio recordings and an additional sixteen fossil mammal skeletons give depth to the museum's fossil exhibits.



Great White Throne, Zion National Park; Frank Jensen photo.

Utah State University, Geology Bldg., Logan, UT 84322. Numerous mineral displays; open year round when school is in session. Contact Dr. Don Fiesinger.

Weber State University Museum of Natural Science, 3750 Harrison Blvd., Ogden, UT 84408; 801/626-6653. Dinosaur, fossil, mineral, and rock exhibits; small full-skeletal Allosarus mount.

Western Mining and Railroad Museum, 296 S. Main St., Helper, UT 84526; 801/472-3009. Small museum in historic railroading town situated in the heart of Utah's coal country.

Westminster College of Salt Lake City, 1840 S. 1300 E., Salt Lake City, UT 84105. Numerous display cases with fossil, mineral, and rock specimens in several hallways peripheral to the De-

Philip Richardson, a structural engineer, has worked in Utah's Bingham pit and is a field collector of Utah minerals.

Thor's Hammer, Bryce Canyon National Park; Tom Till photo.

partment of Chemistry. Collection was assembled by Westminster's defunct Department of Geology but has remained on public display; open year round when school is in session.

Interesting Utah Sites, Tours, and Events

Barrick Mercur Gold Mines Visitor Center, Mercur Canyon, south of Tooele, Utah. Mining, gold-processing, and mineral exhibits; summer only, call 801/268-4447 for information.

Cleveland-Lloyd Dinosaur Quarry, 35 miles south of Price in Cleveland, Utah. Contact Bureau of Land Management office in Price for information, 801/637-4584. A small visitor center is located at this site, where over ten thousand dinosaur bones have been excavated. This is a working quarry, with a small dinosaur exhibit, and home to Utah's Allosaurus.

Dinosaur Quarry Visitors Center, near Jensen, Utah (6 miles north of junction of U.S. 40 and Route 149); call 801/789-3799 for information. On view in the quarry wall are dinosaur bones embedded in their original rock and buri l position. Display signs and interpretive exhibits provide information; open summers through Labor Day; free.

Kennecott's Bingham Canyon Open-Pit Copper Mine Overlook, 25 miles southwest of Salt Lake City, Utah. Observation deck and mining exhibits, with copper-mining and copper-processing video presentation; open April through October; call 801/322-7300 for information; small fee.

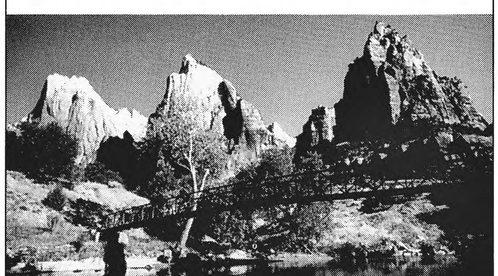
Ogden River Parkway, near mouth of Ogden Canyon, off of Twelfth Street, Ogden, Utah. Outdoor dinosaur park with life-sized dinosaur replicas and picnic tables; no admission.

Timpanogos Cave National Monument, Route 3, P.O. Box 200, American Fork, UT 84003; 801/756-5238 or 801/756-5239; small fee. Seasonal (summer), cave tours.

Tintic Silver Festival, Eureka, Utah. Town celebration with mining and silver exhibits and a parade, held on the third weekend in August; call 801/433-6842 for information.

Tours for Collecting Utah Minerals. Collecting tours of Utah's Thomas Mountain Range and other select Utah locations. Target minerals are topaz, red beryl, durangite, and other associated minerals of the western Utah rhyolites. Tours are available all year and any day of the week, depending on weather and advance reservations. Must supply own transportation, accommodations, and provisions. Rates $25 and up per person per day, depending on location and number in party. Some restrictions may apply.

For information, call or write John Holfert, 1263 S. Cannon Dr., Farmington, UT 84025, phone 801/451-4536; or Steve Allred, 3888 Marshall Rd., Erda, UT 84074, phone 801/884-3908. □



Three Patriarchs, Zion National Park.

Of Geologic Interest

- **Six National Parks**
  - **Arches**
  - **Bryce Canyon**
  - **Canyonlands**
  - **Capitol Reef**
  - **Great Basin**
  - **Zion**
- **Six National Monuments**
  - **Cedar Breaks**
  - **Dinosaur**
  - **Hovenweep**
  - **Natural Bridges**
  - **Rainbow Bridge**
  - **Timpanogos Cave**
- **Two National Recreation Areas**
  - **Flaming Gorge**
  - **Glen Canyon**
- **Seven National Forests**
- **Forty-four State Parks**

Minerals of the

Big Indian Copper Mine

SAN JUAN COUNTY, UTAH

ARNOLD G. HAMPSON
P.O. Box 1379
1301 Merritt Way
Dolores, Colorado 81323

Unless noted, all photos by the author and of specimens from his collection

THE BIG INDIAN COPPER MINE is an open-pit copper mine located within the Big Indian mining district in San Juan County, Utah, approximately 33 miles northwest of Monticello and about the same distance southeast of Moab. The mine has been a noted source of exceptionally fine specimens of azurite rosettes and clusters since 1981. At that time, azurite and malachite specimens from the locality were labeled as coming from the Blue Grotto prospect.

Later, from 1982 through 1984, Mike Madson and associates mined high-quality azurite rosettes and clusters as well as malachite from an open cut at the Blue Jay claim, which is adjacent to the Blue Grotto prospect. Again in 1988 and 1989 in a mining operation located on the same vein on the Nevada claim, Graham Sutton and Bob Lane recovered a large quantity of similar azurite specimens.

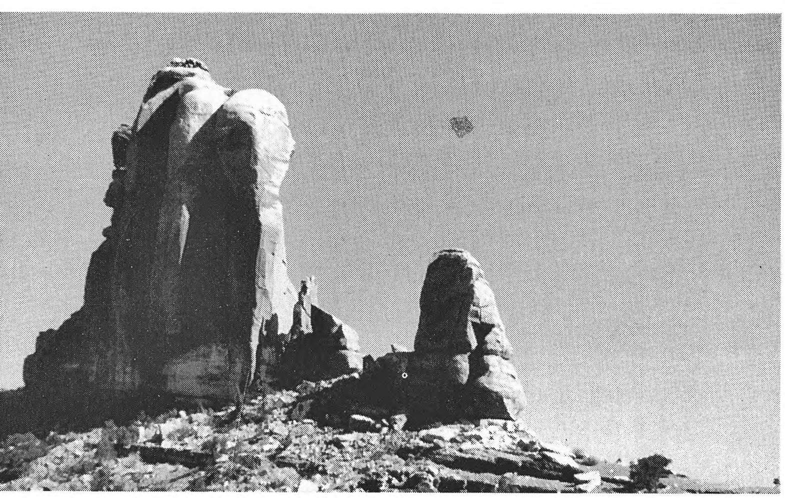


Figure 1. **Big Indian Rock, 7 miles south of the Big Indian Copper mine along San Juan County Route 106 (Big Indian Road).**

In addition to very attractive azurite and malachite, a number of copper arsenates and associated minerals also may be found, most occurring as microsized crystals from the Blue Jay pit. The copper arsenates thus far identified are chalcophyllite, clinoclase, conichalcite, cornwallite, olivenite, and tyrolite. These are associated with azurite, chalcocite, chrysocolla, copper, cuprite, malachite, aurichalcite, barite, goethite, and wulfenite.

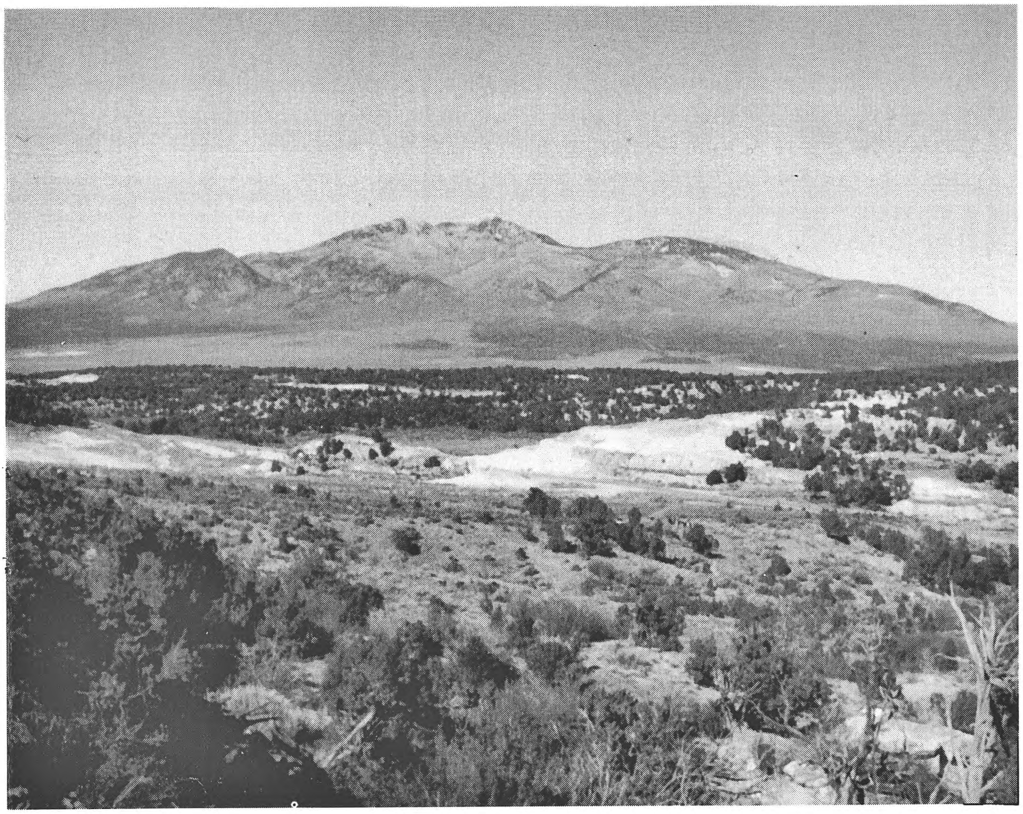
Location

The Big Indian Copper mine is situated in southeastern Utah in the northeastern portion of San Juan County and in the northern part of Lisbon Valley. The mine is approximately 4 miles north of the noted uranium discovery made by Charles A. Steen in 1952—the Mi Vida mine—that initiated the uranium boom of that era on the Colorado Plateau. (The Big Indian Copper mine should not be confused with the Big Indian Uranium mine, also in Lisbon Valley but approximately 8 miles further south.)

The Big Indian Copper mine is located within the SW ¼ of Sec. 27, the SE ¼ of Sec. 28, the NE ¼ of Sec. 33, and the N ½ of Sec. 34, T. 29 S., R. 24 E. of the Salt Lake Base and Meridian. The Blue Jay pit, the most westerly workings of the mine, is shown on the U.S. Geological Survey 7.5-minute Sandstone Draw quadrangle (provisional edition 1987), where it is referred to as the "Open Pit Mine." Geodetic coordinates of the Blue Jay pit are 38°14′42.2″ latitude and 109°16′18.8″ longitude.

The mine can be reached by driving south on San Juan County Route 113, the paved Lisbon Road, from the junction with Utah State Route 46, 6.6 miles east of La Sal Junction. A distance of 4.9 miles places one opposite the Blue Jay pit, located 200 feet to the west of the road.

Arnold Hampson is an active micromounter and photomicrographer. He last wrote for Rocks & Minerals *on "Mineral Photography through the Microscope" (March/April 1992).*



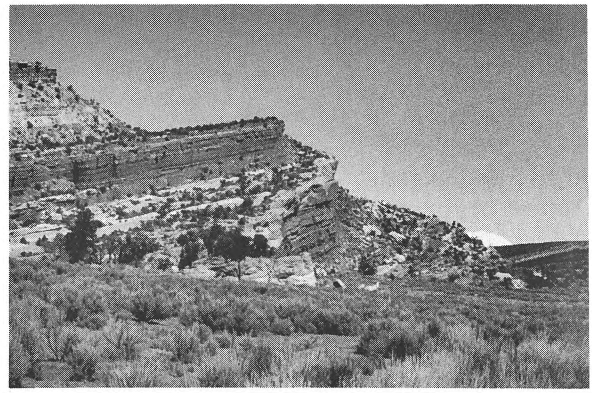
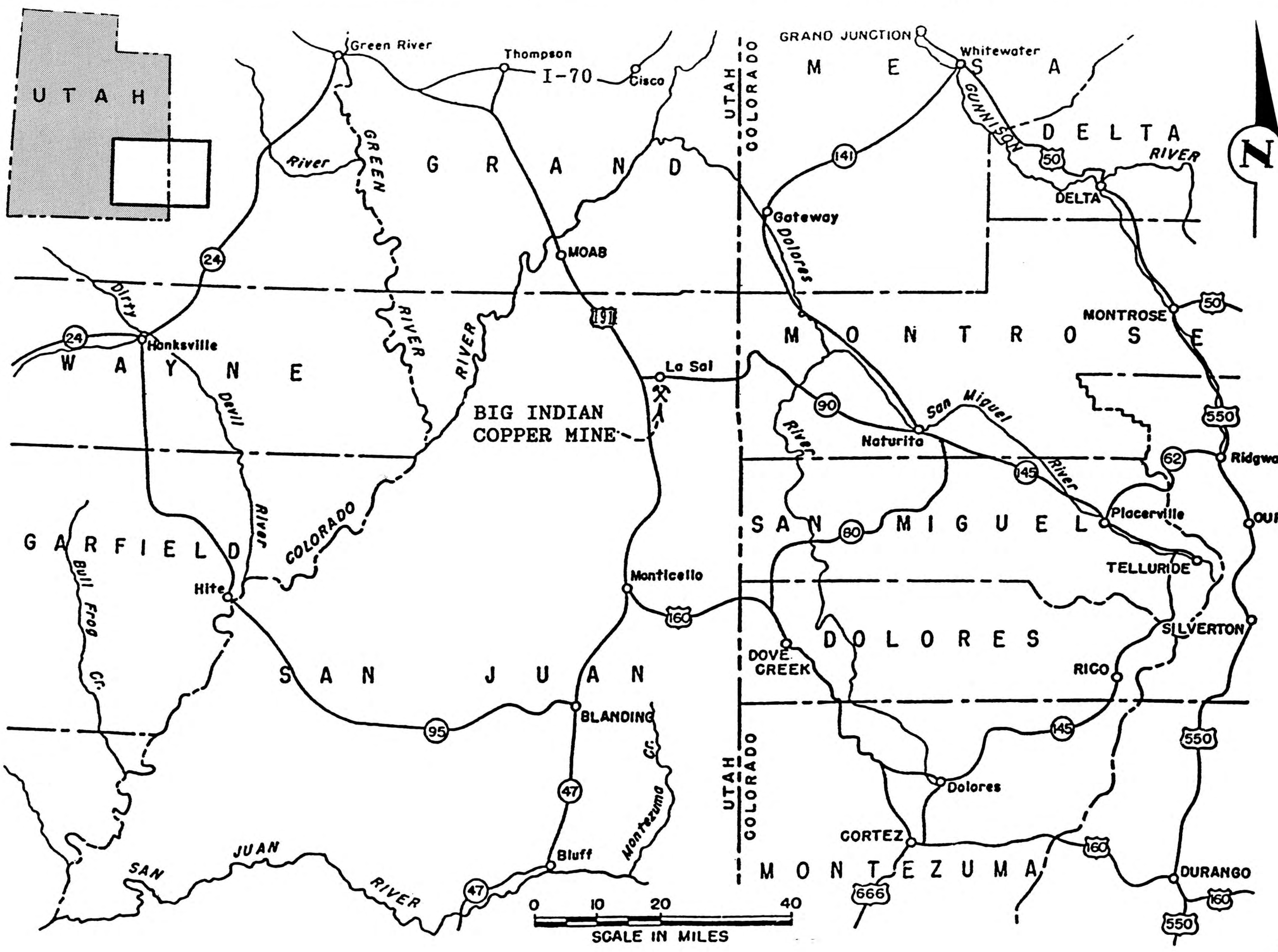


Figure 3 (above). **The upthrown side of the Lisbon Valley fault exposing the vertical red sandstone of the Wingate Formation over the Chinle Formation, both of Triassic age, located 6 miles south of the Big Indian Copper mine.**

Figure 2 (left). **Big Indian Copper mine located in the middle distance with the La Sal Mountains in the background centered approximately 14 miles to the north.**

Figure 4 (below). **Location map of the Big Indian Copper mine (from Steen et al. 1953).**



History

What was to become the Big Indian Copper mine many centuries later was quite probably first worked for minerals by the Anasazi Indians, the "Ancient Ones" of the American Southwest. While mining for azurite, the owner of the Nevada claim came across three complete skeletons plus an additional skull. All the bones had turned green from partial replacement by malachite. Examination of the site suggests that these bodies were buried alive in the sandy clay gouge of a tunnel collapse while mining azurite from 700 to 1,200 years ago (Jones 1991).

The Big Indian district was organized on 19 June 1892 (Butler et al. 1920). Beginning about 1903, copper ore was being mined from Cretaceous sandstone (Dakota Formation) in the Big Indian Valley (Lekas and Dahl 1956); and by 1912, there were four patented claims in the district (Butler et al. 1920).

By 1918, a mill for processing ore had been constructed adjacent to and south of the active claims. The milling process consisted of agitating the crushed copper ore with a sulfur dioxide solution, then separating the copper-bearing solution from the insoluble portion of the ore, and, lastly, precipitating the copper by boiling the pregnant solution (Morgan 1923).

The main orebody, 15–25 feet thick, consisted of oxidized copper minerals that had impregnated a bed of sandstone cropping out at the surface. It was estimated to contain about 100,000 tons of ore grading 3% copper. Below and separated by 20 feet of shale was a similar sandstone bed hosting an orebody carrying about 1% copper and said to be in the millions of tons. This lower orebody had been developed by tunnels and winzes to a depth of 75 feet and was known to extend for at least 500 feet in length and width (Morgan 1923).

Prepared in 1926 was a claim map entitled Big Indian Copper Mine. It shows several claims in the area and such features as the Blue Jay shaft, the mill, several buildings, a tunnel, and the locations of shafts and winzes. Most of the structures were situated approximately 0.5 mile southeast of the Blue Jay shaft. The only claims in addition to the Blue Jay that appear to have had mining development at that time were the Durango, Mineral Point, Copper King, and Jim Dandy. The Blue Jay claim is separated from the other four by the Nevada claim, which shows no development on the 1926 map.

Isachsen (1954) notes that during World War II copper was mined by open-pit methods at the Big Indian Copper mine but that production had ceased by 1954.

When first visited by the author in December 1968, active mining was taking place on the Nevada and adjacent claims east of the county road. Copper ores were being leached in ponds located adjacent to and south of the mining operation. It appeared that this particular mining operation had been active for several years. It was not until approximately 1973 that extensive mining began in the Blue Jay pit.

In August 1974, all of the claims comprising the Big Indian Copper mine were owned by Centennial Development Company. Mining operations ceased that year when an overly steep wall of the Blue Jay pit collapsed (Hasenohr 1976). Later in 1974, these mining properties were acquired by Noranda Mining Company and subsequently by the Big Indian Uranium Corporation of Salt Lake City, Utah. Because the uranium industry was severely depressed at the time, Big Indian was unsuccessful; so a buyer for the property was sought during the period from 1980 through 1982 (Mike Madson, pers. com. 1992).

In 1978, Mark Luttrell, a geology student at Mesa State College in Grand Junction, Colorado, discovered attractive azurite crystal clusters in clay gouge in a roadcut along the east side of the Blue Jay pit. Local collectors recovered additional crystals from this site for several years (Dick Dayvault, pers. com. 1993).

Commercial Mineral Collecting

In 1981, after becoming aware of the presence of azurite crystal clusters, a group of commercial mineral collectors tunneled northwesterly into the hillside from the roadcut, traversing the Blue Jay claim. The venture yielded several hundred fine azurite rosettes, crystal groups, and balls (Mike Madson, pers. com. 1992).

About 100 feet of the azurite-bearing ground was mined before the tunnel was caved. Most of the recovered specimens were sold at the California Federation Show held in Anaheim that year, with the locality reported as the Blue Grotto prospect (Wilson 1981).

In June 1982, Mike Madson Minerals of Grand Junction, Colorado, obtained a lease on the Blue Jay and adjoining claims from Western Consolidated Mines of Lakewood, Colorado, which had acquired the property earlier that year. Madson and the other principals of his group, Allen Smith and Charles Fedler, conducted an open-cut mining operation on the hillside just west of the azurite-bearing roadcut on the Blue Jay claim. During the two-year period from June 1982 through June 1984, the Madson group mined approximately 1,200 tons of sandstone and clay of which 7.2 tons contained azurite and malachite. After removing the clay and cleaning the material, about 7,200 pounds of azurite was recovered. The principal product consisted of broken and smaller azurite nodules and comprised 70% of the material produced. This was marketed in Japan and China as paint pigment, known commercially as "azurite grain." Split azurite geode pairs were sold as jewelry material and made up approximately 10% of the total production. The remaining 20% of salable material consisted of in excess of twenty thousand individual azurite geodes as well as many hundreds of unusual azurite-malachite groups (Madson 1985). Madson estimates the value of their operation to have been $240,000 (Mike Madson, pers. com. 1992). Azurite rosettes over 1.5 cm in diameter were recovered and offered for sale as specimen material, with the smaller rosettes and broken pieces being marketed as paint pigment (Dick Dayvault, pers. com. 1993).

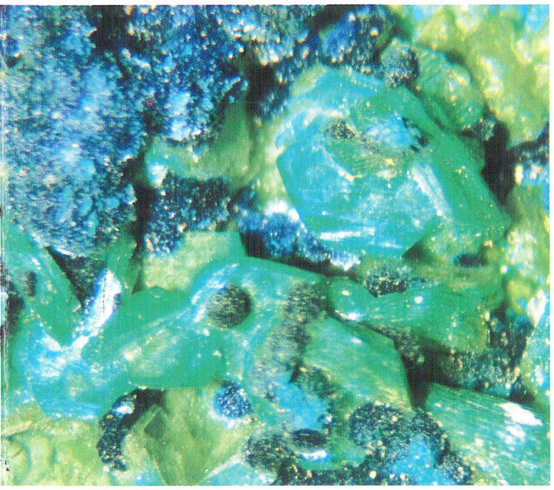


Figure 5. Chalcophyllite with azurite collected in 1968 from the Nevada claim; largest chalcophyllite crystal 1.5 mm across.

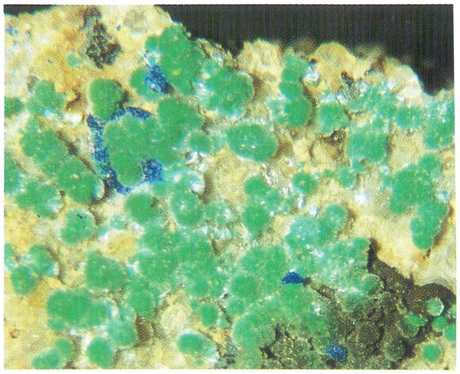


Figure 7 (above). Malachite sprays collected in 1970 from the Nevada claim; width of view 0.9 mm.

Figure 6 (left). Azurite nodule, 7 × 5 cm, on malachite, Big Indian Copper mine. Terry Huizing specimen and photo.

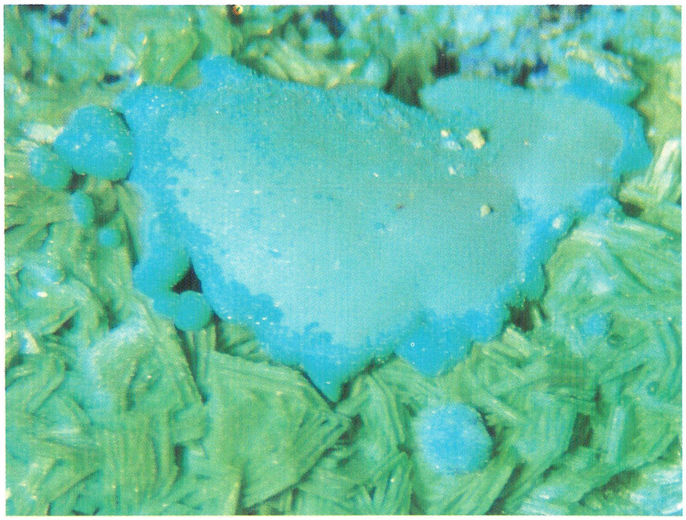


Figure 8. Chrysocolla after chalcophyllite with tyrolite collected in 1968 from the Nevada claim; width of view 1.2 mm.

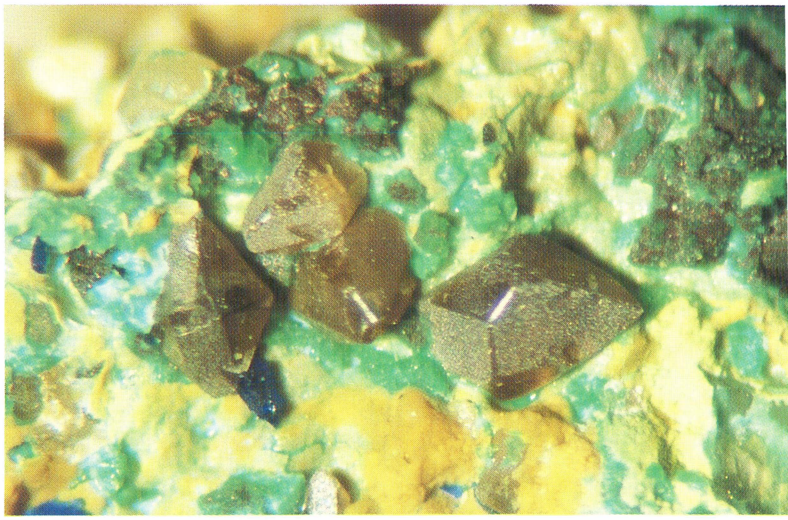


Figure 10. Wulfenite with malachite from Blue Jay pit; length of largest wulfenite crystal 1.0 mm.

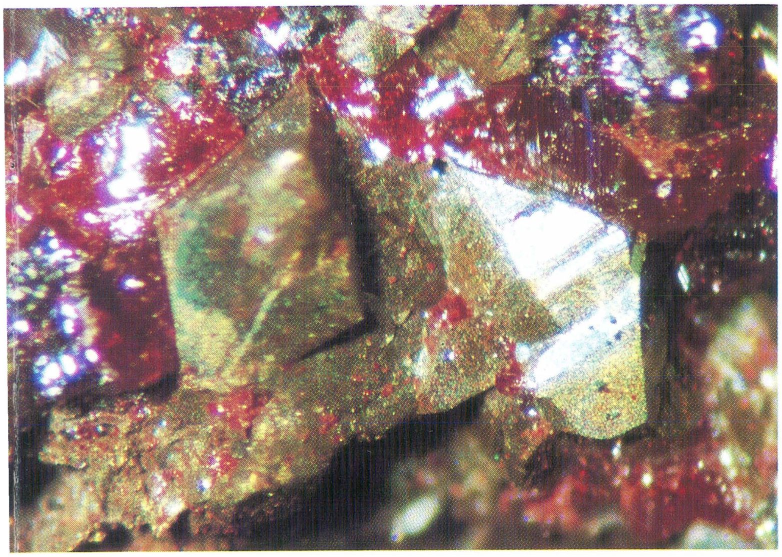


Figure 9. Copper with cuprite from the Blue Jay pit; copper crystals 1.0 mm in length.

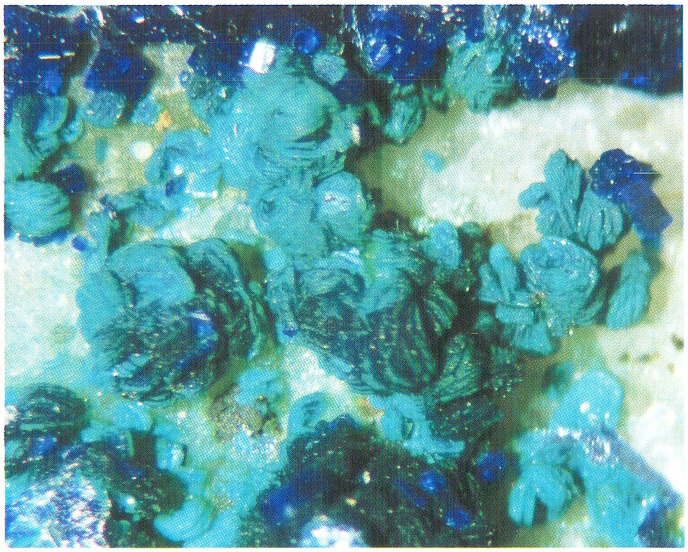


Figure 11. Cornwallite with azurite from the Blue Jay pit; width of view 0.6 mm.

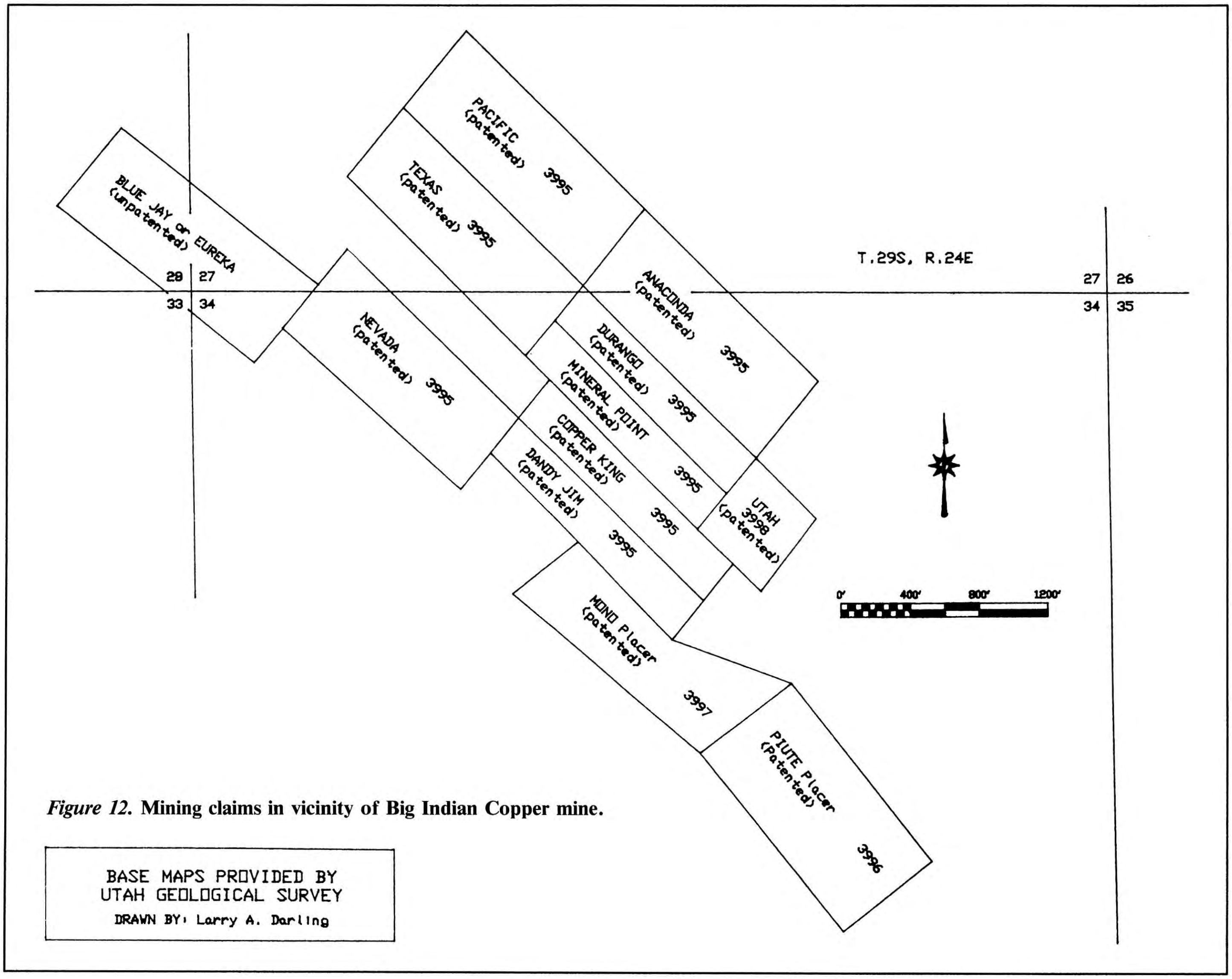


Figure 12. **Mining claims in vicinity of Big Indian Copper mine.**

In 1985, eight patented claims of the Big Indian Copper mine were put on public auction by San Juan County, Utah. Four unassociated parties obtained two patented claims each and now individually comprise the ownership of the Big Indian Copper mine. Steve Kosanke of La Sal, Utah, is the present owner of the Nevada and Texas claims (Steve Kosanke, pers. com. 1992).

In the fall of 1988 and the spring and summer of 1989, Graham Sutton and Bob Lane mined a portion of the Nevada claim that they had leased from Steve Kosanke. This open cut, adjacent to the former Blue Grotto and Mike Madson operations, produced one hundred thousand specimens of azurite rosettes and minor malachite. In addition, 6,000 pounds of broken nodules were marketed for paint pigment (Graham Sutton, pers. com. 1992).

At the present time, just east of County Road 113 opposite the Blue Jay pit, there appears to be a small-scale intermittent screening operation for azurite nodules used in the jewelry trade. The nodules occur in decomposed sandstone and generally range from 5 to 25 mm in diameter.

Geology

Copper mineralization at the Big Indian Copper mine occurs along the down-thrown block of the Lisbon Valley fault. This fault forms a major structural break along the crest of the Lisbon Valley anticline, with its surface evidence beginning at a point approximately 5 miles west of the small settlement of La Sal and extending southeasterly for approximately 16 miles.

Isachsen and Evensen (1956) report that the Lisbon Valley anticline is a salt structure formed primarily by plastic flow and local thickening of salt and gypsum of the underlying Paradox Formation. The Lisbon Valley fault cuts the anticline longitudinally, placing the Jurassic Morrison Formation in contact with the Pennsylvanian Hermosa Formation. The fault dips steeply to the northeast with a maximum stratigraphic throw in excess of 3,800 feet. It is thought to be the result of differential uplift rather than subsidence because the upthrown limb of the anticline is considerably more domed and dips more steeply than its opposite limb.

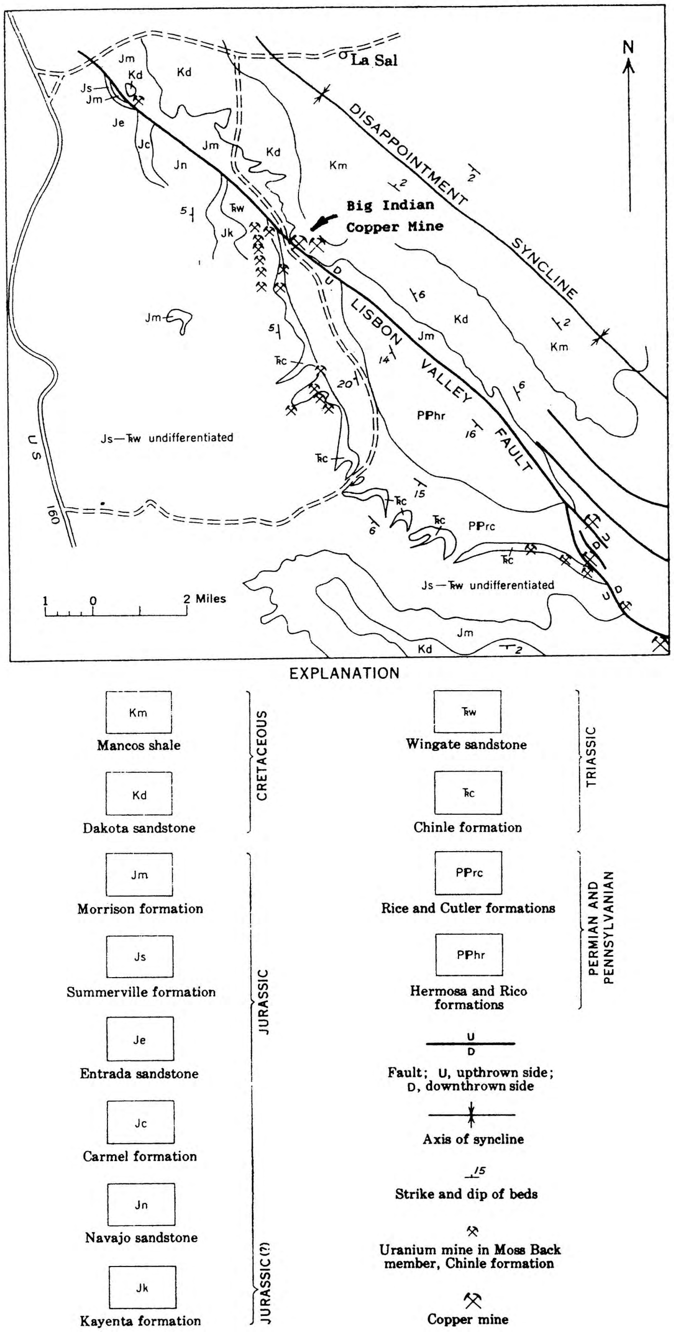


Figure 13. **Generalized geologic map of Lisbon Valley, San Juan County, Utah (from Isachsen and Evensen 1956).**

Isachsen (1954), in agreement with several other researchers, believes the copper deposits to be of hydrothermal origin. The deposit was formed when copper-bearing solutions migrated up the Lisbon Valley fault zone and mineralized the Dakota Sandstone.

Morrison and Parry (1986) suggest that copper mineralization along the fault is derived from copper-bearing fluids that originated from the La Sal intrusive center and were driven deeply underground during the uplift of the La Sal Mountains. The circulating fluids from greater depths, upon mixing with brines of the Paradox Formation, became saline fluids. Vertical faults, such as the Lisbon Valley fault,

Figure 14. **The Blue Jay pit of the Big Indian Copper mine.**

allowed for an upward migration of the saline fluids, where mixing with shallower, less saline, and more reducing fluids resulted in the precipitation of the copper mineralization presently occurring along the fault.

Hasenohr (1976) reports that copper minerals distributed along the Lisbon Valley fault occur within the Dakota Sandstone as fault and fracture fillings, void fillings, and replacements of calcite and chalcedony cements, sulfide nodules, carbonate spheres, cement of fault breccia, and replacement of fossil wood fragments.

Mineralogy

Aurichalcite, $(Zn,Cu)_5(CO_3)_2(OH)_6$, is rare in the Blue Jay pit, where it occurs as acicular crystals that form sky-blue radial sprays up to 2 mm across. It has been confirmed by microprobe analysis.

Azurite, $Cu_3(CO_3)_2(OH)_2$, commonly occurs as 3-8-cm rosettes of subparallel crystals and as individual crystals to 2.5 cm in length. Found with the rosettes in the roadcut area of the Nevada and Blue Jay claims are radiating and spherical groups to 12 cm of azurite with malachite. Also occurring on the Nevada claim are spherical concretions of azurite up to 5 cm in diameter, often with hollow centers that contain microsized azurite crystals. The smaller of these concretions are locally referred to as "blueberries." Blue to blue-black prismatic crystals to 5 mm in length and thin tabular crystals in sprays and as individuals occur on sandstone fractures in the Blue Jay pit. Azurite crystals partially and completely altered to malachite have also been found.

In addition to its common association with malachite, azurite is found with barite, chalcocite, chalcophyllite, chrysocolla, clinoclase, conichalcite, copper, cornwallite, cuprite, goethite, kaolinite, psilomelane, and wulfenite.

Most of the azurite that has found its way into the specimen market has been commercially collected as rosettes and crystal groups from the Blue Grotto prospect, the Blue Jay claim, and the Nevada claim, all on the same vein and in close proximity to each other.

Barite, $BaSO_4$, is rare and occurs as white to clear groups of tabular crystals and as thin pointed blades up to 0.4 mm in length. It is associated with azurite in fractures within the Dakota Sandstone at the Blue Jay pit.

Calcite, $CaCO_3$, is found as a cementing agent of sandstone.

Chalcocite, Cu_2S, is present in the Blue Jay pit as dark gray masses in veins and veinlets associated with malachite, azurite, olivenite, and wulfenite. Chalcocite, djurleite, and digenite are the dominant sulfides present in the fault breccias (Hasenohr 1976).

Chalcophyllite, $Cu_{18}Al_2(AsO_4)_3(SO_4)_3(OH)_{27} \cdot 33H_2O$, occurs sparsely as micaceous, tabular hexagonal, blue-green crystals to 3.0 mm; they are occasionally associated with azurite crystals and spherical groups. Crystals of chalcophyllite may be partially or completely altered to pale yellowish-brown chrysocolla. Chalcophyllite was found during open-pit mining of the Nevada claim in the late 1960s and more recently in the Blue Jay pit. Its identity has been verified by microprobe analysis.

Chalcopyrite, $CuFeS_2$, occurs as small blebs in massive chalcocite in the Blue Jay pit.

Chrysocolla, $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$, occurs as pale turquoise-blue masses with azurite and rarely with barite; it also occurs as 0.2-mm spheres and crusts of pale blue-green matted fibers. As a pseudomorph after chalcophyllite, it occurs as yellow-brown crystals that are fully and partially altered and that are associated with chalcophyllite. Microprobe analysis confirmed the identity of chrysocolla.

Clinoclase, $Cu_3(AsO_4)(OH)_3$, occurs as dark bluish-green elongated crystals to 0.7 mm, singly and as radiating groups, on fractures or growing on crystalline azurite, malachite, and tyrolite. Some single crystals lying flat on sand grains along fractures exhibit sharp double terminations. It is also found as densely intergrown subparallel crystal groups. Some clinoclase crystals have rounded faces that terminate in a smooth point, much like an arrowhead, whereas other euhedral crystals exhibit a tapered wedgelike termination. Clinoclase has only been observed in the Blue Jay pit, where it occurs sparsely. Its identity has been verified by microprobe analysis and X-ray diffraction methods.

Conichalcite, $CaCu(AsO_4)(OH)$, occurs as 0.5-mm, bright blue-green, thin tabular crystals and as intergrown groups with chalcophyllite. It also occurs as bright blue-green, fine-grained, micaceous crusts perched on 0.5-mm spheres of azurite with chalcophyllite. Conichalcite was confirmed by microprobe analysis.

Copper, Cu, occurs as small masses embedded in cuprite and associated with azurite and malachite. One copper crystal enclosed in cuprite has been observed. Plates of native copper up to 10 cm with encrusting cuprite were collected in the 1970s (Dick Dayvault, pers. com. 1993).

Cornwallite, $Cu_5(AsO_4)_2(OH)_4 \cdot H_2O$, is rare and occurs as 1-mm, botryoidal, translucent green crusts and as overgrowths on azurite crystals in the Blue Jay pit. The color of cornwallite may appear dark blue-green when it occurs as an overgrowth on azurite. Microprobe analysis confirmed its presence.

Covellite, CuS, associated with chalcocite and djurleite is present in very minor amounts. It occurs as fine lamellae intergrown with and partially replacing the djurleite; as composite masses of several intergrown covellite lamallae; as larger, approximately 0.5-mm, bladed crystals embedded in digenite; and as finely disseminated grains within sooty chalcocite (Hasenohr 1976).

Cuprite, Cu_2O, found in the Blue Jay pit, occurs mostly as deep red masses exhibiting a submetallic luster. Small open spaces in massive cuprite occasionally contain partially developed crystals that appear to be modified octahedra. Hasenohr (1976) observed that a few veinlets of cuprite consisted of masses of fine needlelike crystals of the variety chalcotrichite. Cuprite has been observed enveloping native copper and is typically associated with azurite and malachite. Occasionally, octahedral crystals to 0.7 mm occur; some are partially altered to malachite and are associated with azurite, malachite, psilomelane, and wulfenite. Cuprite has also been found as small blebs within chalcocite.

Digenite, Cu_9S_5, occurs as grayish-white material and is one of the dominant sulfides present in the fault breccias within the Blue Jay pit (Hasenohr 1976).

Djurleite, $Cu_{31}S_{16}$, chalcocite, and digenite are the dominant sulfides in the fault breccias (Hasenohr 1976).

Enargite, Cu_3AsS_4, occurs with tennantite in some of the fracture fillings either intergrown with or replacing tennantite. Small blebs of native copper have also been noted in association with enargite (Hasenohr 1976).

Goethite, α-$Fe^{+3}O(OH)$, as yellow-brown spherical aggregates exhibiting an internal radiating concentric structure, commonly occurs in seams in sandstone associated with azurite in the Blue Jay pit.

Kaolinite, $Al_2Si_2O_5(OH)_4$, occurs as a massive, compact, white earthy mineral that fills open spaces in sandstone and that is associated with azurite and malachite. It is also found as scaly white masses associated with malachite and as masses filling voids between grains of quartz sand.

Malachite, $Cu_2(CO_3)(OH)_2$, occurs commonly as velvety aggregates of acicular crystals in spherical, botryoidal, and stalactitic forms that are typically associated with azurite and cuprite. One micromass of arborescent malachite was observed that contained cuprite centers, suggesting that the specimen represents arborescent copper that had first completely altered to cuprite and later partially altered to malachite. Malachite additionally occurs as fibrous radiating sprays in sandstone fractures and as partial and complete pseudomorphs of prismatic azurite crystals. A number of old malachite specimens were incorrectly labeled brochantite; no brochantite has been reported from this location (Dick Dayvault, pers. com. 1993). Malachite occurs commonly with azurite and is also found with chalcocite, chrysocolla, copper, kaolinite, psilomelane, wulfenite, and unknown no. 1.

Olivenite, $Cu_2(AsO_4)(OH)$, has been found rarely as pale olive-green acicular crystals to 1.5 mm in length associated with chalcocite. It also occurs as grayish-white fibrous sprays of crystals to 1.5 mm associated with crystals of azurite on sandstone fracture surfaces. It has only been found in the Blue Jay pit, and its identity has been confirmed by microprobe analysis.

"*Psilomelane*" is commonly present in the Blue Jay pit as black botryoidal crusts, ranging up to 25 mm across, on sandstone and is associated with tyrolite, azurite, and malachite. Isachsen (1954) reports that manganese staining is common along fractures. Microprobe analysis confirmed "psilomelane" as a mixture of manganese oxides.

Pyrite, FeS_2, is reported by Isachsen (1954) and Bullock (1981).

Quartz, SiO_2, as grains of sand is the main constituent of the sandstone host rock that is frequently impregnated by azurite, malachite, and other minerals. Quartz crystals up to 2 mm across have been observed in vugs and fractures in sandstone on the Nevada claim.

Sphalerite, (Zn,Fe)S, occurs as a fracture filling of fissure veins (Hasenohr 1976).

Tennantite, $(Cu,Fe)_{12}As_4S_{13}$, as 0.1-1.2-mm interlocking anhedral crystals, is a minor constituent in sulfide fracture fillings (Hasenohr 1976).

Tenorite, CuO, is reported by Hasenohr (1976) as veinlets and fracture fillings in sandstone in the Blue Jay pit. It also occurs as microscopic crystals in partially oxidized djurleite and also as a coating on cuprite.

Tyrolite, $CaCu_5(AsO_4)_2(CO_3)(OH)_4 \cdot 6H_2O$, occurs in the Blue Jay pit as sky-blue foliated crusts and masses filling the seams and void spaces between sand grains; as micro-sized fibrous radiating crystal groups to 2.0 mm in diameter associated with manganese oxides; and as tiny spherical aggregates composed of micaceous plates. Occasionally, clinoclase crystals are found perched on tyrolite. Microprobe analysis and X-ray diffraction confirmed its presence.

Wulfenite, $PbMoO_4$, occurs as honey-yellow to dark tan euhedral crystals of pyramidal habit, up to 1.0 mm, with an adamantine luster. They exhibit a number of unusual forms; however, the dominant form is the second-order upper and lower pyramid. The crystals are perched on sandstone and are associated with azurite, malachite, chalcocite, cuprite, and an unidentified yellow mineral. Microprobe analysis showing the presence of lead and molybdenum confirmed these crystals to be wulfenite.

Unknown no. 1 occurs as a dull yellow powdery material and as small masses that occasionally show microstalactitic forms. It thinly covers malachite, quartz grains, and kaolinite. Microprobe analysis shows the presence of lead, vanadium, and copper and suggests that most of the material may be mottramite. This mixture also includes some clay and vanadium oxide or vanadium hydroxide.

Unknown no. 2 occurs as small green masses and spherical aggregates associated with azurite; its appearance is similar to that of conichalcite. Microprobe analysis indicates that this mineral is composed of approximately 35% copper and 12% arsenic and suggests the mineral species arhbarite with the formula $Cu_2(AsO_4)(OH) \cdot 6H_2O$. X-ray diffraction work on this mineral has thus far been inconclusive in attempting to confirm a species.

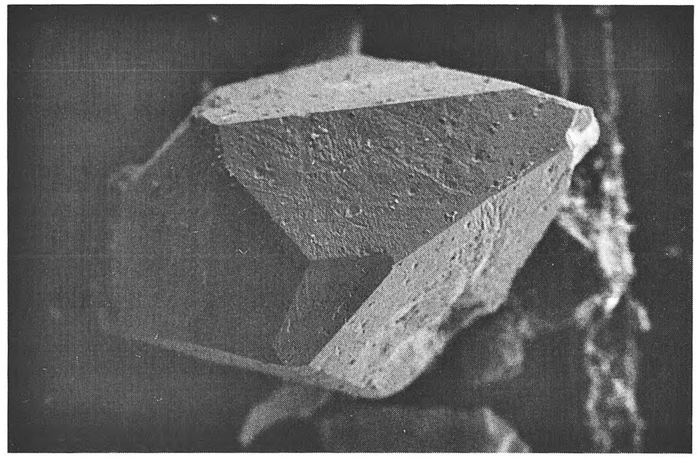


***Figure 15.* SEM of wulfenite crystal from the Blue Jay pit; length of crystal approximately 0.8 mm.**

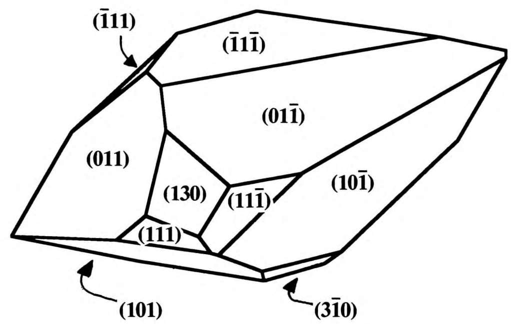


***Figure 16.* Computer drawing of the distorted wulfenite crystal shown in figure 15 with the Miller indices noted on the crystal faces.**

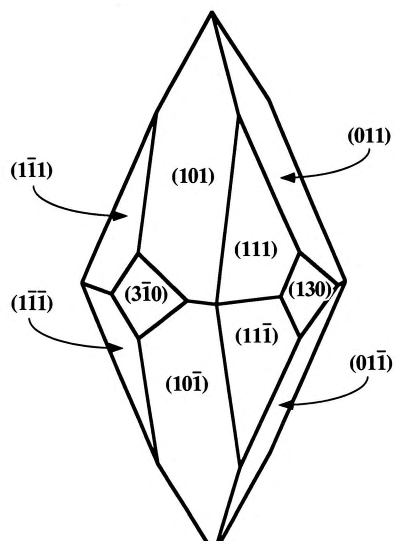


***Figure 17.* Computer drawing of the ideal shape of the wulfenite crystal shown in figure 15. The dominant forms consist of upper and lower second-order tetragonal pyramids. These are modified by minor upper and lower first-order tetragonal pyramids and the third-order tetragonal prism (the kite-shaped faces).**

Conclusions

In recent years, the only active mining taking place at the Big Indian Copper mine has been on a modest scale for the commercial collecting of azurite rosettes and clusters. Specimens of the copper arsenates collected by the author are chiefly from outcrops and from boulders within the upper oxidized zone of the presently inactive Blue Jay pit.

The sulfides reported by Hasenohr (1976) undoubtedly occurred in the Blue Jay pit at a depth below that which is presently exposed. It is believed that collapse of the pit's high wall in 1974 buried the sulfide ore exposed in the lower levels.

Should mining be resumed, more and a larger variety of species may be exposed. At the present time, attractive microspecimens of several copper species can be found within the Blue Jay pit and on the Nevada claim.

Anyone planning a collecting trip to the Big Indian Copper mine should first obtain permission to enter patented or leased property. The Nevada claim, where recent commercial mining of azurite specimens has taken place, is presently posted "No Trespassing" by its owner, Steve Kosanke of La Sal, Utah.

Acknowledgments

I gratefully acknowledge the support and assistance given by several individuals in the preparation of this article: Joe Marty for locating and forwarding unpublished reports; Mike Madson for providing a history of his azurite mining operations; Pat Haynes and Will Moats for accompanying me on collecting trips and bringing the presence of unusual material to my attention; Carrie Hampson for scanning collected material through the binocular microscope and locating crystallized areas for study and preparation for micromounts; Graham Sutton and Steve Kosanke for providing information on recent mining activity; Paul Hlava, Sandia National Laboratory, Albuquerque, for the SEM photo, the computerized drawings, and his microprobe analyses that confirmed the identity of several copper arsenates and associated minerals; Jim Wilson, Weber State University, for performing X-ray diffraction work; Robin B. Halverson for typing the draft copies of this article and making needed revisions on a regular basis; and Peter Modreski, Dick Dayvault, Will Moats, and Tom Rosemeyer for reviewing the manuscript and offering helpful suggestions.

REFERENCES

Bullock, K. C. 1981. *Minerals of Utah.* Utah Geological and Mineral Survey bulletin 117.

Butler, B. S., et. al. 1920. *The ore deposits of Utah.* U. S. Geological Survey professional paper 111.

Hasenohr, E. J. 1976. Copper mineralization in the Lisbon Valley, San Juan County, Utah. Unpublished master's thesis, Ohio State University.

Isachsen, Y. W. 1954. Ore deposits of the Big Indian Wash—Lisbon Valley area. In *Uranium deposits and general geology of southeastern Utah: Guidebook to the geology of Utah, Number 9*, 95–105. Utah Geological Society.

Isachsen, Y. W., and C. G. Evensen. 1956. Geology of uranium deposits of the Shinarump and Chinle formations of the Colorado Plateau. In *Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for United Nations' International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955*, 273–75. U. S. Geological Survey professional paper 300.

Jones, B. 1991. Minerals-in-depth: Azurite. *Rock & Gem* 12(3): 38–39.

Lekas, M. A., and H. M. Dahl. 1956. The geology and uranium deposits of the Lisbon Valley anticline, San Juan County, Utah. In *Geological and economic deposits of east and central Utah: Intermountain Association of Petroleum Geologists 7th Annual Field Conference*, 161–68.

Madson, M. E. 1985. The Blue Jay azurite deposit (abs.). In *6th Annual New Mexico Mineral Symposium: Nov. 9–10, 1985, Socorro, New Mexico*, 3.

Morgan, H. J. 1923. Mill operation of the Big Indian Copper Company (1918). Unpublished master's thesis, University of Utah.

Morrison, S. J., and W. T. Parry. 1986. Formation of carbonate-sulfate veins associated with copper ore deposits from saline basin brines, Lisbon Valley, Utah: Fluid inclusion and isotopic evidence. *Economic Geology* 81:853–66.

Steen, C. A., G. P. Dix, S. W. Hazen, and R. R. McClellan. 1953. *Uranium-mining operations of the Utex Exploration Company in the Big Indian district, San Juan County, Utah.* U. S. Bureau of Mines information circular 7669.

Wilson, W. E. 1981. What's new in minerals? *Mineralogical Record* 12:387. □

Although perhaps best known for its topaz, red beryl, variscite, and azurite, Utah boasts an array of mineral species.

AN OVERVIEW OF RECENT

Mineral Collecting in Utah

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MINERAL COLLECTING IN THE STATE of Utah has undergone a resurgence over the last ten years that has led to the development of numerous new collecting sites and the rediscovery of old locations. During the past five years, this renewed collecting activity has resulted in the discovery of as many as eight new minerals and many more species new to Utah.

Here we present a list of localities in Utah that have either been historically important or have recently produced mineral specimens of collector interest. It should be noted that there are hundreds of other localities in Utah from which some specimens may have been produced and many localities that may produce such material in the future. The intent of this article is to summarize those localities most likely to be represented by material in a collection of Utah minerals rather than to provide an exhaustive listing. The data assembled is based on the personal knowledge of the authors, supplemented by reference to *Mineral Localities of Utah* (Bullock 1970).

Listing of a location in this article does not give permission to visit or collect material; indeed, some of these locations have long been closed and are inaccessible to collectors. Many specimens were produced when mining districts were active in the late 1800s through the 1960s. With the exception of some districts mentioned below, most historically active mining districts in the state have been inactive for decades, although claims and property rights remain current and some exploration activity occurs on an irregular basis.

Beaver County

Lincoln district: The Creole mine, located at the south end of the Mineral Range between Beaver and Milford, has

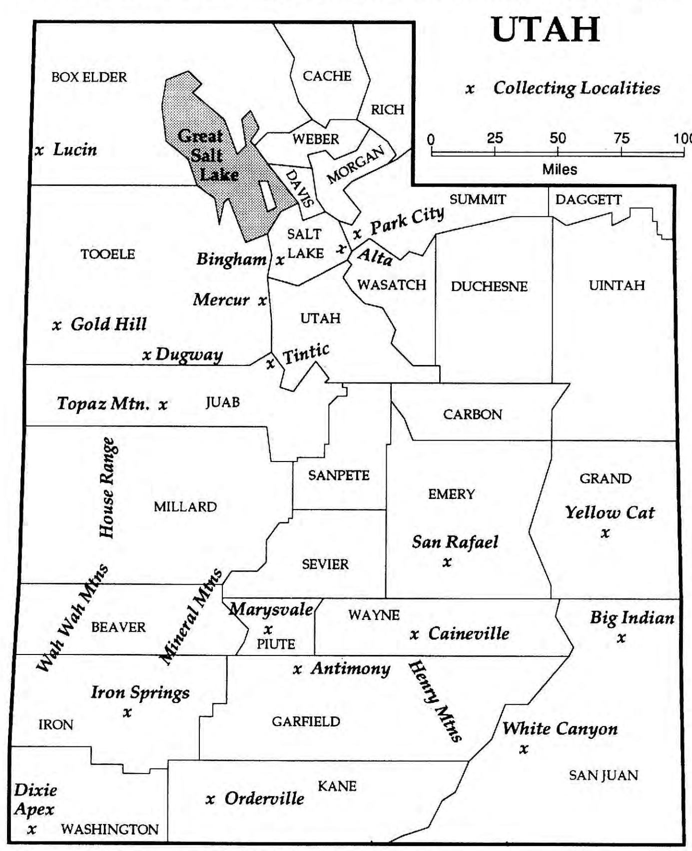

Figure 1. **Selected Utah collecting localities.**

Philip Richardson is a structural engineer who has worked in the Bingham pit and is a well-known field collector of Utah minerals.

Dr. James R. Wilson is a mineral collector, mineralogist, and professor of geology at Weber State University in Ogden, Utah.

Dr. Paula N. Wilson is a mineral collector, geochemist, and assistant research professor in the Department of Geology and Geophysics at the University of Utah.

large dumps on which can be found a variety of skarn minerals (garnet, hematite, and actinolite) as well as pyrite and bismuthinite in veins of massive calcite. Serpierite, the Ca-Cu-Zn sulfate, occurs at this locality. Also found is chrysocolla with azurite and malachite on black, copper-sulfide–coated plates.

Mineral Mountains (Rock Corral area): This small batholith has miarolitic cavities containing orthoclase feldspar and smoky quartz. Most collecting occurs on the west side of the range centered around the Rock Corral, a local recreation area. Baveno twins and other types of twinning are common to the feldspar in some pockets. A few specimens of spessartine garnet on smoky quartz have been collected as have sceptered amethyst crystals. Aquamarine, usually frozen in the matrix, occurs in a few locations. Wulfenite is known from one small prospect, and scheelite and related skarn minerals occur in a series of small abandoned mines peripheral to the batholith on the east side of the range.

Pine Grove district: This old mining district is the site of a deeply buried porphyry molybdenum deposit that has been periodically evaluated by mining companies. More recently, slightly sceptered amethystine quartz has been produced from a claim in this area. Many crystals have a brilliant luster; some exhibit skeletal growth and may have clay and/or fluid inclusions. Some specimens from this locality were mistakenly labeled "Mineral Mountains."

Preuss (Newhouse) district: The Cactus mine and nearby workings have pink crystals of anhydrite, goethite pseudomorphs after siderite, and sprays of tourmaline in quartz crystals. A few nice pyrite crystals, up to several centimeters on an edge, have been collected in this area as well. The road to the Cactus mine was gated recently, and entry is now restricted.

Rocky district: The Maria mine and the Bawana mine are large open pits that were worked in the 1960s for copper and still provide the opportunity to collect magnetite, chrysocolla, azurite, malachite, brochantite, and contact metamorphic minerals. The rare species stringhamite was described from this locality, and clintonite, the calcium mica, is abundant here.

Beaver Lake district: Across the valley from the Rocky district is the site of another large open pit, the OK mine, which has produced some very nice azurite, malachite, and acicular brochantite. Some specimens of azurite show replacement by malachite.

Wah Wah Mountains: The Violet claims—owned by Rex Harris and others of Delta, Utah—are still producing gem-quality red beryl, marketed through Tina's Jewelry and Gems in Delta and by mineral dealers at all major shows. Red beryl is unique to the rhyolites of the western United States and was originally referred to as "bixbite" (a name that is now discredited). The specimens occur in clay seams in the rhyolite in the form of simple prismatic crystals elongated along the *c*-axis. Although many crystals have opaque inclusions, quite a few have good clarity and color, in whole or in part, that makes them suitable for gemstones. Red beryl from this locality differs in crystal

Figure 2. **Amethystine quartz, Pine Grove district, Beaver County; specimen 11 × 7 × 5 cm. Phil Richardson specimen, Joe Marty photo.**

habit from red beryl of the Thomas Range (see below), although their geologic occurrence in rhyolite is similar. Red beryl from the Wah Wah Range is seldom associated with topaz crystals, whereas beryl with topaz and bixbyite are common in the Thomas Range.

Skarns in the vicinity of Wah Wah Pass on Utah Highway 21 have yielded large, pale green grossular garnets, some of which have cores of andradite. One area, under claim, has produced a large number of simple dodecahedral crystals, averaging 1 cm with the largest up to 2.5 cm.

Star Range district: The Harrington-Hickory and the Rebel mines have supplied a diverse suite of copper minerals as well as wulfenite and vanadinite mainly as micro- to thumbnail-sized specimens.

Box Elder County

Pilot Range: The mines of Tecoma Hill are best known for wulfenite that occurs in a variety of forms along with hemimorphite and plattnerite. The wulfenite typically occurs as paper-thin crystals but also as tabular, blocky, and dipyramidal crystals. Aurichalcite has been found here in attractive specimens on a brown limonite matrix. Other minerals found at Tecoma Hill include aragonite, cerussite, and smithsonite. The nearby Copper Mountain mine has malachite, cuprite, and native copper in nodules of copper-bearing clay (gibbsite).

The quarry near Lucin (Utahlite Hill) still produces var-

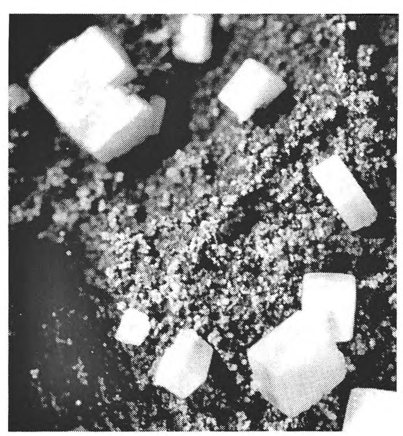

Figure 3. **Wulfenite crystals to 2 mm, Tecoma Hill mine, Lucin district, Box Elder County; Joe Marty specimen and photo.**

iscite with small vugs containing metavariscite. Crandallite and the variety of other aluminum phosphates that occur in the more famous Clay Canyon location are not found here. Variscite from Lucin occurs in a white quartzite, and polished specimens have surfaces that are spotted, mottled, or threadlike in appearance. Recent collecting at the private quarry has unearthed some of the finest material ever collected there. Especially stunning are specimens that exhibit "eyes"—concentrations of color shades in concentric bands. Variscite also occurs near Snowville.

Davis County

Great Salt Lake: In this and other counties that border the Great Salt Lake, it may be possible to find crystals of gypsum (up to 15 cm) and halite along the shore and in the muds of the lake. Less-common minerals such as aragonite, blödite, glauberite, mirabilite, and thenardite occur under appropriate conditions of salinity and temperature but may not be stable in collections.

Emery County

San Rafael Swell area: The Dexter mine in Calf Mesa continues to be a source of a wide variety of hydrated iron sulfates and phosphates, including alunogen, coquimbite, copiapite, diadochite, römerite, and voltaite. Excellent glassy purple crystals of coquimbite occur here. A great variety of uranium minerals were produced from these mines.

The area for several miles north and south of the interstate on the east side of the Swell has abundant jasper as both solid nodules and as geodes. Celestine, calcite, and quartz occur as both solid fillings and as crystals within the jasper concretions. Some of the quartz-bearing geodes have microcrystals of goethite on the quartz.

Celestine also occurs as a vein in the south-central part of the Swell about 20 miles southeast of Emery, where claim holders and collectors have extracted large plates and crystals from interlacing joint fractures within sandstone. Crystals are up to 10 cm on an edge, but the material is commonly fractured. The celestine is pale sky-blue and in direct sunlight fades to colorless or milky crystals.

Figure 4. **Celestine crystals, 13.5 × 9 × 5.5 cm, San Rafael Swell area, Emery County. Phil Richardson specimen, Joe Marty photo.**

The mines of Temple Mountain and numerous other localities in this county have produced many different uranium minerals along with arsenic and a variety of sulfides and arsenides in minor amounts. Logs and organic debris host the uranium/vanadium mineralization. Sulfide material oxidizes to produce szomolnokite, rozenite, kornelite, ferricopiapite, and erythrite.

Garfield County

Blue Spruce Campground area: Jasper is widespread in this area, particularly in the gullies.

Coyote Creek (antimony) district: This area has produced massive stibnite, often with curved striated patterns; it occurs in sandstone, and crystals are uncommon.

Henry Mountains: Octahedral pyrite crystals as well as large masses of malachite have come from a mine in Bromide Basin.

Grand County

Floy Station, Thompson, Yellow Cat, Poison Strip districts: These areas, located generally south of I-80, east of Green River and north of Arches National Park, are areas in which abundant jasper and agate occur. In the Thompson area, agate pseudomorphs of barite and aragonite can be found. The aragonite pseudomorphs exhibit the pseudohexagonal form that results from twinning. Much of this area was mined for uranium, and many different uranium minerals occur here.

North Mountain, La Sal Mountains: This area has been a source of azurite, malachite, bornite, pyrite, and quartz. Quartz ranges from colorless to deep smoky in color.

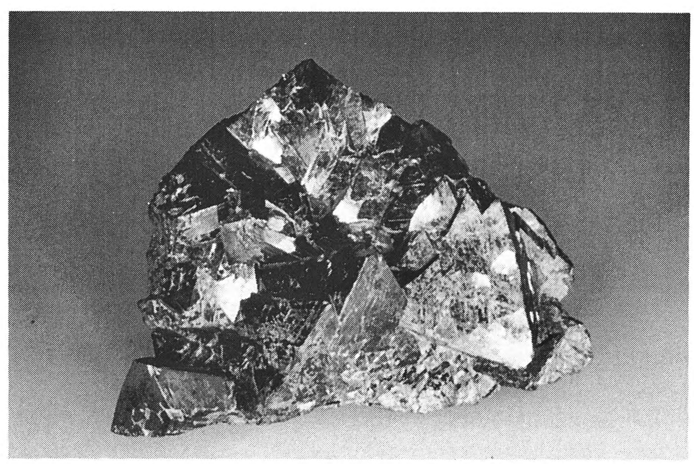

Figure 5. **Magnetite, 4.5 × 3.5 cm, Three Peaks area, Iron County. Phil Richardson specimen, Terry Huizing photo.**

Iron County

Iron Springs district: This famous mining area is located immediately west of Cedar City, and the large open-pit mines at Granite Mountain, Iron Mountain, and Three Peaks are visible for miles. Large masses of magnetite occur as replacement bodies in limestone. In addition to these large masses, there are countless fissures that were mineralized; these are generally more likely to have well-developed crystals. Veins in the Three Peaks area recently produced hundreds of very lustrous octahedral crystals (up to 4 cm on an edge) and several plates of crystals. The principal mineral is magnetite, often as lodestone, with accompanying pyroxene, apatite, siderite, calcite, amethyst, and other less-common minerals.

Escalante district: The Escalante Silver mine is now closed. Although most of the ore produced here was massive material, some micromounts of chlorargyrite, fluorite, and malachite were collected.

Figure 6. **Pseudobrookite, 0.95 cm high, Juab County. Dan Behnke photo.**

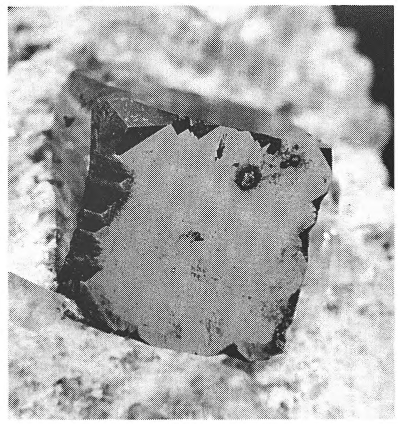

Figure 7. **Bixbyite, 1.1 cm across, Thomas Range, Juab County. Martin Zinn specimen, Jeff Scovil photo.**

Juab County

Deep Creek Mountains: Beryl, fluorite, quartz, and scheelite are known to occur at various mines and prospects throughout the Deep Creek Mountains. Large crystals of quartz, some in excess of 1 meter, have been reported from the Indian reservation at the south end of the Deep Creek Range.

Honeycomb Hills: The Spider mine has yielded specimens of autunite, boltwoodite, thomsenolite, sklodowskite, saleeite, and tridymite.

Thomas Range (Topaz Mountain): Without a doubt, this is the premier area for mineral collectors in Utah, and hundreds of collectors from across the United States and foreign countries are annually drawn to the white rhyolite of these mountains in search of topaz and other minerals.

Topaz is the most common and most sought after mineral to be found here. As you drive into the area, clear fragments of topaz sparkle in the sand along the road, causing many a driver to halt in the road and try to find the source of the brilliant reflection. This leads to one of the first lessons to be learned here: Tiny crystals make big sparkling reflections. When first exposed in the rock, topaz is a orange-brown sherry color but rapidly loses this color in direct sunlight. It also fades upon long exposure in strongly lit mineral cabinets. The Bureau of Land Management has set aside an area in Topaz Valley (Topaz Cove) for mineral collectors, and it is to this area that most people go. In spite of the large number of visitors, topaz and other minerals are still abundant. The color and transparency of the material found in Topaz Valley make it the best topaz in the Thomas Range.

Topaz occurs as prismatic crystals with a variety of other crystal forms (dipyramids, prisms, and pinacoids) that can give crystal terminations a sharp chisel-like appearance, a tapered flat-topped look, or a rounded appearance from a multitude of small faces. Because topaz has excellent basal cleavage, some flat-topped specimens may actually be broken, and collectors purchasing specimens should examine them carefully.

Topaz occurs at many localities throughout the Thomas Range, and collectors who wish to explore outside of Topaz Valley will find ample area to roam. Some topaz will have inclusions, often hematite, or "sand" (rhyolite), sometimes to the extent that the crystal is completely opaque. At some locations, pink topaz occurs, typically as small crystals (up to 1 cm), and this color does not fade in the sun.

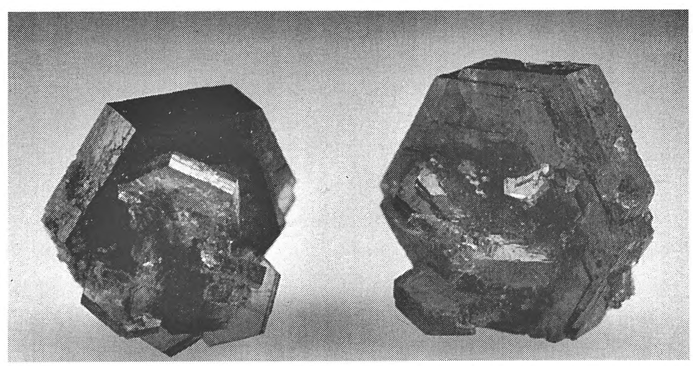

Figure 8. **Red beryl, left crystal 0.9 cm, Thomas Range, Juab County. John Holfert specimen, Jeff Scovil photo.**

In addition to topaz, red beryl and bixbyite can be found in the Thomas Range. Red beryl here is in the form of flat hexagonal discs; these may be found along the west wall in Topaz Valley. In recent years, a Thomas Range claim owned by John Holfert and Steve Allred has produced abundant red beryl in which the discs are aggregates forming "rosettes"; on occasion, several discs may be attached at angles to each other. (*Note: Collecting on this or other claims in*

Figure 9. **Topaz, 8.3 mm high, Thomas Range, Juab County. Dan Behnke photo.**

the Thomas Range is not allowed without prior arrangements with the claim holders.)

Bixbyite occurs as shiny black metallic cubes, sometimes with trisoctahedral modifications. It can be found alone or perched on topaz or altered garnet. Bixbyite is generally a few millimeters on edge, but specimens up to 1.5 cm have been found, principally in the north part of the range.

Garnet with a high spessartine component can be found at various locations throughout the range, but much of it has been altered to hematite. Thus, vitreous, translucent specimens are relatively rare. A pocket of large lustrous garnets was discovered in 1992 on the Holfert-Allred claim mentioned above. Some of these garnets exhibit alternating bands of altered and unaltered garnet, giving them striped (zebra) faces. Garnet Basin, Antelope Ridge, and locations in and around Topaz Valley have produced garnets of varying quality. Some exhibit only the trapezohedron whereas others show combinations of the trapezohedron and dodecahedron.

Specular hematite is common throughout the Thomas Range, often as small flakes on and included within topaz. More spectacular examples of hematite occur as plates and rosettes. A claim owned by Mike Sprunger in the nearby Drum Mountains has produced spectacular large plates.

Pseudobrookite occurs as individual needles or radiating clusters of acicular crystals up to 1.5 cm. It can be found throughout the range, sometimes occurring with topaz and hematite.

An isolated tin-bearing vein in the Thomas Range has produced the world's best specimens of durangite. Associated minerals are cassiterite (as crystals and wood tin), hematite, topaz (small and clear), tridymite, magnetite, ilmenite, and tantalite.

Other minerals found in the Thomas Range include fluorite and amethyst. Chalcedony from the Thomas Range fluoresces brilliant green. The uranium mineral weeksite was first identified from an open-pit mine along the east flank of the Thomas Range.

Spor Mountain district: This area is adjacent to the Thomas Range on its western side and is the site of active mining operations for beryllium that occurs as bertrandite in altered volcanic ash. No crystals or minerals of collector interest occur in the open-pit mines, although masses of chalcedony occur that fluoresce bright green. In the surrounding area are many abandoned fluorite and uranium mines with microcrystals of fluorite.

Tintic district: Tintic is one of Utah's famous mining districts in which large numbers of mining operations over the years have exploited the ores. The base-metal deposits of lead, copper, and zinc with their high silver and gold content have kept mining companies interested in this region for decades. However, development of the district was difficult because the complex geology of the folded and faulted ore-bearing sedimentary layers is concealed beneath layers of volcanics and alluvium.

Early mining of the oxidized copper ores unearthed world-class specimens of such copper arsenate minerals as clinoclase, olivenite, conichalcite, tyrolite, and arsenobismite. Major collections assembled at the turn of the century may also contain specimens of cerussite, crandallite, enargite, native silver, hessite, petzite, malachite, plumbojarosite, or argentojarosite. This district is the type locality of tinticite, and the mineral zunyite also occurs here. Large quantities of "turgite" (hematite with absorbed water), an iridescent iron ore, have been removed from the Dragon mine. Some of the mines that were known specimen producers are Bullion-Beck, Carissa, Centennial Eureka, Grand Central, Mammoth, and the Sioux-Ajax.

This mining district has recently produced many micro-sized specimens of copper arsenates as the dumps are reworked for a heap-leaching gold operation.

Kane County

Orderville: This small Utah town has several rock shops with an abundance of septarian nodules that are mined from claims south of town. Permission to collect on the claims is usually available (check at Joe's Rock Shop), but because the nodules are extracted from a layer deep below

Figure 10. **Septarian nodule, 9 cm high, Orderville, Kane County. Terry Huizing specimen and photo.**

Figure 11. Durangite, 3.2 mm high, on hematite, Thomas Range, Juab County. C. W. Allred specimen, Shane Allred photo.

Figure 12. Topaz, 2.8 cm high, Thomas Range, Juab County. Phil Richardson specimen, Terry Huizing photo.

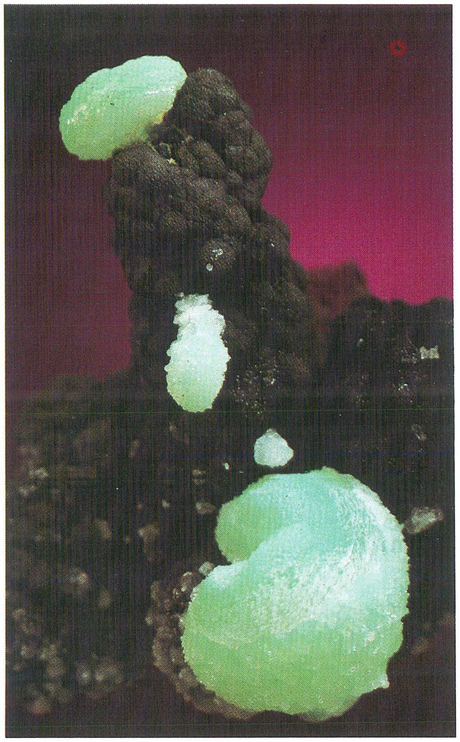

Figure 13 (right). Adamite, 2.8 cm high, Gold Hill, Tooele County. Jim Walker specimen, Jeff Scovil photo.

Figure 14. Variscite nodule, 9.2 cm across, Fairfield, Utah County. Martin Zinn specimen, Jeff Scovil photo.

Figure 16. Red beryl, 1.8 cm long, Wah Wah Mountains, Beaver County. Martin Zinn specimen, Jeff Scovil photo.

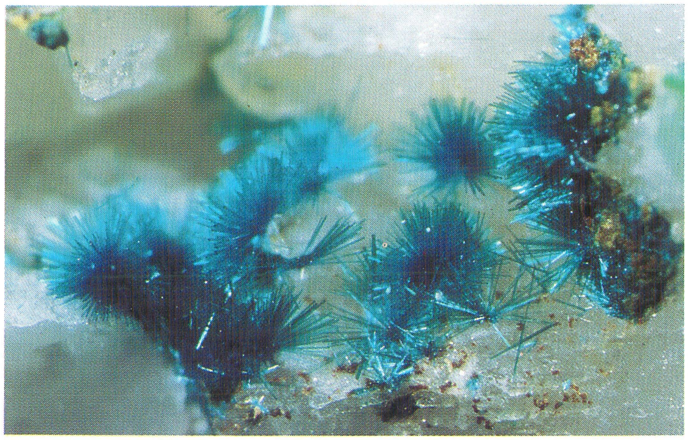

Figure 15. Connellite crystals on quartz, Gold Hill mine, Tooele County; width of view approximately 8 mm; Joe Marty specimen and photo.

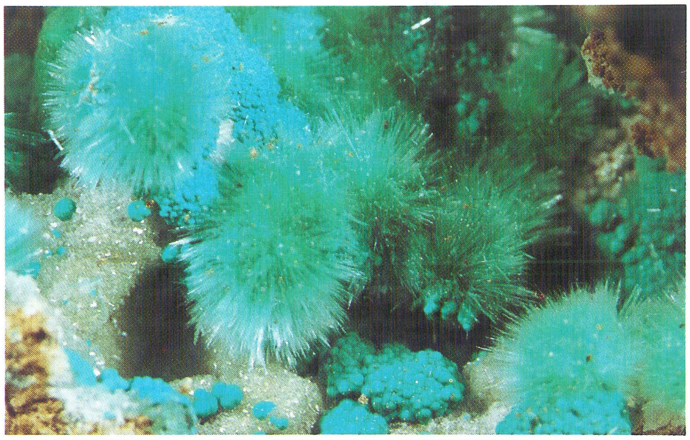

Figure 17. Microcrystals of aurichalcite with rosasite, Hidden Treasure mine, Ophir Hill area, Tooele County. Phil Richardson specimen, Joe Marty photo.

the surface, collectors usually only find scraps left by the excavators.

Millard County

Antelope Springs (Wheeler Amphitheater): This area is famous for its trilobites (see article in this issue), but collectors can also find abundant limonite pseudomorphs after pyrite. These are small (up to 1 cm) but well formed and highly lustrous.

Black Rock area: In this vicinity is found obsidian, including the red, black, and snowflake varieties. Snowflake obsidian is a result of cristobalite inclusions.

House Range (Amasa Valley, Notch Peak, Painter Spring): The intrusive granite that forms the bulk of this desert mountain range is host to quartz veins that have produced large (reportedly 60-cm) quartz crystals and some feldspar crystals. Clear, smoky, and amethystine quartz crystals to 20 cm have been collected by the authors, although most crystals have had their surfaces etched by late-stage fluids in the rock. Peripheral to the intrusion is a contact metamorphic zone in which massive garnet, vesuvianite, and sprays of actinolite occur along with some scheelite. A placer gold operation has been intermittently active in Amasa Valley, a high mountain basin. Chalcopyrite and molybdenite occur in the intrusive near Painter Spring.

Sunstone Knoll (Clear Lake): This small hill of basalt adjacent to Utah Highway 257 between Delta and Milford is the source of abundant cleavage pieces of labradorite that occur as phenocrysts in the basalt. Handfuls of the fragments can be picked up by strolling around the alluvial flats surrounding the hill or by collecting on the hill itself. The labradorite is a pale straw-yellow color and is nearly transparent. Some aragonite also occurs in the basalt. The location is under claim but is open to collectors, and a register is maintained.

Twin Peaks: Various prospects and quarries in the Twin Peaks area have produced specimens of martite, a hematite pseudomorph after magnetite. Iron mineralization occurs in fractures in a rhyolite and is associated with apatite and augite, much like the iron deposits of the Iron Springs district of Iron County.

Piute County

Marysvale area: Marysvale is a small town in the center of a long-active mining area. Originally, mines were worked for gold, lead, zinc, and silver. The Deer Trail mine, which was active in the 1960s, is best known for pale green fluorite in dodecahedral or cubo-octahedral forms, although early specimens were cubic. This material is covered with fine drusy quartz, which can be removed using hydrofluoric acid. The old mines in the Deer Trail area produced such rare minerals as tiemannite and various tellurides.

During the 1950s, there was a major uranium-mining industry in the area, with the uranium occurring in altered volcanic rocks. Along with the uranium minerals, such molybdenum minerals as jordisite, ilsemannite, and umohoite were found. Alteration of the volcanic rocks resulted in large deposits of alunite, which was mined for its aluminum content.

In recent years, collectors have sought zeolites in the volcanic rocks. Zeolites are common cavity fillings in several areas east and south of Marysvale. Most common are stilbite, heulandite, mordenite, and chabazite. Natrolite, scolecite, and thompsonite also have been found. Most volcanic ash in the area has undergone zeolitization, but crystals occur only in a few locations.

Rich County

Crawford Mountains: Strip mines for phosphate in the Crawford Mountains have been the source of microcrystals of fluellite.

Salt Lake County

Big Cottonwood Canyon (Brighton): The area around Big and Little Cottonwood canyons was the site of Pb-Zn-Ag mining during the late 1800s and continuing intermittently until the 1930s. Some of the mines extended under the ridge between the two canyons, and many mines that were originally separate were later interconnected. Because of the proximity of the mines to a large urban area and ski resorts, there has been an aggressive program to seal open mine portals and shafts.

Most of the mines in this area had a relatively simple assemblage of ore and gangue minerals, such as pyrite, bornite, galena, cerussite, sphalerite, smithsonite, and other related species, but few of the specimens were noteworthy. The most famous of the old mines, as far as mineral specimens are concerned, is the Carbonate mine, a source of spectacular aurichalcite. The adits are now caved, and the dumps have little to offer.

Today, the most important collecting area in Big Cottonwood Canyon is the Mountain Lake and related mines, where the rare borate ludwigite is present in abundance. Although mostly massive, magnetite is the most common metallic mineral found on the mine dumps.

Local collectors have found small crystals of pyromorphite on quartzite at the Baby McKee mine, near the Cardiff mine, in Cardiff Fork of Big Cottonwood Canyon.

Little Cottonwood Canyon (Alta): There are three stocks that have intruded the rocks of the Little Cottonwood Canyon area: one near the mouth of the canyon and two at the head of the canyon in the vicinity of Alta. These have resulted in a variety of contact metamorphic minerals such as wollastonite, garnet, epidote, vesuvianite, clintonite, titanite, spinel, specular hematite, forsterite, and periclase. Some of the mines near Alta produced some unusual and spectacular mineral specimens. Large masses of cerussite, composed of closely packed acicular crystals, were found at the West Toledo mine and probably others. The Emma and Little Emma mines were the source of the rare sulfide tungstenite as well as stolzite, but their dumps were used in the construction of parking lots for the ski area at Alta.

At the present time, collectors can find specimens of wulfenite, hemimorphite, and aurichalcite on the old dumps on the mountainside above town. Less common are pyrite (sometimes pseudomorphed by limonite), cerussite, and other secondary minerals. In Grizzly Gulch and Albion Basin near Alta, collectors can find nice examples of the contact metamorphic minerals. In White Pine Canyon and elsewhere in the intrusives can be found molybdenite and its alteration product, ferrimolybdite.

Bingham district: The mines of the Bingham area have produced a wide variety of mineral species, although the locality is not noteworthy for fine-quality specimens. The public can drive into the mining area to a viewing platform overlooking the gigantic open pit, but the high headwalls and limited personnel at the mine make collecting trips impossible; consequently very little specimen material comes out of the pit. In recent years, some of the minerals from Bingham that have been acquired by collectors include native copper (as flattened dendrites on quartzite), vivianite, spinel-twinned galena, and tetrahedrite. Some galena specimens have a tabular habit as a result of the alignment of Kersch Law twinned crystals. In 1989, one of the authors (JRW) identified green botryoidal material previously thought to be wavellite as faustite, a Cu-Zn-Al phosphate. Small green crystals perched on the faustite were determined to be wavellite. The phosphate minerals are associated with clay alteration in the deeper part of the pit.

Older specimens are quite likely to have come from one of the underground mines that operated in the peripheral region of the pit. Some of these mines were active until the 1950s, including the U. S. mine and the Lark mine, which produced abundant well-crystallized pyrite. Many specimens of pyrite occurred with quartz and have a colorful surface oxidation. The Lark mine produced tetrahedrite, enargite, pyrite with protruding quartz growths, and pyrite with remobilized galena. Other mine names that can be found with specimen material from earlier days are Highland Boy, Butterfield, and Carr Fork.

San Juan County

Big Indian district (Big Indian Wash–Lisbon Valley area): The mines of this and other districts in San Juan County are characterized by uranium-vanadium mineralization. Certain individual mines also have arsenic, selenium, copper, and/or silver mineralization. The uranium-vanadium minerals include becquerelite, carnotite, coffinite, doloresite, montroseite, paramontroseite, pascoite, tyuyamunite, uraninite, and vanoxite. One mine has produced pyrite nodules coated with microcrystals of bornite and covellite and also pseudomorphs after the pyrite nodules.

The Big Indian mine has produced a large amount of azurite in the form of nodular aggregates in clay seams. A major mining effort in the late 1980s yielded several hundred flats of azurite as both single flat radiating clusters up to 5 cm and as azurite aggregates on a malachite matrix in plates up to 25 cm across. The copper arsenates clinoclase, tyrolite, olivenite, and cornwallite occur here also.

Similar mineralization is seen in the *Elk Ridge area, Montezuma Canyon, Paradox Valley*, and the *White Canyon districts*. In the *White Canyon district*, the Happy Jack mine has produced a large number of mineral species, including the following: allophane, antlerite, azurite, barite, becquerelite, bieberite, bornite, boltwoodite, brochantite, carnotite, chalcanthite, chalcocite, chalcopyrite, covellite, erythrite, galena, gersdorffite, goethite, greenockite, gypsum, hematite, ilsemannite, jarosite, johannite, magnetite, malachite, marcasite, metatorbernite, metazeunerite, microcline, phosphuranylite, pyrite, quartz, romanechite, sabugalite, schoepite, schorl, sepiolite, siderotil, skutterudite, sphalerite, sulfur, torbernite, uraninite, uranopilite, uranophane, and zippeite.

Summit County

Park City district: This area is one of the most important Pb-Zn-Ag districts in the West and has produced many aesthetic specimens. Park City is particularly well known

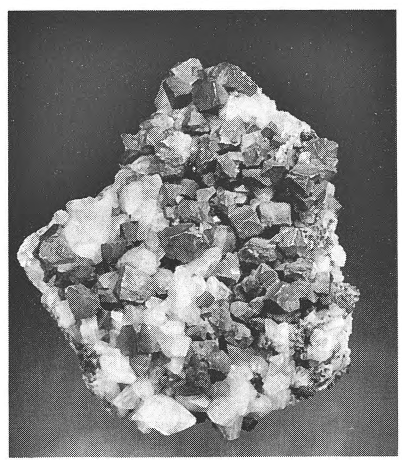

Figure 18. **Argentite and calcite, 9.2 cm high, Silver King mine, Park City district, Summit County. Martin Zinn specimen, Jeff Scovil photo.**

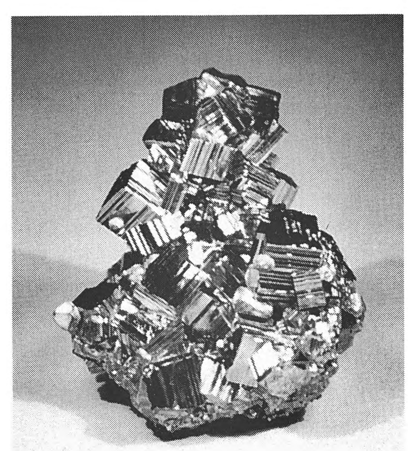

Figure 19. **Pyrite crystals, Daly-Judge mine, Park City district, Summit County; specimen 8.0 × 5.5 × 5.0 cm; Solon Hammack specimen, Joe Marty photo.**

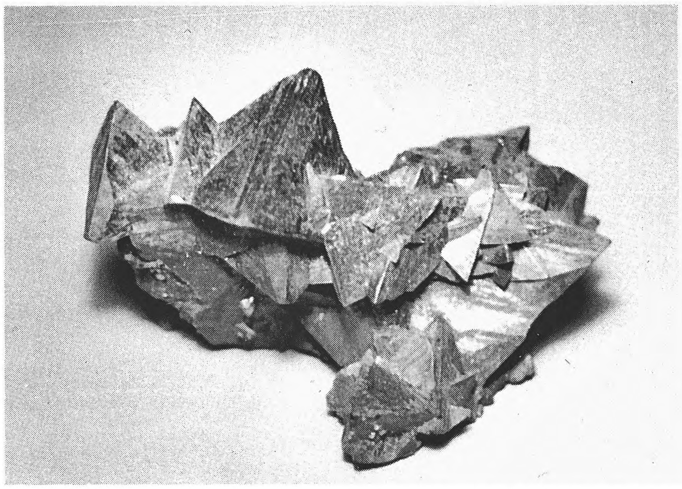

Figure 21. **Tetrahedrite crystals, Daly-Judge mine, Park City district, Summit County; specimen 9.0 × 5.5 × 4.6 cm; Solon Hammack specimen, Joe Marty photo.**

for pyrite crystals, including some of the world's best specimens of pyritohedral crystal forms. Pyrite is often associated with quartz and large tetrahedrite crystals. Pyrite crystals of recent vintage are typically heavily striated cubes up to 1.5 cm associated with cubo-octahedra of galena and greenish complex crystals of sphalerite. Recently recovered tetrahedrite crystals have been as large as 3 cm on an edge, but most average 1 cm. Other sulfosalts found in the mines of the Park City district include geocronite, enargite, boulangerite, bournonite, zinkenite, and jamesonite. Individual mines from which significant numbers of well-crystallized specimens have been obtained are Daly-Judge, Mayflower, Ontario, Park City Consolidated, Silver King, and Silver King Consolidated Mines. Because of the proximity of rapidly developing ski areas and condominiums, there are problems with access, water quality, and land usage in the Park City area, resulting in much of the land and mine dumps being closed to the public.

Tooele County

Amatrice Hill: This is one of several phosphate localities in Utah. Minerals from this location are found in fissured and brecciated zones within limestone and quartzite and include variscite, crandallite, millisite, and wardite.

Dugway district: The Dugway Range adjoins the Thomas Range on the north but is composed primarily of sedimentary rocks rather than rhyolite. The major exception is the occurrence of the Dugway geodes, which are found in a volcanic ash on the southwest side of the range. The geodes are lined with chalcedony and sometimes contain quartz crystals. Careful examination of the quartz crystals will often reveal scepter growth.

At the north end of the Dugway Range is a small mining district that produced pyritic copper ore and fluorspar. Pyrite crystals up to 5 cm have been found in clay seams in some of the mines. The crystals are typically highly distorted pyritohedra. A small percentage of the pyrite has silver-colored masses of sphalerite as epitactic overgrowths. Pyrite also occurs as clusters of cubes on massive hematite.

Much of the fluorite is massive, but some pale green and pink cubes and octahedra have been found. Small quartz crystals in some of the fluorite veins may exhibit scepters. Some mines in the area were developed in veins of barite, and milky-white blades of barite to 10 cm, some with pale to dark purple cubes of fluorite several millimeters in size, have been found in pockets.

The Bertha claim has been a prolific producer of chalcanthite specimens. Hairlike crystals several centimeters long occur coating dolomite matrix; they are associated with pyrite and selenite.

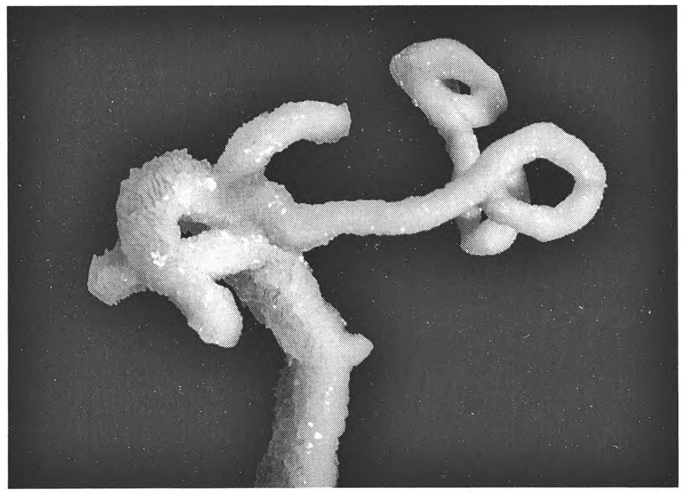

Figure 22. **Calcite helictite, 5.5 cm across, Trail Gulch, Tooele County. Terry Huizing specimen and photo.**

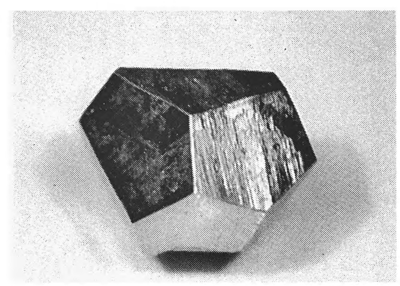

Figure 23. **Pyrite crystal, 2.1 × 1.5 × 1.5 cm, Four Metals mine, Dugway district, Tooele County. Phil Richardson specimen, Joe Marty photo.**

Figure 24. **Jarosite crystals, Gold Hill mine, Tooele County; width of view approximately 10 mm; Joe Marty specimen and photo.**

Several mines throughout the district yield nice micromount material of azurite, cerussite, galena, hematite, hemimorphite, malachite, quartz, smithsonite, and wulfenite.

East Erickson: Some collections contain beryl specimens (aquamarine) from the intrusives of Hard-to-Beat Canyon and Sheeprock Canyon in the Sheeprock Mountains. Many specimens are heavily included and typically occur as radiating sprays frozen in a granitic matrix. Other aquamarine localities in Tooele County are Granite Mountain (inaccessible because of its location on an Air Force bombing range) and a location on the Ibapah Indian Reservation.

Gold Hill district (Clifton): This district has been mined for gold, arsenic, and tungsten and may be mined for gold again in the near future. It has produced an incredible variety of minerals, primarily arsenates, including scorodite, adamite, arsenosiderite, austinite, beudantite, conichalcite, mimetite, mixite, olivenite, pharmacosiderite, quartz (Japan-law twin), and calcite. Recent collecting has produced nice specimens of bayldonite, clinoclase, connellite, cornubite, cornwallite, mixite, and philipsburgite.

Lookout Pass area: In 1987, prospectors Terry and Bob Steele found a jasperoid bearing 5-mm grains of the rare thallium mineral parapierrotite in association with stibnite. Most of the stibnite is altered to cervantite and stibiconite. Avicennite, the thallium oxide, as well as pierrotite have been reported to occur in this material, but this has not been personally verified by the authors. This occurrence is of limited extent, and no other minerals of collector interest have been found.

Mercur (Camp Floyd) district: The mines of the Mercur area were originally developed to exploit the rich silver ore, primarily cerargyrite, that occurred in exposures of a jasperoid known as the silver chert. Associated minerals are barite and stibiconite. Relatively little mercury was ever produced from the mines because most of the red color that attracted the original prospector was iron stain. Seeing no visible gold, miners were confused by the assayers reports of gold in their ore. With the development of modern mining technology and cyanide leaching, Mercur joined the rising numbers of sediment-hosted disseminated gold deposits, in which the gold is too small to be seen even with a microscope, but the deposit is mineable because of the large tonnage of ore available.

Most deposits of this type are characterized by an As-Ba-Hg-Sb-Tl geochemical signature. At Mercur, orpiment and realgar are the most common sulfide minerals. Crystals of realgar and orpiment are sometimes found in calcite veins, but much of the material is massive. Pyrite, stibnite (usually oxidized to stibiconite and cervantite), barite, quartz, calcite, melanterite, and very minor cinnabar also occur.

Mercur has an overall high thallium background and has yielded a number of Tl minerals. In the early 1980s, a vug was found containing lustrous dark red lorandite crystals up to 3 cm. An effort to locate more lorandite crystals in 1988 led to the discovery of a new thallium mineral, gillulyite [$Tl_2(As, Sb)_8S_{13}$], which was abundant in a relatively small area of the mine. Unfortunately, by the time the mineral was identified as a new species, the location had been removed by mining activity. Examination of the samples of gillulyite with the electron microprobe established the presence of lorandite and raguinite. This is probably only the second documented occurrence of raguinite in the world. Subsequent collecting resulted in the discovery of another new thallium mineral, fangite (Tl_3AsS_4), found in only one specimen. For the past two years, the mine has been working in oxidized material containing virtually no sulfides.

Ophir district (Dry Canyon, Lion Hill, Silveropolis Hill): This is a Pb-Zn-Ag district that was active up until the 1960s, when the Ophir Hill mine closed. The Hidden Treasure mine in Dry Canyon was a source of very nice rosasite, hemimorphite, aurichalcite, and smithsonite in recent years until an unfortunate incident involving the Boy Scouts resulted in the mine being sealed. Mines on Lion Hill and elsewhere in the district intersected watercourses, some of which were filled with calcite crystals in branching aggregates. The calcite occurs as stalactites, helectites, fish-tail twinned scalenohedra, and clusters of parallel groups nicknamed pineapple calcite.

Uintah County

This county is better known for its dinosaur fossils than for mineral occurrences, but a wide variety of hydrocarbons are found in the area. Although these are not minerals, their abundance in Uintah County is worthy of note. Asphalt occurs at Asphalt Ridge, Evacuation Creek, PR Springs, and Whiterocks Canyon. Gilsonite is found at Asphalt Wash, Bonanza, Fort Duchesne, and prospects in the area.

Utah County

American Fork district: This district is south and across the ridge from the Alta district in Salt Lake County and is a continuation of the Pb-Zn-Ag mineralization that occurs there. Of particular interest in this district is the Bog mine at the head of American Fork Canyon, where large crystals of gem-quality pale green sphalerite were found. Several of these specimens can be seen in the Hutchings Museum in Lehi, Utah. Other mines, such as the Yankee mine, are known for large masses of pyrite, although no good material has been found in recent years. Small pyromorphite crystals, similar to those found near the Cardiff mine in Big Cottonwood Canyon, have recently been found in American Fork Canyon in the vicinity of Silver Lake.

Clay Canyon: This locality is at the south end of the Oquirrh Range, approximately 3-4 miles west of Fairfield, Utah. Variscite nodules encrusted with the phosphates crandallite and wardite occur in a highly brecciated limestone. Most material was recovered by underground mining, and little—if any—can be found there today. Attractive lapidary specimens are marked by their multicolored

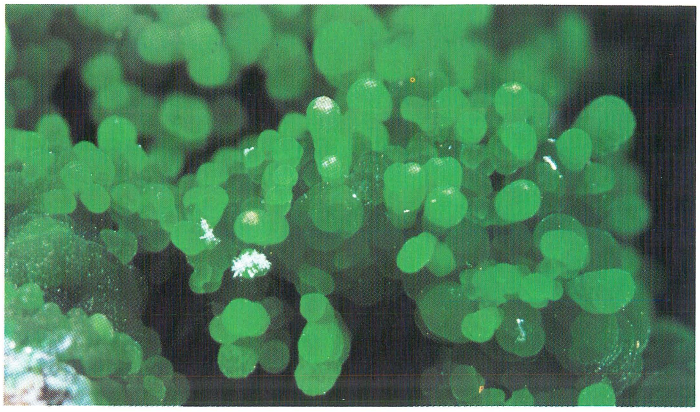

Figure 26. Conichalcite, Gold Hill mine, Tooele County; width of view approximately 8 mm. Joe Marty specimen and photo.

Figure 25 (left). Calcite (vanadian), 7.1 cm across, San Juan County. Chris Wright specimen, Jeff Scovil photo.

Figure 27. Mixite crystals to 4 mm, Northern Spy mine, Tintic district, Utah County; Joe Marty specimen and photo.

Figure 28. Realgar crystal, 1.4 × 0.8 cm, on calcite, Barrick Mercur Gold mines, Mercur district, Tooele County. Phil Richardson specimen, Joe Marty photo.

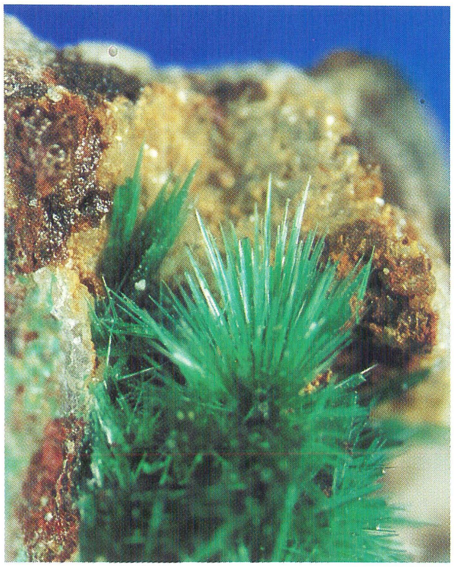

Figure 29. Brochantite crystals to 4 mm, OK mine (Blueacre site), Beaver Lake district, Beaver County. Phil Richardson specimen, Joe Marty photo.

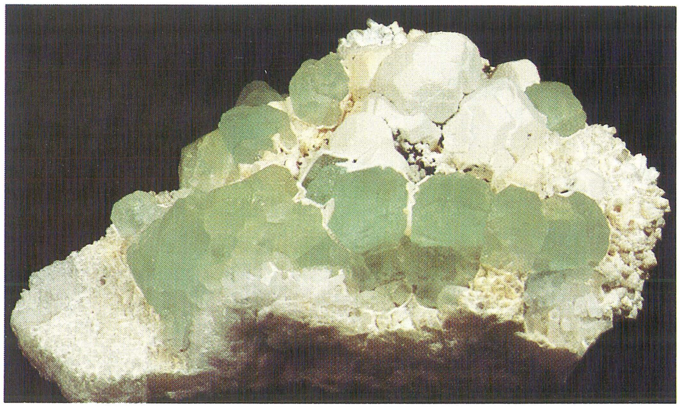

Figure 30. Fluorite with quartz, Mount Baldy mining district, Piute County; specimen 15 × 10 × 6 cm. Phil Richardson specimen, Joe Marty photo.

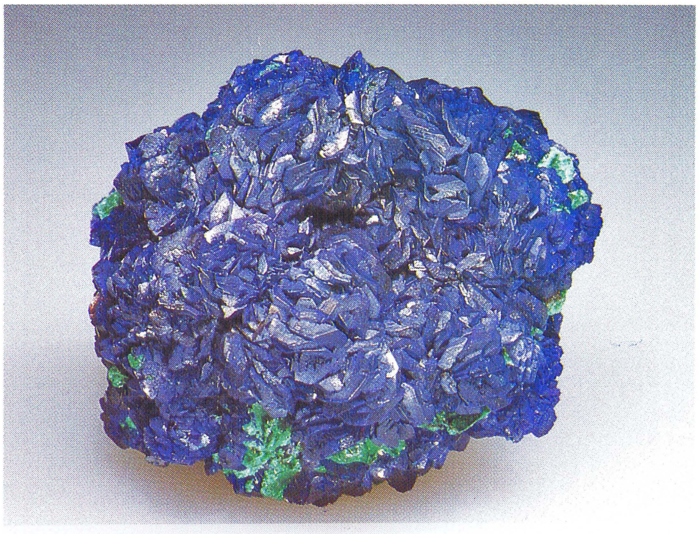

Figure 31 (right). Azurite nodule, 6.5 cm, Big Indian mine, San Juan County, Phil Richardson specimen, Terry Huizing photo.

designs of contrasting colors and shades of blue, green, yellow, and white. Cabochons appeared on the world market in the early 1940s and were noted for their "eyes," concentric circular areas of color. They were sold under trade names such as "utahlite." Other phosphates found in these nodules are alunite, apatite, englishite, gordonite, millisite, overite, as well as many other now-discredited mixtures of phosphates.

East Tintic district: This is the eastern part of the Tintic district of Juab County. The Trixie mine is operating at the present time, and the Burgin mine was active up until the 1970s. A large ore reserve remains at depth in the Burgin mine, but the high temperatures encountered in the mine, along with low metals prices, made continued mining uneconomic. The Burgin produced plates of intergrown crystals of pale pink to gray rhodochrosite and also stalactites of rhodochrosite, possibly after selenite. Also found were specimens of acanthite with barite on drusy quartz, assorted sulfides and sulfosalts, selenite, and native copper.

Pelican Point area: Located on a ridge crest overlooking Utah Lake, the Cedarstrom claims have produced large pseudomorphs of limonite/goethite after pyrite. The pseudomorphs are found singly and in large groups, typically as cubes in a fossiliferous limestone that has been altered to a clay. Individual pseudomorphs are up to 6 cm on an edge, and groups may be as much as 22 cm in length.

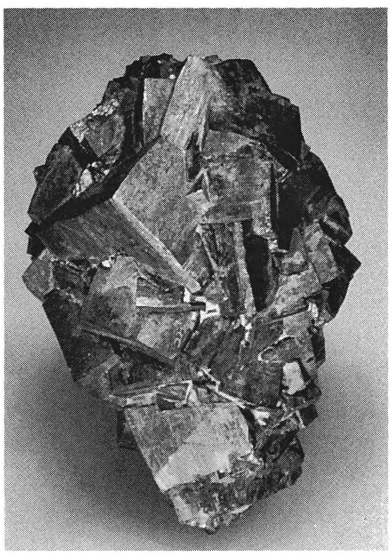

Figure 32. **Goethite after pyrite, 6.5 cm, Cedarstrom claims, Utah County. Phil Richardson specimen, Terry Huizing photo.**

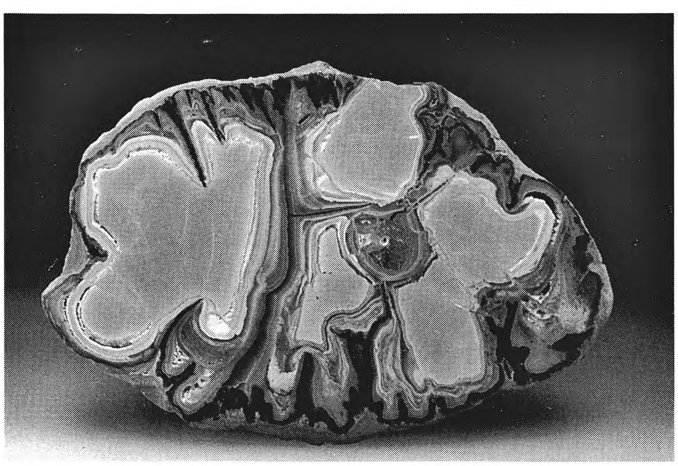

Figure 33. **Variscite nodule, 12.5 cm across, Fairfield, Utah County. Martin Zinn specimen, Jeff Scovil photo.**

Thorpe Hills: This area, south of the Oquirrh Mountains, is noted for a small prospect in which the unusual mineral sulvanite and its weathering product, volborthite, occur. Sulvanite is also known to have been found in the rocks of the Mercur area to the north. At Thorpe Hills, sulvanite was originally identified from the mine dump and then later was found to occur over a several-hundred-foot width within the same stratigraphic horizon as the prospect. The mineral occurs as metallic cubes in calcite-quartz veins in a brecciated carbonaceous limestone.

Wasatch County

Clayton Peak area: The contact zone of this stock has areas in which spinel, clintonite, vesuvianite, and garnet occur. Less common are small hemispheres of scolecite. Chabazite is also reported from this location.

Soldier Summit: In this vicinity are a number of old mines once worked for such solid hydrocarbons as the wax ozocerite and the coal-like nigritite.

Washington County

Silver Reef district: Mines of this area produced silver and copper minerals, such as acanthite, cerargyrite, native silver, and chalcocite. Some were U-V-Se mines in which carnotite, autunite, and volborthite were important minerals.

Dixie Apex mine (Tutsagubet district): This mine is famous for spectacular specimens of azurite, malachite, and pink smithsonite. Some of the better-known specimens are azurite-malachite casts after selenite. During the 1980s, the mine was reactivated, and new material as well as the waste on the dumps was processed for germanium and gallium. Extraction problems forced the shutdown and sale of the mine. The loss of the dumps makes it unlikely that much new material will be obtained. Because the mine is in relatively unstable ground, the mining operation involved excavating small adits and filling them with concrete as soon as mining was completed in that area. Some nice azurite, obtained from the mine in the course of mining operations, has been preserved in collections. A small vein of adamite crystals was exposed at the time of a mine visit by two of the writers of this paper (JRW and PNW), and a few specimens were obtained.

Wayne County

Caineville area: During recent years, a claim in this vicinity, labeled Deep Creek Wash, produced numerous large crystals of selenite, some of which were 1 meter or more in length. Many smaller crystals about 30 cm long were found. Potential is good for more material of this type.

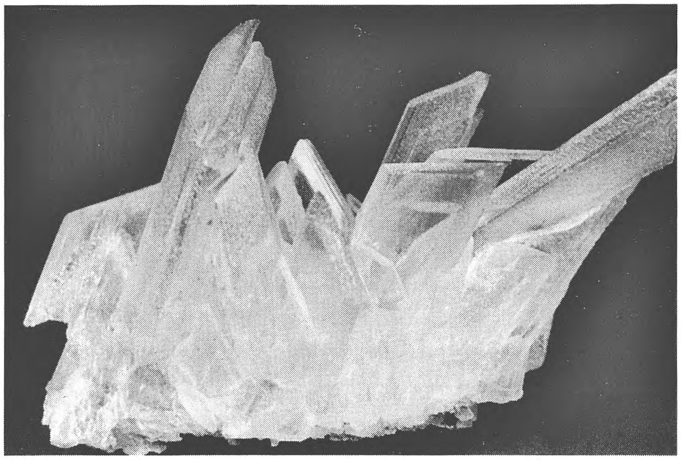

Figure 34. **Gypsum, variety selenite, partially coated with blebs of psilomelane, Deep Creek Wash, Caineville area, Wayne County; specimen 15.5 × 10.5 × 9 cm. Phil Richardson specimen, Joe Marty photo.**

BIBLIOGRAPHY

The following is a list of references that provide a wide range of information on mineral localities in Utah. They range from general interest books and articles to technical papers by professional mineralogists. Some of the more obscure references can be found in the library of the University of Utah and the library of the Utah Geological Survey.

In addition, the Utah Geological Survey is publishing a new guide to mineral and fossil locations in the state. This publication should be out during 1993.

Barlow, J. F. 1979. Red beryl of the Wah Wah's. *Lapidary Journal* 32(12):2540–70.

Bennion, B. D. 1967. Clay Canyon—Best deposit of variscite. *The Utah Report* 5(7):6–7. Utah Federation of Gem and Mineral Societies.

Bulletin of the Mineralogical Society of Utah. (This mineral club was extremely active and privately published high-quality accounts of collecting in Utah. The years 1941–1959 are particularly good.)

Bullock, K. C. 1977. *Mineral localities of Utah.* Utah Geological and Mineral Survey bulletin 117.

El-Shatoury, H. M., and J. A. Whelan. 1970. *Mineralization in the Gold Hill mining district, Tooele County, Utah.* Utah Geological and Mineral Survey bulletin 83.

Harris, D. 1958. The geology of Dutch Peak area, Sheeprock Mountains, Tooele County, Utah. *Brigham Young University Research Studies, Geological Series* 5(1). Provo, Utah: Brigham Young University.

Haynes, P. E. 1987. Notes from the Four Corners. *Mineral News* 3(9):5.

———. 1990. Notes from the Four Corners. *Minerals News* 6(8):3.

Holfert, J. 1978. *A field guide to topaz and associated minerals of Topaz Mountain, Utah.* Privately published.

James, L. 1984. The Tintic mining district. *Survey Notes* 18(2): 1–13. Utah Geological and Mineral Survey.

Milby, F. 1980. An examination of red beryl. *Gems and Gemology* 16(12):405–8.

Montgomery, A. 1934. A recent find of bixbyite and associated minerals in the Thomas Range, Utah. *American Mineralogist* 19:82–87.

———. 1935. Minerals of the Thomas Range, Utah. *Rocks & Minerals* 10:161–68.

———. 1970–1971. The phosphate minerals of Fairfield, Utah. *Rocks & Minerals* (four-part series) 374:667–74; 375:739–45; 376:3–9, 75–80.

Nassau, K., and D. L. Wood. 1968. An examination of red beryl from Utah. *American Mineralogist* 53:801–6.

Nolan, T. B. 1935. *The Gold Hill mining district.* U. S. Geological Survey professional paper 177.

Palache, C. 1934. Minerals from Topaz Mountain, Utah. *American Mineralogist* 19:14–15.

Ream, L. R. 1979. The Thomas Range, Wah Wah Mountains, and vicinity. *Mineralogical Record* 10(5):261–78.

———. 1987. Micro minerals near Milford, Beaver County, Utah. *Mineral News* 3(3):11.

———. 1988. Uranoan thorite in rhyolite at Thomas Range, Juab County, Utah. *Mineral News* 4(4):10.

Richerson, D., and J. Pfeifer. 1987. Durangite and associated minerals from the Thomas Range, Utah. *Mineral News* 3(1):1–2.

Sargent, K. A., and H. S. Zeller. 1984. *Sand-calcite crystals from Garfield County, Utah.* U. S. Geological Survey bulletin 1,606.

Shigley, J. E., and E. E. Foord. 1984. Gem-quality red beryl from the Wah Wah Mountains, Utah. *Gems and Gemology* 20(4):208–21.

Staatz, M. H. 1963. *Geology of the beryllium deposits in the Thomas Range, Juab County, Utah.* U. S. Geological Survey bulletin 1142–M:1–36.

Staatz, M. H., and W. J. Carr. 1964. *Geology and mineral deposits of the Thomas and Dugway ranges, Juab and Tooele counties, Utah.* U. S. Geological Survey professional paper 415.

Stowe, C. H., and L. E. Perry. 1979. *Rockhound guide to mineral and fossil localities in Utah.* Utah Geological and Mineral Survey circular 63.

Thomssen, R. W. 1991. Forgotten phosphates of Fairfield. *Lapidary Journal* 45:46–53.

Waisman, D., and E. Fier. 1987. Barite and fluorite from the Dugway Mountains, Utah. *Mineral News* 3(4):2. ☐

CONNOISSEUR'S *Choice*

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PYRITE Park City District, Utah

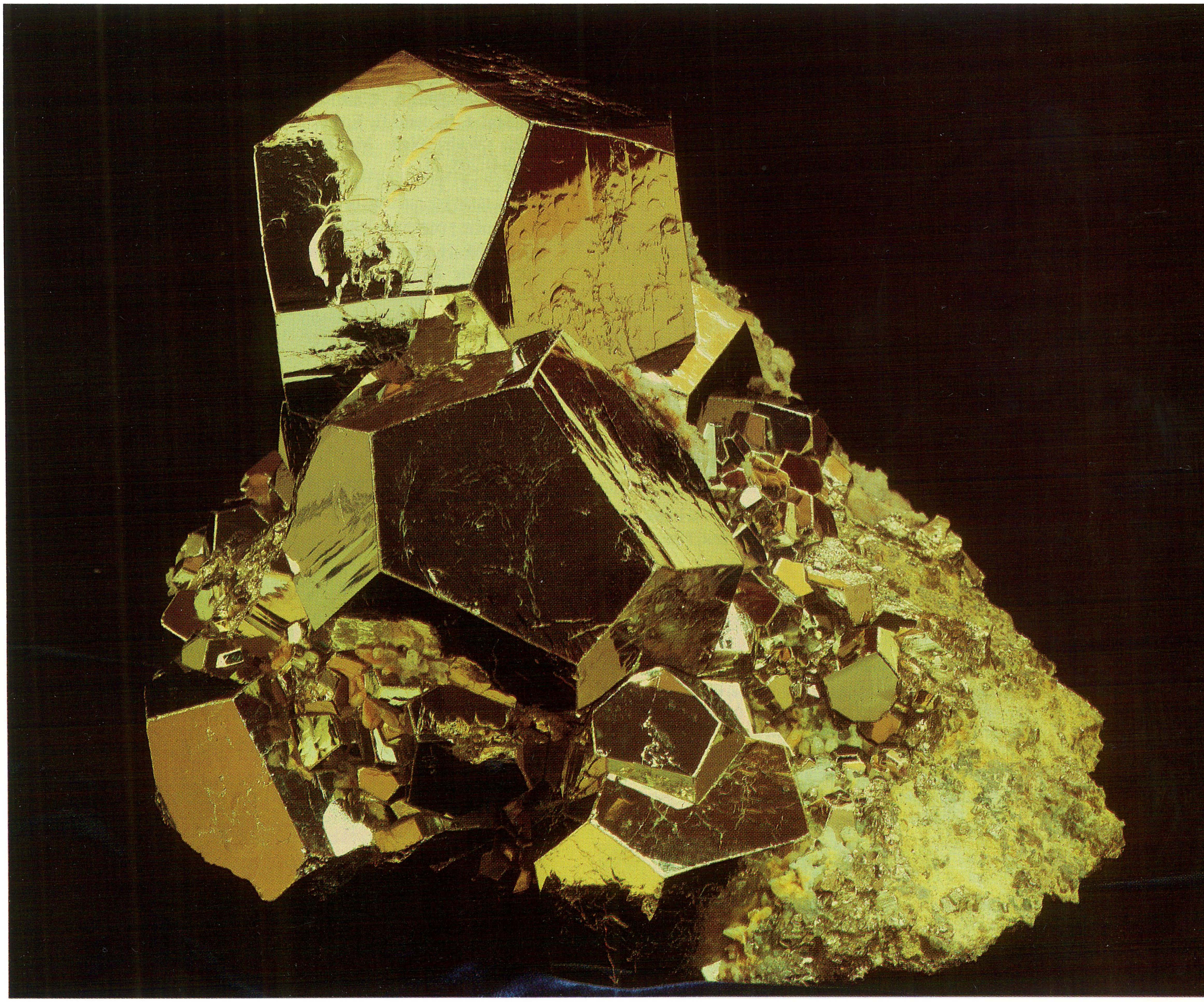

Figure 1. **This particularly attractive pyrite specimen is from one of the many mines in the Park City district, Utah, a location well known for pyrite and associated sulfide minerals. The specimen was originally part of a collection assembled by the late geologist and mineral dealer Alfred Buranek. The collection was ultimately donated on behalf of the Whitmore Oxygen Corporation to the University of Utah Department of Geology and was later transferred to the Utah Museum of Natural History. The specimen, which carries the number UMNH-2321, was depicted twice in 1981 in a black-and-white photograph accompanying articles discussing the then-new museum's Norton Hall of Minerals (Allred 1981a, b). The largest crystal is approximately 3 inches across. Photo by John Telford.**

Additional information on the Park City district and its minerals can be found in U.S. Geological Survey professional paper 77 by J. M. Boutwell (1912). A photograph of a similar pyrite specimen from the Daly-Judge mine can be found on plate 26 of the Boutwell publication.

THIS ISSUE'S CONNOISSEUR'S CHOICE mineral is pyrite. Along with quartz and other jewelry species, pyrite ranks among the most familiar of all minerals. Who has not heard of "fool's gold," or noticed the wonderfully repetitive cubes of pyrite for sale at nature stores in major malls or museum shops in any of the country's natural history museums, or seen the crystalline aggregates forming the irregular sparkling bases for scenes composed of pewter figurines available in literally hundreds of gift shops nationwide.

Pyrite occurs in a myriad of environments and forms. Its mineralogy has been studied by many scientists and has been known and described at least since the days of Pliny. Despite its seemingly simple chemistry and crystallography, new insights into its crystal structure were still being determined as recently as 1969 (Brostigen and Kjekshus 1969). A well-illustrated paper dealing with pyrite and its crystal forms by Gait (1978) is recommended for additional information on this interesting species.

Pyrite is isometric and is most commonly observed in well-developed cubes, pyritohedra, or octahedra, or combinations of these forms. Crystal size can be quite large, ranging up to 10 inches or more. Most crystals exhibit striations, and some cubes exhibit unusual elongation with twists and even rings reported. Granular, globular, and stalactitic masses of pyrite are relatively common, and flattened aggregates called *suns* are found in several locations. Both penetration and contact twins are relatively common in pyrite, with one interesting penetration type resulting in twins known as *iron crosses*.

The physical properties of pyrite are distinct and include its pale brass-yellow color and pronounced metallic luster. It has a greenish-black streak that contrasts markedly with its color, and under certain conditions it tarnishes to a darker yellow or brown or to a play of iridescent colors. Pyrite is brittle and is relatively dense (5.01). It has a hardness of about 6.5, a conchoidal to uneven fracture, poorly developed cleavage, and several indistinct parting directions.

When pure, pyrite is simple iron disulphide (FeS_2). Both nickel and cobalt can substitute sparingly for iron. Generally, related iron sulfides include troilite (FeS) and the pyrrhotite polymorphs ($Fe_{1-x}S$). Pyrite also is dimorphous with the familiar mineral marcasite and forms a series with cattierite (CoS_2).

Pyrite can be formed under a wide variety of geological conditions that range from simple diagenesis of sedimentary materials to complex polymetallic hydrothermal systems. It is very common as an accessory mineral in many fundamental rock types, such as carbonaceous shales and coal, a variety of igneous rocks including pegmatites, and contact metamorphic rocks. In some instances, pyrite is the dominant mineral in bodies of rock large enough to be mined as a source of sulfur or is the major mineral in sulfide bodies mined for associated copper, lead, and zinc.

From the standpoint of fine mineral specimens, there are

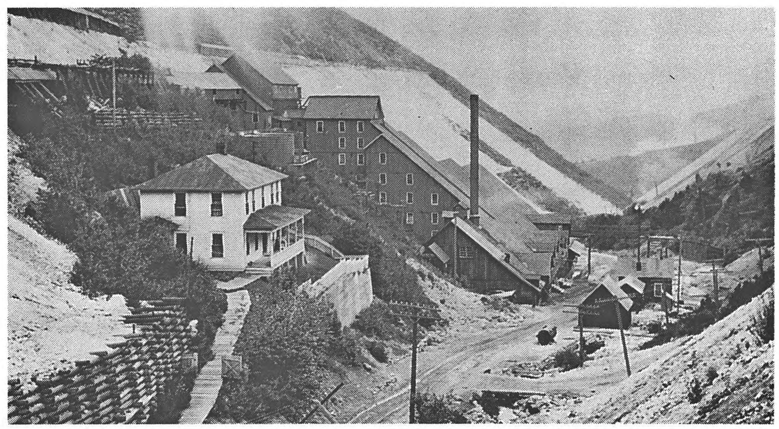

Figure 2. **Turn-of-the-century view of Daly-Judge Mill near portal of Daly-Judge mine, Park City, Utah. Photo courtesy Photography Archives, Utah State Historical Society.**

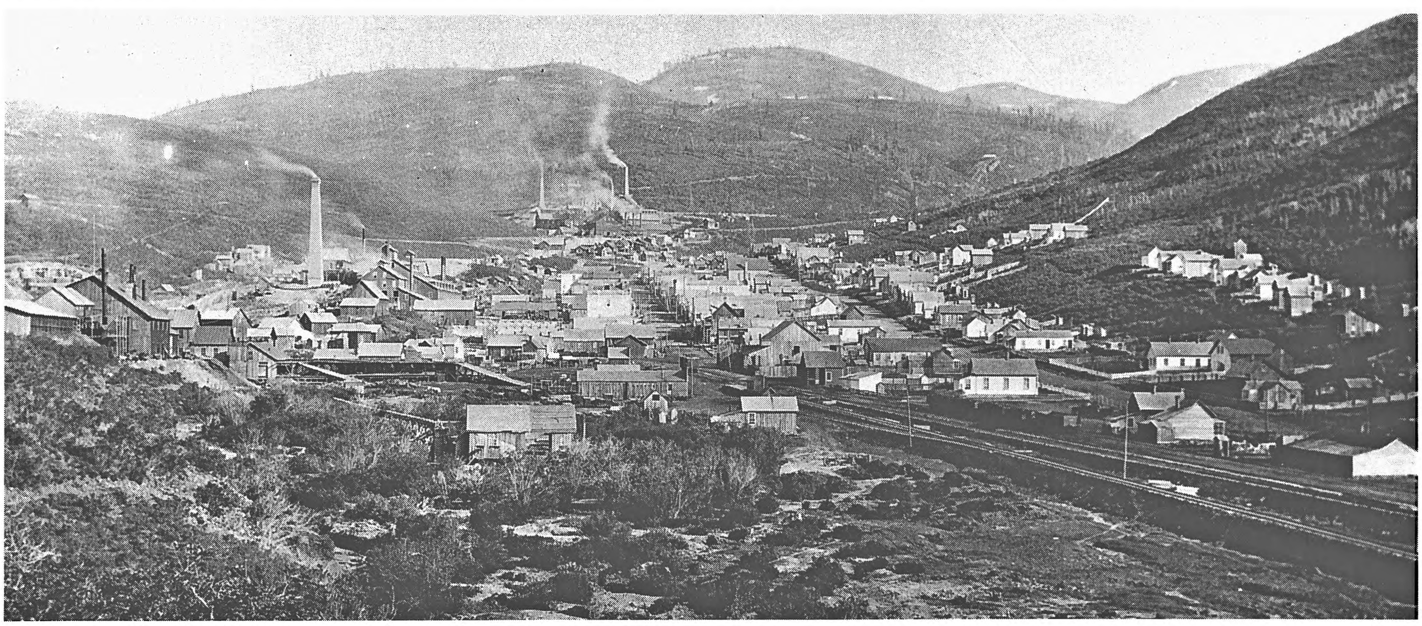

Figure 3. **Park City, Utah (ca. 1880s). Photo courtesy Photography Archives, Utah State Historical Society.**

COLOR SPONSORS for this series during 1993 are the Cincinnati Mineral Society and the Mineral Section of the Houston Gem and Mineral Society.

many notable localities worldwide. Some of the best are those produced from base- and precious-metal vein systems and related occurrences, such as those typical of the Rocky Mountains and the Andes. Exceptional specimens have been produced in recent years from several Peruvian localities, including the Quiruvilca mine, La Libertad, and Huánzala, Huánuco. Specimens of almost equal quality were produced from the tin-silver occurrences of Oruro, Llallagua, and other Bolivian districts during their heyday. Spectacular pyrite cubes—some reaching 10 inches on edge—have been produced from the Climax molybdenum mine in Colorado, and exceptional specimens were once produced from the nearby Leadville district. Also well represented in many collections are bright groups of pyritohedra from the Eagle mine at Gilman and mines at Rico, both districts also in Colorado. Further north, desirable specimens of complex pyrite crystals were produced for decades from the copper mines at Butte, Montana.

Interesting pyrite specimens have also been found at localities in the eastern United States. These include striated cubes to several inches in diameter from the Carleton talc mine, Chester, Vermont; sharp octahedra from the French Creek iron mines, Chester County, Pennsylvania; abundant iron-cross twins from Schoharie, New York; and modified cubes from the pyrophyllite mines of central North Carolina.

Pyrite is known in fine specimens from a number of intriguing or exotic localities. For years Rio Marina on Elba was one of the most noted pyrite specimen localities, and—thanks to the efforts of a succession of aggressive mineral dealers—almost every major museum has one or more exceptional groups of Elba pyritohedra. More recently, single or intricate groups of interpenetrating, lustrous simple cubes have been available from Ambasaguas and Navajun, Logroño, Spain. Less available though exceptionally well crystallized are the pyrite specimens from the active Nanisivik mine on Baffin Island, Canada.

Finally, pyrite is also of significant interest to fossil collectors in that it is commonly a preserving agent or replacement mineral in reducing environments. Well known are the pyritized brachiopods from numerous localities in the midwestern states and pyritized trilobites from the Frankfort Shale of central New York.

REFERENCES

Allred, C. W. 1981a. Utah's new Norton Hall of Minerals. *Lapidary Journal* 35:2572–85.

______. 1981b. Norton Hall of Minerals, Utah Museum of Natural History, Salt Lake City. *Rocks & Minerals* 56:256–60.

Brostigen, G., and A. Kjekshus. 1969. Redetermined crystal structure of pyrite (FeS_2). *Acta Chem. Scand.* 23:2186–88.

Gait, R. I. 1978. The crystal forms of pyrite. *Mineralogical Record* 9:219–29. □

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The Repete Mine

SAN JUAN COUNTY, UTAH

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All photos by the author and of specimens from the author's collection

THE REPETE MINE is located in San Juan County, Utah, in the NE ¼, SE ¼ of section 8 and the NW ¼, SW ¼ of section 9, Township 39S, Range 25E. It is 21.5 miles southeast of Blanding and 2.5 miles east-northeast of the Hatch Trading Post. It can be found on the Cajon Mesa 15-minute quadrangle map.

History

James Menlove discovered uranium-rich mudstones in this area on 7 November 1954. The following day Menlove and his partner, Melvin Dalton, staked the original Pete claims and on 1 December 1954 recorded a total of twenty-eight claims with the San Juan County clerk's office. Mining apparently started under the name of Even Odds, which was later changed to Canyonlands. The pre-1967 ore production was 27,070 tons of 0.25% uranium ore.

Milton Nielson leased the property in the late 1960s, but his production is not known. James Goode leased the property and mined it on three different occasions from 1969 until 1976. Although his earlier production is not known, Goode's 1976 production was 2,353.5 tons of ore, which yielded 6,740 pounds of U_3O_8, the end product of uranium milling.

In 1976, there was an adit to the southeast that connected underground with an adit coming in from the north. In the underground workings, Goode started a drift to the west but did not take it all the way to the surface.

In 1978, Energy Fuels Nuclear purchased the property and drilled more than six hundred test holes. They completed driving the westerly adit to the surface and also drove in a new, fourth adit next to it. They renamed the mine the Repete mine.

Felix, Marcelino, and Marc Mendisco leased the property and mined it from the spring of 1986 until January 1987, when caving started to become a big problem. The author was able to visit the mine on three occasions during this period. It was on these visits that the new mineral haynesite was collected. The author observed it in the high-grade ore piles and asked the miners if they could point out its locations within the mine. The miners agreed, and a few boxes of specimens were soon collected. Samples were given to Dr. Peter Modreski and to Paul Hlava for testing. Their microprobe results were comparable, showing only uranium and selenium, and samples were later sent to Dr. Michel Deliens (Deliens and Piret 1991).

The mine's total production to June 1987 was at least 60,854.5 tons of ore of variable percent, yielding 210,740 pounds of U_3O_8. To this amount must be added Nielson's and Goode's unknown production.

Collecting in the mine is quite dangerous. At the present time, only the southeast adit is accessible—the other three

Figure 1. **Southwesternmost adit of the Repete mine during active mining operations in 1985.**

Patrick E. Haynes is a field collector, geologist, and part-time mineral dealer.

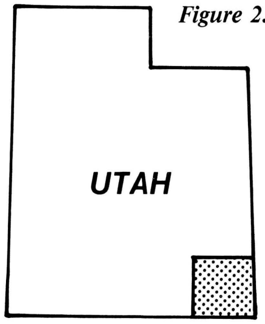
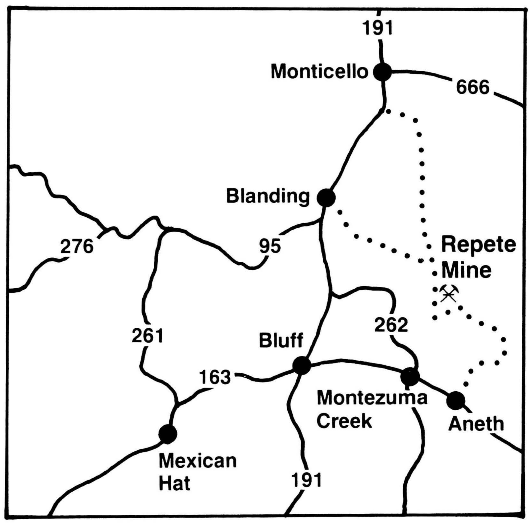


Figure 2. **Location map.**



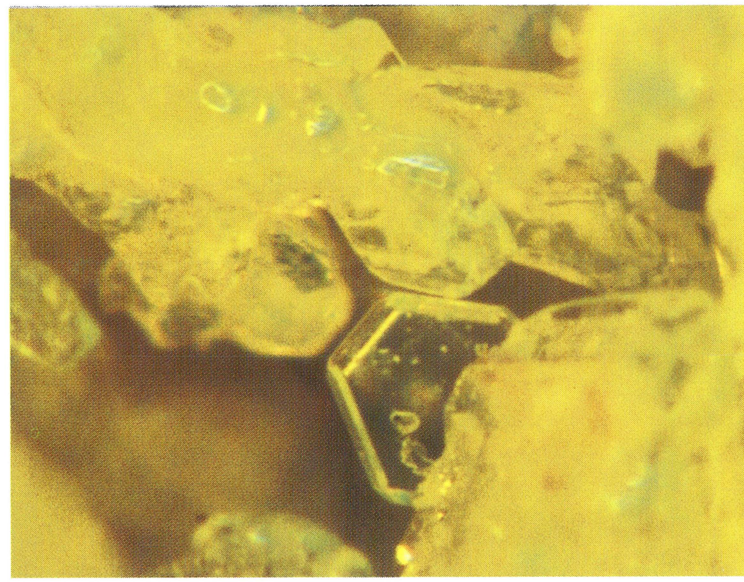


Figure 3 (right). **Andersonite, 0.4 mm, from underground workings.**

Figure 4 (lower right). **Haynesite (#2926), field of view 5 mm; collected underground.**

adits have collapsed. James Menlove of Monticello, Utah, has filed the 1992 annual assessment work, so the mine is now back in his hands. Permission to visit the property should be obtained from him.

Local Geology

The rocks in the area consist of sandstone, mudstone, conglomerate, claystone, and minor limestone of Jurassic and Cretaceous age. The Jurassic Morrison Formation is represented by the Brushy Basin Member, which is predominately mudstones and claystones, and possibly by the Westwater Canyon Member, which is mostly crossbedded sandstone layers (Peterson and Turner-Peterson 1987). Some of the lower outlying areas have exposures of crossbedded sandstone that may be part of the Westwater Canyon Member. The Brushy Basin Member makes up the bulk of the hill on which the Repete mine is located. It is easily recognizable by the slope-forming mudstones and claystones of varying colors, which can sometimes create a "badlands" type of topography.

The Repete mine is in a horizon of gray mudstone that locally grades into thin sandstone layers. In the upper part of the member above the mine, and interbedded with mudstone layers, are cliff-forming layers of sandstone and a cherty conglomerate up to 12 feet in thickness. This conglomerate and some of the mudstones can weather to a distinctive black color. The presence of dinosaur bone and petrified wood in the Brushy Basin rocks occurring in adjacent areas suggests a continental origin. Whereas the mudstones and claystones probably represent lake or extensive alluvial plain deposits, the sandstones and conglomerates represent stream deposits (Huff and Lesure 1965).

Capping the upper part of the hill is the Burro Canyon Formation, which is of continental origin represented predominately by fluviatile sediments. Sandstone, conglomeritic sandstone, mudstone, and claystone are the dominant rocks, and the formation is generally a cliff-former. The top of the hill has a 2.5-foot-high residual boulder of sandy limestone, indicating that the hilltop is in the upper part of the formation (Huff and Lesure 1965).

The Repete mine lacks the abundance of organic matter associated with ore deposition at many mines on the Colorado Plateau. The occurrence of uraninite in the mudstone is very likely through precipitation from uraniferous groundwaters. About 10 miles to the north is the Montezuma Canyon mining district. Its uranium deposits are in the Salt Wash Member of the Morrison Formation. Many of these deposits exhibit common organic debris. This comparison makes the selenium-rich Repete mine in the Brushy Basin Member locally unique.

Minerals

Andersonite, $Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$, is best observed underground with the aid of an ultraviolet lamp because it fluoresces a bright lime-green under both short- and longwave radiation. Typically, it occurs as thin films that are not easily distinguishable from the matrix. However, it can form as thicker coatings and as aggregates up to 2 cm thick in the mudstone. Etched microscopic hexagonal crystals can be found in these aggregates. Andersonite is frequently associated with boltwoodite.

Boltwoodite, $HK(UO_2)SiO_4 \cdot 1.5H_2O$, is the most common of the three secondary uranium minerals found at the Repete mine. Underground it coats fracture surfaces, occurring as yellow to yellowish-green spheres and minute (<1 mm), tightly clustered radiating crystals. It can also be found in the old ore piles and in some of the surface exposures near the mine adits.

Ferroselite, $FeSe_2$, occurs as very tiny (<0.6 mm), anhedral to euhedral, brassy to dark gray, metallic grains in a mudstone matrix or on fracture surfaces. The grains sometimes have a slight pink tint. It also occurs as acicular radiating microscopic crystals that are visually identical to and in intimate association with selenium. Oxidation of ferroselite results in a brown alteration rim of limonite.

Gypsum, $CaSO_4 \cdot 2H_2O$, is found throughout the mine as films that fill fractures in the rock and as microscopic crystals reaching 1 mm.

Haynesite, $(UO_2)_3(OH)_2(SeO_3)_2 \cdot 5H_2O$ (Deliens and Piret 1991a, b), occurs as yellow to occasionally yellowish-orange microscopic crystals and aggregates up to 1 mm. It can also form radial smears on fracture surfaces. It was found at only three locations within the mine; at one, gypsum and ferroselite are the only visible associated minerals. At the other two locations, it is associated with andersonite, boltwoodite, ferroselite, gypsum, marcasite, and selenium.

Marcasite, FeS_2, occurs as metallic, brassy, subhedral aggregates to 1.5 mm and as dull gray, euhedral, pseudo-octahedral crystals to 0.7 mm in a mudstone layer in association with haynesite and ferroselite.

Selenium, Se, occurs as metallic, brassy to dark gray, acicular crystals to 0.6 mm, typically radiating, with a subtle pink tint. It is intimately associated with ferroselite.

Uraninite, UO_2, is quite fine grained and is not seen in hand samples or under the microscope. Mudstone that lacks any visual evidence of uranium mineralization can be some of the mine's most radioactive ore, which is probably due to fine-grained disseminated uraninite.

Acknowledgments

I wish to thank the following: the Mendisco family for allowing me to visit their mining operation and to collect samples; Marc Wilson and Steve Bringe for allowing me to use the photomicrography equipment at the New Mexico Bureau of Mines and Mineral Resources; Michael Schubat (Utah Geological Survey) for suggesting or supplying references; James Menlove, Energy Fuels Nuclear (Fredonia office), and James Goode for historical information; Paul Hlava and Dr. Peter Modreski for their microprobe work; Dr. Michel Deliens and Dr. Paul Piret for their research and publication efforts; and Dr. James Wilson, Dr. Paula Wilson, and Dr. Robert Gait for reviewing the article.

REFERENCES

Craig, L. 1981. Lower Cretaceous rocks, southwestern Colorado and southeastern Utah. In *Rocky Mountain Association of Field Geologists—1981 Field Conference*, 195–200.

Deliens, M., and P. Piret. 1991a. La haynesite, selenite hydrate d'uranyle, nouvelle espece minerale de la mine Repete, comte de San Juan, Utah. *Canadian Mineralogist* 29:561–64.

______. 1991b. Haynesite, uranyl selenite hydrate, a new mineral species from the Repete mine, San Juan County, Utah [abstract]. *American Mineralogist* 77:447.

Fleischer, M., and J. A. Mandarino. 1991. *Glossary of mineral species 1991*. Tucson: The Mineralogical Record.

Huff, L. C., and F. G. Lesure. 1965. *Geology and uranium deposits of Montezuma Canyon area, San Juan County, Utah.* U.S. Geological Survey bulletin 1,190.

Peterson, F., and C. E. Turner-Peterson. 1987. The Morrison Formation of the Colorado Plateau: Recent advances in sedimentology, stratigraphy and paleotectonics. *Hunteria* 2:1–18.

Kennecott's
Bingham Canyon Mine
A BRIEF HISTORY

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Historical photos courtesy
Photograph Archives
Utah State Historical Society

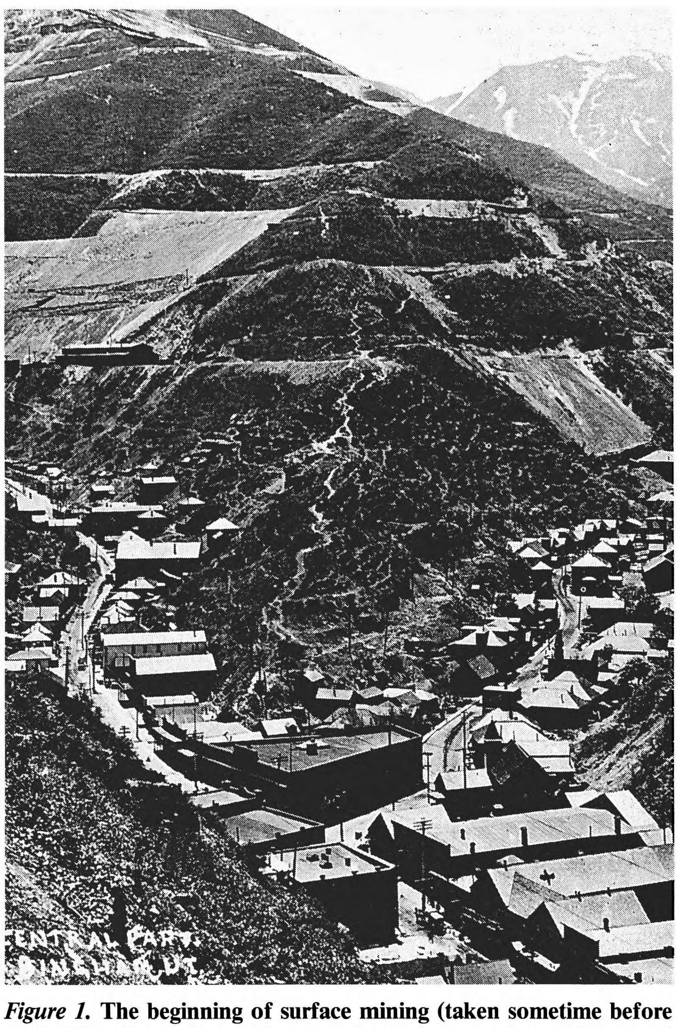

Figure 1. **The beginning of surface mining (taken sometime before 1909). This mountain has disappeared; in its stead is the giant pit of today.**

THE WORLD'S FIRST OPEN-PIT copper mine lies approximately 26 miles southwest of Salt Lake City, deeply cut into the eastern flank of the Oquirrh Mountains in Salt Lake County. This mountain range rises 4,000 feet above a deep alluvium-filled valley floor that was once a broad desert. Today, this region is the most populous segment of the Wasatch Front and is home to approximately seven hundred thousand people.

To the north, the range is bounded by the Great Salt Lake; to the south, it tapers into a series of gently rolling hills. Hidden within is a vast low-grade copper porphyry ore deposit that was slowly transformed into the world's largest open-cut copper mine.

Early Mormon pioneers envisioned a different picture of wealth. Arriving in the Salt Lake Valley in 1847, they viewed the then heavily forested Oquirrh Range as a vast resource for grazing, farming, and timber. In 1848, Brigham Young, head of the Church of Jesus Christ of Latter-Day Saints (Mormons), dispatched Sanford and Thomas Bingham to drive a herd of church-owned horses and cattle onto the high ground of the eastern flank, near the main canyon, of the Oquirrhs. It was here that the Bingham brothers established a settlement in the canyon that was to carry their name.

Sanford and Thomas were the first people of record to notice mineralization on the mountain slopes of Bingham Canyon. Brigham Young, however, vigorously denounced exploration for mineral wealth. He felt that the promise of easy riches would lure many away from the pursuit of farming, which to him was their most important reason for establishing a community in this new territory.

It wasn't until 1863 that a farmer, George Ogilvie, showed several Bingham Canyon ore specimens to the local military commander, Col. Patrick Connor. The colonel was well versed in prospecting and encouraged a mining venture. At the time, the purpose of the military presence was twofold: to protect mail routes and to neutralize the Mormons. It was felt that a "gold rush," with its influx of miners, might help attain the second goal.

Late in 1863, Connor, with George Ogilive and twenty-seven other men, located the Jordan claim, the first official

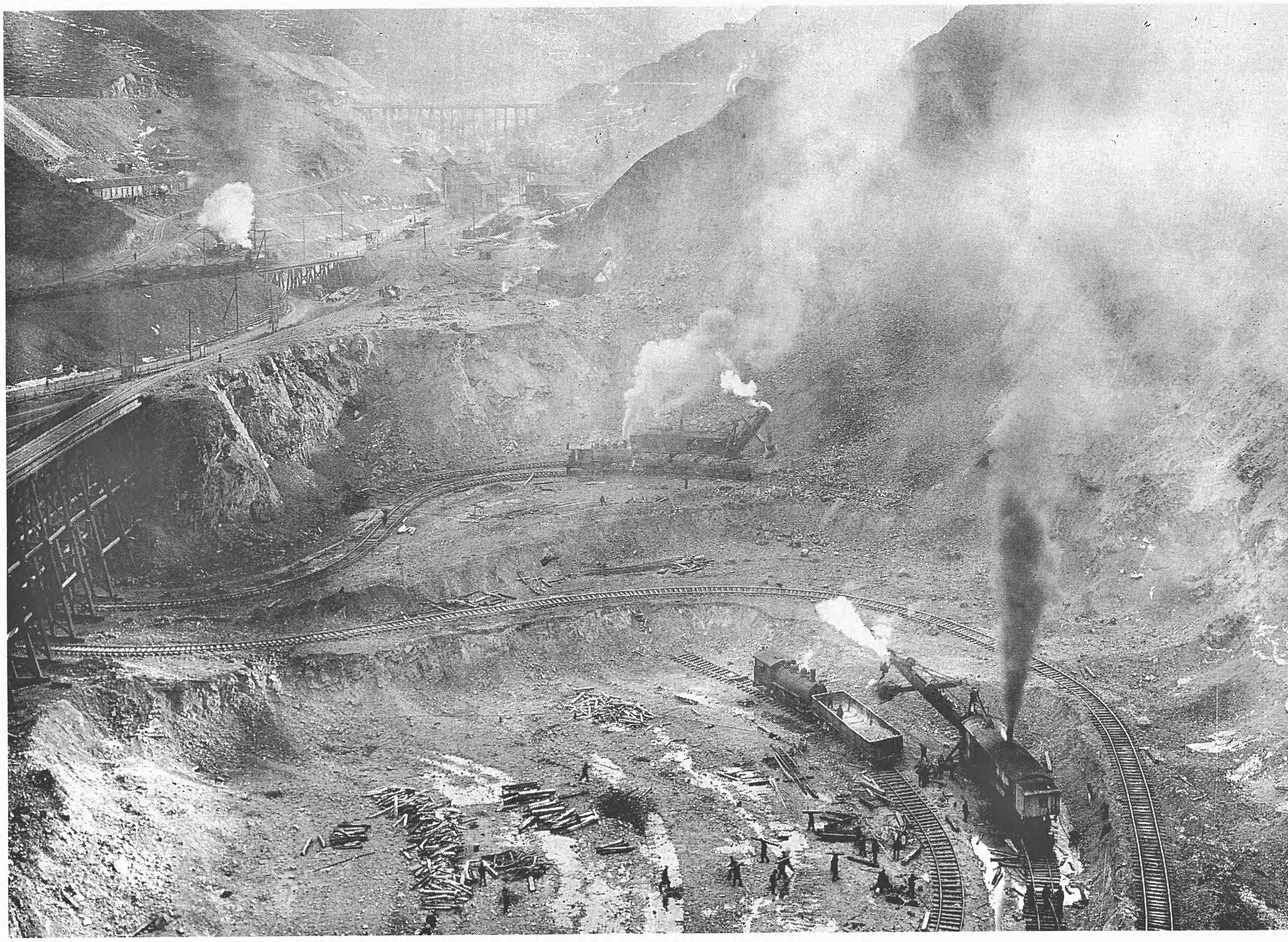

Figure 2. Utah Copper Company mine, looking down into pit at Bingham (taken 16 January 1909).

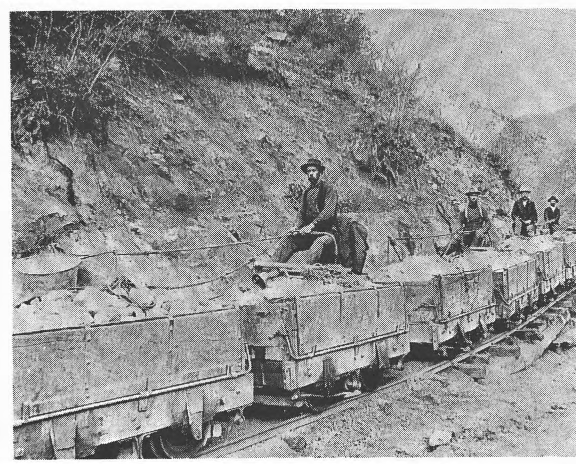

Figure 4 (above). Orecars coming down from mines in upper Bingham (ca. 1892); cars were pulled up by mules and then coasted down.

Figure 3 (left). Early bench-cut mining, Boston Consolidated mine, Bingham, Utah (taken 9 April 1907).

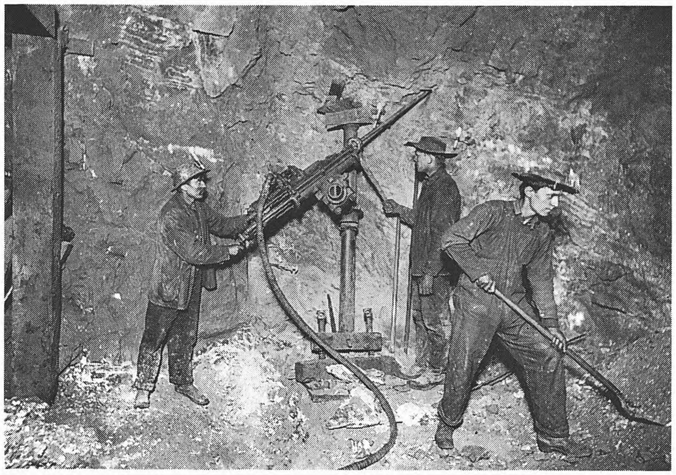

Figure 5. **Underground mining at Bingham near turn of the century. Highland Boy machine drill on level 7 of the Utah Consolidated mine, Bingham, Utah.**

legal claim in Utah. This led to the development of the West Mountain district, which was later ratified to include almost the entire eastern flank of the Oquirrh Mountains. News of the strike brought a flurry of prospecting, and a placer gold deposit was located in lower Bingham Canyon in 1864. During the following twenty years, the rich surface ores of copper, lead, and silver were discovered, mined, and milled.

By 1896, large-scale underground copper mining had begun with the discovery of large shoots of low-grade pyritic copper ore, which radiated out from the monzonite intrusive into the surrounding sediments. It was here, in upper Carr Fork of Bingham Canyon, that the Highland Boy was established as Utah's first copper mine.

Problems continually arose with transportation and the need to develop a means for bulk mining of the low-grade deposits. Despite several financial mine failures, the vastness of the deposit fueled inventiveness. It was perceived that a revolutionary concept of mass mining and concentrating of low-grade deposits could bring Bingham into the big leagues.

Leonard S. Arrington and Gary B. Hansen (1963) organized a monograph—entitled *The Richest Hole on Earth, A History of the Bingham Copper Mine*—around the following four stages of development:

(1) The Pioneer Era, 1848–1886, during which the rich surface ores of Bingham were discovered, mined, milled, and shipped to distant centers for refining and marketing. (2) The Promotional Era, 1887–1902, involving particularly the activities of "Colonel" Enos A. Wall and Samuel Newhouse in acquiring, developing, and marketing the moderately rich and low-grade sulphide and porphyry ores at Bingham. (3) The Formative Years, 1903–1910, during which new equipment and processes were developed and tested and a successful porphyry copper-mining industry established. There was experimentation, trial and error, and companies competing for capital, engineers, and publicity. Above all, this key period featured the formation of the fabulous Utah Copper Company, which built the first concentrator for porphyry copper and shared with the Boston Consolidated Mining Company the honor of pioneering in the use of steam shovels. The period ended with the absorption of Boston Consolidated by Utah Copper. (4) The Period of Growth and Expansion, 1911–1963, in which the Guggenheims provided the financial wherewithal for the worldwide operations of an expanding Utah Copper and subsequently its parent, the Kennecott Copper Corporation—largest producer of copper in the world. Utah Copper was transformed from a developmental local enterprise into a corporate enterprise of vast magnificence. As with the transition from Andrew Carnegie to U.S. Steel, and from John D. Rockefeller to Standard Oil, Utah Copper changed from a fief presided over by a local "captain of industry" to a giant business with far-flung connections and interests. The Guggenheims directed the overall policies in a colossal concern that included smelting, refining, and selling on a world market, while the determined Jackling and his resourceful friends managed day-to-day production affairs in Utah.

Interesting Facts about Bingham Canyon

• Kennecott's Bingham Canyon mine is the world's largest manmade excavation: 0.5-mile deep and 1,900 acres.

• The world's tallest building, the Sears Tower, 1,454 feet tall, would reach only halfway up the side of the mine.

• At the top, it is nearly 2.5 miles from one side of the mine to the other.

• A mountain once stood where the huge bowl is now. Five billion tons of material have been removed since open-pit operations began here in 1906.

• Approximately two-thirds of all Utah mineral production has come from the Bingham Canyon mine.

• Bingham Canyon ore has yielded more than 12 million tons of copper metal whose cumulative value exceeds eightfold the yields of the Comstock lode, Klondike, and California gold rushes combined.

• Approximately 250,000 tons of material are removed daily. (About one-half is ore and one-half is "overburden" material.)

• It takes 1 ton of ore to produce 11 pounds of copper. Bingham Canyon ore contains an average of only 0.6% copper.

• Kennecott Utah Copper employs more than 2,400 men and women at the mine, ore haulage, grinding and concentrating plants, smelter, refinery, power plant, and offices.

• Kennecott's Utah Copper Division produces approximately 280,000 tons of refined copper annually plus significant quantities of molybdenum, gold, and silver.

Source: *Kennecott's Bingham Canyon Mine: The World's First Open-Pit Copper Mine* (pamphlet), Kennecott Utah Copper.

Throughout the 1960s and 1970s, the Bingham Canyon mine was exploited by diesel-electric truck and rail haulage. By the mid-1980s, however, the mine was no longer economically viable as copper prices fell, labor costs escalated, the ore-grade percentage of copper continued its decline, and the waste stripping ratios climbed. At this time, a modernization program was undertaken to resurrect and transform the mine into the model of efficiency seen today.

Modern copper production starts as rigs drill a refined pattern or series of holes into 50-foot levels of the mine. The holes are then filled with an explosive, which when triggered sets off a controlled blast that fractures and loosens the rock. Thirty-four-cubic-yard electric shovels load the ore or overburden into 190-ton diesel-electric trucks. The trucks can readily move about the Bingham pit, delivering the ore to the in-pit crushers.

The "relocatable" gyratory ore crushers reduce the ore to pieces no larger than 10 inches in diameter. Crushed ore is transported on a 6-foot-wide conveyor belt 5.2 miles out of the pit to a new stockpiling area; 10,000 tons of ore an hour can be moved into a covered 350,000-ton stockpile. Smaller conveyor belts move the ore into a new concentration facility nearby. Here, a 34-foot diameter semiautogenous grinding mill reduces the ore to less than 0.5 inch in diameter. The ore next encounters a ball mill, where it is ground to the consistency of a fine powder.

A trip through a flotation cell creates a slurry that can be thickened, allowing the metals to be separated; the metals float to the surface stuck to the bubbles of the agitated fluid. Once a concentrate reaches 28% copper, it is pumped 17 miles to a new filtration plant. After filtration, the concentrate is heated to a molten state, from which additional impurities are removed. A 98% molten copper solution is then poured into forms called *anodes* and cooled. Electrolytic refining removes further impurities, yielding a product that is 99.98% pure copper.

After an investment of 650 million dollars, the modernized Kennecott Utah Copper is now among the world's lowest-cost copper producers. With the copper's associated metals of gold, silver, and molybdenum, the Bingham Canyon mine will stay competitive for years to come.

Philip Richardson, a structural engineer, has worked in the Bingham pit and is a field collector of Utah minerals.

REFERENCES

Arrington, L. J., and G. B. Hansen. 1963. *The richest hole on Earth: A history of the Bingham Copper mine.* Utah State University monograph series 11(1).

Bailey, L. R. 1988. *Old Reliable, a history of Bingham Canyon, Utah.* Tucson: Westernlore Press.

Boutwell, J. M. 1933. Copper deposits at Bingham, Utah. In *Copper resources of the world*, 347–59. Sixteenth International Geological Congress.

Bray, R. E., and J. C. Wilson, eds. 1975. *Guide book to the Bingham mining district.* Society of Economic Geologists. □

Minerals of the

Centennial Eureka Mine,

Tintic District, Eureka, Utah

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ll mineral photographs by Joe Marty and, unless therwise noted, of specimens from his collection

TINTIC DISTRICT in Utah has been mined for silver, copper, lead, and zinc since 1869. The district divided into two subdistricts: (1) The Main Tintic trict, centered on the town site of Eureka and ing the towns of Mammoth and Silver City, and (2) ast Tintic subdistrict, which is centered on the oned town site of Dividend.

y few mineral specimens have been collected from intic district during the last fifty years. This has ed because some of the old mine dumps in both tricts were recently reworked for low-grade gold. All Centennial Eureka mine dump was screened. The sized material was hauled to leach pads for the re- of gold, and the remaining oversized or remnant ers were left in situ. These boulders provided a rich for mineral specimens, including a variety of mineral species that have not been available from the mine for decades; mineral species new to the Tintic district and to the state of Utah; and mineral species that are new to science. Currently, seventy-one recognized mineral species and four unnamed minerals are known from the Centennial Eureka mine. Many occur as well-formed and colorful crystals, making collecting, viewing, and identifying them extremely enjoyable. The majority of the species occur as microsized euhedral crystals.

arty, a medical technologist, enjoys collecting, study-d photographing minerals, especially micromounts. tin C. Jensen, research mineralogist and scanning n microscopist, works at the Mackay School of at the University of Nevada-Reno, and is an avid ollector of minerals from the western United States. lrew C. Roberts, research mineralogist and X-ray r diffraction specialist, works at the Geological of Canada, Ottawa, and frequently describes new ls from both Canada and the United States.

Location

The town of Eureka is approximately 70 miles south of Salt Lake City and can be reached by paved and well-traveled roads. The Centennial Eureka mine, in the Main Tintic subdistrict, is located about 1 mile southwest of the town of Eureka on the north slope of Eureka Ridge. The main shaft and dumps are situated in the NW ¼ of section 24, T. 10S., R. 3W. and are shown on the Eureka, Utah, 7.5' quadrangle map. The mine can be seen by driving west of Eureka 1 mile, stopping at the Bullion Beck mine monument, and looking south (up the ridge) at the very large and magnificent headframe, a well-preserved remnant of past mining activities. Over 70 feet tall, it was constructed from timbers reportedly imported from Norway.

History and Production

Originally called the Blue Rock mine, the Centennial Eureka mine was first opened in 1876; and, during the next fifty years, it was the most productive mine in the Main Tintic subdistrict. The principal metals produced were gold, silver, copper, and a very small amount of lead. During the early days of active mining, the gross value of the ore was approximately $30/ton, and the annual production was approximately 100,000 tons (Lindgren, Loughlin, and Heikes 1919). A more recent compilation by Centurion Mines Corporation (the present lessee of the mine) of older data showed the total Centennial Eureka production of recovered metals to be as follows: gold, 656,300 ounces; silver, 23,900,000 ounces; and copper, 79,500,000 pounds. When all of the metal production is taken into account and expressed in today's dollars, the total is $405,400,000. Of all the Tintic district mines, only

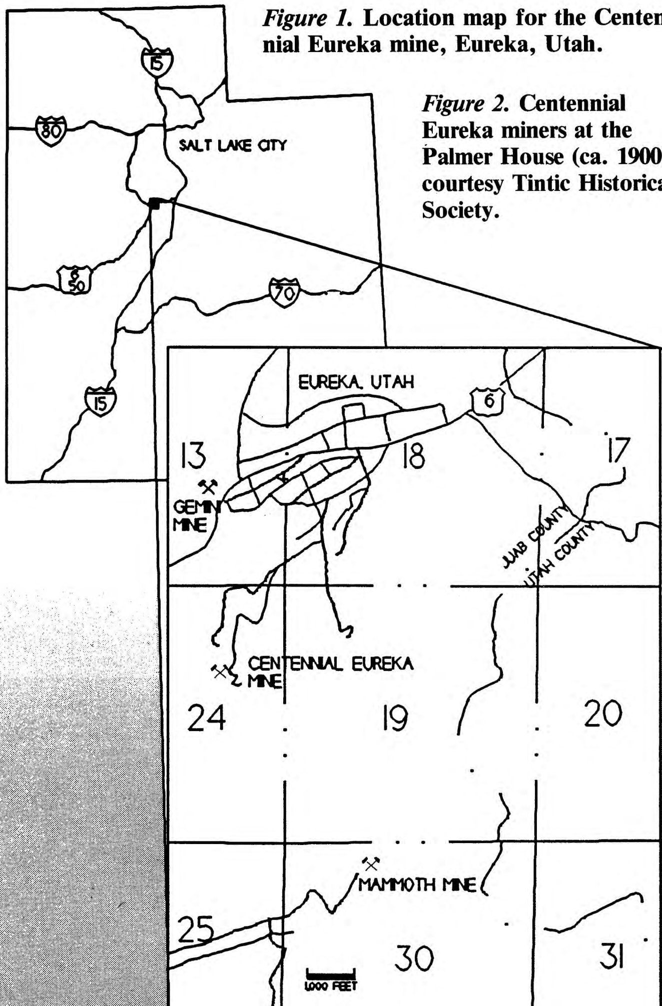


Figure 1. **Location map for the Centennial Eureka mine, Eureka, Utah.**

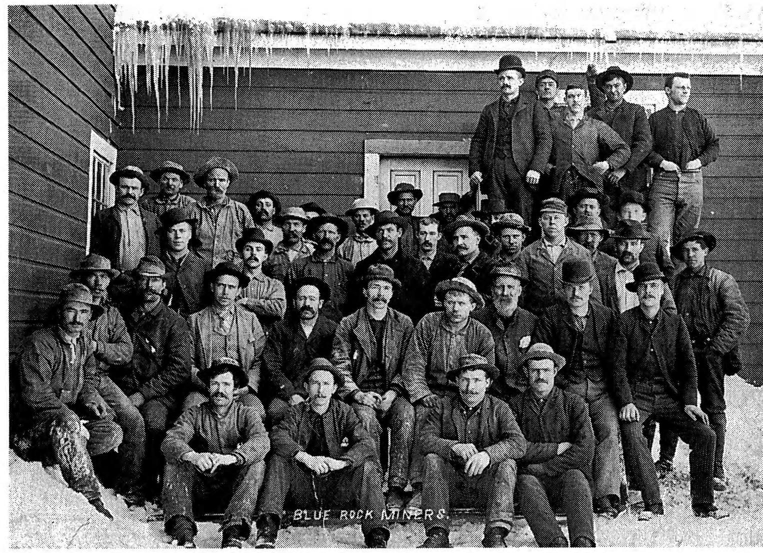


Figure 2. **Centennial Eureka miners at the Palmer House (ca. 1900); courtesy Tintic Historical Society.**

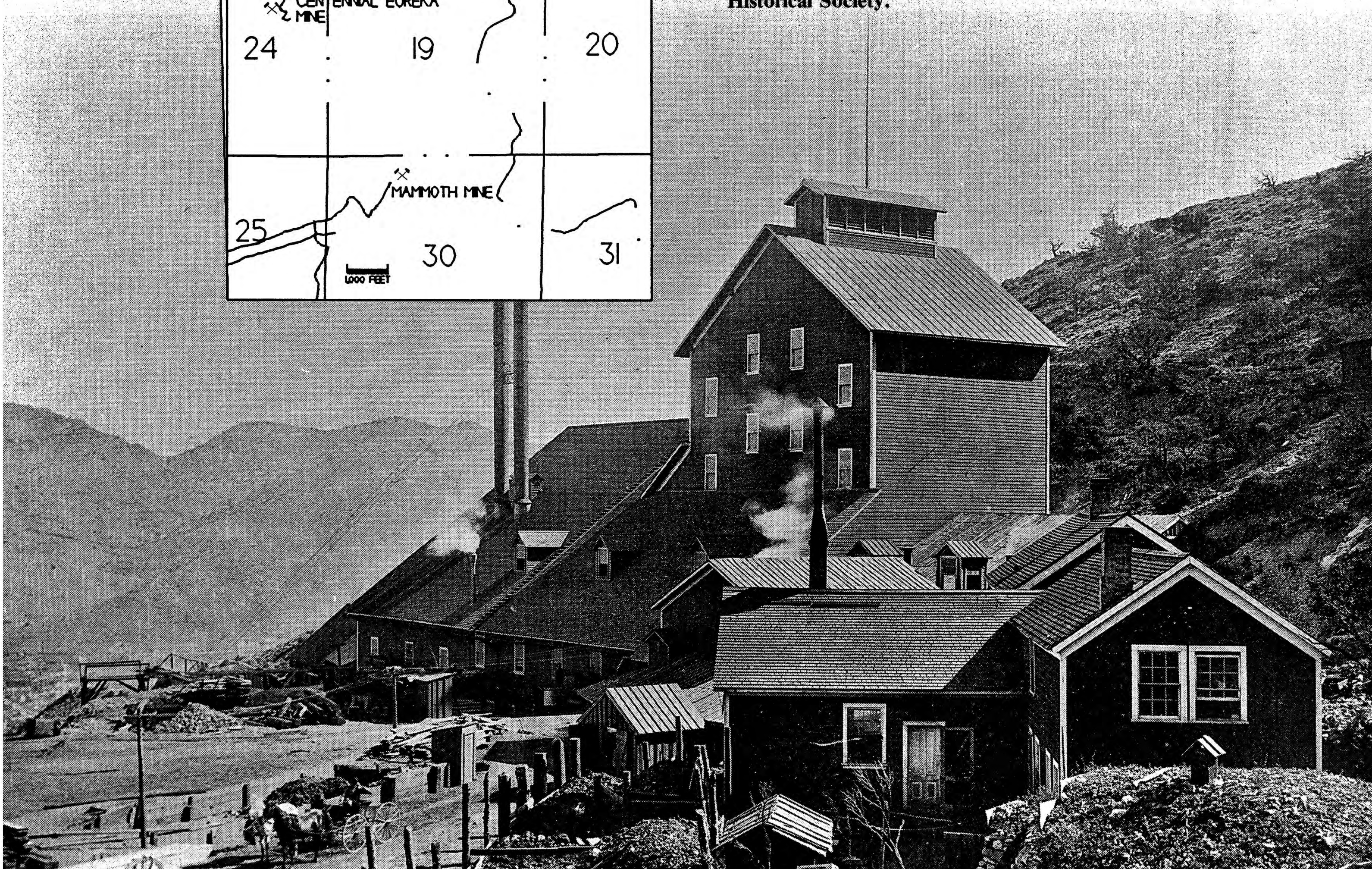
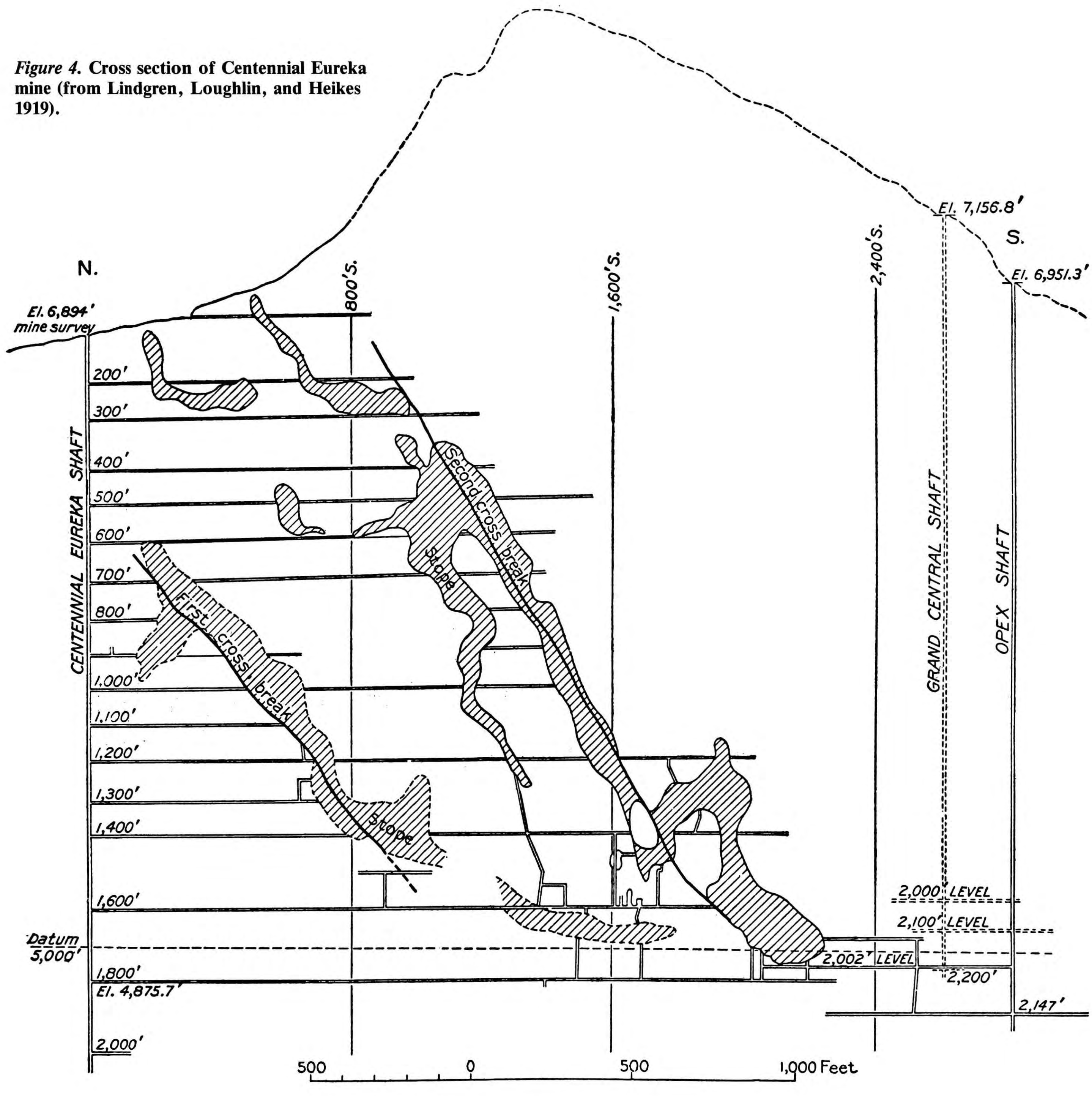


Figure 3. **The Centennial Eureka mine (ca. 1896); courtesy Utah Historical Society.**

Figure 4. **Cross section of Centennial Eureka mine (from Lindgren, Loughlin, and Heikes 1919).**



the Chief Consolidated, with a total metal production of $524,320,000, exceeded the Centennial Eureka.

Geology and Ore Deposits

The Centennial Eureka mine is situated in a thick section of Paleozoic sedimentary rocks (Morris and Lovering 1961), including limestone, dolomite, and quartzite. These rocks were extensively faulted and folded, providing a means of entry and localization for the ore-forming solutions, which originated from the Silver City Stock (Morris and Mogensen 1978), an Oligocene-aged monzonite porphyry intrusion south of the Tintic district (Lovering 1949). The very large columns (or pipes) of ore that formed are best described as massive replacement deposits and were mined from the surface to an approximate depth of 2,200 feet.

The workings at the Centennial Eureka mine are enormous and were developed by twenty levels, which include at least 20 miles of drifts, cross-cuts, raises, and shafts. The collar of the main shaft is at an elevation of 6,887 feet and has a total depth of 2,281 feet, penetrating to 4,606 feet above sea level. Some of the stopes are overwhelming in size; for example, the California stope ranges up to 125 feet wide and is over 1,000 feet long.

The deep water table (about 2,000 feet below the sur-

The Tintic district has been known to mineral collectors as a famous copper arsenate locality for 125 years. The Centennial Eureka mine, which produced 80 million pounds of copper along with large amounts of gold and silver, is currently the source for many new and exciting mineral species.

face) permitted significant oxidation of the original primary minerals and was the single most important factor in the formation of the large suite of secondary minerals that are now present. Instead of abundant primary sulfide minerals, such as pyrite, enargite, and chalcopyrite, there are now many oxides of iron and copper, such as goethite, cuprite, and tenorite. Other primary sulfide minerals, including galena, wurtzite, and acanthite, were altered to "sand carbonate" (cerussite), hemimorphite, and chlorargyrite, respectively. Unoxidized minerals were reached at and below the water table but were not as economic to mine due to the lack of supergene enrichment.

Early mining, close to the surface, produced mainly oxidized copper in the form of secondary copper arsenates, malachite, native copper, and cuprite with the associated gangue minerals of quartz and barite. Silver was present as chlorargyrite. (Wouldn't it have been fun to go through the ore! Samples of the ore may have been the source of the large olivenite and clinoclase crystals that came from the mine in its early years of production.) As mining operations continued to deeper levels, the predominant ore was enargite with increasing amounts of gangue barite.

When collecting on the dump, it was not possible to determine where in the mine any particular specimen may have originated. In general, materials from the deeper levels were on top of the dump. Now that the dumps have been turned and removed, any possible correlations between samples and their respective locations within the mine have been virtually erased. The altered enargite boulders that contain so many secondary minerals probably were mined below level ten (1,000 feet below shaft collar); very little enargite was found above this level (Lindgren, Loughlin, and Heikes 1919).

Interestingly, there is still ore at the bottom of the Centennial Eureka mine below the water table. The mine closure in 1927 was the result of generally poor economic conditions, the antiquated mine design, and the necessity of excessive hand labor in the movement of ore to the haulage ways (Spenst Hansen, pers. com.).

Mineralogy

The majority of the minerals described below have been collected recently from material exposed on the dump. As with many microminerals, one cannot be absolutely certain of identification until further testing has been performed. Identifications of many of the following minerals are routine and have been made by crystal morphology, color, and associations. In selected instances, qualitative chemical analysis utilizing scanning electron microscopy coupled with an energy dispersive X-ray microanalyzer (SEM and EDS) has been helpful. Other phases were verified by X-ray powder diffraction (XRD).

The minerals have been divided into primary (sulfides and gangue), secondary, and unknowns.

Primary Minerals

Acanthite, Ag_2S, is rare and occurs as grayish-black metallic grains to 2 mm associated with quartz and chrysocolla. The few examples observed to date have been produced from boulders containing suites of secondary hydrated copper tellurium oxide minerals.

Barite, $BaSO_4$, is very common, and several generations of crystals have been observed. Some crystals have been entirely dissolved, leaving only a cast of the former tabular crystal. Barite occurs both on and in quartz, most commonly as white to colorless tabular crystals. Individual crystals are well formed and may reach up to 2.5 cm in length. Boulders containing barite and enargite have been found that also contain colorful, well-crystallized secondary minerals, such as mixite, beudantite, jarosite, duftite, clinoclase, tyrolite, carminite, and olivenite.

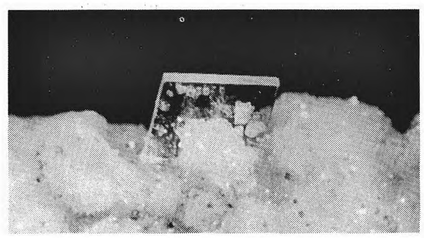


***Figure 5.* Colorless barite crystal with quartz inclusions on quartz; barite crystal 1.8 mm wide.**

Chalcopyrite, $CuFeS_2$, surprisingly uncommon in samples collected recently from the dump, has been found as small kernels to 1 cm exhibiting the mineral's typical metallic golden-yellow appearance.

Enargite, Cu_3AsS_4, is the most common metallic grayish-black sulfide mineral on the dump. Its two distinct cleavages (110) are diagnostic. Cleavage masses and rarer single crystals have a bladed columnar appearance and are vertically striated. Galena, which is much less common, can be distinguished by its three cleavage planes. Crystals up to 2.5 cm, wholly enclosed within silicified matrix, have been found. Individual free-standing crystals are generally much rarer and smaller. Chalcocite and later covellite are typical oxidation products that coat enargite.

Boulders containing massive altered enargite are highly desirable to the mineral collector because of the excellent chances for associated secondary crystallized minerals. Countless numbers of these boulders have been smashed to smithereens by mineral collectors. Occasionally, one may actually see where enargite has been replaced by exquisite crystallized secondary carbonate, arsenate, and tellurium minerals. Such associations typically include olivenite, tyrolite, clinoclase, pharmacosiderite, malachite, barite, and chrysocolla.

Galena, PbS, is uncommon on the dump and occurs most typically as partially oxidized grains and kernels, to 2 cm, associated with duftite, rosasite, hemimorphite, and mimetite. Although galena occurs in all of the Tintic mines, it is not abundant in those deposits that contain substantial enargite and barite, such as the Centennial Eureka mine.

Jalpaite, Ag_3CuS_2, has been tentatively identified as corroded steel-gray crystals and overgrowths associated with enargite crystals that line quartz vugs. Associated minerals include tetrahedrite, wurtzite, polybasite, and beudantite.

Marcasite, FeS_2, has very rarely been found on the dump as radiating spherules, to 3 cm, possessing a metallic white appearance and wholly enclosed within enargite-bearing jasperoid samples.

Polybasite, $(Ag,Cu)_{16}Sb_2S_{11}$, is very rare and has been observed as slightly corroded, gray-black, hexagonal crystals, to 0.2 mm, in quartz-lined vugs of siliceous enargite-bearing boulders. Other associated minerals include crystallized tetrahedrite, jalpaite, wurtzite, and beudantite.

Pyrite, FeS_2, is surprisingly uncommon on the dump, and the majority of samples observed to date are massive. The species seldom occurs in association with enargite but is more commonly found as vuggy to solid masses, up to 3 cm, in association with quartz and rarer goethite. Small cubes of brown oxidized pyrite (now goethite) are commonly found in association with many of the secondary minerals.

Primary or gangue *quartz,* α-SiO_2, is widespread as fine-grained replacements of limestone and dolomite (jasperoid). Quartz may also occur as drusy coatings of 1-2-mm colorless brilliant crystals lining cavities.

Crude crystals to 0.5 mm of arsenian *tetrahedrite*, $(Cu,Fe)_{12}Sb_4S_{13}$, have rarely been found within vugs in siliceous enargite-bearing boulders.

Wurtzite, (Zn,Fe)S, occurs as slightly corroded red-brown, elongated, hexagonal crystals, to 0.2 mm, associated with polybasite, jalpaite, tetrahedrite, chalcocite, and beudantite. Only a few examples have been seen.

Secondary Minerals

Adamite, $Zn_2(AsO_4)(OH)$, occurs as very lustrous, white to green, 1-2-mm equant crystals on goethite, or less commonly as prismatic crystals with prominent chisel-like terminations. Adamite is typically opaque, although a few translucent green crystals have been found.

Beautiful, dark green, well-formed, *antlerite*, $Cu_3(SO_4)(OH)_4$, crystals to 3 mm occur in cavities of massive cuprite and malachite. A few truly spectacular specimens have recently been recovered, although the species is quite rare at this locality.

Aragonite, $CaCO_3$, occurs as colorless to white acicular

Table 1. Mineral species and selected parameters, Centennial Eureka dump, Tintic district, Juab County, Utah

Mineral	Abundance	Maximum dimension mm
Primary		
Acanthite	VR	2
Barite*	A	25
Chalcopyrite*	S	10 (X)
Enargite*	C	25 (X)
Galena*	R	20 (X)
Jalpaite	R	N.A.
Marcasite	R	30 (M)
Polybasite	R	0.2
Pyrite*	S	30 (M)
Quartz*	A	2.0 (X)
Tetrahedrite	VR	0.5
Wurtzite	VR	0.4
Secondary		
Adamite	S	2.0
Antlerite	R	3.0
Aragonite*	R	5.0
Arseniosiderite	R	0.03
Arsenogoyazite	R	0.03
Aurichalcite	R	1.0
Azurite*	C	3 (X)
Barium-Pharmacosiderite	S	1.2
Beudantite	S	0.1
Bindheimite	R	0.03
Brochantite*	R	0.5
Bromargyrite*	VR	—
Calcite*	A	25
Carminite	R	0.5
Cerussite	VR	1.0
Cesbronite	VR	0.5
Chalcocite*	R	1.0 (X)
Chenevixite	S	N.A.
Chlorargyrite*	R	0.2
Chrysocolla*	A	N.A.
Clinoclase*	C	8
Conichalcite*	C	1.2 (Spheres)
Connellite	R	0.5
Copper*	R	8 (M)
Cornubite	VR	0.5
Cornwallite*	C	1.5 (M)
Coronadite	R	N.A.
Covellite	R	N.A.
Cuprite*	S	0.4 (X)
Dolomite*	S	3.0
Duftite	C	0.3
Dugganite	VR	0.14
Gartrellite	VR	0.1
Goethite	C	0.4 (X)
Gold*	R	(18 microns)
Hemimorphite	S	2.0
Hinsdalite	R	0.2
Jarosite*	C	0.5
Malachite*	A	0.8 (X)
Mimetite	S	0.8
Minrecordite	R	(6 microns)
Mixite	S	5.0
Olivenite*	S	2.0
Philipsburgite	VR	1.0
Plattnerite	VR	(20 microns)
Plumbojarosite	S	1.0
Posnjakite	R	0.2
Pyrolusite	R	20
Quartz	C	2
Rosasite	S	1.0

Table 1.—Continued

Mineral	Abundance	Maximum dimension mm
Secondary		
Scorodite*	VR	0.3
Segnitite	VR	0.1
Silver*	R	—
Strashimirite	R	0.3
Svanbergite	R	0.5
Tenorite	S	N.A.
Tsumcorite	VR	1.0
Tyrolite*	C	2.5
Xocomecatlite	R	0.4
Zeunerite*	R	0.1
Unknowns		
Unknown no. 1	R	0.2
Unknown no. 2	VR	0.14
Unknown no. 4	R	0.3
Unknown no. 8	VR	0.2

VR, very rare; R, rare; S, scarce; C, common; A, abundant; —, not found; X, crystalline; M, massive; *, species reported in literature; N.A., not applicable.

crystals ranging from 0.5 to 5 mm in length. It has been found perched on calcite crystals in cavities but is uncommon on the dump. In the past, large natural caves that were intersected by mining operations contained abundant formations of both calcite and aragonite.

Arseniosiderite, $Ca_2Fe_3^{+3}O_2(AsO_4)_3 \cdot 3H_2O$, has been found as red-brown rosettes of platy crystals, less than 0.03 mm in length, associated with quartz, carminite, and duftite.

Very rare *arsenogoyazite*, $(Sr,Ca,Ba)Al_3(AsO_4,PO_4)_2(OH,F)_5 \cdot H_2O$, occurs as white crystals, less than 0.03 mm, on olivenite and chenevixite. Identification is based on chemical composition and crystal morphology.

Aurichalcite, $(Zn,Cu)_5(CO_3)_2(OH)_6$, occurs very rarely on the dump in association with hemimorphite and rosasite. Bladelike crystals exhibit the typical pale blue silky appearance and do not exceed 1 mm in length.

Azurite, $Cu_3(CO_3)_2(OH)_2$, is very common in boulders exposed on the dump. The species is typically well crystallized and is associated with malachite. Small orange pharmacosiderite crystals may rarely be associated with the azurite. (It is a very pleasant surprise to take home "just" azurite and then find beautiful pharmacosiderite crystals after further examining the specimens under the microscope.)

Barium-pharmacosiderite, $BaFe_8^{+3}(AsO_4)_6(OH)_8 \cdot 14H_2O$, occurs as brown to orange cubes up to 1.2 mm. The species has been found in altered enargite boulders associated with tyrolite, clinoclase, arseniosiderite, and azurite.

Beudantite, $PbFe_3^{+3}(AsO_4)(SO_4)(OH)_6$, is common within siliceous enargite-bearing boulders. Beudantite crystals are pseudocubic rhombohedra no larger than 0.1 mm; they are lustrous and vary from yellow-green to brown. Jarosite, which also occurs at the locality, is similar in

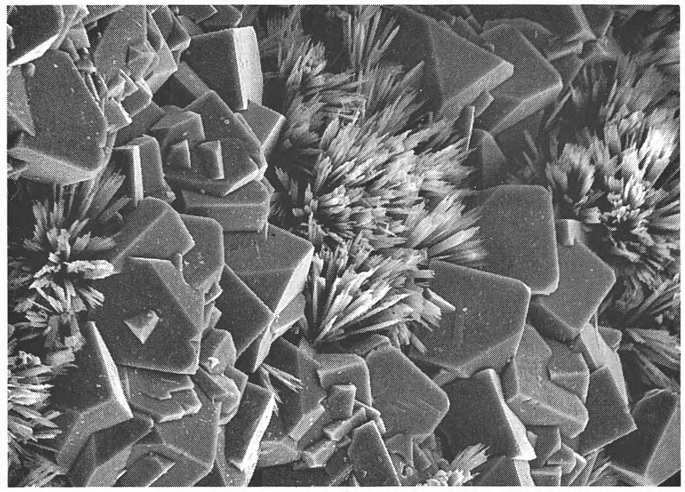


Figure 6. **SEM of druse of pseudocubic brown beudantite crystals, to 20 microns, associated with fibrous green malachite tufts.**

habit and color and may be confused with beudantite. However, at the Centennial Eureka mine, beudantite is an earlier mineral paragenetically and occurs closely associated with sulfide minerals, primarily enargite. In contrast, jarosite forms much later and is found on fracture and joint surfaces of more highly altered rocks.

Bindheimite, $Pb_2Sb_2O_6(O,OH)$, occurs as thin yellow coatings on massive quartz. It is probably not particularly rare but is difficult to recognize in the field. The species occurs predominantly on vuggy corroded quartz in association with cuprian adamite and tsumcorite.

Brochantite, $Cu_4(SO_4)(OH)_6$, has not yet been positively identified from boulders on the dump. However, some olivenite crystals collected from the 1,200-foot level of the mine have exhibited small crystalline green patches, to 0.5 mm, of corroded brochantite.

Bromargyrite, AgBr, was the reported derivation for the original name of the mine, "Blue Rock." This species has not been observed on dump material during the current investigation. It is unclear how the name Blue Rock originated, since bromargyrite is not blue. Because bromargyrite and chlorargyrite are associated with chrysocolla, it is possible that the original name for the mine was derived instead from the blue-colored chrysocolla so abundant at the mine.

Calcite, $CaCO_3$, the most abundant mineral on the dump, occurs as intergrown and terminated rhombohedral and scalenohedral crystals, as well as being the chief constituent of the massive limestone. Specimens that contain large calcite crystals typically have little in the way of secondary minerals. Underground exposures still exist that consist of large vugs lined with sharp, opaque chocolate-brown scalenohedral crystals.

Carminite, $PbFe_2^{+3}(AsO_4)_2(OH)_2$, is rare, occurring as cherry-red acicular crystals no larger than 0.5 mm. Radiating sprays of carminite occur on quartz and are closely associated with yellow beudantite and arseniosiderite.

Cerussite, $PbCO_3$, occurs on galena as cream-white to colorless, rather unspectacular, subhedral crystals to 1 mm. Associated minerals include duftite, rosasite, mimetite, and hemimorphite.

Cesbronite, $Cu_5^{-2}(Te^{-4}O_3)_6(OH)_2{\bullet}2H_2O$, the exceptionally rare secondary copper tellurium mineral, has recently been verified from the Centennial Eureka mine. Crystals are no larger than 0.5 mm and occur as grass-green, thin, tabular individual crystals and rarely as clusters. Only a few specimens are known; they have been derived from boulders containing prolific assemblages of other secondary tellurium-bearing species.

Chalcocite, Cu_2S, in addition to being a common and widespread alteration product of enargite, also rarely occurs as steel-gray corroded crystals to 1 mm in quartz-lined vugs.

Chenevixite, $Cu_2^{+2}Fe_2^{+3}(AsO_4)_2(OH)_4{\bullet}H_2O$, is uncommon and occurs as dark olive-green coatings and botryoidal masses on drusy quartz crystals in association with stubby, bladed olivenite crystals. It is difficult to visually distinguish chenevixite from conichalcite or duftite. Confirmation of the identity of these phases is best ascertained by microchemical testing.

Chlorargyrite, AgCl, was recently located on the dump by the authors and was reported by former workers as constituting a significant portion of the high-grade silver ore mined in the earlier days.

Chrysocolla, $(Cu,Al)_2H_2Si_2O_5(OH)_4{\bullet}nH_2O$, is very common and occurs as masses exhibiting the characteristic blue to blue-green color. "Cracked" coatings and spherules have been found locally that may cover or replace any of the other secondary minerals. In rare instances, some of the secondary copper tellurium minerals may be mistaken for chrysocolla.

Clinoclase, $Cu_3(AsO_4)(OH)_3$, from the Tintic district is well known to mineral collectors worldwide. Although spherules up to 3.0 cm have been reported from the Tintic district (Palache and Berry 1946), clusters up to 2.5 cm from the Centennial Eureka dump are the largest examples that have recently been collected. This dark blue mineral is particularly aesthetic but unfortunately is uncommon. It is typically associated with enargite, tyrolite, pharmacosiderite, and cornwallite in boulders of sugary quartz and bladed barite.

Conichalcite, $CaCu^{+2}(AsO_4)(OH)$, is relatively common on the dump, and specimens with surfaces to several centimeters entirely coated with the species have been observed. In general, it occurs as light apple-green druses and as individual balls to 1 mm. Some specimens exhibit beautiful euhedral crystals to 0.2 mm. Duftite and chenevixite can easily be confused with conichalcite, but in most instances the characteristic apple-green color should serve as a reliable determinative factor.

Well-formed *connellite*, $Cu_{19}Cl_4(SO_4)(OH)_{32}{\bullet}\ 3H_2O$, crystals were formerly recovered from the nearby Grand Central mine, located to the south of the Centennial Eureka property boundary (Lindgren, Loughlin, and Heikes 1919). On specimens collected recently from the Centennial Eureka dump, connellite has rarely been found within specimens of vuggy enargite/quartz in association with beudantite. The connellite occurs as pale blue acicular needles no larger than 0.5 mm.

Small masses of native *copper*, Cu, have rarely been discovered in association with massive cuprite, malachite, and tenorite.

Cornubite, $Cu_5(AsO_4)_2(OH)_4$, is very rare and occurs as rosettes of light green platelike crystals, up to 0.5 mm, in close association with malachite.

Cornwallite, $Cu_5(AsO_4)_2(OH)_4{\bullet}H_2O$, is common on material scattered about the dump and is seen in most siliceous enargite/barite boulders. Although it may be similar in appearance to malachite, it does not exhibit the characteristic fibrous habit and slightly paler green color of the carbonate. Exceptional cornwallite crystals have been found, attaining sizes of up to 1.5 mm, and may possibly be the finest crystallized examples of the species yet known.

Coronadite, $Pb(Mn^{+4},Mn^{+2})_8O_{16}$, has been tentatively identified in vugs of dolomite, where it occurs as sooty brown-black clusters to 0.1 mm, associated with minor hemimorphite.

In addition to being a relatively common alteration product of enargite, *covellite*, CuS, has also been rarely found as iridescent indigo-blue to black skeletal masses, to 1.5 mm, locally lining quartz vugs in enargite and barite-bearing boulders.

Cuprite, Cu_2O, is uncommon on the dump and typically occurs as small semitranslucent red masses. Euhedral and lustrous cuprite crystals to 0.4 mm have been rarely observed. Boulders containing cuprite characteristically may possess associated native copper, malachite, and tenorite.

Dolomite, $CaMg(CO_3)_2$, both as a rock type and as rhombohedral crystals, is relatively common throughout the dump material. Vuggy samples may contain open spaces, up to 3 cm wide, that are lined with druses of white to pale pink secondary dolomite crystals up to 3 mm in length.

Duftite, $PbCu(AsO_4)(OH)$, is surprisingly common, even though it has not been reported from the mine or district until this article. The species typically occurs as olive-green subhedral bladed crystal clusters less than 0.3 mm. It

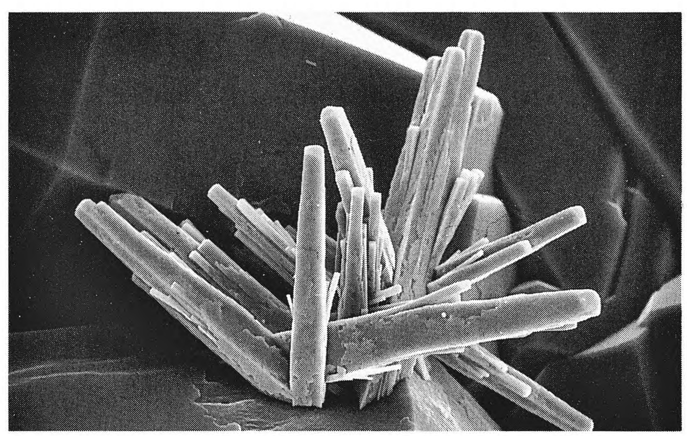


Figure 7. **SEM of diverging cluster of apple-green orthorhombic calcian duftite crystals, to 40 microns, on quartz crystals.**

may be associated with quartz, malachite, beudantite, rosasite, and/or hemimorphite. Confusion could easily arise in the identification of this species, for chenevixite and conichalcite can appear remarkably similar. Microchemical analysis would be the best method to reliably differentiate these species. Significant substitutions of calcium have also been noted in most duftite specimens when examined by EDS, and pure duftite appears to be quite rare.

A single sample containing well-crystallized *dugganite*, $Pb_3(Zn,Cu^{+2})_3(Te^{+6}O_6(AsO_4)(OH)_3$, has been found at the Centennial Eureka dump and is the first reported occurrence of this mineral from Utah. It occurs as stubby, euhedral, pale green, hexagonal crystals, to 0.14 mm, scattered on drusy quartz crystals. Identity has been confirmed by SEM with EDS and by XRD. The species was found in a boulder containing other secondary hydrated copper tellurium oxide minerals.

Only one specimen of *gartrellite*, $Pb(Cu^{+2},Fe^{+2})_2(AsO_4,SO_4)_2(CO_3,H_2O)_{0.7}$, was found in association with carminite and conichalcite. The mineral occurs as a yellow microcrystalline crust and as small spearlike crystals up to 0.1 mm. Yellow-green coatings on rock surfaces are not uncommon on the dump; therefore, gartrellite may not be particularly rare. The mineral was confirmed by both SEM with EDS and by XRD.

Metallic black adamantine *goethite,* $\alpha\text{-}Fe^{+3}O(OH)$, crystals, 0.1 to 0.4 mm, occur rarely and are found in association with pyrite and quartz. The species is also widespread as iron-oxide coatings and earthy masses (limonite).

Visible native *gold*, Au, was not found on the dump by these writers but was formerly one of the major metals recovered from the mine and the district. A general association between copper and gold was noted by earlier workers and has been substantiated by at least the few samples recently collected. Native gold, with some silver (as electrum), has been detected as rounded grains to 18 microns wholly included within crystalline enargite. The species can be identified by SEM and backscattered imaging but would otherwise be difficult to locate.

Hemimorphite, $Zn_4Si_2O_7(OH)_2 \cdot H_2O$, is uncommon on the dump and is found as colorless, translucent to white, prismatic crystals up to 2 mm long. Crystals tend to occur as radiating clusters associated with rosasite, duftite, mimetite, and more rarely with aurichalcite.

Hinsdalite, $(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$, is very rare and has been found as thin, trigonal, whitish crystals to 1 mm associated with secondary hydrated copper tellurium oxide minerals. Microchemical analysis is required to distinguish the mineral from svanbergite, which also occurs in the same boulders and with the same associations.

Jarosite, $KFe_3^{+3}(SO_4)_2(OH)_6$, is locally common in boulders exposed on the dump. The species has been observed as crystals to 0.5 mm that exhibit a typical orange-yellow color and brilliant luster. Jarosite is a very late mineral paragenetically, which assists in its identification.

Although the term *limonite* is no longer used as a mineral species, it is deeply embedded in the literature. The minerals that were described as limonite are hydrous iron oxides, mostly goethite.

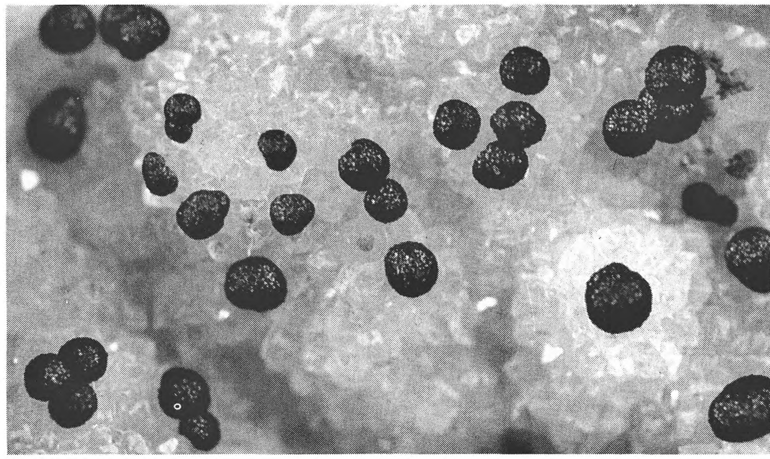


Figure 8. **Malachite spheres on quartz; width of view 12 mm.**

Malachite, $Cu_2(CO_3)(OH)_2$, is very common and can be found as massive examples to several centimeters in thickness, as bright green acicular crystals to 0.8 mm, and as botryoidal vug fillings. It is typically a late-stage mineral, which serves to distinguish it from earlier-formed species, such as cornwallite and conichalcite. The most common associations are altered enargite and azurite.

Mimetite, $Pb_5(AsO_4)_3Cl$, occurs as dull yellow coatings and as rare translucent to transparent crystals ranging from 0.2 to 0.8 mm. It is uncommon but is consistently associated with hemimorphite, duftite, and rosasite.

Minrecordite, $CaZn(CO_3)_2$, occurs as micron-sized rinds on dolomite crystals. Very interesting specimens of crystallized dolomite have been collected that exhibit thin outer zones containing high zinc concentrations, enough to be properly termed minrecordite. Backscattered imaging in the SEM shows these zones to be 5-6 microns thick, grading quickly into a more typical magnesium-rich dolomite.

This phenomenon may be a more common occurrence than is presently recognized. The high zinc regions of the Tintic dolomite crystals are confined to only the outer zones of the rhombohedra and have not been observed along later fractures or cleavages that penetrate into the crystal. This feature suggests that the zinc did not originate as a later replacement or alteration.

Excellent examples of *mixite*, $BiCu_6(AsO_4)_3(OH)_6 \cdot 3H_2O$, have been found on the Centennial Eureka dump, although superior specimens have recently been recovered from another of the Tintic mines, the Northern Spy mine. Mixite occurs as radiating sprays of acicular light green crystals up to 5 mm. It is locally common and tends to occur in silicified barite-rich boulders. All of the mixite examined so far in the Tintic district has been a calcian variety (W. S. Wise, pers. com.) and is similar to the variety found at the Gold Hill mine, Tooele County, Utah (Kokinos and Wise 1993).

Olivenite, $Cu_2(AsO_4)(OH)$, is a common oxidation product of enargite found in boulders from the dump. The species occurs only as olive-green crystals that vary from elongated to stubby. The largest single crystals attain sizes up to 2 mm. Vugs completely lined with olivenite crystals measure up to 2 cm and are not uncommon. Olivenite was also one of the ores mined and due to its appearance was called "wood copper" by the miners.

Philipsburgite, $(Cu,Zn)_6(AsO_4,PO_4)_2(OH)_6 \cdot H_2O$, has now been verified at the Centennial Eureka mine. The species is quite rare, but several examples have been recently collected. The mineral occurs as crystallized spherules to 1 mm and as clusters of spherules, which closely resemble cornwallite but which are a paler green. Philipsburgite can be distinguished from cornwallite by optical properties or by microchemical tests for zinc and phosphorous.

Plattnerite, PbO_2, has been found very rarely as lustrous black crystals to 20 microns perched on the ends of malachite fibers.

Plumbojarosite, $PbFe_6^{+3}(SO_4)_4(OH)_{12}$, is widespread in small amounts and typically occurs as flattened trigonal crystals, to 1 mm, that are remarkably similar in appearance to jarosite. Plumbojarosite crystals tend to be a paler yellow color and occur in vugs with copper arsenates, two features that serve well to distinguish it from jarosite.

Beautiful deep blue crystals of *posnjakite*, $Cu_4(SO_4)(OH)_6 \cdot H_2O$, have been found in some enargite-rich jasperoid boulders. Within drusy quartz-lined vugs, it occurs as elongated and modified lustrous crystals, to 0.2 mm, associated with beudantite, enargite, and barite.

Pyrolusite, $Mn^{+4}O_2$, is potentially widespread and occurs as typical dendrites, to 2 cm, on joint surfaces of brecciated limestone and quartz.

Quartz, α-SiO_2, crystals have rarely grown in close association with other secondary minerals, and it is much less common than primary quartz. These secondary quartz crystals are typically colorless, translucent, and prismatic with a sugary appearance. Secondary quartz rarely occurs perched on olivenite crystals.

Rosasite, $(Cu,Zn)_2(CO_3)(OH)_2$ commonly occurs as blue-green spherules, up to 1 mm, ubiquitously associated with hemimorphite, duftite, and mimetite.

Although fine bluish-green crystals of *scorodite*, $Fe^{+3}AsO_4 \cdot 2H_2O$, have been reported from the Centennial Eureka mine (Lindgren, Loughlin, and Heikes 1919), only one specimen has been seen by the present authors.

The Centennial Eureka mine is the second world occurrence for the recently described species *segnitite*, $PbFe_3H(AsO_4)_2(OH)_6$. The species is rare, with perhaps five specimens having been discovered to date, and is present as minute yellow-brown spherules, to 0.1 mm, in quartz-lined vugs associated with crystallized beudantite, philipsburgite, and zincian olivenite.

Native *silver*, Ag, has not been found on the dump by the current authors but has been reported by others (Lindgren, Loughlin, and Heikes 1919).

Strashimirite, $Cu_8(AsO_4)_4(OH)_4 \cdot 5H_2O$, is rare and occurs as radiating sprays of pale green crystals to 0.3 mm. The only other associated minerals are goethite, quartz, and barite.

Svanbergite, $SrAl_3(PO_4)(SO_4)(OH)_6$, is also rare and occurs, as with hinsdalite, as small, cream-colored, opaque, flattened, rhombohedral crystals associated with the assemblage of secondary hydrated copper tellurium oxide minerals.

Tenorite, CuO, has been found in cuprite-rich samples as gray-black to brown coatings and masses intimately associated with native copper.

Beautiful orange to yellow examples of crystallized *tsumcorite*, $PbZnFe^{+2}(AsO_4)_2 \cdot H_2O$, have been verified by XRD methods on samples from vuggy quartz boulders. It may be locally common as both single flattened crystals and as radiating fan-shaped groups of crystals to 1 mm. Cuprian adamite crystals and goethite are associated minerals.

Tyrolite, $CaCu_5(AsO_4)_2(CO_3)(OH)_4 \cdot 6H_2O$, is one of the more notable species from the Tintic district and occurs at the Centennial Eureka mine as deep green thin-bladed prismatic crystals and as micaceous fan-shaped aggregates up to 2.5 mm. Tyrolite is most typically associated with corroded enargite and crystallized pharmacosiderite and clinoclase.

The very rare species *xocomecatlite*, $Cu_3^{+2}Te^{+6}O_4(OH)_4$, has also been verified from the Centennial Eureka mine. This is the second world occurrence of this mineral, after the type locality at Moctezuma, Mexico. It occurs as pale green crystallized spherules, up to 0.4 mm, and is very similar in morphology to malachite. A chemical test for tellurium or effervescence in dilute hydrochloric acid will help to distinguish these two species. Within boulders containing the secondary hydrated copper tellurium oxide minerals, xocomecatlite is not particularly rare. Surfaces of drusy quartz, 1 cm across, heavily covered with xocomecatlite spherules, have also been collected.

Zeunerite, $Cu(UO_2)_2(AsO_4)_2 \cdot 10\text{-}16H_2O$, has been found on the dump in vuggy, siliceous, enargite-rich boulders. Green platy crystals, 0.1 mm, occur rarely within cavities. The species was also previously reported as being extremely rare (Lindgren, Loughlin, and Heikes 1919). Interestingly, no other uranium-bearing minerals have yet been observed from the district.

Unknowns

The following unknown minerals have been discovered during recent collecting and are being further characterized for eventual submission to the IMA Commission on New Minerals and Mineral Names.

Unknown no. 1, tentative formula $Cu_3TeO_6 \cdot H_2O$, is relatively rare at the Centennial Eureka mine. It occurs as both thin interstitial olive-green coatings on drusy quartz and as millimeter-sized dark green-black nodules lining drusy quartz vugs. It is cubic with a *P*-lattice and a refined unit-cell parameter $a = 9.555$ (2) Å. The six strongest lines in the X-ray power pattern [*d* in Å(I)] are 4.26 (40), 2.763

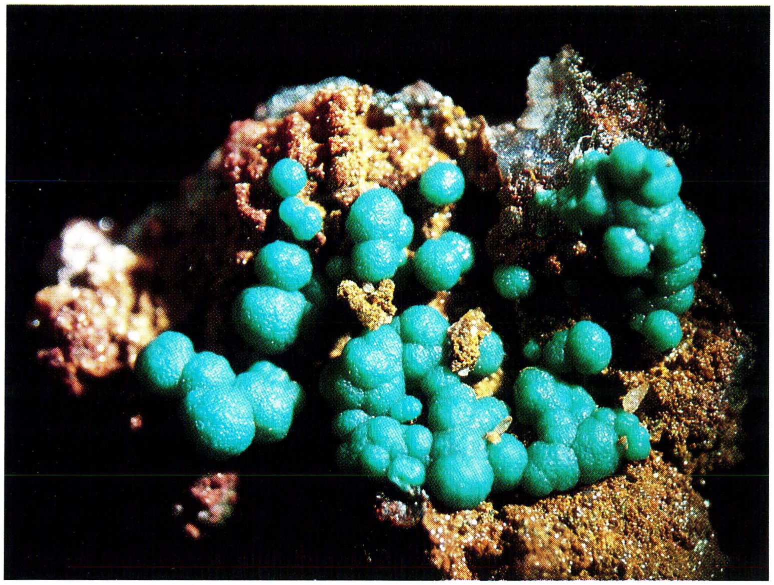


Figure 9 (far left). **Rosasite; width of view 8 mm.**

Figure 10 (left). **Yellow beudantite crystals on quartz; width of view 3 mm.**

Figure 11. **Carminite crystals on quartz; width of view approximately 2 mm; Martin Jensen specimen.**

Figure 12. **Single cesbronite crystal approximately 0.3 mm; Martin Jensen specimen.**

Figure 13. **Azurite crystals on quartz; width of view approximately 4 mm; Martin Jensen specimen.**

Figure 14. **Adamite crystals on quartz; width of view 6 mm.**

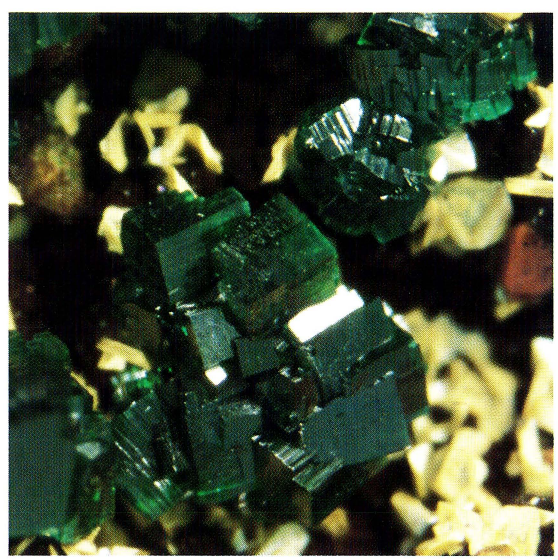


Figure 15. **Cornwallite crystals; width of view 3 mm.**

(100), 2.384 (70), 1.873 (40), 1.689 (80), and 1.440 (60). This mineral has also been found at the McAlpine mine, Tuolumne County, California.

Unknown no. 2, tentative formula $Cu_6Te_2^{+6}O_{11}(OH)_2 \cdot 2H_2O$, is very rare and occurs as isolated emerald-green rhombohedra perched on drusy quartz associated with unknown no. 1 and xocomecatlite. Unknown no. 2 is monoclinic, pseudospace group $P\,2_1/n$, with reduced unit-cell parameters $a = 9.204$, $b = 9.170$, $c = 7.584$Å, $\beta = 102.32°$. The six strongest lines in the X-ray powder pattern [d in Å (I)] are 6.43 (100), 3.217 (70), 2.601 (40), 2.530 (50), 2.144 (35), and 1.750 (35).

Unknown no. 4, hydrated $(Cu,Zn)(TeO)(AsO_4)Cl$, is the most common of the unknown minerals found recently and occurs as isolated blue-green spherules up to 0.3 mm, on drusy quartz, as thin blue-green crusts interstitial to quartz, and as blue-green botryoidal crusts on quartz. Unknown no. 4 is pseudohexagonal, but the true symmetry is unknown at this time. Preliminary electron probe analyses give CuO 38.58, ZnO 21.18, TeO_2 13.74, As_2O_3 13.14, Cl 1.69. The six strongest lines in the X-ray powder pattern [d in Å (I)] are 19.0 (100), 9.56 (60), 4.12 (40), 3.814 (70), 2.529 (70), and 1.560 (70).

Unknown no. 8, tentative formula $Cu_2Te^{+6}O_4(OH)_2$, is very rare; only five specimens are known. The species occurs on drusy quartz as isolated grass-green, elongate crystals, to 0.5 mm, associated with chrysocolla and cesbronite. The mineral is monoclinic, space group $P\,2_1/n$, with refined unit-cell parameters $a = 9.095$, $b = 5.206$, $c = 4.604$ Å, $\beta = 98.69°$. Preliminary electron probe analyses give CuO 44.15, TeO_2 43.19. The six strongest lines in the X-ray powder pattern [d in Å(I)] are 4.51 (40), 4.34 (60), 3.838 (50), 2.891 (70), 2.598 (100), and 1.834 (40).

Conclusion

The Centennial Eureka mine contributed to the colorful history of Eureka and provided many jobs and much wealth for the state of Utah (Notarianni 1992). It was the largest mine and produced the greatest quantity of ore during the early years of the Tintic district, enabling the district to be one of the major base-metal producers in the western United States during the late-nineteenth and early-twentieth centuries. The mine has also produced a wide variety of diverse primary and secondary mineral species. The current exposure of much fresh new material on the dump has given insight to the mine's interesting mineralogical environment. Mineral collectors will likely continue to benefit from the district's wide diversity of minerals, which include many unusual, rare, and new species.

Current Status

The Centennial Eureka mining properties currently are held under lease by Centurion Mines Corporation. Potentially economic new gold ore zones have recently been identified in the south end of the mine and will likely be worked through the old 500-foot-level haulage tunnel, called the Holden tunnel (S. Hansen, pers. comm. 1993). The material on the dumps was sold to North Lily Mining Company and screened during 1991 and 1992. Prior to the first snowfall of 1992, the ridge slopes were recontoured and the ground was revegetated. Because the mine dumps have been picked over quite thoroughly, it is now more difficult to find good mineral specimens.

AUTHORS' UPDATE

AS THIS ARTICLE goes to press, the authors have collected and identified a number of other mineral species at the locality. Probably the most interesting discovery is that of the world's largest quetzalcoatlite crystals. They occur as radiating sprays of capri-blue acicular needles to 1.5 mm resting on drusy quartz crystals. The species is very rare, and only four specimens are currently known.

Another species from the locality is hematite, which has been verified by XRD as an alteration mineral of pyrite in samples containing unknown no. 8.

Acknowledgments

The authors would like to thank Spenst Hansen of Centurion Mines Corporation for permission to collect specimens at the Centennial Eureka mine dump. We are extremely fortunate that Dr. Hansen recognizes the value of preserving the mineralogy of this great mine. Richard Thomssen and William Wise provided editorial assistance, and Jim McGlasson did the art work for the map. Thanks are also extended to the employees of the Utah Geological Survey for freely providing information during this study.

REFERENCES

Kokinos, M., and W. S. Wise. 1993. Famous mineral localities: The Gold Hill mine, Tooele County, Utah. *Mineralogical Record* 24:11-22.

Lindgren, W., G. F. Loughlin, and V. C. Heikes. 1919. *Geology and ore deposits of the Tintic mining district, Utah*. U. S. Geological Survey professional paper 107.

Lovering, T. S. 1949. *Rock alteration as a guide to ore—East Tintic district, Utah*. Economic Geology monograph 1.

Morris, H. T., and T. S. Lovering. 1961. *Stratigraphy of the East Tintic Mountains, Utah*. U. S. Geological Survey professional paper 361.

Morris, H. T., and A. P. Mogensen. 1978. Tintic mining district, Juab and Utah counties, Utah. In *Field excursion C-2: Guidebook to mineral deposits of southwestern Utah*, ed. by D. R. Shaw and P. D. Rowley, 41-48. Utah Geological Association publication 7.

Notarianni, P. F. 1992. *Faith, hope and prosperity: The Tintic mining district*. Tintic Historical Society.

Palache, C., and L. G. Berry. 1946. Clinoclasite. *American Mineralogist* 31:243-58.

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BRONSON FERRIN STRINGHAM (1907–1968)

Stringhamite, $CaCuSiO_4 \cdot H_2O$, is a deep blue, hydrous copper calcium silicate, originally discovered at the Bawana mine, Beaver County, Utah (Hindman 1976). Its structure was determined on crystals from the Christmas mine, Gila County, Arizona (Hawthorne 1985). The monoclinic crystals, up to 0.1 mm across, from the type locality are dominated by the forms {011} and {101}, modified by {010} and {111}. At the Bawana mine, stringhamite occurs with thaumasite on fractures in a diopside-magnetite skarn. At the Christmas mine, it is found with wollastonite and whelanite.

BRONSON F. STRINGHAM spent most of his career at the University of Utah, where he taught mineralogy, optical mineralogy, and courses in rock alteration. He died at the age of sixty while he was professor and head of the Department of Mineralogy and still actively engaged in teaching. His friend and colleague Thomas S. Lovering of the U.S. Geological Survey published a fine memorial to Stringham in 1970, which was used extensively to write this biography. Another memorial to Stringhom was published by the Geological Society of America (Eardley 1969).

Bronson Stringham was born 28 July 1907 in Salt Lake City, Utah, into a pioneer family. The stories told by one of his grandmothers, who as a young girl traveled across the plains in an oxcart, provided Bronson with the foundation for his ongoing interest in the pioneer history of Utah. In 1941, he married a lovely geology student, Lucille Oblad, to whom he had become engaged when he was a geology instructor at the University of Utah. They had three children: a son, Michael Kerr, and two daughters, Cynthia Ann and Susan Marie.

As a youngster, Bronson's interest in mineralogy and geology was sparked by a neighbor, Dr. Frederick J. Pack, professor and head of the Department of Geology at the University of Utah. Pack gave Bronson his lifelong interest and enthusiasm for mineralogy and geology. So when the time came to study for a career, majors in mineralogy and geology were an obvious choice.

During undergraduate work at the University of Utah, he assisted Dr. Herbert E. Gregory in mapping the rocks of southern Utah. These summers in the field triggered yet another of Bronson's continuing interests: geological field studies. He graduated with a B.S. degree in 1933 and went on to Columbia University in New York for postgraduate work. Here, Professors Paul F. Kerr and Charles H. Behre provided the final impetus to his dedication to mineralogy and geology. In 1936, he returned to the University of Utah as an instructor and spent all his spare time and summers doing geological field work in the West Tintic district, west of Eureka, Utah. In 1941, he was awarded his Ph.D. from Columbia with a thesis that incorporated the field work of the previous few years.

Kerr paid the following tribute to Bronson Stringham:

> Bronson's contributions to the mineralogy and geology of the State of Utah will be greatly missed. Through his own work, and the excellent work of his students, a number of fine contributions on the mineralogy of Utah have appeared. These will stand in the literature as a lasting memorial to his achievements. I am sure that not only science in general, but the geological fraternity in Utah will miss him greatly.

The mineralogy and geology of West Tintic continued to interest him, and he was fortunate enough to get leave from the university in the latter years of World War II to join a group of specialists, headed by Dr. T. S. Lovering, who were doing a detailed study of the area's geology, rock alteration, and geochemistry. Stringham's contribution to this group involved much of the detailed petrographic studies of the rocks in thin section, and he became an expert in the identification of mineral species in unusually fine-grained aggregates, a skill that to this day continues to be extremely difficult. He also did extensive surface and underground geological mapping. The Tintic district contains a sequence of carbonate rocks that have undergone considerable alteration caused by various combinations of heat and pressure produced by igneous activity. The understanding of rock alteration and its use as a clue to discovering ore

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Dr. Robert I. Gait, an executive editor of Rocks & Minerals, *is curator of mineralogy at the Royal Ontario Museum.*

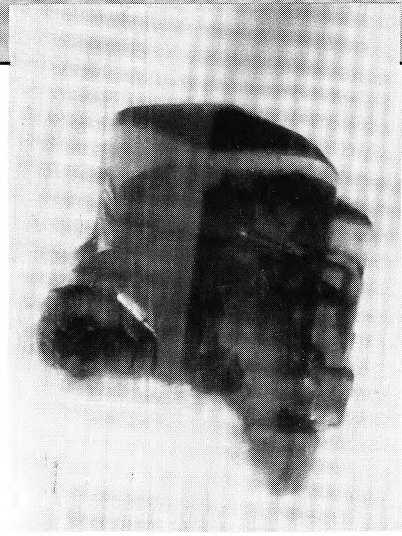
deposits was the goal of Lovering's group, and Stringham's contribution was an important one. The experience also gave him an ongoing interest in rock alteration, a subject he taught up to the time of his death. One of the minerals he discovered at this time and subsequently described was tinticite (Stringham 1946), a clay-like mineral with crystals not exceeding 1 micron across.

Stringham's experiences and wide interests provided him with the all-round knowledge to be an excellent teacher. He had an in-depth knowledge of practical field geology, an understanding of complex systems of rock alteration, tremendous petrographic skills, and a comprehensive knowledge of mineralogy. His academic career following his doctorate started with his promotion to assistant professor in 1941. After returning to university life in 1946, subsequent to his work with Lovering, he became associate professor; in 1948, he was appointed acting head of the new Department of Mineralogy. In 1950, he was again promoted, this time to full professor and confirmation as department head, a position he held until his death.

Stringham's most important contribution to mineralogy and geology is considered by many to be his paper entitled "Relationship of Ore to Porphyry in the Basin and Range Province, U.S.A." (Stringham 1958). In it he demonstrates that nearly all disseminated copper ores are found in porphyritic rocks and not in evenly crystallized (holocrystalline) rocks, such as granite or quartz monzonite. In his field career, he visited and collected from nearly every stock (massive igneous intrusion) in Utah, Nevada, and Arizona and many in Colorado. His studies of alteration in rocks led him into detailed studies of clay minerals, another of his specialties. He had a major consulting interest in exploration techniques for ceramic clay deposits and helped local brick and tile manufacturers by identifying the clay minerals with which they were working.

During the postwar need for uranium, Stringham helped many prospectors in the difficult matter of identifying secondary uranium minerals, which often occur as powdery, yellow to orange material or as minute crystals. Throughout his career his interest was directed at the economic development of Utah, and he made a significant contribution to the geological map of Utah.

He was a fellow of both the Mineralogical Society of America and the Geological Society of America; a member of both the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers; and a charter member of both the Geochemical Society and the Clay Minerals Society. He was instrumental in the formation of the Utah Geological Society and was active in the honorary geological society Sigma Gamma Epsilon (SGE), being twice vice-president of the western province of SGE and elected grand historian in 1965, a position he held until he died.



Stringhamite (ROM # M45613), azure blue crystal 0.4 mm high, Christmas mine, Gila County, Arizona. Photomicrograph by Violet Anderson.

Stringham seems to have been the ideal "professor." He was dedicated to his field, had a wide-ranging knowledge and the ability to communicate it enthusiastically, took a personal interest in his students, led extensive and informative field trips, and even though strict, was kind and sympathetic when the need was there.

Lovering's final paragraph in his memorial to Stringham provides a touching and sincere insight:

> Bronson Stringham was a dynamic affable man, whose outstanding characteristic was his love of the good things in life, which I believe he would have defined as family, friends, field work, teaching, research, good food and good stories. He relished them all! It must have been a man like Bronson that inspired the proverb 'A merry heart doeth good like a medicine.' He loved his family, he loved his friends, and he loved any occasion for merriment. We will miss his genial smile and bubbling laugh.

Acknowledgments

My thanks to Dr. James A. Whelan of Salt Lake City, who kindly read the manuscript and provided additional information and the portrait of Stringham.

REFERENCES

Eardley, A. J. 1969. Memorial to Bronson F. Stringham. *Proceedings of the Geological Society of America* [for 1968].

Hawthorne, F. C. 1985. The crystal structure of stringhamite. *Tschermaks Mineralogische und Petrographische Mitteilungen* 34:15–24.

Hindman, J. R. 1976. Stringhamite, a new hydrous copper calcium silicate from Utah. *American Mineralogist* 61:189–92.

Lovering, T. S. 1970. Memorial of Bronson F. Stringham. *American Mineralogist* 55:607–14.

Mitchell, R. S. 1979. *Mineral names: What do they mean?* New York: Van Nostrand Reinhold.

Stringham, B. 1946. Tinticite, a new mineral. *American Mineralogist* 31:395–400.

______. 1958. Relationship of ore to porphyry in the Basin and Range Province, U.S.A. *Economic Geology* 53:806–22.

Taken together, Utah's exposed outcrops, with their abundant and diversified fossils, provide one of the world's most complete fossil records.

Some Middle Cambrian Fossils of Utah

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Artwork by Val and Glade Gunther

WOULD YOU LIKE TO SEARCH for treasures in Utah? The Bear River Range, Promontory Mountains, Wellsville Mountains, House Range, and Drum Mountains are just a few of the places that contain "hidden treasures." These valuables are not in gold, silver, or precious stones but in fossils that tell us what some of the very early life forms were like. Although many fossils have little economic value, most are of scientific importance. The information gained by the discovery and study of fossils is very important to add to our limited knowledge of the history of life on Earth.

Amateur collectors can greatly contribute to scientific knowledge by searching for fossils in hills, canyons, and valleys, by keeping good records, and by reporting unusual finds to universities and professional paleontologists. Without good locality and stratigraphic data, however, fossils merely become curiosities of little value.

Many articles have been written about Utah fossils, but most are scattered in technical publications spanning many decades. During the past twenty-five years, the authors put together large collections from some of the rich outcrops of Cambrian rocks found in some of the eighty Cambrian formations that have been recognized in Utah. Cambrian fossils in particular are mentioned because they are among the earliest life forms that have left us a good record.

Geologic History

The Cambrian began approximately 570 million years ago and lasted nearly 75 million years, making it the oldest and longest of the Paleozoic periods. Taken together, Utah's exposed outcrops, with their abundant and diversified fossil assemblages, provide some of the world's most complete fossil records.

Cambrian sediments were deposited across the entire state and have since been subject to erosion, especially following mountain-building. At least half the volume of the original Cambrian rock has been removed by erosion. The most complete outcrops today are found in areas where original deposits were thickest.

All evidence paints a picture of Utah in Cambrian time as being vastly different from what it is today. In Early and Middle Cambrian times, the ocean shoreline migrated east-

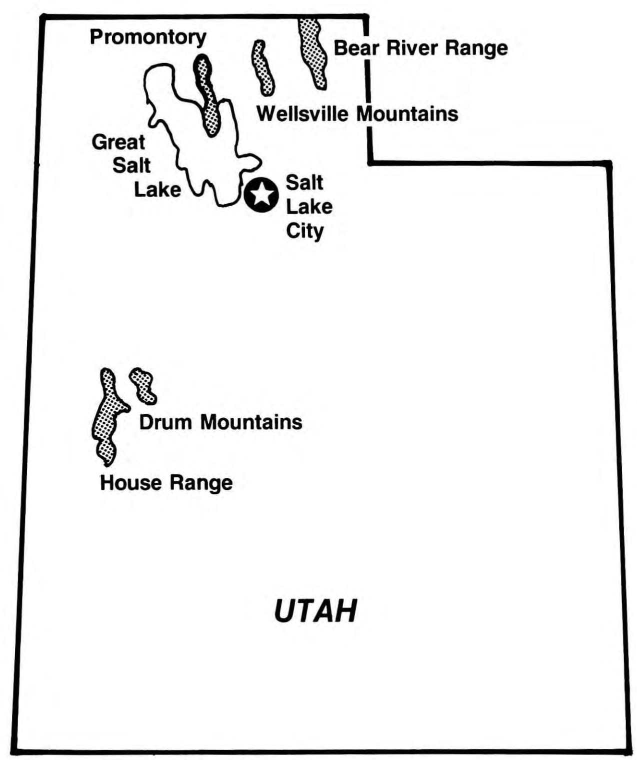

Figure 1. **Index map of Utah showing main areas of Cambrian outcrops where fossils can be collected.**

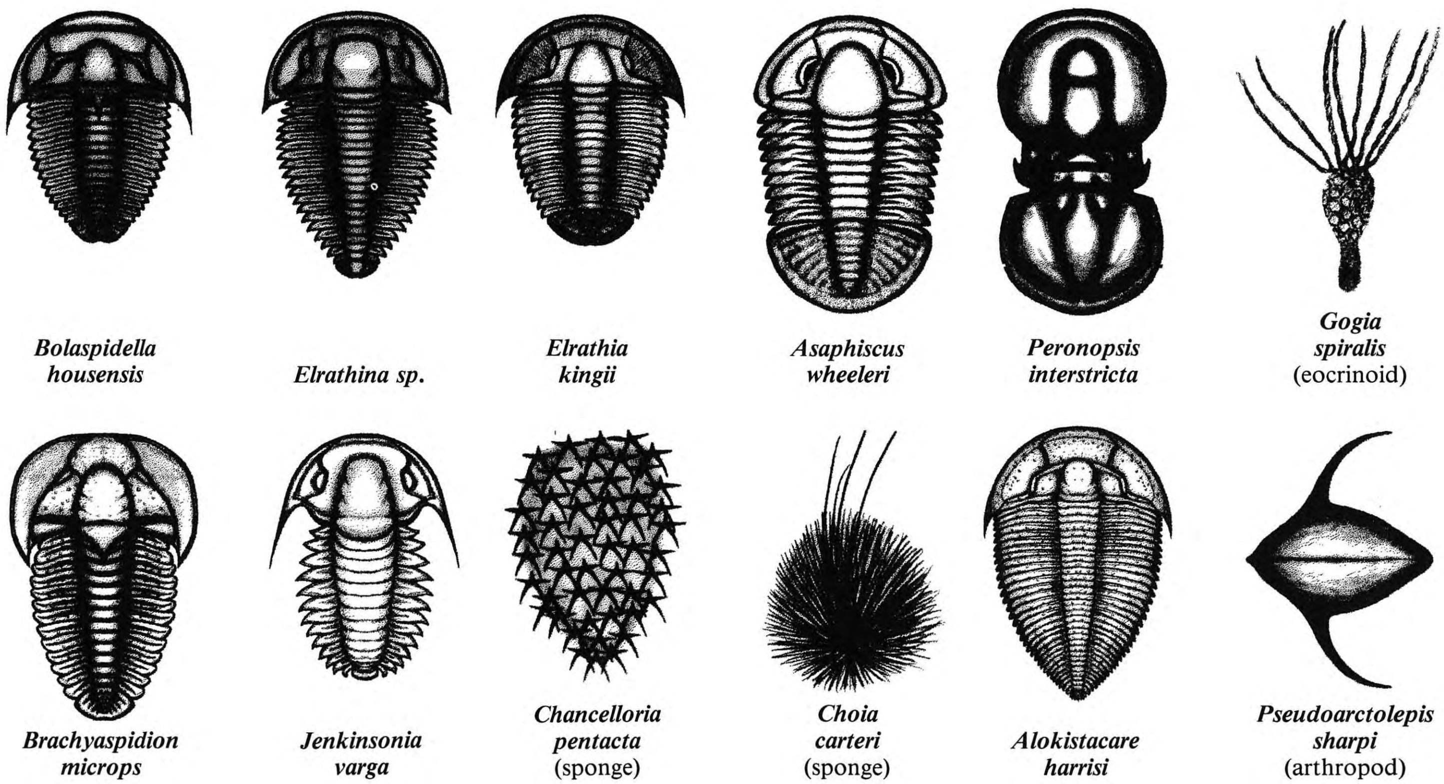

Figure 2. **Some representative fossils from the Wheeler Shale.**

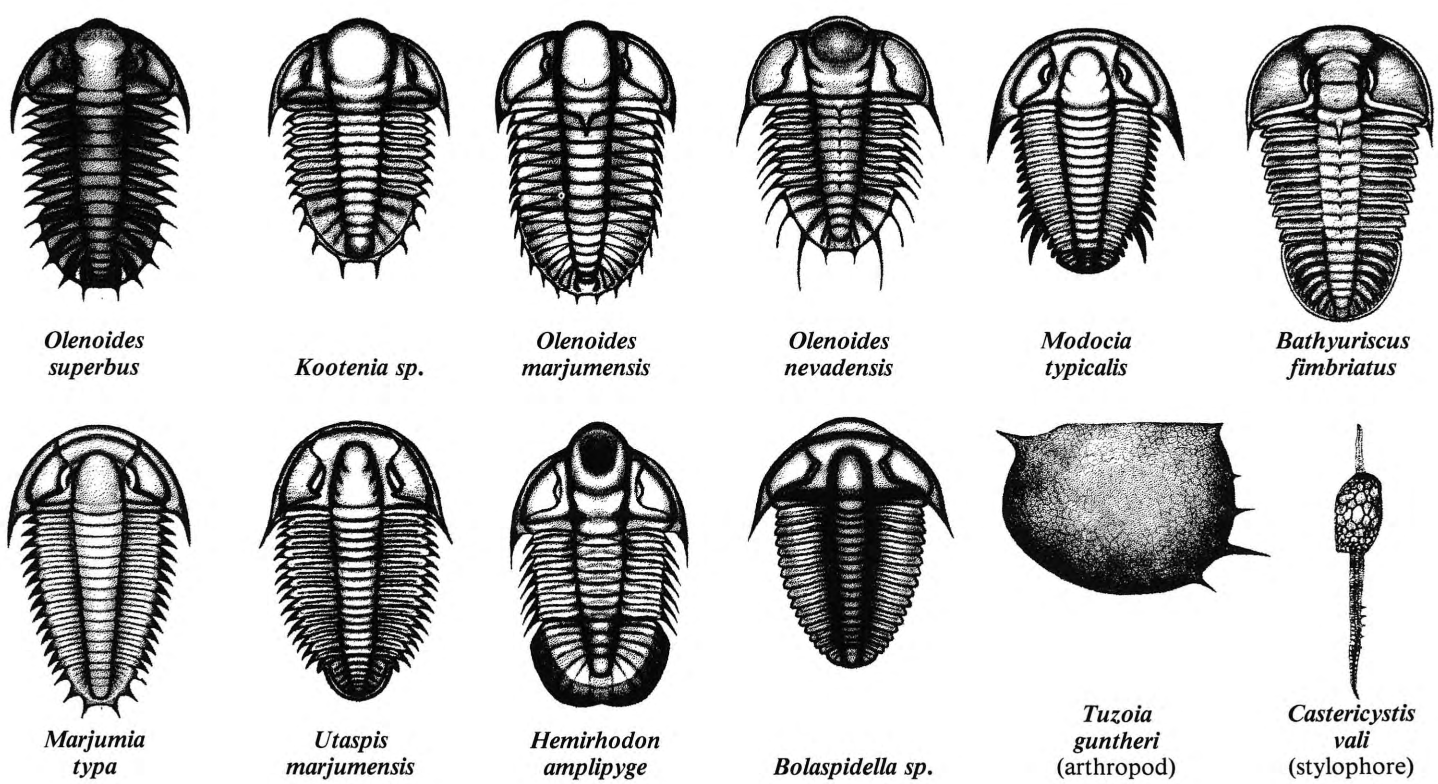

Figure 3. **Some representative fossils from the Marjum Formation.**

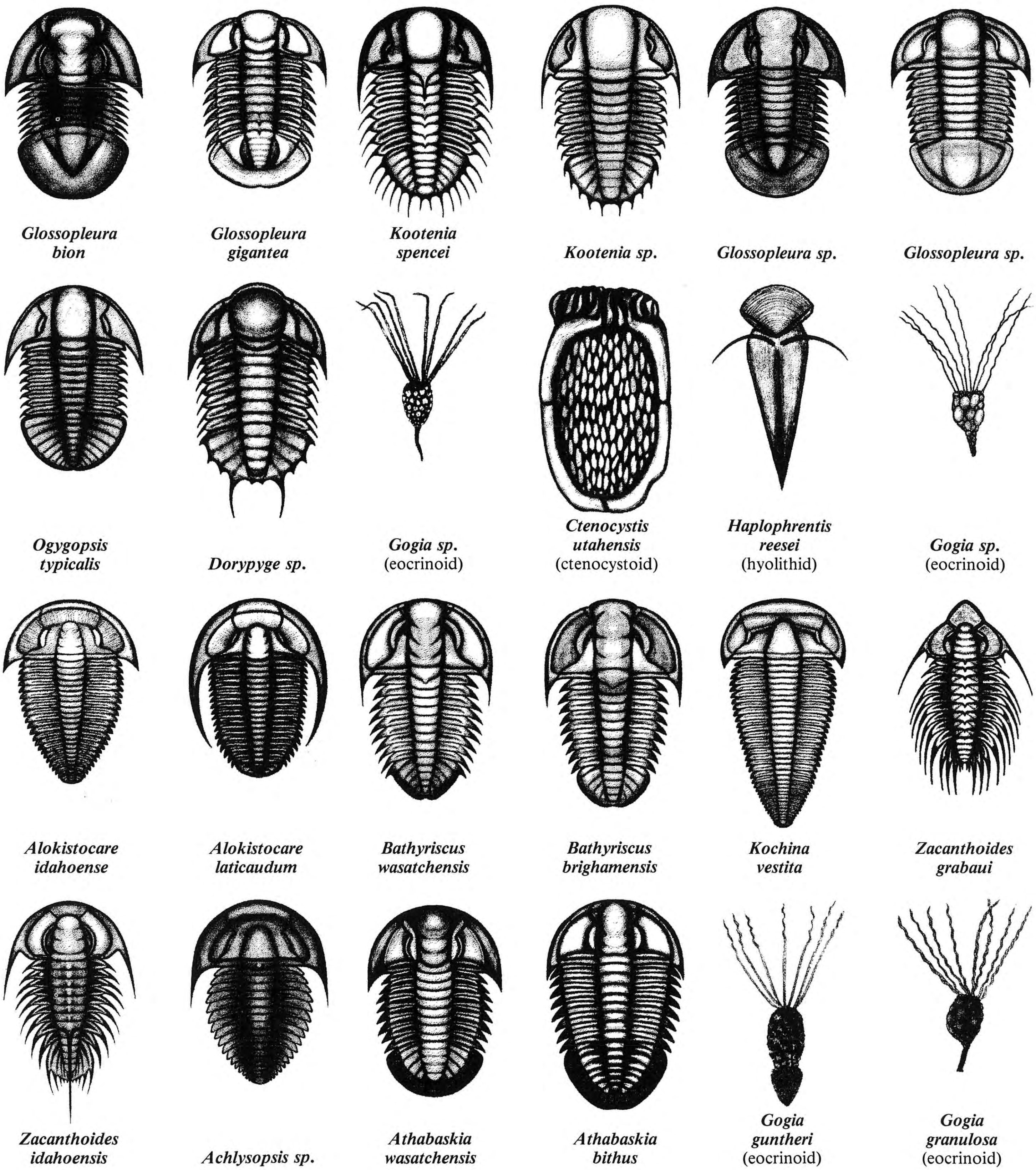

Figure 4. **Some representative fossils from the Spence Shale.**

ward from Nevada into central Utah. By Late Cambrian, marine waters covered nearly the entire state; no mountains of significance were present; and the equator ran northward through Utah. It was under these warm tropical conditions that deposition of limey mud covered and preserved the marine life then present and left us a rich fossil record. Some of the most fossiliferous formations—and also those most often collected by both amateurs and professionals—are the Spence Shale in northern Utah and the Wheeler, Marjum, and Weeks formations in west-central Utah. In the Wheeler Shale alone, commercial collectors, under permit, have mined specimens of the trilobite *Elrathia kingii.* These most common trilobites can be found in museums, shops, and private collections worldwide.

Fossil Descriptions

Hundreds of species of trilobites have been described from Cambrian deposits in Utah (see reference list). Although trilobites appear to be the most abundant, they were not necessarily the most dominant life forms present in those ancient seas. Because of their hard chitinous exoskeleton, trilobites were more easily preserved and left a better fossil record. Soft-bodied animals are seldom preserved, and so less is known about them. Some notable exceptions, however, are being found, and they add to our knowledge of the diversity of life in the Cambrian. Because their preservation is not as good as that of the trilobites, many are unfortunately often overlooked and disregarded by people not trained to recognize them.

A partial list of major groups of Cambrian fossils found in Utah to date includes the following:

1. Cyanobacteria and algae. Five genera of cyanobacteria (blue-green algae) and three species of noncalcareous algae have recently been documented (Robison 1991).
2. Microfossils. Radiolarians and other microfossils have recently been found, but little research has been done, and all remain undescribed.
3. Sponges. To date fourteen genera and twenty-four species of sponges have been described from the Spence, Wheeler, and Marjum formations (Rigby 1983). Several others have been found but remain undescribed.
4. Cnidarians. Specimens of *Scenella* have been found. Although authors consider this form to be molluscan, others place it in the hydrazoans.
5. Brachiopods. Both articulate and inarticulate brachiopods are commonly found in most formations.
6. Mollusks. Distribution of mollusks, except for hyoliths, tends to be patchy. Hyoliths, however, are quite abundant, especially in the Spence Shale. Some authors suggest these may represent a separate phylum (Robison 1991).
7. Worms. Numerous soft-bodied vermiform specimens have been collected, although most are too poorly preserved to be given a definite assignment.
8. Arthropods. As in most Cambrian faunas, arthropods clearly dominate Utah localities, with trilobite taxa being numerous in the majority of localities. At least twenty non-trilobite genera have been described; others await study and description. Specimens typically display excellent preservation, and many are found in articulated condition; this makes them highly sought after by collectors.
9. Echinoderms. Of the thousands of articulate eocrinoid specimens collected from Cambrian deposits in North America, more than half are from Utah. Some come from "gardens" with one hundred or more individuals on a single slab, suggesting the gregarious nature of these animals, as well as live burial. Several classes of other echinoderms are present; several species of carpoids occur in large numbers. Edrioasteroids have been found in the Marjum Formation.
10. Miscellaneous animals. Several enigmatic fossils have been found, some resembling those of the Burgess Shale in Canada. Most have yet to be studied and described, and more are being discovered each year, some of which are unique to Utah.
11. Trace fossils and coprolites. Trace fossils are quite rare, but those found include "feather stitch" burrows of probable sea anemones, trilobite trails, medusoidlike impressions, and worm burrows. Large round coprolites are locally common in the Spence Shale, with some containing mixed skeletal shell fragments of trilobites, brachiopods, and echinoderms, indication that their producer was either a scavenger or a predator (Robison 1991).

The figures depict a few representative fossils found in Utah's Cambrian formations.

The authors have had several fossil species named after them, including some illustrated with this article.

Lloyd Gunther is a retired biologist for the U.S. Fish and Wildlife Service. Val Gunther is a metallographer at Thiokol Corporation, and Glade Gunther is a student at Brigham Young University.

REFERENCES

Gunther, L. F., and V. G. Gunther. 1981. *Some Middle Cambrian fossils of Utah.* Brigham Young University geology studies. Vol. 28, pt. 1.

Hintze, L. F. 1973. *Geologic history of Utah.* Brigham Young University geology studies. Vol. 20, pt. 3.

Rigby, J. K. 1983. Sponges of the Middle Cambrian Marjum Limestone from the House Range and Drum Mountains of western Millard County, Utah. *Journal of Paleontology* 57: 240–70.

Robison, R. A. 1991. Middle Cambrian biotic diversity: Examples from four Utah Lagerstatten. The early evolution of metazoa and the significance of problematic taxa. *Proceedings of an international symposium held at the University of Camerino 27–31 March 1989.* New York: Cambridge University Press.

Sprinkle, J. 1973. *Morphology and evolution of blastozoan echinoderms.* Harvard University Museum of Comparative Zoology special publication.

Stokes, W. L. 1986. *Geology of Utah.* Occasional paper number 6 of the Utah Museum of Natural History. □