Geology of Nevada

Jonathan G. Price

Preprint from Castor, S.B., Papke, K.G., and Meeuwig, R.O., eds., 2004, Betting on Industrial Minerals, Proceedings of the 39th Forum on the Geology of Industrial Minerals, May 19–21, 2003, Sparks, Nevada: Nevada Bureau of Mines and Geology Special Publication 33.

Abstract

Geology plays a central role in Nevada's human history, economy, and future. Cordilleran tectonics have created the Basin and Range landscape and interior drainage of the Great Basin, provided a rain shadow to make Nevada the nation's driest state, and generated frequent earthquakes along normal and strike-slip faults. Geology is key to reducing risks from Nevada's natural and anthropogenic hazards (earthquakes, flash floods, drought, land subsidence, erosion after wildland fires, landslides, swelling and collapsing soils, radon, arsenic, and others).

Nevada's geologic fortunes make it the leading state in the production of gold, silver, barite, lithium, and mercury and a major producer of geothermal power and gypsum. The metals are primarily related to igneous activity, with major pulses of magma during the Jurassic, Cretaceous, and Tertiary. Barite is mined from Paleozoic sedimentary rocks, and gypsum occurs in sedimentary beds of Permian, Triassic, Jurassic, and Tertiary age. Lithium is extracted from brine beneath an unusual playa. Geothermal power production primarily occurs along Quaternary faults.

We are in the midst of the biggest gold-mining boom in American history. The Carlin trend is one of the world's premier gold-mining regions, and reserves along the trend and elsewhere in Nevada will sustain the boom for at least two more decades. Nevada's booming population will continue to increase demands for construction raw materials and for geological information to help manage growth while minimizing losses from geological hazards.

The geology of Nevada is the foundation of its natural resources and is closely linked to its human history. The complex geologic history of the state relates to such resources as minerals, water, and energy; to environmental issues; and to natural hazards. This article draws heavily from the references listed in the bibliography for general information on the geology of the state, particularly Stewart (1980), Stewart and Carlson (1978), Price and others (1999), and Price (2002).

Mountain ranges in Nevada, commonly about 10 miles wide and rarely longer than 80 miles, are separated by valleys. The geologic structure that controls this basin-and-range topography is dominated by faults. Nearly every mountain range is bounded on at least one side by a fault that has been active, with large earthquakes, during the last 1.6 million years. For the last several million years, these faults have raised and occasionally tilted the mountains and lowered the basins. Over the years, these basins have filled with sediments that are derived from

Figure 1. The Carson Range, with Lake Tahoe in the background, near Genoa and Walley's Hot Springs, Douglas County; photo by Terri Garside. A prominent fault scarp occurs at the base of the range.

erosion of the mountains and that are locally tens of thousands of feet thick.

Many of the range-bounding faults are still active (Figs. 1 and 2). Nevada is the third most seismically active state in the nation (behind California and Alaska); over the last 150 years, a magnitude 7 or greater earthquake has occurred somewhere in Nevada about once every 30 years. Most faults are normal, although some are strike-slip faults. The most apparent zone of strike-slip faults in Nevada is in a 50-mile wide swath along the northwest-trending border with California, the Walker Lane. These northwest-trending faults are accommodating part of the motion between the Pacific Plate, which is moving relatively northwest, and the North American Plate, which is moving relatively southeast. The San Andreas Fault takes up most of the motion between these two plates. The generally north-south trend of mountain ranges in most of Nevada transforms into northwest-trending ranges within the Walker Lane.

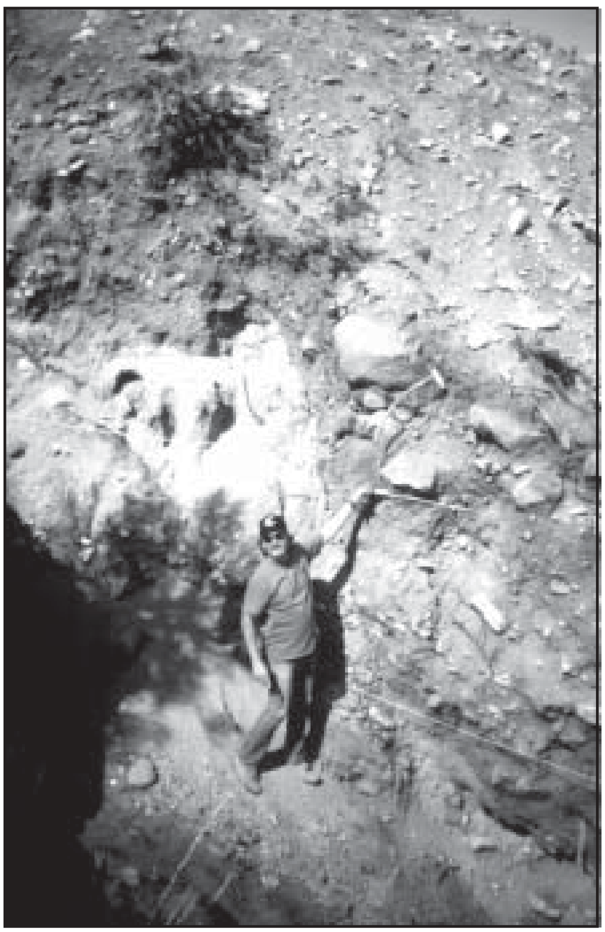

Figure 2. Backhoe trench along the Genoa fault near Walley's Hot Springs, south of the town of Genoa, Douglas County. The maximum displacement along the fault during its last event, about 550 to 650 years ago, was 18 feet (Ramelli and others, 1999). See www.nbmg.unr.edu/dox/sp27.pdf for Nevada Bureau of Mines and Geology Special Publication 27, a booklet on Living with Earthquakes in Nevada, for more information about earthquake hazards.

The climate of Nevada is closely tied to the geologic structure and resultant topography. Judging from fossil evidence of plants that grew in different parts of California and Nevada in the past, the Sierra Nevada (in California and far western Nevada) rose to current elevations only within the last six million years. Today the Sierra Nevada and other high mountains in California trap moisture coming off the Pacific Ocean and leave Nevada the driest state in the nation. Only a few rivers leave Nevada. These include the Bruneau, Jarbidge, and Owyhee Rivers in northeastern Nevada, which flow north into the Snake River in Idaho, and the White and Virgin Rivers in southeastern Nevada, which flow into the Colorado River (Fig. 3). The Colorado, which is the largest river in Nevada, gets the bulk of its water from the Rocky Mountains to the east and provides much of the municipal and industrial water for Las Vegas and other communities in southern Nevada before flowing southward into the Gulf of California. Most of Nevada, however, is part of the Great Basin, a large area with no drainage to the ocean and centered on Nevada but including parts of California, Oregon, Idaho, and Utah. The Truckee, Carson, and Walker Rivers, which provide much of the drinking, industrial, and agricultural water for northwestern Nevada, flow generally eastward from the Sierra Nevada to terminal lakes and lowlands in the desert (Pyramid Lake, the Carson Sink, and Walker Lake, respectively). The Humboldt River, which supplies much of northeastern Nevada with drinking, agricultural, and industrial water, flows southwestward into Humboldt Lake, and, when the lake fills, into the Carson Sink.

During glacial times (most recently about 10,000 years ago), large expanses in the Great Basin were covered by water. Great Salt Lake and the Bonneville Salt Flats in Utah and parts of far eastern Nevada were once part of ancient Lake Bonneville, and Pyramid Lake, the Carson Sink, and Walker Lake were once connected in ancient Lake Lahontan. Native Americans occupied the shores of these lakes as early as 10,000 to 12,000 years ago. Glaciers existed in the higher mountains, carving some of the spectacular U-shaped valleys in the Ruby Mountains (Fig. 4) and sculpting high-mountain topography in the Sierra Nevada. Glaciers are still present high in the Ruby Mountains and Snake Range in eastern Nevada.

Groundwater, mostly from aquifers in alluvial basins, is used throughout the state. In some basins, groundwater has been pumped out more rapidly than it is naturally recharged from rain and snowmelt; this causes significant lowering of the groundwater table and can affect the land surface. In Las Vegas Valley, cracks have developed locally in the ground (near preexisting faults), and in a

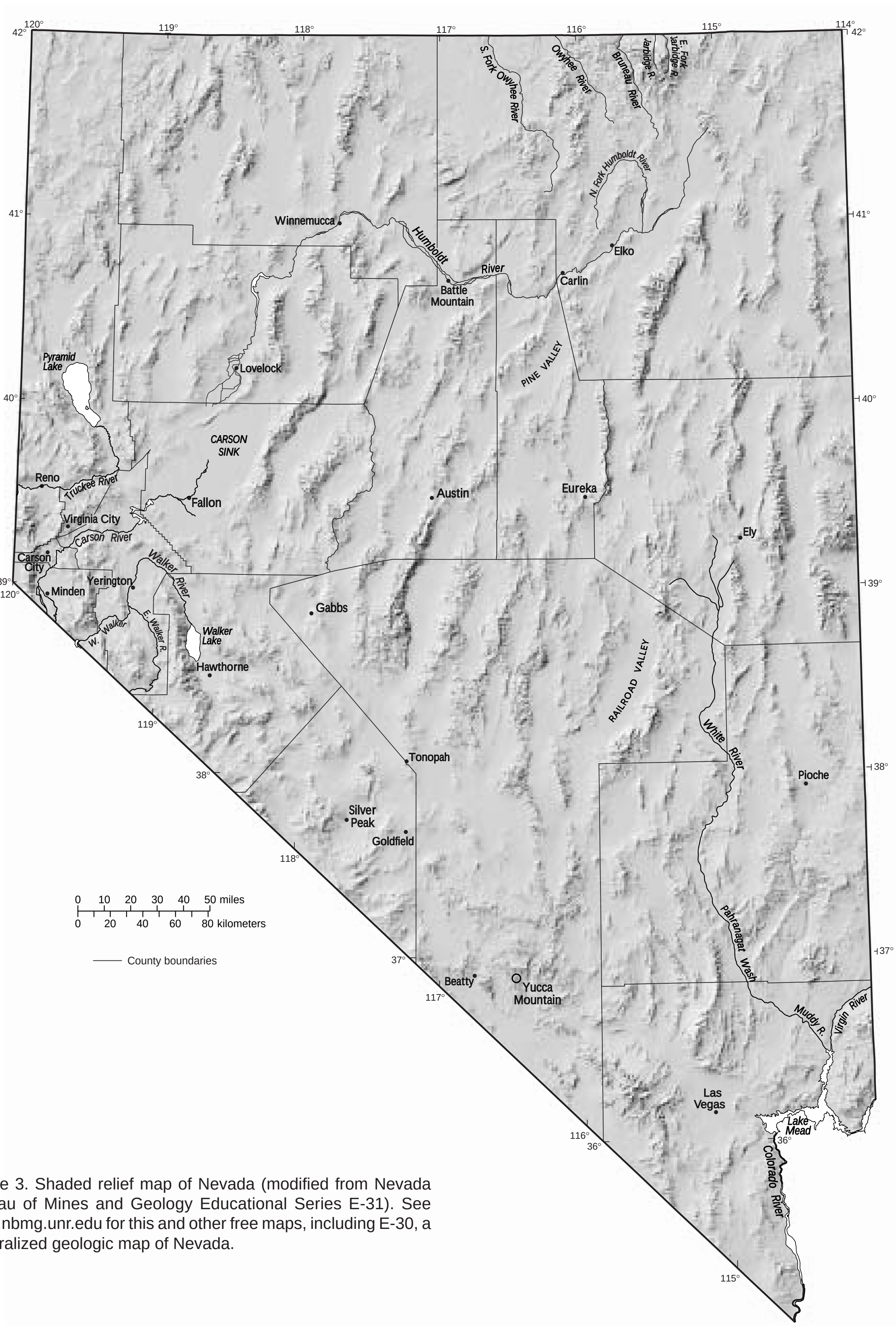

Figure 3. Shaded relief map of Nevada (modified from Nevada Bureau of Mines and Geology Educational Series E-31). See www.nbmg.unr.edu for this and other free maps, including E-30, a generalized geologic map of Nevada.

Figure 4. Hanging valley, carved by glaciers, that is a tributary of Lamoille Canyon, Elko County.

few places the land has subsided more than 6 feet in the last 60 years (Fig. 5).

On a percentage basis, Nevada is the fastest growing state in the country. The U.S. Census Bureau reported a population of 1,201,833 in 1990 and 1,998,257 in 2000. Most of the increase has occurred in and around the urban areas of Las Vegas and Reno-Carson City. Urban expansion in the Las Vegas area has been at a rate of about two acres per hour and is expected to continue at a rapid rate. The Nevada State Demographer has projected the population to be 2.8 million in 2010 (Fig. 6). This increasing population places demands on groundwater and other resources.

The ecological regions of Nevada are directly linked to the climate, elevations of the mountains, and rocks. A combination of precipitation and rock type (with the help of ubiquitous microbes) dictates the types of soils that develop and the plants that grow, which, in turn, affect the types of animals that survive. Geologic evidence (primarily fossils) shows us that climate has changed substantially even within the last 10,000 years. For example, mammoths and camels once lived near springs and now mostly dry lakes in Nevada, as recently as 11,000 years ago.

Although Nevada is, on the average, quite dry (with about 10 inches of rainfall across the state, but locally less than 5 inches in some lowlands and over 40 inches in high mountains), major

Figure 5. The land surface dropped about 5 feet since this well was drilled at the Las Vegas Valley Water District well field near the Meadows Mall, Clark County. Photo by John Bell, 1980.

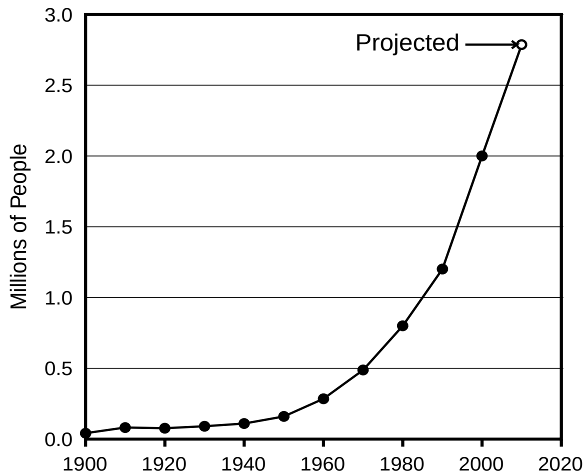

Figure 6. Nevada population. Data from the U.S. Census Bureau (www.census.gov) projected to 2010 by the Nevada State Demographer.

storms have caused significant floods and occasional landslides. Geologic evidence (and recorded history) abounds for large floods on the major rivers and "dry" washes throughout the state.

Major events in the geologic history of Nevada are highlighted in Table 1. A western continental margin, similar to the Atlantic coast of today, persisted for hundreds of millions of years before the more active, Pacific coast margin of today began to take shape about 360 million years ago. Repeated and prolonged periods of interactions between the North American Plate and oceanic plates, expressed in folds, thrust faults, strike-slip faults, normal faults, igneous intrusions, volcanism, metamorphism, and sedimentary basins, are recorded in the rocks.

Nevada rocks document volcanic and intrusive igneous activity intermittently and repeatedly from earliest geologic history to within the last few thousand years. Nevada's igneous rocks are connected to sea-floor spreading about 450 million years ago (much like the Mid-Atlantic Ridge or the East Pacific Rise today), collisions of ancient and modern plates, and hot spots in the Earth's mantle and perhaps outer core (some Nevada volcanic rocks can be correlated with the Yellowstone hot spot, which, as a result of plate tectonics, was once underneath and produced volcanoes in southern Idaho and northern Nevada). Some of the volcanic rocks in western Nevada represent the precursor of the Cascade Range, and significant intrusions about 40, 100, and 160 million years ago are probably linked to similar plate-tectonic settings, whereby oceanic plates were subducted beneath western North America.

Most, but not all, ore deposits in Nevada are associated with igneous activity. In some cases, metals came from the magmas themselves, and in other cases, the magmas provided heat for circulation of hot water that deposited metals in veins and fractured sedimentary rocks. Some spectacular mineral specimens occur in ore deposits that formed when magmas intruded and metamorphosed sedimentary rocks. Even today, driven locally by deep circulation along faults and perhaps locally by igneous activity, hot water shows up in numerous geothermal areas. Nevada produces approximately $100 million worth of geothermally generated electric power annually, and geothermal resources also are used for agriculture, industrial applications, and space heating.

Nevada produces approximately $3 billion worth of mineral commodities each year (Figs. 7 and 8). Nevada is the nation's leading gold producer, accounting for approximately 75% of U.S. production and 10% of world production. Much of the gold comes from a northwest-trending belt of gold deposits in northeast Nevada known as the Carlin trend. One of the interesting features of the Carlin trend is that nearly all of the gold is contained in microscopic particles within Paleozoic sedimentary rocks. Although the sedimentary hosts for the gold are more than 250 million years old, the actual mineralization may have occurred much later (approximately 40 million years ago) in association with igneous activity.

We are currently in the midst of the biggest gold-mining boom in American history (Fig. 9). The U.S. production so far in the current boom, the period from 1980 through 2002, has exceeded 170 million ounces of gold. This is significantly greater than the total production during the era of the California gold rush (1849 to 1859, with 29 million ounces), the Comstock (Nevada) era from 1860 to 1875 (with 34 million ounces), and the period from 1897 to 1920, when Goldfield (Nevada), the Black Hills (South Dakota), Cripple Creek (Colorado), and by-product production from copper mines in Arizona and Utah contributed to cumulative production of 95 million ounces. Reserves on the Carlin trend and elsewhere in Nevada are sufficient to sustain the boom for at least two more decades.

Nevada, the Silver State, is also the nation's leading producer of silver, barite, mercury, and lithium. Much of the silver is a co-product or by-product of gold production, and all the mercury currently produced is a by-product of precious metal recovery. Lithium is extracted from brine that occurs in Tertiary valley-filling sediments near Silver Peak (Fig. 10). Other commodities that are currently mined in Nevada include gypsum, limestone (for cement and lime), clays, salt, magnesite, diatomite, silica sand, dimension stone, and crushed rock, sand, and gravel for construction aggregate. In the past, Nevada has been a significant producer of copper, lead, zinc, tungsten, molybdenum, and fluorite. Active exploration and recent discoveries of new ore deposits attest to the potential for finding additional ones.

Table 1. Geologic time scale with major events in Nevada history.

Million years before present		
	CENOZOIC	
	Quaternary	Modern earthquakes, mountain building, volcanism, and geothermal activity are expressions of Basin and Range extension that began in the Tertiary Period. The crust is being pulled apart in Nevada, causing valleys to drop relative to mountains. Prior to 10,000 years ago, ice ages caused glaciers to form in the higher mountains and large lakes to develop, in places connecting today's valleys.
1.6		
	Tertiary	Basin and Range extension began about 30 to 40 million years ago. Igneous activity during the Tertiary Period was caused not only by extension but also by subduction (descent of oceanic crust into the Earth's mantle) of oceanic plates beneath the North American Plate and, in northern Nevada, by motion of the crust over the Yellowstone hot spot in the mantle. Numerous Nevada ore deposits, including most major gold and silver deposits and the copper ores near Battle Mountain, formed during this time. Gypsum deposits formed from evaporating lakes in southern Nevada.
65		
	MESOZOIC	
	Cretaceous	The Cretaceous Period and Mesozoic Era ended abruptly with the extinction of dinosaurs and many marine species; chemical, mineralogical, and other geological evidence suggests that these extinctions were caused by a large meteorite striking the Earth. Numerous granitic igneous intrusions, scattered throughout Nevada, originated from subduction along the west coast of North America. Much of the granite in the Sierra Nevada formed at this time. The igneous activity caused many metallic mineral deposits to form, including the copper-gold-silver-lead-zinc ores at Ruth, near Ely in White Pine County, copper-molybdenum ores north of Tonopah in Nye County, and tungsten ores in several mining districts. In southern and eastern Nevada, sheets of rocks were folded and thrust from the west to the east during the Sevier Orogeny (mountain building), which began in Middle Jurassic time and ended at or beyond the end of the Cretaceous Period.
144		
	Jurassic	A subduction zone to the west caused igneous intrusions, volcanism, and associated ore deposits, including copper deposits near Yerington. Sandstones, including those in the Valley of Fire, were deposited in southeastern Nevada, and sedimentary gypsum deposits formed in northwestern Nevada.
208		
	Triassic	The general geography of Nevada during the Triassic Period was similar to that during the Jurassic Period—igneous activity in the west and deposition of sedimentary rocks in continental to shallow marine environments to the east. Explosive volcanism produced thick ash-flow tuffs in west-central Nevada. Economically important limestone, gypsum, and silica-sand deposits formed in southern Nevada. The Sonoma Orogeny, which began during Late Permian time and ended in Early Triassic time, moved rocks from the west to the east along the Golconda Thrust in central Nevada. The large marine reptiles at Berlin-Ichthyosaur State Park lived during the Triassic Period.
251		
	PALEOZOIC	
	Permian	Volcanism to the west and deposition of thick limestones to the east were characteristics of much of the Paleozoic Era in the Great Basin. Some marine gypsum deposits formed in southern Nevada.
290		
	Pennsylvanian	The Antler highland, formed earlier, was eroded and shed sediments into the basins to the east. Carbonate rocks were deposited in eastern and southern Nevada.
320		
	Mississippian	During the Antler Orogeny, from Late Devonian to Early Mississippian time, rocks were folded and thrust from the west to the east. The Roberts Mountains Thrust, below which many of the gold deposits in north-central Nevada occur, formed at this time. Conglomerate, sandstone, siltstone, and shale were deposited in the thick basin of sediments derived from the Antler highland, and carbonate rocks were deposited further east.
360		
	Devonian	Limestone was deposited in eastern Nevada, and shale, chert, and economically important barite were deposited in northeastern and central parts of the state. No record of middle to lower Paleozoic rocks exists in the western part of the state. The quiet, shallow-marine tectonic setting that persisted earlier in the Paleozoic Era began to change, as small land masses from the Pacific Ocean collided with western North America.
418		
	Silurian	Carbonate rocks (dolomite and limestone) in the eastern part of the state and silica-rich rocks (shale, sandstone, and chert) in the central part of the state record similar deposition to that during the rest of the middle to early Paleozoic Era.
438		
	Ordovician	Marine deposition during the Ordovician Period was similar to that during the rest of the early Paleozoic Era, with the exception of basalts (metamorphosed to greenstones) locally interbedded with sedimentary rocks found today in the central part of the state. Some sedimentary barite deposits and copper-zinc-silver ores formed in sea-floor sediments during this time.
490		
	Cambrian	Middle and Upper Cambrian deposition resembled that during much of the Paleozoic Era, with carbonate rocks to the east and shale plus sandstone to the west. Lower Cambrian and uppermost Precambrian rocks are characterized by quartzite and metamorphosed siltstone throughout much of Nevada.
543		
	PRECAMBRIAN	
		The oldest rocks in Nevada (at least 2,500 million years old in the East Humboldt Range in northeastern Nevada and at least 1,700 million years old in southern Nevada) are metamorphic rocks (including gneiss, schist, marble, and metamorphosed granite, pyroxenite, hornblendite, and pegmatite). Precambrian rocks also include granites (about 1,450 million years old) and younger sedimentary rocks. Beginning approximately 750 million years ago, Antarctica and Australia may have rifted away from western North America, setting the stage for the development of a western continental margin that is similar to the Atlantic coast of today. A shallow marine, tectonically quiet setting persisted in eastern Nevada for the next 700 million years.

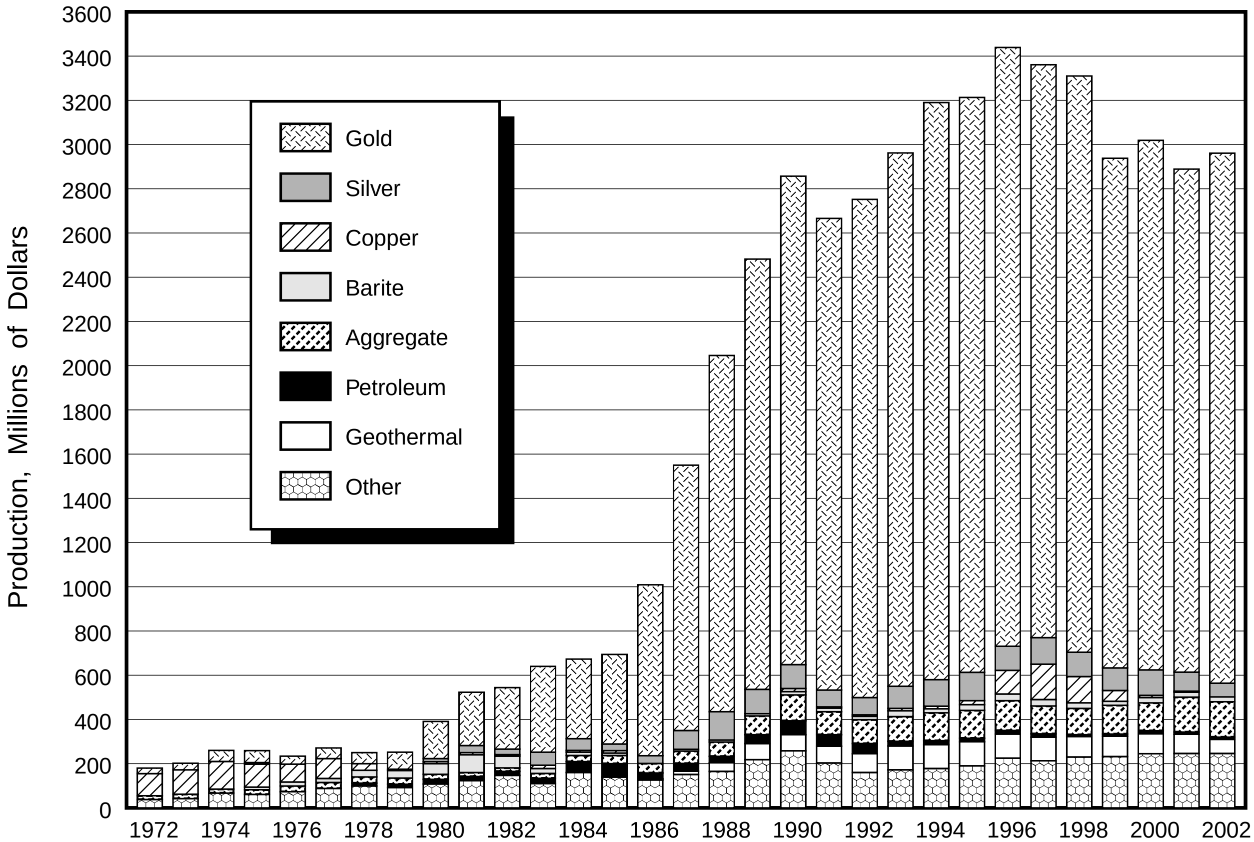

Figure 7. Nevada mineral, geothermal, and petroleum production, 1975-2002. Details on Nevada mineral production are available in Nevada Bureau of Mines and Geology Special Publications MI-2001 (www.nbmg.unr.edu/dox/mi/01.pdf) and P-14 (www.nbmg.unr.edu/dox/mm02.pdf).

Nevada became a State in 1864, during the Civil War (hence the motto "Battle Born"), in part as a result of mineral wealth. The 1859 discovery of silver-gold ores on the Comstock Lode enticed miners and prospectors, many of whom had come to California a decade earlier in search of gold. Over the decades that followed, they spread out from Virginia City, discovered other major mining camps, and established many nearby towns in Nevada (Austin, Battle Mountain, Beatty, Carlin, Elko, Ely, Eureka, Gabbs, Goldfield, Las Vegas, Lovelock, Pioche, Tonopah, Winnemucca, Yerington) and other parts of the western United States.

Nevada also produces some oil, although production is small relative to that in major oil states. An interesting aspect of Nevada petroleum production is that some of the oil is associated with hot water, although lower in temperature but otherwise much like the geothermal fluids that formed gold and silver deposits. Another curiosity is that some of the oil is trapped in fractured volcanic rocks, although the ultimate source of the petroleum was from organic matter in sedimentary rocks. Most of the oil has come from the eastern part of the state, primarily Railroad and Pine Valleys.

Some environmental hazards are associated with the abundant igneous rocks in Nevada. For example, many groundwaters in Nevada contain elevated concentrations of radon. Because radon is common in silica-rich igneous rocks, and because these rocks are widespread in the mountains and make up much of the sediment in the valleys, radon occurs in groundwater, soil, and air. Similarly, arsenic is relatively abundant in certain types of igneous rocks and is locally a problem as a dissolved natural constituent in Nevada groundwater and surface water. The proposed repository for high-level nuclear waste at Yucca Mountain is in Tertiary ash-flow tuffs, and Quaternary cinder cones occur nearby (Fig. 11).

Given Nevada's mineral, energy, and water resources, its challenges in terms of environmental protection, and its exposure to natural hazards, geology will continue to play a central role in the state's economy, growth, health, safety, and history.

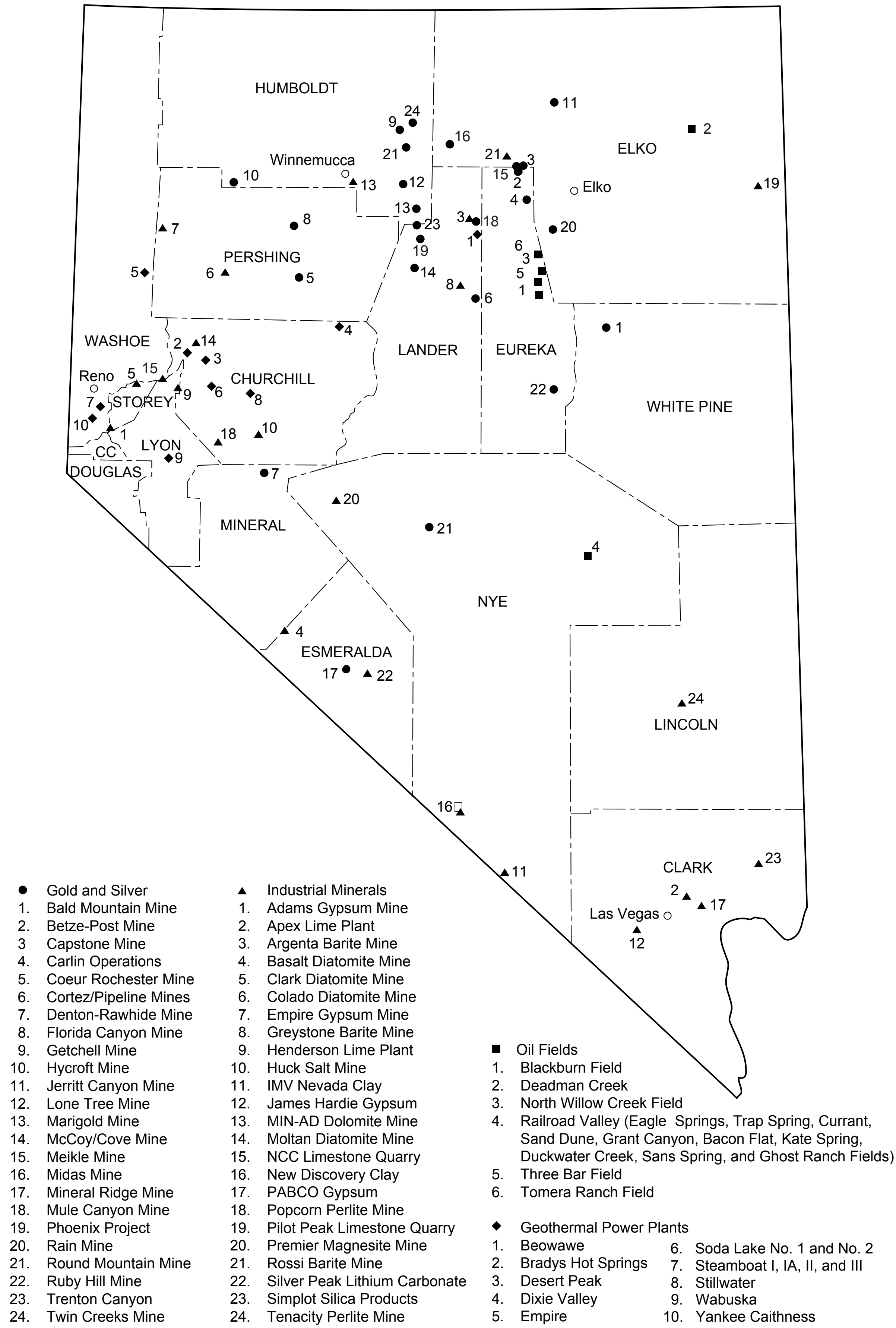

Figure 8. Major Mines, oil fields, and geothermal plants in Nevada, 2002.

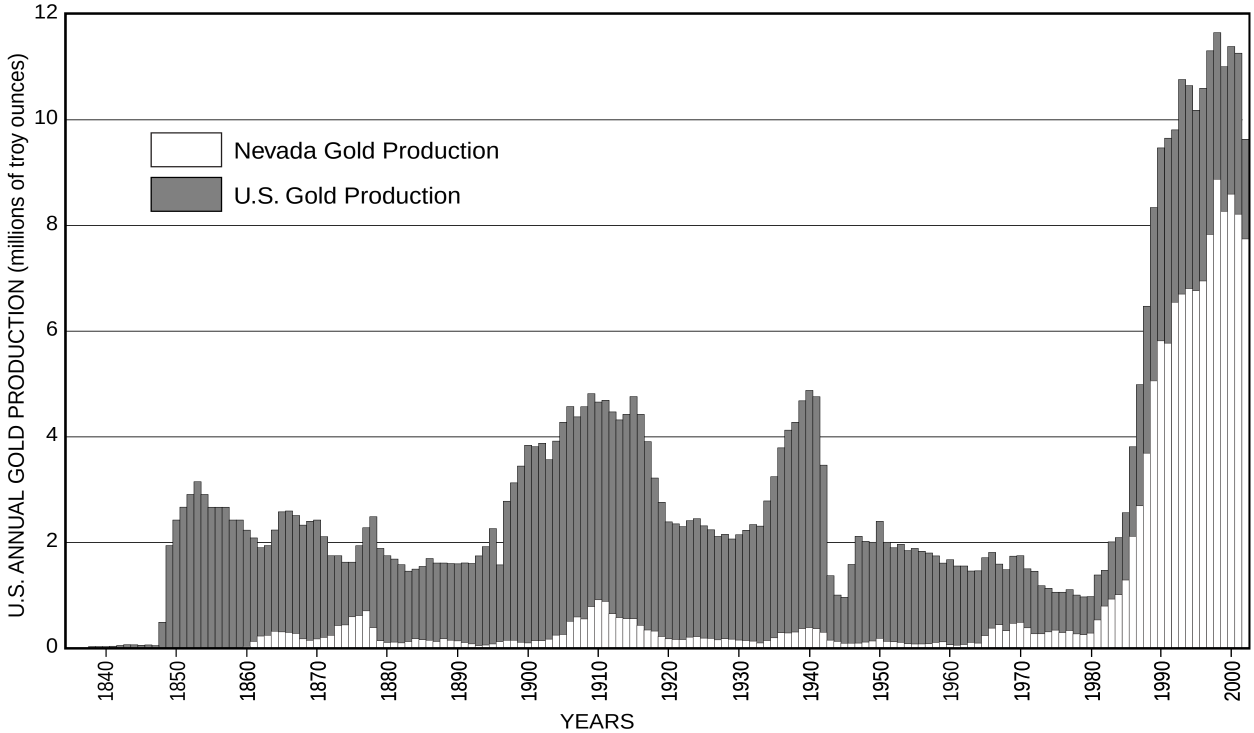

Figure 9. U.S. and Nevada gold production from 1835 through 2002. Data from Dobra (1998) and the U.S. Geological Survey.

Figure 10. A Quaternary cinder cone at the north end of Clayton Valley, Esmeralda County, is reflected by the brine pool that is part of the lithium mining operation in the valley. Lithium-rich brines are pumped to the surface, where they are allowed to evaporate in the sun. The solution precipitates halite, NaCl, before being processed to remove lithium.

Figure 11. Black Cone, 1 million-year-old cinder cone, Yucca Mountain in distance, Nye County.

ACKNOWLEDGMENT

I thank Chris Henry, Steve Castor, Larry Garside, Jim Faulds, and Dick Meeuwig for help with earlier versions of this manuscript and Rick Schweickert and Jim Carr for constructive comments on this latest version.

BIBLIOGRAPHY

(references and suggested reading)

Dobra, J.L., 1998, The U.S. Gold Industry 1998: Nevada Bureau of Mines and Geology Special Publication 25, 32 p.

Lush, A. P., A. J. McGrew, A. W. Snoke, and J. E. Wright 1988, Allochthonous Archean basement in the East Humboldt Range, Nevada: Geology v. 16, p. 349-353.

Price, J.G., 2002, Geology of Nevada: The Professional Geologist, v. 39, no. 4, p. 2-8.

Price, J.G., Henry, C.D., Castor, S.B., Garside, L.J., and Faulds, J.E., 1999, Geology of Nevada: Rocks and Minerals, v. 74, no. 6, p. 357-363.

Price, J.G., Meeuwig, R.O., Tingley, J.V., La Pointe, D.D., Castor, S.B., Davis, D.A., and Hess, R.H., 2002, The Nevada mineral industry - 2001: Nevada Bureau of Mines and Geology Special Publication MI-2001, 66 p. (Overview by J.G. Price and R.O. Meeuwig, p. 3-12.)

Purkey, B.W., and Garside, L.J., 1995, Geologic and natural history tours in the Reno area: Nevada Bureau of Mines and Geology Special Publication 19, 211 p.

Ramelli, A.R., Bell, J.W., dePolo, C.M., and Yount, J.C., 1999, Large-magnitude, late Holocene earthquakes on the Genoa fault, west-central Nevada and eastern California: Seismological Society of America Bulletin, v. 89, no. 6.

Smith, G.H., and Tingley, J.V., 1997, The history of the Comstock Lode: Nevada Bureau of Mines and Geology Special Publication 24, 328 p.

Stewart, J.H., 1980. Geology of Nevada: Nevada Bureau of Mines and Geology Special Publication 4, 126 p.

Stewart, J.H., and Carlson, J.E., 1977, Geologic map of Nevada: Nevada Bureau of Mines and Geology Map 57, 1:1,000,000 scale.

Stewart, J.H., and Carlson, J.E., 1978. Geologic map of Nevada: U.S. Geological Survey, 1:500,000 scale.

Tingley, J.V., and Pizarro, K.A., 2000, Traveling America's loneliest road, A geologic and natural history tour through Nevada along U.S. Highway 50: Nevada Bureau of Mines and Geology Special Publication 26, 132 p.

Tingley, J.V., Purkey, B.W., Duebendorfer, E.M., Smith, E.I., Price, J.G., and Castor, S.B., 2001, Geologic tours in the Las Vegas area. Expanded edition: Nevada Bureau of Mines and Geology Special Publication 16, 140 p.

www.nbmg.unr.edu (the Web site of the Nevada Bureau of Mines and Geology).