

# NEVADA BUREAU OF MINES

**BULLETIN 65**

## **MINERAL AND WATER RESOURCES OF NEVADA**

Prepared by the  
U.S. GEOLOGICAL SURVEY  
and the  
NEVADA BUREAU OF MINES

as  
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88th Congress, 2nd Session



**MASTER**

**MACKAY SCHOOL OF MINES  
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**1964**

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## FOREWORD

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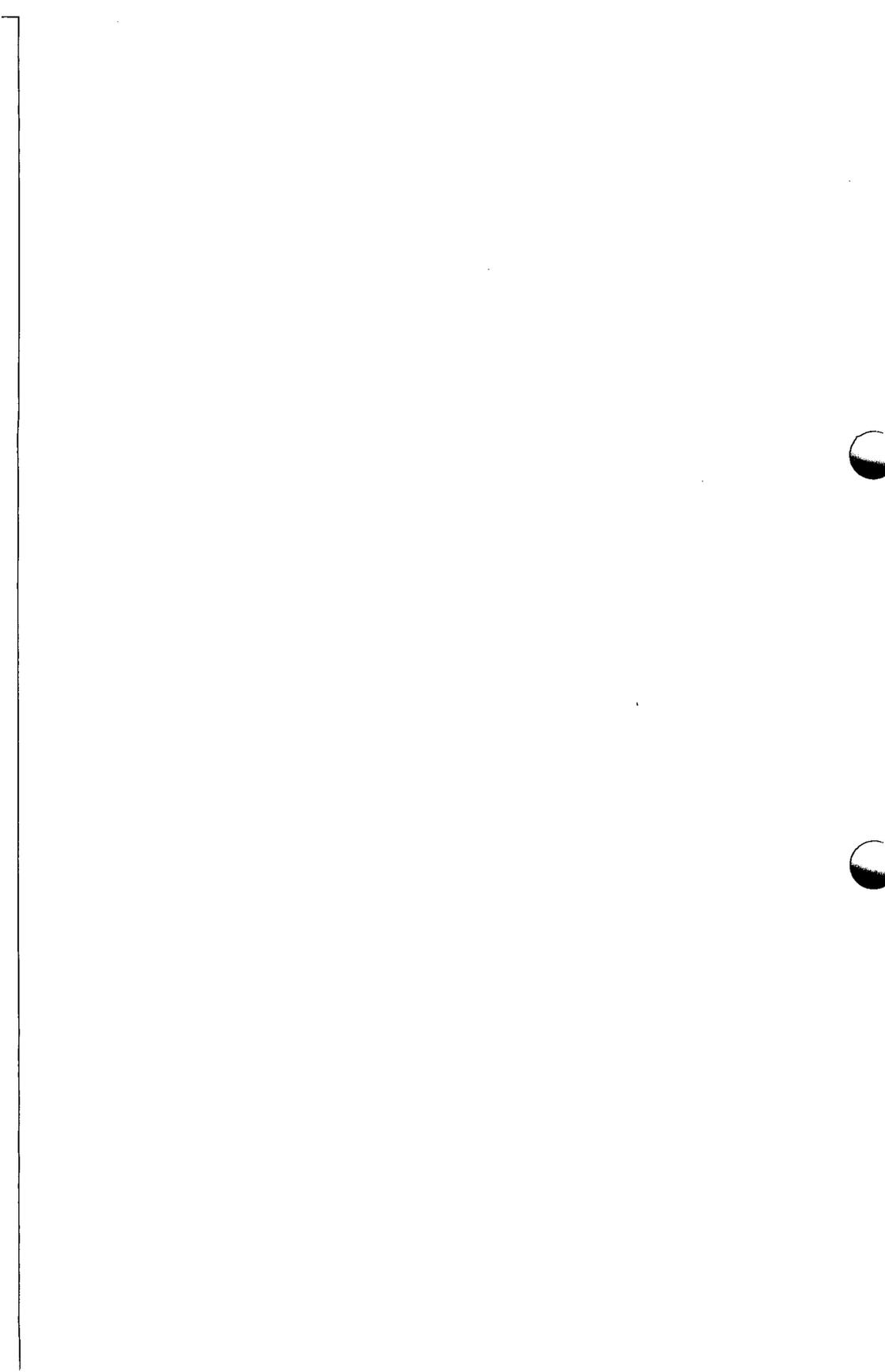
Although many reports on Nevada's mineral resources have been issued over the years both by federal agencies and by the Nevada Bureau of Mines, the need for a summary of the State's mineral and water resources has long been recognized. The present report, "Mineral and Water Resources of Nevada," compiled by staff members of the U.S. Geological Survey and of the Nevada Bureau of Mines at the request of Senator Howard W. Cannon of Nevada, fulfills that need.

The report was printed as a United States Senate Document, in which form it has been distributed to many Nevada citizens. When Senator Cannon was informed that the Nevada Bureau of Mines wished to include the report in its mineral industry publication series, so that it would be available for many years, he kindly arranged for the printing of additional copies by the U.S. Government Printing Office. These additional copies have been purchased by the Nevada Bureau of Mines and the report is herewith released as the Bureau's Bulletin 65.

The report will serve as a valued reference to people of Nevada and professional workers in government and industry who are interested in the mineral and water resources of the State. It provides data from which further development of these resources can proceed.

VERNON E. SCHEID, *Director*  
*Nevada Bureau of Mines*

September, 1964  
Mackay School of Mines  
University of Nevada



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## INTRODUCTION

(By H. R. Cornwall, U.S. Geological Survey, Menlo Park, Calif.)

The mineral and water resources of Nevada are summarily described in this report. Following a general description of the mineral industry and of the geology of the State as a whole, the occurrence, distribution, and relative importance of individual commodities are discussed in some detail. All mineral commodities are described that are known to occur in Nevada and that might have economic significance in the foreseeable future, whether or not they have been mined.

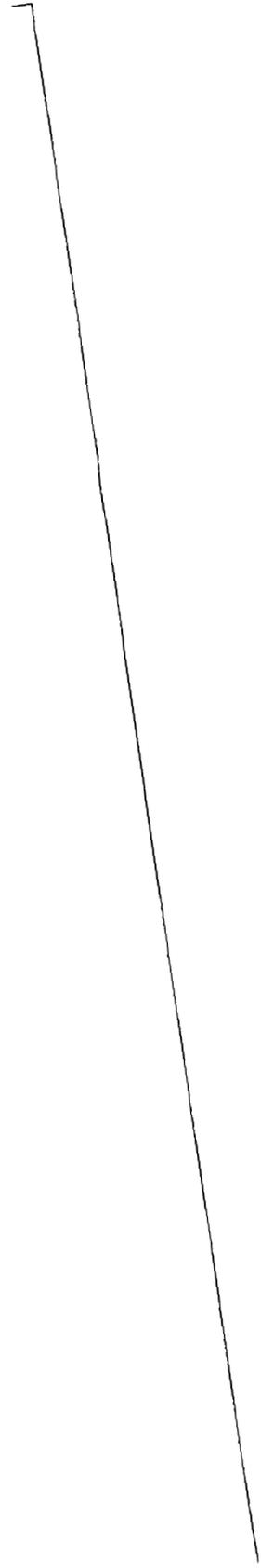
In the description of the geology of the State, a section on economic geology describes the distribution of the metallic and nonmetallic mineral deposits both areally and with respect to the general geologic features. A knowledge of the pattern of distribution of known mineral deposits of various types is essential to the successful search for new ore bodies. A section on mineral exploration discusses the methods and problems of exploration, and also considers which commodities in Nevada offer the greatest promise of new discoveries in the future.

Water resources are described rather fully in this report; water in this generally arid part of the Great Basin is vital to the economy of the State and to the well-being of its people. Sources of waterpower and geothermal power are also discussed.

This report was prepared jointly by members of the Nevada Bureau of Mines, and of the U.S. Geological Survey. Mr. Paul Gemmill, Nevada Mining Association, and Mr. L. A. Wright, Pennsylvania State University, were invited to write the sections on perlite and talc because of their knowledge of these commodities. Authorship of individual sections is indicated at the head of each chapter. All sections not showing authorship were written by H. R. Cornwall, who assembled the report.

The geologic map was compiled from a number of sources as indicated by an accompanying list of references and index map (fig. 4). Great strides have been made in recent years toward the objective of a complete, accurate geologic map of the State. This progress is in large part due to a concerted, joint program of the Nevada Bureau of Mines and the U.S. Geological Survey to prepare geologic maps of all the counties at a publication scale of 1:250,000.

Mineral production data given in the text, unless otherwise cited, are from the U.S. Geological Survey's Mineral Resources of the United States (1880-1921), the U.S. Bureau of Mines Minerals Yearbook (1922-62), and from other data obtained by the Nevada Bureau of Mines at Reno, and the U.S. Bureau of Mines in San Francisco, and Washington, D.C.



## THE MINERAL INDUSTRY IN NEVADA

(By H. R. Cornwall, U.S. Geological Survey, Menlo Park, Calif.)

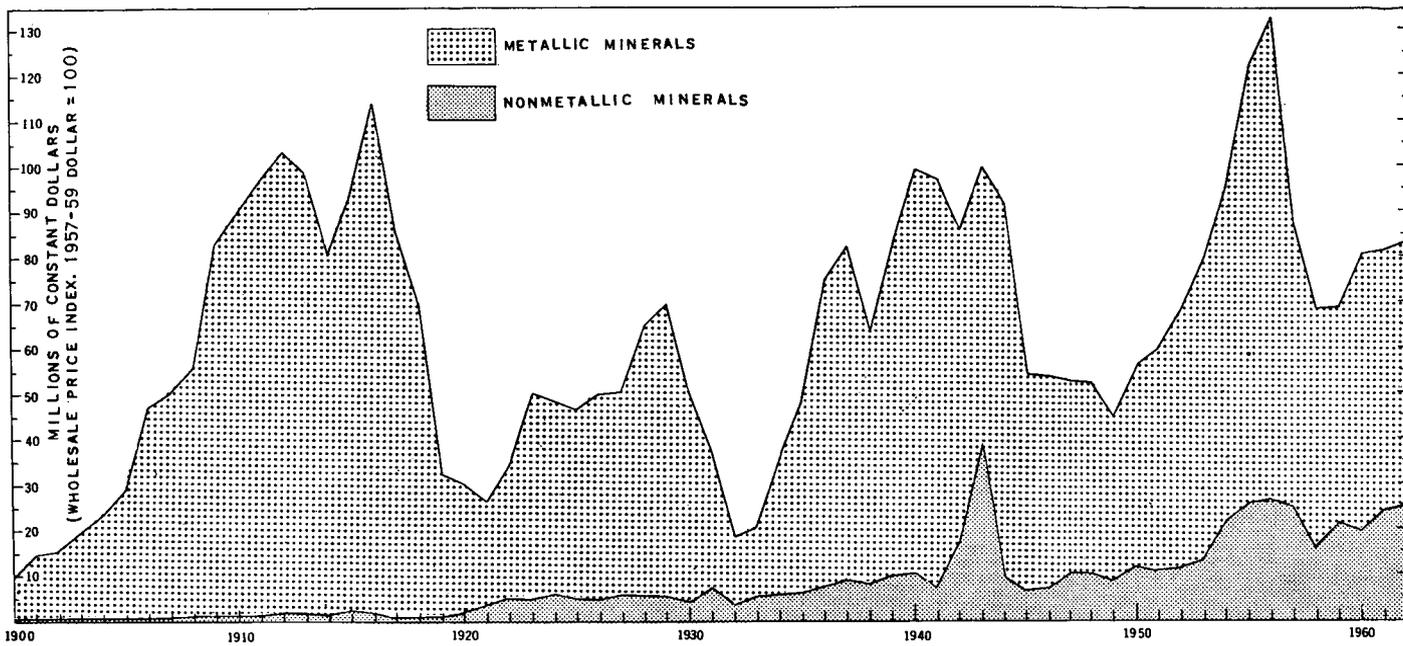
Mining started in Nevada about 1855, and for many years production from mines, mainly of gold, silver, and base metals, completely dominated the State's economy. Production of metallic and non-metallic minerals from 1900 to 1962 are shown in figure 1.<sup>1</sup> In more recent years agricultural and manufacturing output have become significant, but the production of metals and minerals has continued to be dominant. For example, in 1961 total farm marketings amounted to \$47,400,000, whereas metals yielded \$57,481,000 and nonmetallic minerals \$24,052,000 for a total of \$81,533,000. Manufacturing yielded \$67,591,000 in 1958.

The total value of metals and minerals mined in Nevada from the earliest record through 1962 amounts to nearly \$3 billion. Of this \$2,561 million (87 percent) resulted from the production of metals, and \$382 million (13 percent) from nonmetallic minerals. In the metals, production of gold and silver totaled \$1.2 billion and copper production amounted to \$1.1 billion. Other metals, mainly lead, zinc, tungsten, iron, mercury, and manganese netted \$260 million. This is a minimum figure, because the output of certain metals has not been published in years where such publication would reveal production data of individual companies. The production of tungsten, for example, is estimated to total about \$30 million more than the published figures indicate.

In the early days of mining in Nevada gold and silver were the principal metals sought. In 1859 production started from the fabulous gold-silver bonanzas of Comstock lode at Virginia City, Storey County. Production from this district reached a maximum of \$36,301,500 in 1877. The total output for the district during the period 1859-1921 amounted to \$386,347,000 (Lincoln, 1923, p. 226). Following the Comstock development, other rich gold-silver deposits were soon discovered, such as the Reese River district in 1862. Of the base metals copper, lead, and zinc, which commonly occur with gold and silver, only lead was recovered in the early days of mining in Nevada. Lead production was greatest between 1873 and 1881 when output exceeded 12,000 tons per year, with a maximum of 31,000 tons in 1878.

Mining in Nevada almost ceased between 1890 and 1900. In 1900 the rich ores at Tonopah, Nye County, were discovered. Tonopah was principally a silver-gold district, with silver exceeding gold by a ratio of 3:1. Minor amounts of copper and lead also were recovered. Between 1900 and 1921 production totaled \$120,491,000 (Lincoln, 1923, p. 186). Other early producers were Eureka (\$40 million in gold, \$20 million in silver between 1869 and 1892); Goldfield \$84,879,000, principally in gold, between 1903 and 1921); and Reese River (\$50 million).

<sup>1</sup> The values on fig. 1 are "constant dollars," based on the 1957-59 dollar. In other words, actual values have been adjusted to reflect the changing value of the dollar in terms of its purchasing power. For the most part, therefore, the curves mark the significant changes in volume of material produced.



DATA FROM RECORDS OF U. S. BUREAU OF MINES AND U. S. GEOLOGICAL SURVEY.

FIGURE 1.—Mineral production in Nevada, 1900 through 1962.

Significant copper production in Nevada started in 1906, and, except for the depression years of the early twenties and early thirties, has gradually increased ever since to a high of 82,000 tons in 1962 (7 percent of the national total). The total production of copper through 1962 was 2,813,338 short tons. The Ely district, White Pine County, has produced over 2 million tons; the Yerington district, Lyon County, 340,000 tons; and the Mountain City district, Elko County, 105,000 tons. Copper production will probably continue to increase in Nevada, particularly in the Yerington district, where major discoveries have recently been made of iron ore with associated copper.

Iron ore production in Nevada has been small. Total production amounts to about 10 million tons, mostly since 1950. Significant new discoveries have recently been made, however, including a large deposit near Yerington, and resources of material containing 40 percent or more iron are estimated to total  $\frac{1}{2}$  to 1 billion tons. As the demand for iron and steel increases along the Pacific Coast and in Japan, the Nevada deposits are favorably situated to supply these increased demands. It is probable, therefore, that there will be a substantial increase in Nevada iron-ore production in the near future.

Nevada and California have been the major tungsten producers of the United States. Each has produced about 30 percent of the total of the United States, which is second only to China in world production. The value of production in Nevada has been about \$130 million. The greatest periods of production were 1941-49 and 1951-56 when prices were high because of wartime demands. Since 1956 the price has declined and production has dwindled. It is quite certain that renewed demand for tungsten with concomitant increase in price would encourage renewed mining of the metal in Nevada.

The production of nonmetallic minerals in Nevada was practically nil before 1900 and first exceeded \$1 million per year in 1920. The yearly production of nonmetallic minerals in terms of constant (1957-59) dollars is given in figure 1. The rate of production has increased rather steadily since 1920 with upward surges during World War II and the Korean war. In 1962 the total production of nonmetallic minerals was slightly over \$25 million. The nonmetallic minerals include barite, borates, clays, diatomite, fluorspar, gems, gypsum, lime, perlite, salt, sand and gravel, silica, stone, sulfur, and talc. Yearly production of these individual commodities has commonly amounted to less than \$2 million except for sand and gravel (\$9,655,000 in 1962), and gypsum (\$2,952,000 in 1962).

Production of mineral fuels in Nevada has been small. There are no commercial coal deposits, although attempts have been made in the past to mine low-grade coals in Tertiary lake beds. The outlook for petroleum is more promising. The Eagle Springs field, Nye County, currently has three producing wells, and production to date amounts to 717,000 barrels. The third well, completed in March 1964, is a flowing well with initial production exceeding 2,400 barrels per day.

In the following sections the geology and occurrence of the mineral commodities will be discussed in detail. The great variety of geologic environment and types of occurrence of the individual metals and minerals is strikingly apparent from these descriptions.

The abundance and variety of mineral resources in Nevada should continue to be important factors in the expansion of industry in the State in the years ahead. As has been indicated in the preceding discussion, certain commodities, such as copper, iron, and oil, show particular promise of expansion in the future. Renewed mining of tungsten would also undoubtedly result from a rise in price. Substantial resources of other materials, including borates, clays, diatomite, gypsum, dimension stone, lime, and perlite, are available in Nevada and production can be expanded as demand for these items increases in the Pacific Coast market. It is thus apparent that the mineral industry of Nevada will continue to be a vital factor in the State's economy for many years to come.

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### MINERAL EXPLORATION IN NEVADA

(By S. E. Jerome, Nevada Bureau of Mines, Reno, Nev.)

It will be evident in reading this report that Nevada produces an abundance of mineral commodities and that the mineral industry contributes substantially to the economy of the State through jobs, taxes, freight revenues, support of satellitic industries, etc. Only through constant exploration and discovery can the health of the industry be maintained, for it depends on wasting assets.

To approach the problems of exploration with any hope of consistent success requires a combination of competent personnel, high quality geologic mapping, imaginative thinking, willingness to innovate, sophisticated geophysical instrumentation and geochemical analytical techniques, enlightened management or backers, dollars, intelligent persistence even through dips in the economic cycle, drill holes, and pure luck. In some cases the latter seems to be the only ingredient involved, particularly if one is contemplating the successes of his competitors. Exploration personnel should have a thorough knowledge of the mineral business and must understand the effect of changes in technology, new uses, substitutes, changing market patterns and political attitudes.

Most individuals or companies exploring in Nevada are interested only in a small number of commodities at a particular time. This reflects the fact that many companies are vertical organizations whose businesses depend on only one or two commodities; they explore for them, mine or pump them, process them, and market finished products. Examples include the large copper companies whose business is almost entirely dependent on copper and such byproducts as result from mining and processing copper ores, and companies like those operating in the State on gypsum, diatomite, magnesite, and petroleum deposits. Individuals and nonvertical organizations may be interested only in exploration, production, and marketing a raw material to a processing company. The latter's search ordinarily is directed toward those commodities enjoying a reasonably predictable, favorable economic climate; those in urgent need, with a correspondingly high price, induced by strong consumer demand or by the sudden needs of war; those subsidized for one reason or another, including stockpiling, Government exploration loans, subsidy payments, supported metal prices, and accelerated depreciation; those for which

there is speculation of a price increase as is the case with gold; and, those produced in substantial amounts in foreign countries, but for which the political climate is unpredictable.

Commodities found in Nevada and currently high on the list of desirable exploration objectives include: iron, gold, silver, molybdenum, copper, beryllium, petroleum, borate, gypsum, diatomite, clay, glass sand, and various types of "lakebed" salts such as sodium chloride, sodium sulfate, and potassium chloride. Commodities in a transitional stage of improving economic prospects include the perennial problem metals: lead, zinc, and mercury. Those whose fortunes have waned here and elsewhere, but which are certain to return to some importance under stimulation of some of the conditions cited above include: antimony, tungsten, uranium, vanadium, manganese, and fluorite. In considering any mineral, however, it needs to be emphasized that even under an unfavorable economic situation, a deposit unique either in size or quality merits through exploration and possible production. This is especially true if its product could make substantial inroads into established marketing patterns, and provided that a need exists for it in quantity. In contrast, a large, high-grade deposit of cesium-bearing minerals in Nevada might require many years to be fully appreciated and exploited, and today would not be the object of a concentrated, expensive exploration program. One never knows, however, when a scientific breakthrough may catapult a mineral commodity, such as cesium, with a limited market into great demand. Uranium is the outstanding example of our generation.

Some abundant mineral commodities, such as volcanic cinders, sand, gravel, and common stone are of low value and will not stand the addition of substantial freight charges to their exploration and production costs. Processing will upgrade them only to a limited extent. These and similar materials normally are consumed within relatively short distances of points of production. Actually it is the local need that prompts their exploitation in the first place. In a State such as Nevada with a low total population centered in a few cities the exploration for such materials will continue to be a local problem, not attracting major effort. However, such deposits can provide lucrative businesses for small companies or individuals.

Nevada apparently is deficient, or has only meager sources of coal, niobium, titanium, asbestos, nickel, cobalt, vermiculite, aluminum, borax, lithium, and tin; for some of these the optimistic view may be held that the deficiency is apparent and only reflects lack of discovery or the need for a higher price or the need for improved mining and other concentrating methods. It is such optimism about these and other commodities that helps maintain a healthy interest in exploration.

Because of the variety of mineral materials found, the entire State is a potential hunting ground, and any geologic environment might yield something that is or may become of economic interest. However, the search for individual commodities often can be restricted to a particular environment in which certain conditions prevail. Decision on a favorable environment results from study of geological reports and maps in combination with commodity distribution maps. To facilitate such studies, new geological mapping and compilation of past mapping is underway as a cooperative project of the U.S. Geological Survey and the Nevada Bureau of Mines. Results to mid-1962 have been published as map 16, "Progress Geologic Map of

Nevada," by the Nevada Bureau of Mines. The commodity maps of this volume, based on those published by the latter organization, show that some mineral commodities are of widespread, almost random, occurrence; others have a strong tendency to occur in clusters; others are arranged in striking linear patterns; and, some large areas in the State are remarkably free of significant deposits of any kind. These patterns are revealed most effectively on maps showing individual commodities, the procedure usually followed herein.

Although many similarities exist, there are many differences in the exploration methods used for metals, nonmetals, and petroleum. The selection of methods is influenced by two contrasting geologic-topographic situations that characterize the State. In the first, bedrock is exposed, often in substantial relief, over large areas and is susceptible to direct observation and sampling. This is the case in the extensive volcanic plateaus in the northern part, in the Sierra Nevada Province along the southwestern border, and in elongate mountain ranges prominent over a large part of the State. Within these bedrock masses, large areas are obscured by a relatively thin cover of alluvium and vegetation. In the second situation, vast areas are covered with great thicknesses of alluvium and poorly consolidated sediments of varied origin. This condition prevails over about 60 percent of the State in the extensive valleys between ranges. The striking combination of alternating mountain masses and valleys prompts the designation, "Basin and Range Province", for most of Nevada and parts of Utah, California, Arizona, and New Mexico. Throughout this Province exploration problems are similar.

In the bedrock environment it must be determined if the rock exposed is a possible host for the materials being sought, or if it is a concealing cover deposited much later than the materials sought. Thus, while Late Tertiary and younger volcanic rocks in the northern plateaus and in the ranges are potential sources of ash, pumice, perlite, building stone, road metal, and zeolites, and also may contain lake beds with diatomite, salts, and borates, such rocks may also conceal important metalliferous deposits. If those commodities are sought for which the volcanic rocks are host, the exploration problems usually are simpler than the marketing problems and may be limited to direct prospecting, sampling, and drilling. If those materials are sought which the volcanic rocks are likely to conceal, the exploration problems can be extremely difficult and frustrating.

Where rocks are exposed that are likely to have had valuable metalliferous deposits introduced into them, the requirements for discovery are reasonably straightforward and may include all or any combination of the approaches listed below. It is not intended to imply, however, that discovery is the automatic result of such work.

1. A locality known to contain major deposits of a mineral commodity, or many signs of its possible presence, is selected. as mentioned above this is based on study of geologic reports and maps and commodity distribution maps.
2. Rock types, faults, folds, mineralization, and alteration are mapped in considerable detail.
3. The mineralization is sampled and content of valuable minerals established.

4. Geophysical and geochemical surveys are undertaken, using methods appropriate to the geologic situation and to the commodity.

5. The information collected is synthesized and analyzed and favorable exploration targets are defined.

6. The promising targets, usually combinations of favorable geologic structures, likely host rocks, and signs of mineralization and alteration, are explored by drilling and excavation. Interesting situations should be appraised thoroughly rather than subjected to superficial examinations every year or so by different people of the same organization.

One exploration man probably feels as inadequate as the next when he stands at the bedrock-valley fill contact and speculates as to what may lie under the cover and how to go about finding it. It is most logical to concentrate on those covered areas where major mining districts are abundant in adjacent bedrock and occur in alinements that are not merely accidents of erosion, but which can be related to faults, folds, and the distribution of intrusive rocks. For those interested only in finding and disposing of mineral deposits, it could be added that the areas for concentrated exploration might be ones filling all the above requirements and also having the greatest number and variety of important mineral materials. Under such circumstances, the chances of finding something valuable under cover are greater than when only a single commodity is involved. Exceptions would be extensive petroleum reservoirs or widespread, sheetlike bodies of nonmetallic minerals, which may be controlled more by stratigraphic conditions than by structure and positions of intrusive rocks.

In exploring all covered areas the question is presented: Does the prize at the depth expected justify the expenditure required to find and mine it? A typical problem facing those exploring in Nevada for porphyry copper deposits under cover, and a good one for those who like to use computers to assist in solving their exploration problems, is the size and grade that a potential deposit would have to have to justify exploring for it under a blanket of 2,000 feet or more of alluvium.

The physical and chemical characteristics of the commodities sought under cover determine whether geophysical and geochemical methods can aid in the search, and if so, which ones. For example, the ground or airborne magnetometer is most useful and produces the least confusing results of any instrument in exploration for magnetic iron deposits in Nevada but in seeking most deposits of nonmetallic minerals it generally is only an indirect guide to geologic structures and rock types.

The physical and chemical characteristics of the cover, and the inhomogeneities therein, must be evaluated to establish what interferences can be anticipated during geophysical and geochemical work and drilling. Saline ground water can make results of some electrical geophysical methods ambiguous. Buried slabs of volcanic rocks can produce confusing magnetic and gravity anomalies, and the situation is aggravated if the volcanics are tilted. Volcanic rocks also show intricate magnetic patterns that often effectively obscure the magnetic characteristics of underlying ore deposits, or potentially pro-

ductive rocks. Buried magnetite-bearing channels in alluvial valleys also can add to the difficulties.

The thickness and variations in thickness of cover should be determined as completely as is economically feasible from wells and mine openings, and from gravity and seismic surveys. Much discussion among exploration personnel involves the search for mineral deposits in pediments—near-smooth surfaces cut into bedrock—but the first step is to determine where pediments exist and then to define their limits. They slope gently away from the bases of the ranges, and the alluvium blanketing such surfaces gradually thickens valleyward. Projecting geologic data, mineral trends and geochemical data into the pediments and running appropriate geophysical surveys may identify attractive exploration objectives. An interesting situation on a pediment sometimes can be recognized from regional aeromagnetic maps. Usually at some distance out in the valley, the gently sloping alluvium-bed rock contact of the pediment is abruptly dropped for several thousand feet by a hidden fault. Some Nevada ranges are bound by steeply dipping faults, and no pediment area exists; the change is an abrupt one from bedrock in the range to deep fill in the valley. In the case of metallic mineral deposits expected in the hidden bedrock, great thicknesses of covering alluvium can make exploration for them impractical under present conditions. In the case of petroleum, thick alluvium is no deterrent to exploration and also may not be critical in seeking sheetlike nonmetallic deposits, especially those recoverable by pumping through drill holes.

This brief discussion is intended to encourage additional prospecting and exploration in the State. Nothing is easy about the task of maintaining sources of supply of the mineral resources, but the great importance of minerals in the economy of Nevada needs to be better appreciated. The State government provides an equable climate for this work. Unfortunately prospectors and exploration companies here and elsewhere are being increasingly hampered by high costs, metal importation, regulation and other problems. The gradual demise of custom mills and smelters also makes marketing of metallic ores more difficult, particularly for the small operator. Much work remains to be done on basic geology, geographic patterns of mineral commodity distribution, exploration methods, and instrumentation. Such steps as are practical to help solve these problems should be taken by the government and private groups involved and should be the concern of the populace in general.

## GEOLOGY

Deposits of all types of minerals including the mineral fuels have resulted from various geologic processes and events that have been taking place all through geologic history right up to the present. Therefore, to understand and evaluate mineral resources one must be informed concerning the geological background. The following sections on topography, stratigraphy, and structural evolution are intended to provide such a background, and the section on economic geology summarizes the relation of the mineral commodities to the general geologic features of the State.

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## TOPOGRAPHY

(By R. E. Wallace, U.S. Geological Survey, Menlo Park, Calif.)

Nevada lies almost entirely within the Basin and Range province, a region characterized by isolated, elongate, subparallel mountain ranges and broad intervening, nearly flat-floored valleys or basins. The Great Basin is another term applicable to most of Nevada and refers to that major subdivision of the Basin and Range province in which drainage leads to enclosed basins rather than discharging into the sea. Drainage finds outlets to the sea only in the southeastern-most part of the State through the Colorado River system, and in the northeastern part of the State through the Snake River system.

Most mountain ranges throughout the State trend north or northeast and many are somewhat arcuate. Many of the ranges are rather regularly spaced about 15 to 25 miles apart. They are 40 to 80 miles long, and from 5 to 15 miles wide at their bases, with range crests between 8,000 and 10,000 feet above sea level. The highest point, 13,145 feet above sea level, is Boundary Peak on the California-Nevada boundary, and Wheeler Peak near the Utah-Nevada boundary is 13,063 feet above sea level.

The intervening basins owe their plainlike surface configurations largely to subaerial deposition of waste from the mountains. Thus broad, coalescing alluvial fans border most ranges, and it might be said that each range is being drowned in its own debris.

Playa lakes occupy the low parts of enclosed basins, and the nearly level floors of some basins are relicts of more extensive lake beds formed during humid periods in the latter part of the ice age or Pleistocene Epoch. Pyramid Lake and Walker Lake are, in fact, remnants of glacial Lake Lahontan which covered a large area of western Nevada during the Pleistocene.

The lowest point in Nevada, about 490 feet above sea level, is along the valley of the Colorado River at the southernmost tip of the State. From there the valley bottoms and basin floors rise toward the north and east so that although low in relation to the surrounding ranges, they stand at altitudes higher above sea level than, for example,

much of the Appalachian Mountains of the Eastern United States. Representative altitudes of basin floors include: Clayton Valley, 4,300 feet; Black Rock Desert, 3,900 feet; Carson Sink, 3,800 feet; Crescent Valley, 4,700 feet; Ruby Valley, 5,900 feet; and Railroad Valley, 4,600 feet.

The largest river contained within Nevada is the Humboldt River which derives most of its water from the Ruby and East Humboldt Ranges. It flows generally westward then turns southward to end in the Humboldt and Carson Sinks, where its water eventually evaporates. The Walker, Carson, and Truckee Rivers drain the east flank of the Sierra Nevada Mountains in California and flow eastward to undrained basins in Nevada; the Carson River to Carson Sink, the Walker River to Walker Lake, and the Truckee River to Pyramid Lake.

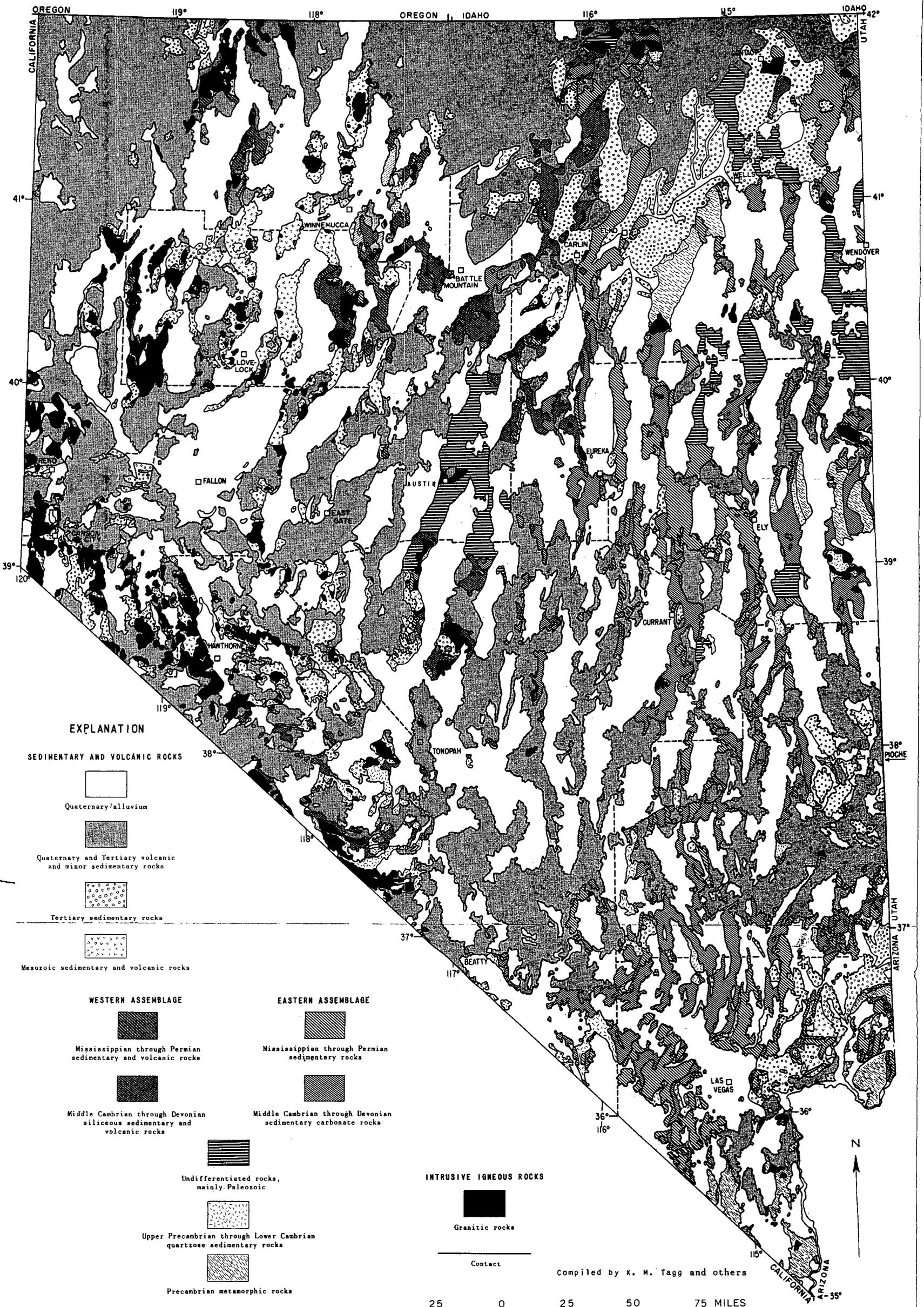
Topographic maps of the entire State of Nevada are available at a scale of 1:250,000 (prepared by the Army Map Service), and maps at a scale of 1:62,500 or 1:24,000 (prepared by the Topographic Division, U.S. Geological Survey) are available for about half (fig. 2) the State. All of these maps can be purchased from the U.S. Geological Survey.

### STRATIGRAPHY

Stratigraphy, as the name implies, comprises the composition, sequence, and correlation of stratified rocks. Sedimentary rocks are lithified sediments, composed of detrital (pebbles, sand, and mud) and chemical (calcite, gypsum, and salt) components, that accumulate either in bodies of water, or subaerially on the land. Nearshore marine gravels, sand, and mud form delta wedges or layers of conglomerate, sandstone, and shale; farther from shore, carbonate deposits, such as banks of limy mud, reefs of organic remains, or accumulations of shells and corals, form layers of argillaceous or bioclastic limestone. On the continents, coarse to fine detrital rocks form alluvial fans and flood-plain deposits of conglomerate, sandstone, and mudstone. In desert basins or playa lakes, evaporite deposits of salt and borate may form; in large lakes of long duration, petroliferous sediments may accumulate.

Layered rocks provide a record of changes in topography, source of sediment, and environments of deposition through geologic time, and provide clues to subsequent structural and chemical alteration. Intervals of geologic time during which sediments accumulated in geosynclinal basins or on continental margins are separated by mountain building intervals—orogenies—often accompanied by intrusion and extrusion of igneous rocks.

The mineral resources of Nevada are directly related to the metamorphic, sedimentary, and igneous rocks that make up the mountains and valleys. Deposits of salt, oil shale, sand and gravel, perlite, and some metallic and nonmetallic minerals are actually rocks. Some of these can be used directly in industry or commerce, whereas others require beneficiation or concentration. Mineral resources are contained in the rocks, and the major rock units in Nevada, beginning with the oldest, the sedimentary and associated igneous rocks, and the events that affected them, are described briefly in the following pages. The principal rock units are shown on the geologic map (fig. 3) and the principal formational units in the different parts of the State are shown on the stratigraphic correlation chart (table 1). Geologic



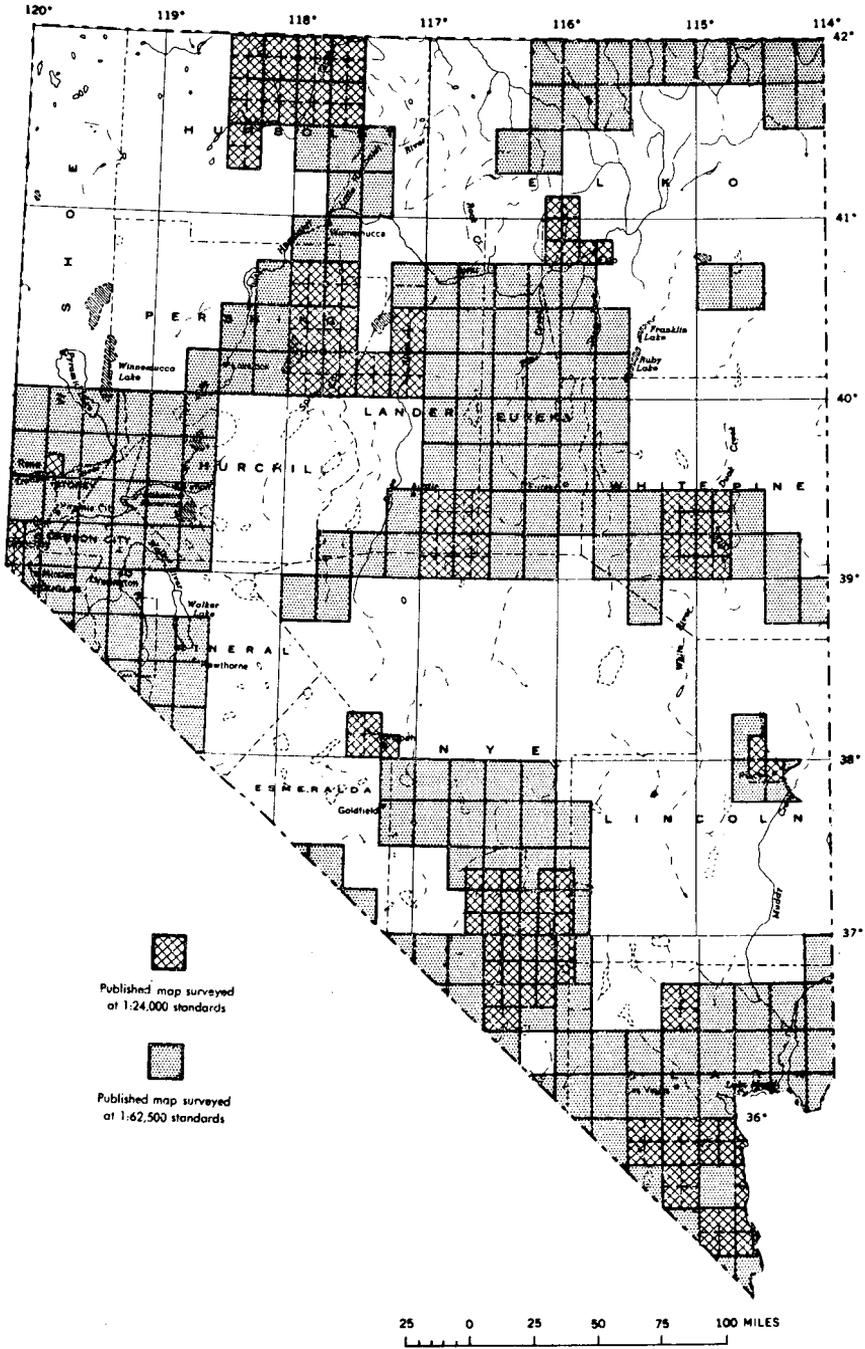


FIGURE 2.—Published topographic maps in Nevada, December 1963.

Table 1.--Generalized stratigraphic  
By J. P. Albers, H. J. Roberts,

Terms in roman type are formally named rock formations, except where identified

Area number shown on index map		1	2	3	4	
Geologic Divisions		Western Humboldt, Washoe, Storey, Ormsby, Douglas, Lyon, and western Mineral Counties	Churchill, Pershing, eastern Humboldt Counties	Elko County	Eastern Mineral, northwestern Nye, and Emerald Counties	
CENOZOIC	QUATERNARY	Recent	Alluvium, dune sand	Alluvium	Alluvium, dune sand	
		Pleistocene	Older alluvium, fanglomerate, terrace gravel, lake beds, basalt, diatomite Lousetown (volcanics)	Lahontan lake beds Fluvial gravels and sand	Older alluvium	Older alluvium Lake deposits Glacial deposits
	TERTIARY	Pliocene	Sedimentary rocks including Alturas, Morgan Ranch, Truckee, Coal Valley and Aldrich Station Kate Peak Andesite Virgin Valley (volcanics)	Local fanglomerate Mesa Basalt	Banbury Hay Ranch Cougar Point Welded Tuff Dacite flows Carlin Andesite flows Humboldt Jarbridge Rhyolite Raine Ranch	Basalt Welded ash flows Gilbert Andesite Oldie Rhyolite-
		Miocene	Cannon Rhyolite and Hartford Hill Rhyolite	Lacustrine deposits Ash flows Basaltic andesite Ash flows, tuff, sedimentary rocks	Seventy Six Basalt Safford Canyon	Emeralds and Siebert Ash flows and rhyolite breccia, including Fraction Breccia
		Oligocene		Rhyolite flows and breccia		Sandstone, shale, and tuff Andesite, dacite, rhyolite
		Eocene			Deadhorse Tuff Welded ash flows Altered andesite	Conglomerata
		Paleocene		Pansy Lee		
		MESOZOIC	Cretaceous	King Lear Unnamed volcanic rocks		
	Jurassic		Unnamed volcanic and sedimentary rocks	Unnamed sedimentary rocks Raspberry Winnemucca Dun Glen Grass Valley Star Peak Group	Aztec(?) Chinle(?)	Dunlap Sunrise Gabbs
	Triassic			Quab Cane Spring Augusta Mn. Favret Dixie Valley Tobin Koipato	Unnamed marine sedimentary rocks	Luning Candelaria Excelsior Pablo Diablo
PALEOZOIC	Permian		Havallah Edna Mn. Thrusz fault	Gerster Kaibab Arcturus Peguop		
	Pennsylvanian		Antler Peak Pumpernickel Highway, Battle	Scrathern Tomera Moleen	Ely	
	Mississippian			Diamond Peak Tonka Chainman	Limestone	
	Devonian			Devils Gate, Guilmette Nevada Simonson Sevy		
	Silurian			Lone Mn., Laketown		
	Ordovician		Valmy Comus	Hanson Creek Fish Haven Eureka Swan Peak Pogonip Group	Palmetto	
	Cambrian			Paradise Valley Harmony Preble Osgood Mtns. Scott Canyon		Emigrant Mule Spring Saline Valley Harkless Poleta
					Prospect Mountain	Campto Deep Spring Reed Wyman
Upper Precambrian	INDEX MAP OF AREAS IN NEVADA					
Lower Precambrian						

# MINERAL AND WATER RESOURCES OF NEVADA

correlation chart for Nevada  
 N. J. Silberling, and J. H. Stewart  
 as groups. *Italicized terms are informally named rock-stratigraphic units.*

5	6	7	8	Geologic Divisions		
Landef, Eureka and northern Nye Counties	White Pine and northern Lincoln Counties	Southern Nye, and western Clark Counties	Eastern Clark, and southern Lincoln Counties			
Alluvium	Alluvium	Alluvium, dune sand	Alluvium	Recent	QUATERNARY  CEENOZIC	
Older alluvium Basalt	Older alluvium Lake deposits Glacial deposits	Basalt Older alluvium	Las Vegas Chewehuevi	Pleistocene		
Andesite, rhyolite,			Basalt Panaca, Muddy Creek Basalt	Pliocene		
Horse Camp	Panaca	Thirty Caves Tuff Papa Canyon Formation	Rhyolitic ash flows and lava flows	Miocene		
Shingle Pass } Needles Range } Window Butte } Currant Tuff } Ash flows } Conglomerate, limestone and sandstone } Dacite } Sheep Pass }	Shingle Pass } Needles Range } Window Butte } Ash flows }		Horse Spring	Oligocene		
		Conglomerate and fanglomerate	Andesite	Eocene		
	Sheep Pass		Conglomerate and sandstone	Paleocene		
Newark Canyon			Base Line Willow Tank	Cretaceous		
Unnamed volcanic rocks				Jurassic		
			Aztec			
			Chinle	Triassic	MESOZOIC	
	Unnamed marine sedimentary rocks		Moenkopi			
			Kaibab Toroweap Red beds	Permian		
Havallah Pumper nickel	Edna Mtn. Garden Valley Antler Carbon Ridge Battle Ely	Gerater Plympton Kaibab Acuturus Pegtop Rib Hill Riepe Spring	Tippisah	Bird Spring Callville		Pennsylvanian
Tonka	Diamond Peak Chaitman Joana Pilot	Diamond Peak Chaitman Joana Pilot West Range	Scotty Wash Peers Spring Bristol Pass	Meiklejohn Eleans Monte Cristo Peers Spring, Chaitman		Mississippian
Slavon	Wenban Devils Gate Nevada	Guillette Simonson Sevv	Devils Gate Fluorspar Canyon Nevada, Sultan	Muddy Peak		Devonian
Fourmile Canyon Elder	Lone Mountain Helix Mountains	Laketom	Lone Mountain Roberts Mountains			Silurian
Valley Vinini	Hanson Creek Eureka Pogonip Group	Ely Springs Fish Haven Eureka Pogonip Group	Ely Springs Eureka Pogonip Group	Goodsprings		Ordovician
Scott Canyon	Windfall Dunderberg Hansburg Secret Canyon Geddes Eldorado Pioche	Mendha Windfall Dunderberg Lincoln Peak Chisholm Lyndon Pole Canyon Pioche Pioche	Nopah Bonanza King Copper Zabrtskie Wood Canyon Stirling Johnnie	Limestone and dolomite Chisholm Lyndon Pioche		Cambrian
	Prospect Mountain	Prospect Mountain McCoy Creek Group		Tupeats, Prospect Mountain		Upper Precambrian
		Gneiss and schist		Gneiss, schist and granitic rocks	Lower Precambrian	

names and ages referred to on this chart do not necessarily follow the usage of the Geological Survey. In general the columns are based largely on published sources, but the Tertiary sections are based largely on unpublished data supplied by H. F. Bonham of the Nevada Bureau of Mines; and J. P. Albers, R. R. Coats, F. J. Kleinhampl, C. R. Longwell, F. A. McKeown, E. H. Pampeyan, J. F. Smith, Jr., D. B. Tatlock, and D. H. Whitebread of the U.S. Geological Survey. Sources used in the compilation of this geologic map are listed in table 2 and shown in figure 4.

TABLE 2.—References used in compilation of Nevada geologic map.

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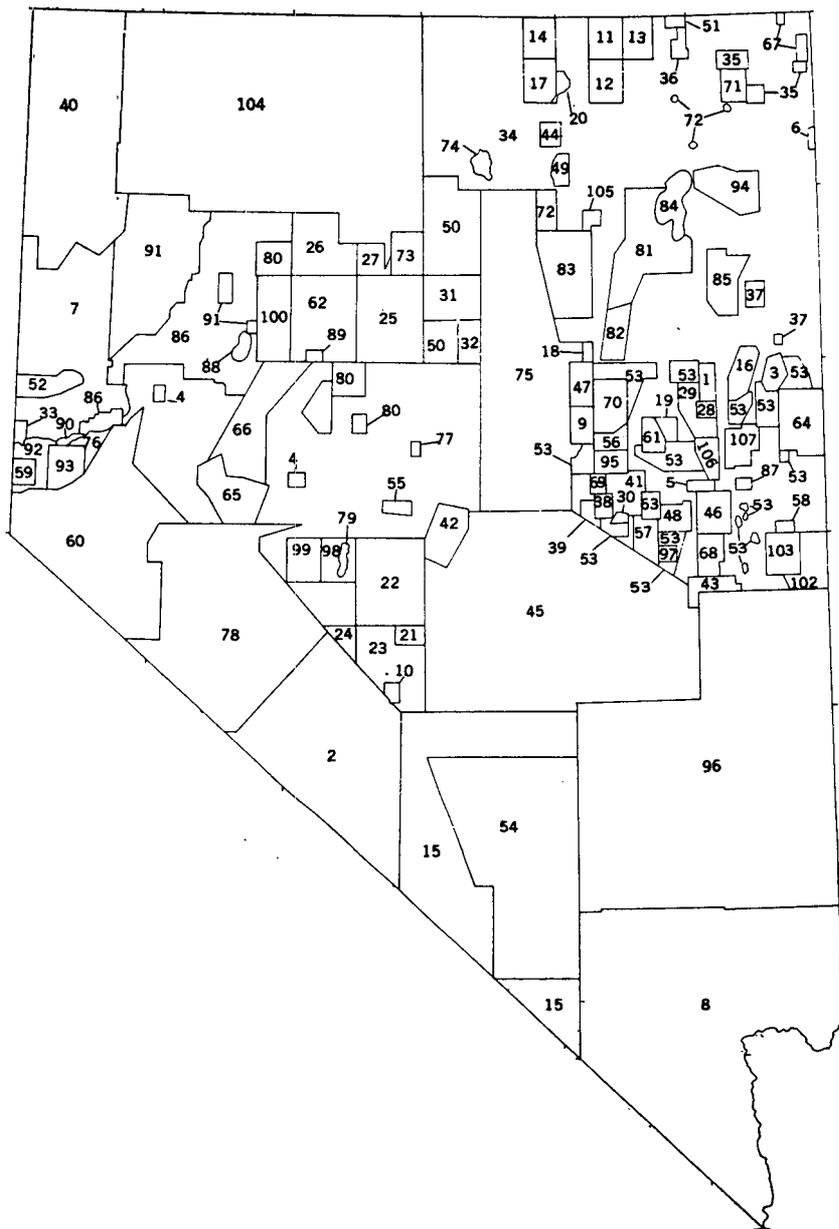


FIGURE 4.—Sources used in compilation of Nevada geologic map. Numbers refer to references listed in table 2.

Many of these sources, in turn, are compilations based on the larger-scaled maps of many geologists who have contributed greatly to the knowledge of the geology of Nevada. The extensive work of T. B. Nolan, H. G. Ferguson, C. W. Merriam, D. F. Hewett, S. W. Muller, and C. R. Longwell in particular supports many of these intermediate compilations from which figure 3 has been prepared.

Status of geologic mapping in Nevada is shown in figure 5.

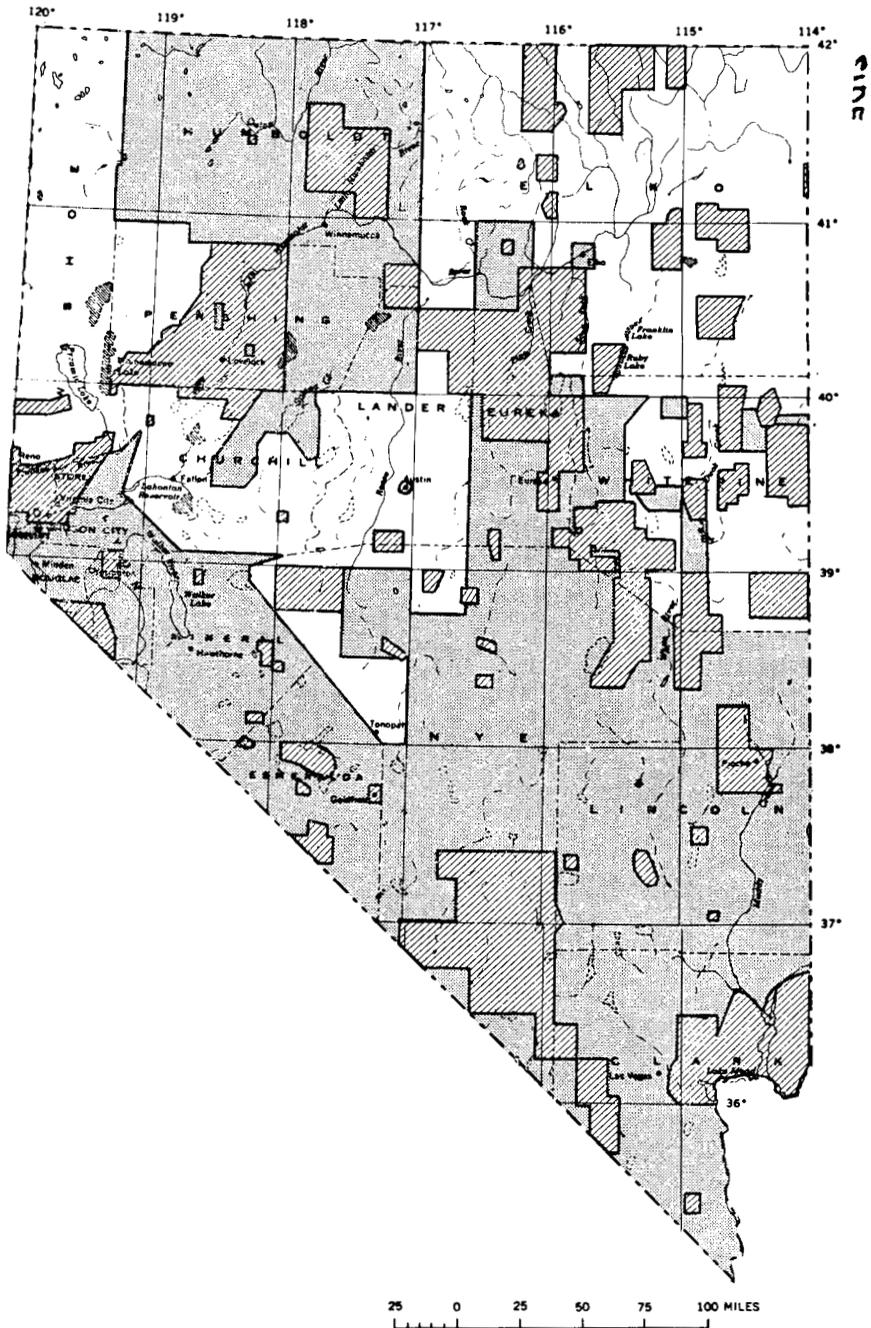


FIGURE 5.—Geologic mapping (including unpublished theses) in Nevada, December 1963. Ruled areas mapped at scales of 1:62,500 or larger; stippled areas mapped at scales ranging from 1:250,000 to 1:62,500.

## PRECAMBRIAN AND LOWER CAMBRIAN ROCKS

(By J. H. Stewart, U.S. Geological Survey, Menlo Park, Calif.)

*Lower Precambrian metamorphic rocks.*—Strongly folded medium- to high-grade metamorphic rocks are the oldest rocks exposed in the State. Metasedimentary gneiss, schist, marble, and associated intrusive granitic and pegmatitic bodies constitute the main mass of these rocks. The metamorphic character indicates a long history of development including deposition, deformation and regional metamorphism, and erosion. The metamorphic rocks form the basement of the Cordilleran geosyncline, a basin that developed during the late Precambrian, and the basal strata in this geosyncline lie with a prominent angular unconformity on these lower Precambrian metamorphic rocks.

The main exposures of the lower Precambrian rocks are along the eastern part of the State in the Newberry Mountains, McCullough Range, El Dorado Mountains, Gold Butte area, and the Virgin Mountains in the southern part of Lincoln and Clark Counties in the northern Snake Range in White Pine County, and in the Ruby Mountains and East Humboldt Range in Elko County.

Dating of these rocks by the Rb-Sr (rubidium-strontium) and K-Ar (potassium-argon) methods gives from 1.1 to 1.7 billion years on outcrops in Clark County (Lanphere and Wasserburg, 1963; Volborth, 1962; and Armstrong, 1963). These dates indicate the age at which metamorphism and granitic intrusion occurred; the original rocks from which the metamorphic rocks formed are older. In the Ruby Mountains, a schist of presumed Precambrian age has undergone a still later metamorphism and now yields a K-Ar age of 25 million years, and the K-Ar age for a similarly ancient granite is 29 million years (Armstrong, 1963).

*Upper Precambrian and Lower Cambrian clastic sequence.*—In late Precambrian time (from about 600 to 1,100 million years ago) a broad seaway, called the Cordilleran geosyncline, formed in western Nevada; at first it was a fairly narrow trough elongated north-south, but during the Early Cambrian the seaway spread eastward into central Utah. The upper Precambrian and Lower Cambrian deposits in this seaway are dominantly clastic. These deposits are thin along the eastern flank and thicken fairly abruptly to the west into the central part of the seaway. In eastern and southern Clark County, which lies along the eastern flank of this seaway, the clastic strata are only 200 to 400 feet thick. In southern Nye County, in White Pine County, and in Esmeralda County, all of which lie in a more central part of the seaway, incomplete sections of these strata are 10,000 to 12,000 feet thick. Strata deposited during late Precambrian and Early Cambrian time consist dominantly of coarse quartzite and conglomeratic quartzite along the eastern flank and fine quartzite, phyllitic siltstone, and carbonate layers in the central part. Deposition started in the central part of the trough and extended progressively farther to the east onto the flank of the trough as it was filled. Most of the sediment in this trough was derived from lower Precambrian metamorphic terranes to the east.

## PALEOZOIC ROCKS

(By R. J. Roberts, U.S. Geological Survey, Menlo Park, Calif.)

Following the deposition of sands and shales during the Precambrian and Early Cambrian, the character of sedimentation changed within the seaway (Roberts and others, 1958). In eastern Nevada the sands gradually gave way to carbonates (limestone and dolomite) which were deposited in shallow seas in which lived abundant marine life such as shellfish, corals, and sponges. In central Nevada the carbonates are interbedded with shales and silts in transitional belt (Hotz and Willden, 1955). The transitional rocks grade westward into sequences of siliceous rocks (chert, shale, and sands) and volcanic rocks (lava and pyroclastics). These rocks were formed offshore, partly in deep water, but locally volcanic islands, like present-day Hawaii, were built on the sea floor. The sediments deposited within each of these environments differ in lithology; for convenience in following discussions they will be called assemblages. The three major assemblages, carbonate, transitional, and siliceous and volcanic were laid down in different parts of the seaway without significant interruptions from Middle Cambrian to the end of Devonian time. The boundaries between the assemblages shifted eastward and westward somewhat during this time, but the major belts remained distinct (fig. 6).

In Late Devonian time mountain building during the Antler orogeny in western Nevada was signaled by a flood of coarse detrital rocks that were shed into eastern and western Nevada (Roberts, 1949; Carlisle and Nelson, 1955; and Roberts and others, 1958, p. 2837). The mountain building culminated in the movement eastward of great thrust plates from the uplifted area; these reached points along a line from Austin to Eureka, and then to Mountain City and covered a belt about 90 miles wide (fig. 7).

Subsequent deformation and erosion has resulted in local removal of the thrust plate, thus exposing rocks of the lower plate in windows (Roberts and others, 1958, p. 2821; Roberts, 1960).

*Middle Cambrian to Devonian rocks*

Throughout eastern Nevada the Middle Cambrian, Ordovician, Silurian, and Devonian rocks aggregate 12,500 to 21,000 feet in thickness (Nolan and others, 1956; Kellogg, 1963). Northwest of Eureka where the carbonate assemblage grades into the transitional assemblage, the section appears to thicken; eastward to the Utah line the section is about the same thickness; southeastward it thins toward the Utah-Arizona shelf.

In eastern Nevada the Middle Cambrian rocks are generally composed of thick dolomite units that grade upward into limestone and shaly limestone of the Upper Cambrian and Lower Ordovician; in western Nevada correlative rocks are mainly interbedded shale, chert, and volcanic rocks (Roberts and others, 1958). Middle Ordovician units in eastern Nevada are vitreous quartzite 300- to 500-feet thick and a little dolomite; equivalents in western Nevada are quartzites that aggregate about 3,000 feet thick, interbedded with shale, chert, and volcanic rocks. Late Ordovician to Early Devonian in eastern Nevada was again a period of dolomite formation but by Late Devonian time limestones predominated; meanwhile, in western Nevada, silt, mud, and chert were being deposited.

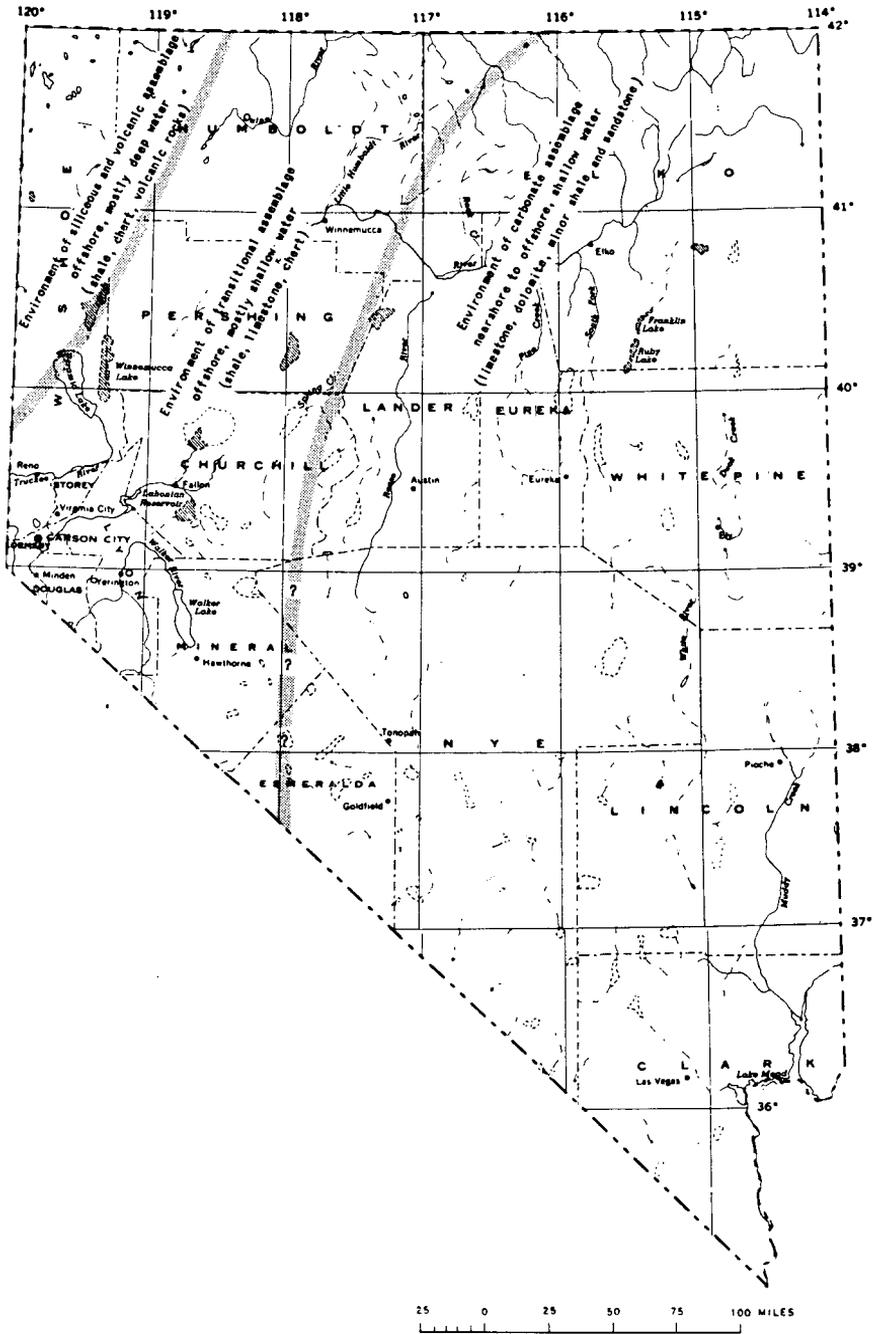


FIGURE 6.—Original depositional environments in Nevada during early and middle Paleozoic time (Middle Cambrian to Late Devonian).

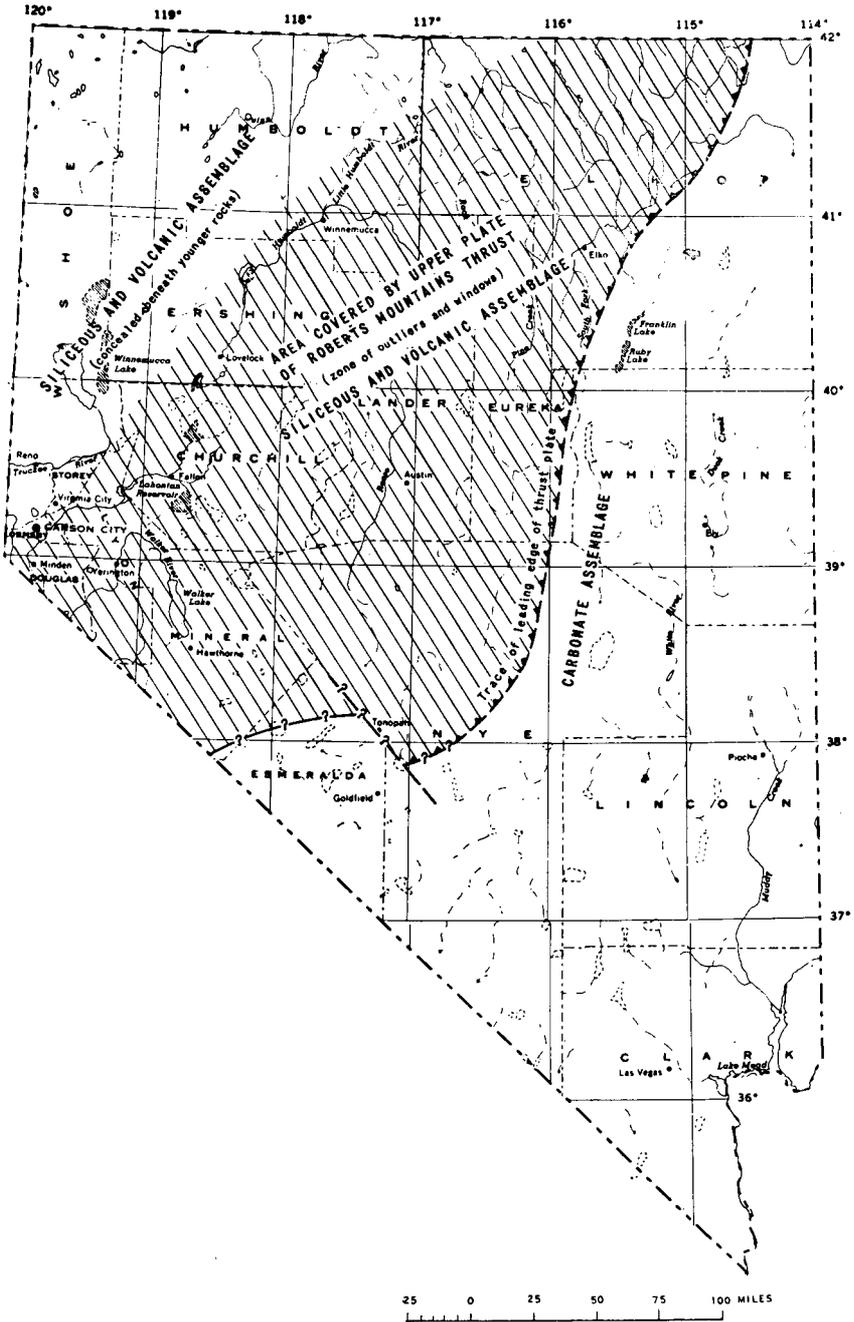


FIGURE 7.—Distribution of Paleozoic facies after thrusting in Early Mississippian time.

*Mississippian to Permian rocks*

During and following mountain building (Antler orogeny, p. 56) that lasted from Late Devonian to Early Pennsylvanian time, great thicknesses of detrital sediments were laid down in central and eastern Nevada. These sediments overlap the (mountain-building) belt and flank older beds, and have been called the overlap assemblage (Roberts and others, 1958) (fig. 8).

In the area around Eureka (Nolan and others, 1956), in the Chainman-Diamond Peak trough, these total about 7,000 feet in thickness; eastward they thin and grade into finer sediments that are about 1,000 to 2,000 feet thick near the Utah State line. During this period of mountain building detrital sediments were also deposited in western Nevada, where they aggregate 10,000 feet or more in thickness in the Pumphnickel-Havallah basin.

By Middle Pennsylvanian the Antler orogenic belt had been largely eroded, leaving only a few islands projecting above the sea. In Late Pennsylvanian and Early Permian even the islands had disappeared, and limestone was being deposited over much of Nevada. In Late Permian, uplift and mountain building in western Nevada began again and culminated in a movement of another major thrust plate eastward onto the roots of the Antler orogenic belt. This younger period of mountain building, the Sonoma orogeny, also resulted in a flood of coarse clastics into the marine waters that still covered eastern Nevada (Silberling and Roberts, 1962). At the end of Permian time much of eastern and central Nevada was uplifted just above sea level. Uplift was not sufficient to cause deep erosion, though erosion may have been locally significant.

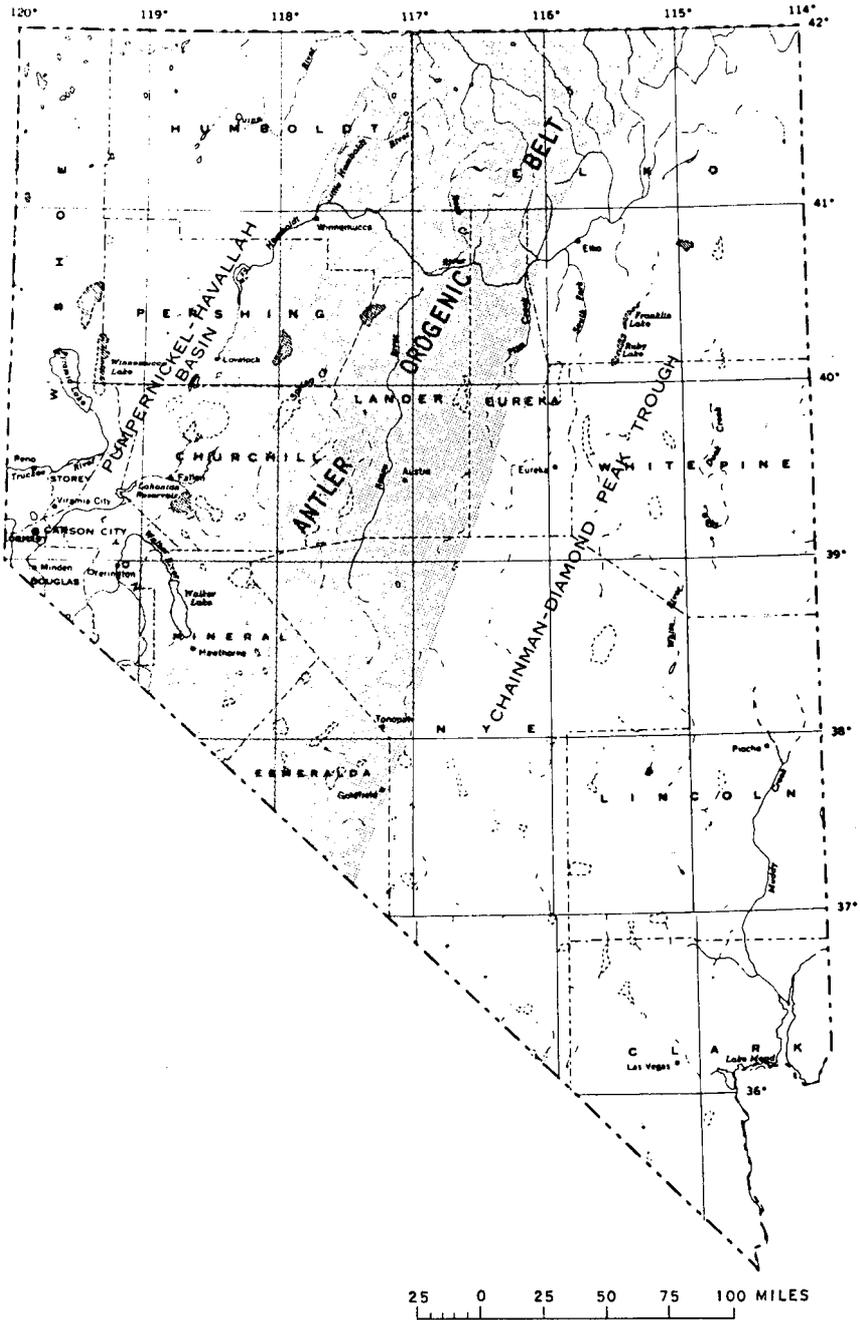


FIGURE 8.—Inferred extent of Antler orogenic belt and flanking basins in Nevada during Mississippian and Pennsylvanian time.

## MESOZOIC ROCKS

(By N. J. Silberling, U.S. Geological Survey, Menlo Park, Calif.)

Mesozoic strata are sporadically and unevenly distributed in Nevada and are extremely diverse in character. Mesozoic time (from about 230 to 65 million years ago) is subdivided from oldest to youngest, into the Triassic, Jurassic, and Cretaceous periods, and though the record is fragmentary and, for the later part of Mesozoic time, quite incomplete, each of these major subdivisions is at least partly represented in Nevada by sedimentary and volcanic rocks. The nature and geographic distribution of these rocks closely reflect the tectonism, or crustal instability, that with varying intensity was active in the region throughout the 165-million-year duration of Mesozoic time. During the early Mesozoic crustal instability was generally limited to gentle uplifting or subsidence affecting large portions of the region more or less uniformly. These events took place independently, and to some extent alternatively, on either side of a belt trending somewhat east of north through the middle of Nevada, and thus the record of subsidence, marine transgression, and sedimentation in northwestern Nevada differs from that in the southern and eastern parts of the State. More intense tectonism in the form of orogenic, or mountain building deformation affected the region beginning in Jurassic time and continuing in one place or another during the rest of the Mesozoic. The strata deposited earlier were uplifted and eroded away from large parts of the area they originally blanketed, and renewed deposition was restricted to the local accumulation of land-laid volcanic rocks and the sedimentary filling of ephemeral, nonmarine, orogenic basins. On the basis of this brief historical review, the Mesozoic strata of Nevada are described below in three parts: the lower Mesozoic of northwestern Nevada, the lower Mesozoic of eastern and southern Nevada, and widely scattered upper Mesozoic stratified rocks.

*Lower Mesozoic of northwestern Nevada.*—Lower Mesozoic strata are widely exposed in northwestern Nevada west of the 118th meridian and north of the 38th parallel. The oldest of these are mainly altered volcanic rocks whose scattered exposures represent the final stages of what is thought to have been a single episode of largely submarine volcanism during the Late Permian and earliest Triassic. The principal outcrops of these old volcanics are in eastern Pershing County (Koipato Group), northwesternmost Nye County (Pablo Formation), and eastern Mineral County (Excelsior Formation). These rocks are characteristically heterogeneous and include more or less altered volcanic tuffs, breccias, and flows, of both siliceous and mafic composition, and much volcanic-derived sedimentary material. What proportion of these were deposited just after the beginning of Mesozoic time, and what proportion just before, is generally indeterminate, but their total thickness may exceed 10,000 feet in places. These are the host rocks for a number of quartz vein mineral deposits, notable examples of which are the silver deposits of the Rochester district in the Humboldt Range.

Deposition of these Permian and Triassic volcanic rocks was followed by a period of gentle uplift, tilting, and erosion in northwestern Nevada, after which marine sedimentation was resumed

near the beginning of the Middle Triassic and continued through Early Jurassic time. The Triassic and Lower Jurassic strata so formed are now found in isolated and structurally jumbled exposures, but they originally formed a thick, laterally and vertically continuous body of rocks. Their present outcrops still roughly delimit the eastern and southern extent into Nevada of the marine basin in which they accumulated. Although more than two dozen different formations have been established to express the complex variety among these rocks, some larger and more generalized lithologic subdivisions can be recognized among them.

The sections exposed in westernmost Nevada, closest to California and the Sierra Nevada, include a large proportion of altered volcanic rocks. Owing in part to metamorphism by igneous intrusion, their composition and stratigraphy is not well known, but they are correlative, and in some places can be seen to interfinger, with nonvolcanic Middle and Upper Triassic strata farther east in northwestern Nevada. Thick sections of this volcanic facies of the Lower Mesozoic are exposed in Douglas, Lyon, and Mineral Counties.

The more eastern, nonvolcanic facies of the Lower Mesozoic in northwestern Nevada comprises mainly shallow-water marine sedimentary rocks, but the lower and upper parts of this succession are significantly different. The lower part is mainly composed of carbonate rock, whereas argillaceous and sandy rocks form most of the stratigraphically higher parts. Deposition of the marine carbonate rocks at the base of this succession began at different times within the Middle and Late Triassic reflecting transgression of the sea eastward and southward into northwestern Nevada. Except for local basal conglomerate and subordinate amounts of noncalcareous clastic rocks derived from adjacent land areas, this part of the section is mainly relatively pure limestone and dolomite. These rocks are formed in large part of the shells and broken-up calcareous hard parts of marine organisms that accumulated on slowly subsiding banks and shoals to thicknesses of several thousand feet in places. Most of the exposures of these carbonate rocks are in a belt a few tens of miles wide extending from eastern Pershing County (e.g., Star Peak Group) south to eastern Mineral County (e.g., Luning Formation). Among the variety of limestone replacement ore deposits found in these rocks are the extensive magnesite deposits near Gabbs in the Paradise Range.

Deposition of the argillaceous and sandy rocks that characterize the higher parts of the Lower Mesozoic in northwestern Nevada began abruptly during the Late Triassic and continued into Early Jurassic time. Though some of these rocks are calcareous, and limestone, or more rarely, gypsum is interbedded with them in places. Argillaceous rocks with some siltstone and sandstone predominate in contrast to the underlying thick sections of relatively pure carbonate rocks. The thickest and least calcareous sections of these predominantly argillaceous rocks (e.g., the Grass Valley and overlying formations) crop out in eastern Humboldt County and central Pershing County where their original thickness probably exceeded 20,000 feet. In most places they have been altered to argillites, slates, and phyllites by low-grade metamorphism. Farther south, in northwestern Nye County and eastern Mineral County, the corresponding sections are more calcareous and thinner (e.g., the Gabbs and Sunrise Formations), though

still on the order of thousands of feet thick. These rocks are thought to have resulted from the introduction of vast amounts of mud into the marine basin by a major Upper Triassic and Lower Jurassic stream system draining from the continental areas to the east. Deltaic deposits were formed as the mouth of this ancient stream system migrated back and forth along the shoreline in north central Nevada, and large amounts of fine-grained sediment were also spread throughout the shallow marine embayment in northwestern Nevada by oceanic currents. Associated with these argillaceous, silty, and sandy rocks are a variety of mineral deposits, the most important of which, like the scheelite deposits near Tungsten and the quicksilver deposits of the Pershing district, commonly occur in the more calcareous parts of the section.

In eastern Mineral County and northwestern Nye County the Lower Mesozoic marine section is overlain either conformably or with strong angular discordance by a heterogeneous assortment of conglomerate, nonmarine sandstone, and volcanic rock (Dunlap Formation) of Early and Middle Jurassic age which documents the beginning of Mesozoic orogeny in western Nevada.

*Lower Mesozoic of eastern and southern Nevada.*—In eastern and southern Nevada, as compared with northwestern Nevada, lower Mesozoic strata are less widely exposed, even though at one time they evidently blanketed much of the area. The most extensive and complete lower Mesozoic exposures from a discontinuous belt trending northeasterly through Clark County into southeastern Lincoln County. Farther north in eastern Nevada widely scattered and isolated patches of related rocks occur in northern White Pine County and eastern Elko County.

The oldest of these rocks are calcareous strata deposited during the latter part of Early Triassic time in an elongate, shallow, inland sea that extended from the area of the middle Rocky Mountains southward across western Utah, eastern and southern Nevada, and perhaps through southeastern California. In northeastern Nevada these rocks consist mainly of calcareous shale and siltstone and impure limestone, and the more complete sections of them may exceed 2,000 feet in thickness. In southern Nevada the genetically related rocks (Moenkopi Formation) are also limestone and impure calcareous strata, but they include gypsiferous beds, and especially in the higher parts of the section, they intertongue southeastward with nonmarine red beds. These Lower Triassic rocks were the last marine strata to be deposited in eastern and southern Nevada; the overlying Upper Triassic and Lower Jurassic rocks, where present, are continental deposits like those that characterize the Colorado Plateaus region of Arizona, Utah, and New Mexico.

In southern Nevada these lower Mesozoic nonmarine rocks have been assigned to the Chinle and Aztec Formations. The Chinle Formation, as the name is presently used in this area, includes lacustrine and fluvial deposits of bentonitic claystone, siltstone, and sandstone which locally aggregate more than 3,000 feet in thickness. A pebbly sandstone in the lower part of the Chinle resembles the Shinarump Member—a well-known unit in Utah and Arizona because of the uranium deposits associated with it. The Shinarump, the oldest of these continental rocks, is commonly dated as Late Triassic, but slow accumulation during most of Middle Triassic time has been

suggested by some authorities. The Aztec Sandstone, equivalent to the Navajo Sandstone of the Glen Canyon Group on the Colorado Plateaus, is a massive, eolian, or wind-deposited sandstone as much as 2,000 feet thick. It is probably Jurassic in age, and is the youngest part of this conformable succession of lower Mesozoic strata.

Nonmarine strata similar to the Chinle and Aztec Formations crop out to the north only in one small area in southeastern Elko County, but their presence here demonstrates that a large part of eastern Nevada was at one time covered by these fluvial and eolian deposits.

*Upper Mesozoic.*—Strata of Late Jurassic(?) and Cretaceous age crop out in widely separated parts of Nevada and seem not to reflect any integrated pattern of deposition.

Volcanic rocks, probably laid and of Late Jurassic or Early Cretaceous age, are known in Douglas County and in northern Eureka County. Heterogeneous nonmarine sedimentary rocks of Early Cretaceous age occur in the Jackson Range (King Lear Formation) in Humboldt County, and near Eureka (Newark Canyon Formation) in the central part of the State, and rocks of late Cretaceous age occur in Clark County (Willow Tank Formation) far to the south. These include both conglomerate and finer grained detrital rocks as well as lacustrine limestone, all of which evidently accumulated in local basins formed during the deformation of the region. Thick deposits of nonmarine sandstone and conglomerate (Baseline Sandstone) in the Muddy Mountains of southern Nevada were evidently derived directly from a local topographic highland during the Late Cretaceous. Other, as yet unrecognized, occurrences of upper Mesozoic volcanic rocks, coarse clastic sedimentary rocks, and lacustrine deposits are to be expected in Nevada.

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### TERTIARY AND QUATERNARY ROCKS

(By J. P. Albers, U.S. Geological Survey, Menlo Park, Calif.)

As a consequence of the great period of mountain building during Mesozoic time, Nevada was elevated well above sea level and has not again been covered by marine waters. A profound unconformity separates the Tertiary from older rocks, and the Tertiary and Quaternary Periods are represented exclusively by terrestrial sedimentary rocks and by volcanic rocks erupted from numerous centers. The sequence of rocks thus differs greatly from place to place, and a state-wide correlation of individual rock units or groups of rock units is not possible, and correlation over an area of only a few hundred square miles is commonly unsatisfactory. An exception are some of the welded tuff units in eastern Nevada which may correlate over areas as large as 5,000 to 10,000 square miles.

Although exact correlations of Tertiary units throughout Nevada are not yet possible, a summary of major Tertiary events is presented here, based on recent reconnaissance mapping, coupled with intensive study of ash flow tuff units in some areas and radiometric age-dating in scattered localities.

The oldest rocks generally recognized as Tertiary throughout Nevada are conglomerates and breccias made up of fragments of pre-Tertiary rocks. In most areas these coarse clastics are overlain with marked angular unconformity by younger rocks and cannot be

more closely dated than simply "early Tertiary." An exception is the breccia that forms the lower unit of the Sheep Pass Formation in White Pine County. This breccia is overlain conformably by fine-grained sedimentary rocks containing fossils of Eocene age (Winfrey, 1960, p. 126). Based on their stratigraphic position and lithologic similarity to the breccia of the Sheep Pass Formation, the basal Tertiary conglomerates and breccias exposed elsewhere in the State are also presumed to have formed mainly during Eocene time but may actually range from Late Cretaceous to early Oligocene.

The earliest Tertiary volcanic rocks were andesitic flows erupted during latest Eocene or very early Oligocene time, and the volcanoes from which these flows came were in Elko, northeastern Nye, and White Pine Counties. Shortly thereafter, in the same regions, great sheets of rhyolitic to dacitic ash flows were erupted. Most of these ash flows are welded, and one of the oldest gives a potassium-argon age of 39 million years, or very early Oligocene. Other welded tuffs in eastern Nevada give potassium-argon ages ranging from 29 to 36 million years. Some granitic rocks were also emplaced at this time. Locally sedimentary beds are interlayered with this volcanic material. It therefore appears that the bulk of deposits formed during the Oligocene were ash flow sheets, some having a lateral extent of 5,000 to 10,000 square miles according to unpublished data of E. F. Cook. Southern and western Nevada were presumably undergoing erosion while this volcanism was going on in eastern Nevada.

During late Oligocene or very early Miocene time volcanic activity began in the western and northern parts of the State. The principal products initially were rhyolitic ash flows and lava flows, giving rise to such units as the Hartford Hill Rhyolite. Later, andesite and dacite lava flows were erupted, chiefly in northwestern Nevada. At the same time sedimentary formations such as the Horse Spring were being deposited in the extreme southern part of the State, while volcanism in eastern Nevada, where so much volcanic activity was going on during the Oligocene, seems to have been more or less dormant; eastern Nevada was probably undergoing erosion during much of the Miocene. It is also worth noting that the Nevada Test Site area in southern Nye County seems to have experienced neither volcanism nor sedimentation until well along in the Miocene; the oldest Tertiary deposit there, excepting local patches of Eocene conglomerate and limestone, is a welded tuff with a K-Ar (potassium-argon) age of a little more than 16 million years.

The great volcanic activity of Oligocene and early Miocene time apparently was accompanied or shortly followed by much block faulting, thereby producing a landscape of considerable relief and containing many basins which became the sites of lakes during late Miocene and early Pliocene. These lakes, which were present throughout much of the State except the southern part, received large quantities of sediment, giving rise to formations known locally as the Esmeralda, Truckee, and Humboldt. A number of K-Ar ages recently published by Evernden and others (1964) support a substantial amount of paleontologic evidence that the bulk of this sedimentation took place between 8 and 13 million years ago, during the same time that extensive ash flows were being erupted from huge calderas in southern Nye County.

After the main period of Miocene and Pliocene lacustrine and fluvial sedimentation, renewed volcanism occurred in much of the northern and western parts of the State, giving rise to additional ash flow deposits in some areas, and to thick andesite and dacite flows in others. Lenses of sedimentary rocks, mostly of small areal extent and commonly including diatomite beds, are interlayered with the volcanics in many places. In Clark County the sedimentary Muddy Creek Formation was formed between eruptions of basaltic rocks. Volcanic activity all but came to an end in late Pliocene and early Pleistocene when basaltic rocks were erupted in many parts of the State. Fanglomerates, fluvial gravels, and deposits of glacial Lake Lahontan were formed in many basins, and morainal deposits accumulated on the flanks of the higher mountains during the Pleistocene. Finally, unconsolidated desert alluvium, and locally sand dunes, deposited by wind and water since the Pleistocene, now largely obscure the older rocks in the valleys of Nevada.

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### IGNEOUS INTRUSIVE ROCKS

(By R. R. Coats, U.S. Geological Survey, Menlo Park, Calif.)

Intrusive igneous rocks comprise a large part of the bedrock in westernmost Nevada. Between Reno and Hawthorne, they are nearly continuous and form an eastward extension of the Sierra batholith. Smaller areas are exposed in the northwestern quarter of the State, and additional bodies there may be concealed beneath a cover of Tertiary and Quaternary rocks.

The bulk of these intrusives are of Mesozoic age; a number are known to be Tertiary in age, and a few are Precambrian or Paleozoic. The intrusives range in composition from granite to quartz diorite; the predominant types are granodiorite and quartz monzonite.

The Mesozoic igneous intrusives, which range in age from 80 to 140 million years, are best exposed in western Pershing and Washoe Counties; farther east, in Humboldt and Elko Counties, the intrusive bodies are smaller, presumably the level of post-Mesozoic erosion is shallower to the east.

Several intrusives of Cenozoic age have been found in Humboldt, Eureka, and Elko Counties. Some are porphyries with a fine-grained, dense groundmass; others are porphyritic quartz monzonites, and granodiorites, indistinguishable from the Mesozoic intrusives. Ages in the range of 36 to 40 million years have been found, but younger intrusives may be found. The textural differences may reflect differences in the height to which the intrusions ascended in the crust.

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### STRUCTURAL EVOLUTION

(By R. E. Wallace, U.S. Geological Survey, Menlo Park, Calif.)

Nevada is characterized by extremely complex geologic structures as a result of superposition, one upon the other, of several periods and types of deformation. The peculiar alternation of elongate mountain masses and intervening flat valleys which characterizes the Basin and Range province reflects a late chapter in the structural evolution of

Nevada, but long before these so-called block mountains were formed, the rocks of the region were crumpled and folded and great slabs of the earth's crust moved as much as 90 miles across other parts of the crust. Deciphering this complex history is essential if we are to understand the distribution of mineral resources and to search successfully for new resources.

*Structural history through early Cenozoic time.*—Relatively little is known about the earliest part of geologic time in Nevada, because rocks of Precambrian age are exposed only in a few ranges in eastern and southern Nevada. Even from this small sample, however, it is clear that sediments had been deposited in ancient seaways, then lithified and subsequently altered to quartzite, gneiss, and schist before the Paleozoic Era began.

The first part of the Paleozoic Era (from about 350 to 550 million years ago) saw the deposition across the State of tremendous volumes of marine sedimentary rocks in a broad north-northeast trending trough called the Cordilleran geosyncline. In gross pattern, limestone and dolomite, with minor amounts of quartzite and shale, were deposited in a belt covering the eastern part of the State while at the same time siliceous rocks, including chert, shale, and silty sandstone, and volcanic rocks were being deposited in the western part of the State. The carbonate rocks were deposited in a Continental Shelf environment, while the siliceous and volcanic rocks were deposited farther from the continental margin, probably adjacent to an archipelago of volcanic islands. Between the two assemblages, rocks of both types interfinger in a transitional assemblage. The continental shoreline during the Paleozoic Era lay generally to the east of Nevada.

Sedimentation persisted in these three belts throughout the first half of the Paleozoic Era until the end of the Devonian Period (about 350 million years ago) when a north-northeast-trending, elongate welt began to rise medially across the State. Within this welt, the so-called Antler orogenic belt (Roberts and others, 1958, p. 2850), rocks became sharply deformed and the great Roberts Mountains thrust developed (see fig. 9), along which masses of siliceous and volcanic rocks rode eastward at least 90 miles over carbonate rocks. There are suggestions that the thrust mass moved, possibly by gravity sliding, in great lobes, first one part moving eastward for awhile, then another; the toes of at least some lobes were submerged in seas at their leading edges.

While the submerged leading edge of the thrust lobes were being blanketed by wedges of sediments, higher parts to the west were being subjected to erosion. Not until Middle Pennsylvanian time (about 290 million years ago) was the welt subdued to a degree that sediments could again be deposited widely across its axis. For example, at Antler Peak beds of conglomerate named the Battle Formation (of Middle Pennsylvanian age) are found deposited across eroded edges of deformed strata of the siliceous and volcanic rocks and of the transitional rocks.

Another period of deformation appears to have occurred in the Permian Period (about 250 million years ago) in north-central Nevada and has been named the Sonoma orogeny (see fig. 10) (Silberling, and Roberts, 1962) but little is known of the total area effected, although to judge by the sharply discordant structures that were produced, it must have been a period of drastic deformation. The Golconda

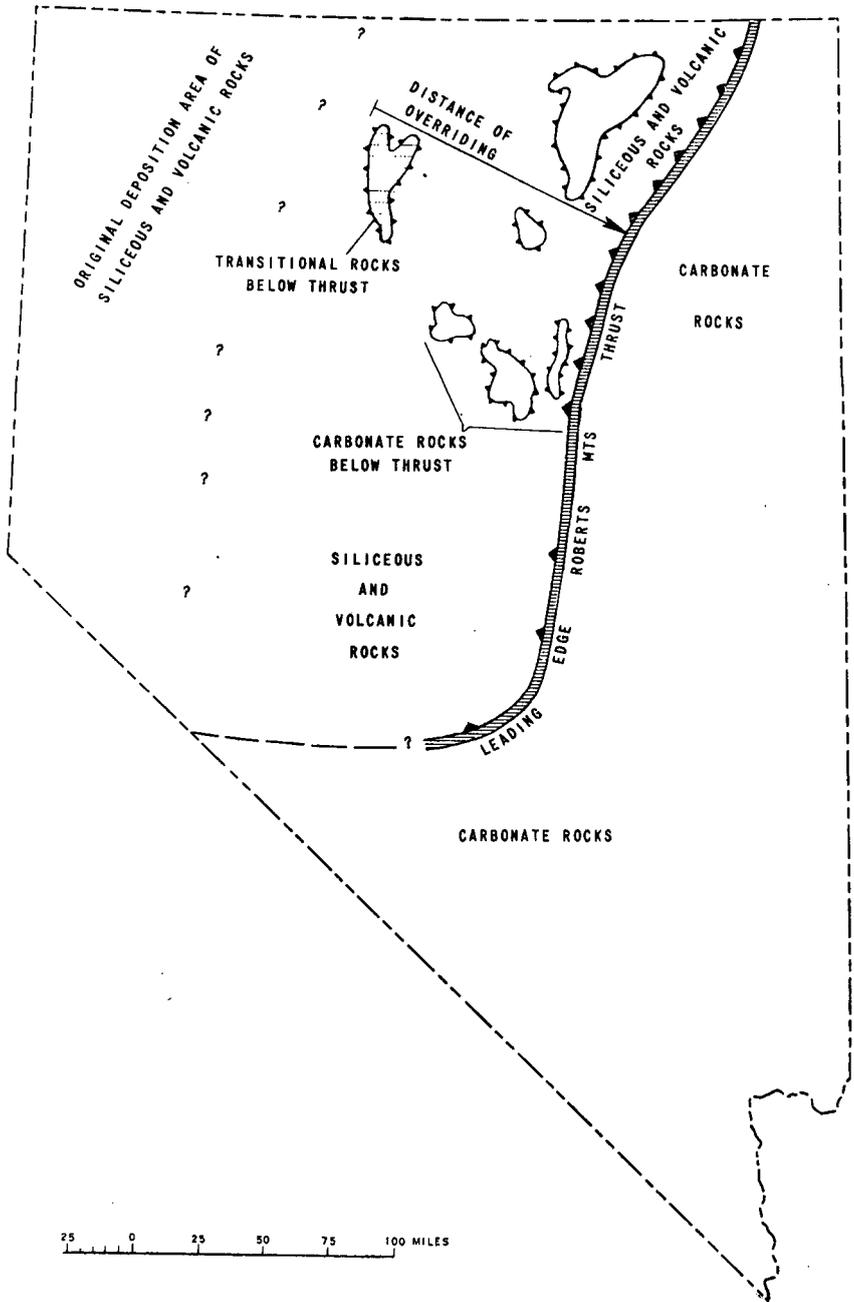


FIGURE 9.—Distribution of early Paleozoic siliceous and volcanic rocks, carbonate rocks, and transitional rocks, and their relation to the Roberts Mountains thrust fault in Nevada.

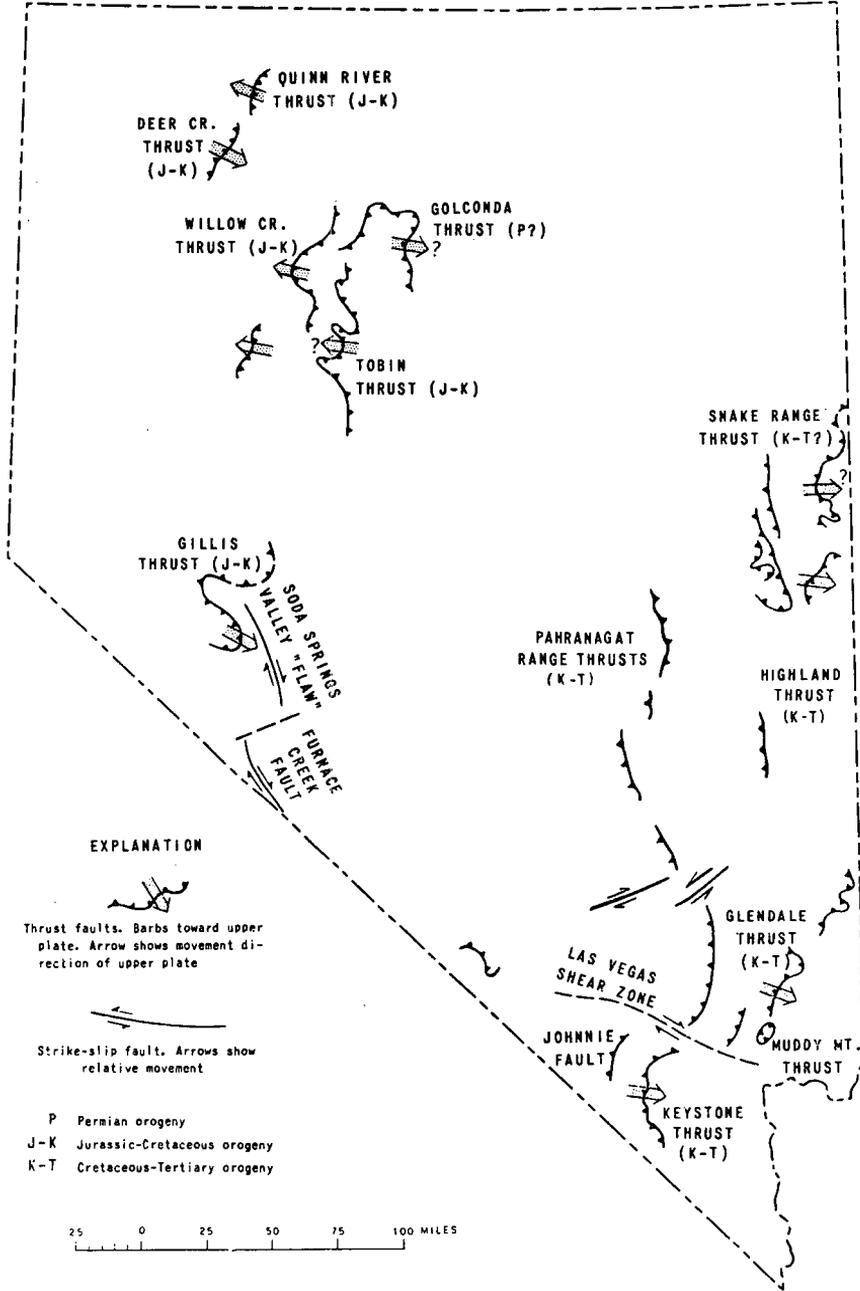


FIGURE 10.—Thrust faults exclusive of the Roberts Mountains thrust fault (shown in fig. 9), and selected strike-slip faults in Nevada.

thrust, to be seen in the vicinity of Golconda Summit along U.S. Highway 40, probably formed at this time.

During Triassic and Early Jurassic time (from about 170 to 230 million years ago) marine sediments, including limestone, dolomite, shale and sandstone, and volcanic rocks again were deposited across much of western Nevada, but seas disappeared from southern Nevada after earliest Triassic time. Following this, sandstone and conglomerate dominantly of continental origin were deposited during Late Triassic and Early Jurassic time.

In Middle and Late Jurassic and Early Cretaceous time (about 140 to 180 million years ago) mountain building forces again became active and again great thrust faults and intricate folds developed. (See fig. 10.) For example, in the vicinity of Hawthorne and Tonopah a slab of the earth's crustal rocks moved southeastward on the Gillis thrust fault and in the Sonoma and East Ranges south of Winnemucca a similar but westward-moving block rode on the Willow Creek and Mullen Canyon thrust faults.

Near the end of this period of mountain building, masses of molten rock worked their way to higher parts of the earth's crust and then solidified and crystallized to form bodies of granitic, monzonitic, and dioritic rocks. The Sierra Nevada batholith which is made up of granite and related rocks came into being at this time. Part of this mass of granitic rock was later to be raised as a block to form the Sierra Nevada Mountains. Although the main block of the Sierra Nevada Mountains lies in California, the eastern margin of the Sierra Nevada batholith may be said to lie at least 50 miles east of the California-Nevada border. Farther to the east in central and eastern Nevada bodies of granitic rocks of this age occur in smaller, apparently discontinuous bodies.

During most of Cretaceous time (from 65 to 135 million years ago) the region of Nevada must have stood at elevations mostly above sea level, because only in a few places have deposits of this age been found, and these include volcanic rocks, lake deposits of limited extent, as well as conglomerates and sandstones which were laid down above or near sea level. Sediments from this Cretaceous landmass were transported both to the east where they were deposited to great thicknesses in Utah, Wyoming, and Colorado and to the west where they were deposited in California.

A fourth great pulse of mountain building activity since the beginning of the Paleozoic, the Laramide revolution, started before the end of the Cretaceous period (about 65 million years ago), and affected a belt along the eastern margin of Nevada and in the western half of Utah. Again thrust plates appear to have moved eastward over underlying parts of the earth's crust. (See fig. 10.) Parts of these thrust plates in Nevada seem to have broken loose more or less along bedding and in the Snake Range, for example, the thrust plate is intricately fractured and broken into a jumble of fault blocks, some of which appear pulled apart as though under tension. To the west in the Egan Range major folds are overturned to the east, and in the vicinity of Eureka multiple plates moved one above another. If one looks west from Las Vegas to the Spring Mountains, a mass of drab-colored Paleozoic sedimentary rocks can be seen resting on brilliantly colored reddish sandstone of Mesozoic age. This juxtaposition of older rocks on younger has been brought about by thrusting along the Keystone thrust fault during the Laramide revolution.

The record of events in early Cenozoic time (about 35 to 65 million years ago) is largely missing, or at least yet unrecognized, in Nevada. Small bodies of molten magma sporadically intruded the upper parts of the crust to solidify into monzonites and related rocks. Topography was probably subdued and lake basins developed extensively in eastern Nevada.

Thus the crust of the earth was prepared as an intricate structural complex even before the final segmentation of the crust into blocks that today characterize the Basin and Range province.

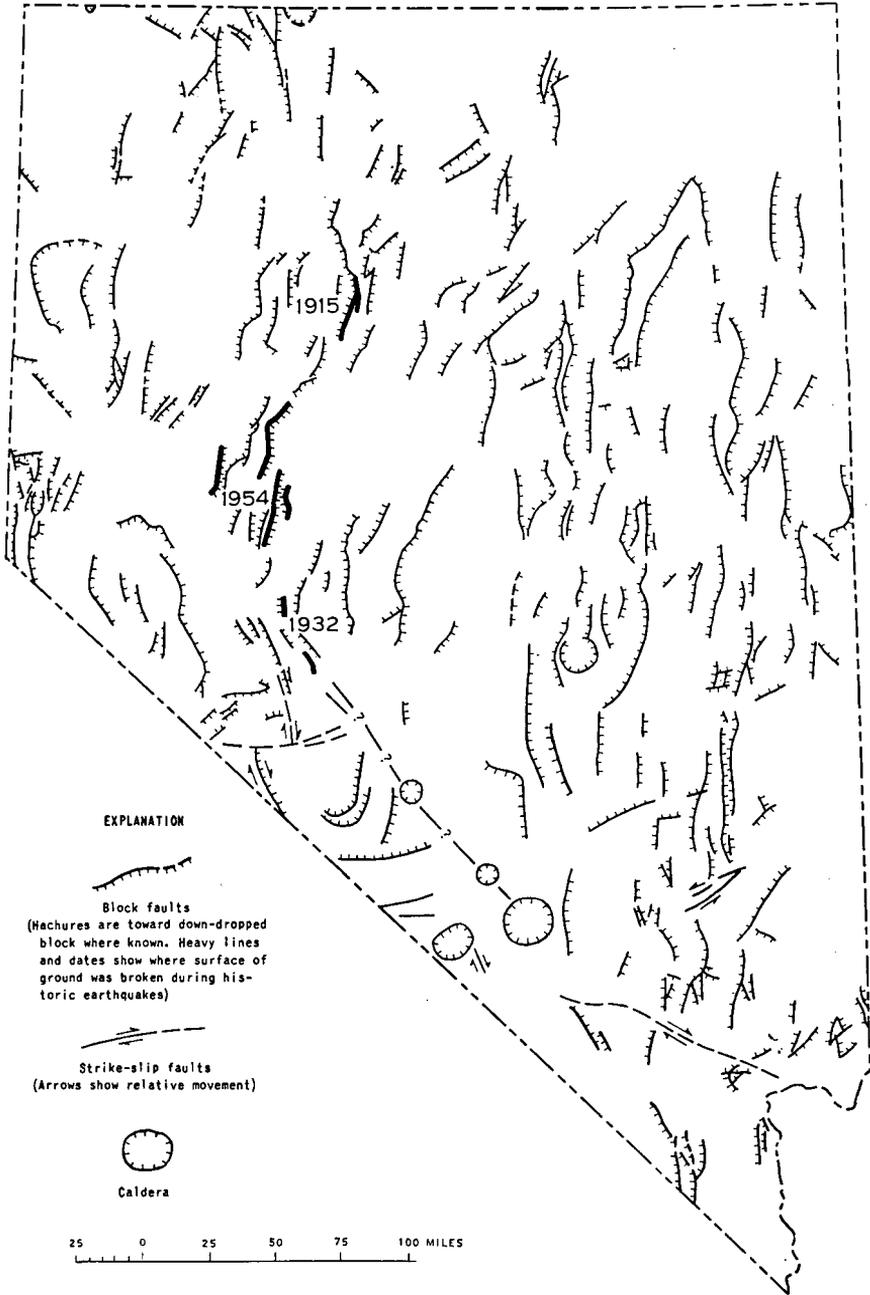
*Basin and Range structures (late Cenozoic time).*—About 30 million years ago volcanism began to build up in intensity and large volumes of molten and fragmental rock were extruded and ejected across the face of Nevada. The start of this volcanism seems to have heralded the present chapter in the geologic evolution of Nevada, the segmentation of the earth's crust into huge blocks, which characterize and control in large measure the present appearance of the Basin and Range province. Here blocks of the earth's crust, bounded by normal faults, and either raised or tilted along these faults, have been sculptured to form the "ranges," whereas sediment accumulated on the lower flanks of tilted blocks or on intervening down-faulted blocks to form the relatively flat-floored "basins" of the province. (See fig. 11.)

Examples of raised blocks or "horsts" are the Humboldt, Ruby, and Toiyabe Ranges. Tilted blocks are well exemplified by the West Humboldt Range, northern Shoshone Mountains, and Cortez Mountains. Moore (1960, p. B409) points out that many of the tilted blocks are probably bounded by fault surfaces, crudely spoon-shaped, which are concave toward the down-dropped block. He also found that blocks are commonly tilted toward regional topographic highs. To some extent, the upper part of the crust has been extended generally east and west in Nevada.

In parts of Nevada this process of block faulting is still continuing; for example, blocks have moved in historic time with accompanying earthquakes and surface ruptures in Pleasant Valley (1915), Dixie Valley (1954), and Gabbs Valley (1932). (See fig. 11.) Scarps formed along blocks which moved during the recent past can be seen along range fronts throughout the State.

In addition to ranges and basins controlled by relative movement of fault-bounded blocks, some topographic relief is the product of gentle folding in late geologic time. For example, the hills at the southwest end of Big Smoky Valley in Esmeralda County and the Hot Springs Range and adjacent Eden Valley in Humboldt County, probably owe their general configuration to folding as much as to faulting.

Although over much of Nevada adjacent fault blocks appear to have moved primarily vertically with respect to each other, in a belt about 50 miles wide along the southwestern border of the State lateral movement of blocks has been especially pronounced. Longwell (1960) and Albers (1963) have shown that this lateral movement was accomplished both by bending on a grand scale of range-size blocks and by lateral slipping along bounding faults. The southwestern part of the belt moved relatively northwestward with respect to the northeastern part. Las Vegas Valley lies along the southern part of this belt and Longwell (1960) thus has named the segment the Las Vegas shear



**FIGURE 11.**—Basin and Range block faults and other selected structures of Cenozoic age in Nevada.

zone. Another part of the belt which passes under Walker Lake was named the Walker Lane by Billingsley and Locke (1939).

Measurement of local variations of gravity indicate that many of the basins are filled to depths of several thousands of feet by poorly consolidated, low-density gravel, sand, and silt probably mostly of Cenezoic age (65 million years and younger). The bedrock floor under these poorly consolidated sediments is below sea level in some basins, in contrast to the summit altitudes of 2 miles or more above sea level attained by some ranges. For example, the floor of Buena Vista Valley east of the Humboldt Range stands at about 4,000 feet above sea level whereas bedrock is more than 4,000 feet below sea level. In Crescent Valley, which stands at about 5,000 feet above sea level, bedrock is over 2,000 feet below sea level.

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## ECONOMIC GEOLOGY

(By R. J. Roberts, U.S. Geological Survey, Menlo Park, Calif.)

The mineral deposits of Nevada belong to two major groups: syngenetic deposits formed at the same time as the enclosing rocks, and epigenetic deposits formed later than the enclosing rocks. Intermediate types in which minerals of both groups have been later rearranged or concentrated by circulating solutions, are also locally important. The mineral deposits may also be divided into two compositional groups, the metallic and the nonmetallic deposits. The metallic deposits such as gold, silver, copper, lead, and tungsten are commonly associated with intrusive rocks and mostly belong to the epigenetic group. The nonmetallic deposits include syngenetic deposits of bedded materials such as clays, gravels, borax, and salt, as well as epigenetic deposits of fluorite and barite, which are associated with intrusives.

### METALLIC DEPOSITS

The principal mining districts in Nevada are shown on figure 12 and 13, which also show the principal metallic or nonmetallic constituents produced in the districts (Ferguson, 1944; Lincoln, 1923). It is immediately apparent that the districts are not randomly distributed, but that some metals and nonmetals are produced mainly in certain parts of the State and that some deposits are alined along belts that cut northwestward, east-west, and northeastward across the State. This distribution is not accidental; it reflects major stratigraphic and structural controls of the most fundamental kind.

Most of the metallic deposits in Nevada are related to intrusive rocks, generally granodiorite to quartz monzonite in composition, that have been injected into the crust as molten magma and later crystallized. In part the ore-forming solutions may have come from the magma, but in part they may have risen from depths along the same channelways that were earlier followed by the magma. Ore bodies subsequently were formed in the intrusive rock and in adjacent wallrocks.

On the geologic map (fig. 3) it is apparent that western Nevada is underlain by formations that are characterized by siliceous and volcanic rocks (Roberts and others, 1958). These include Paleozoic and

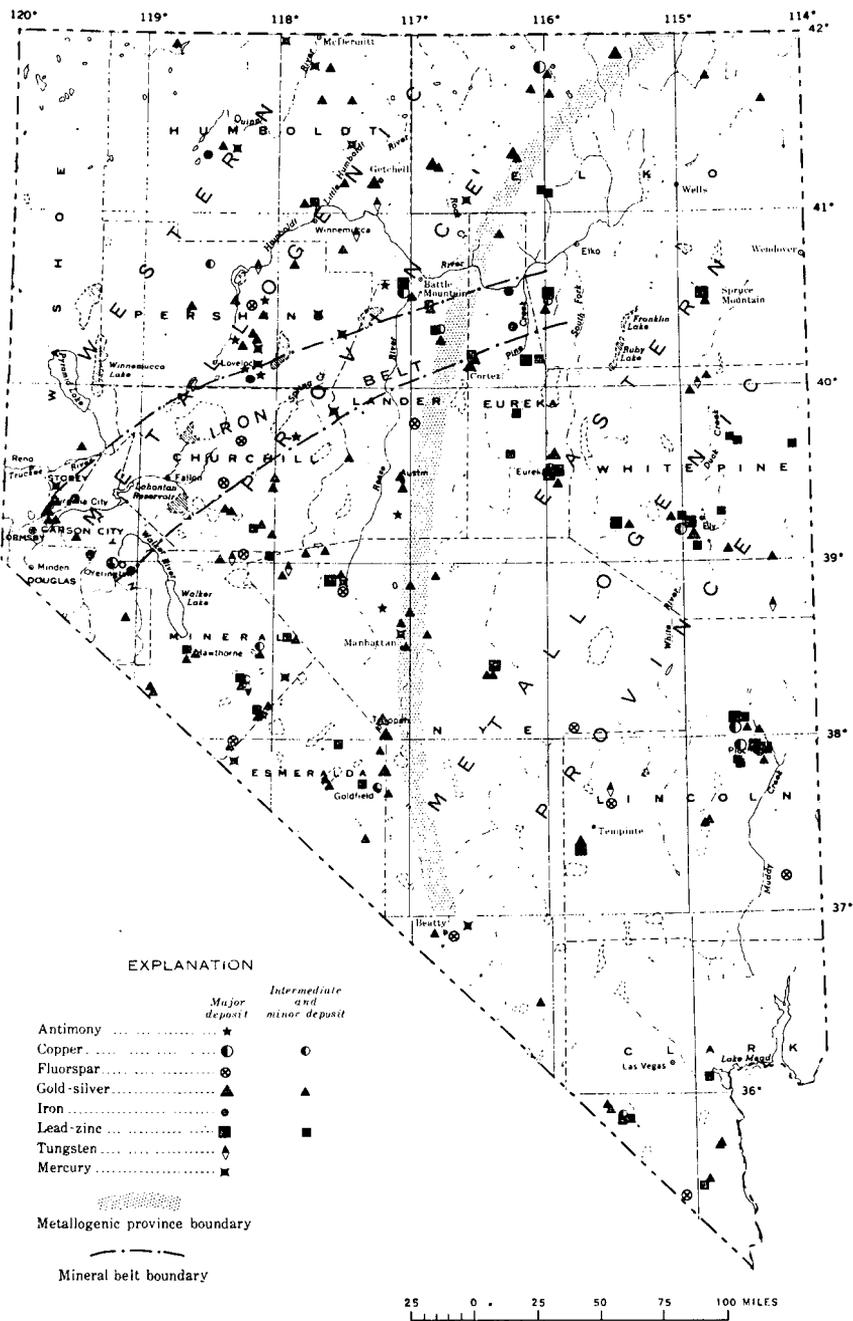


FIGURE 12.—Metallogenic provinces and mineral deposits in Nevada.

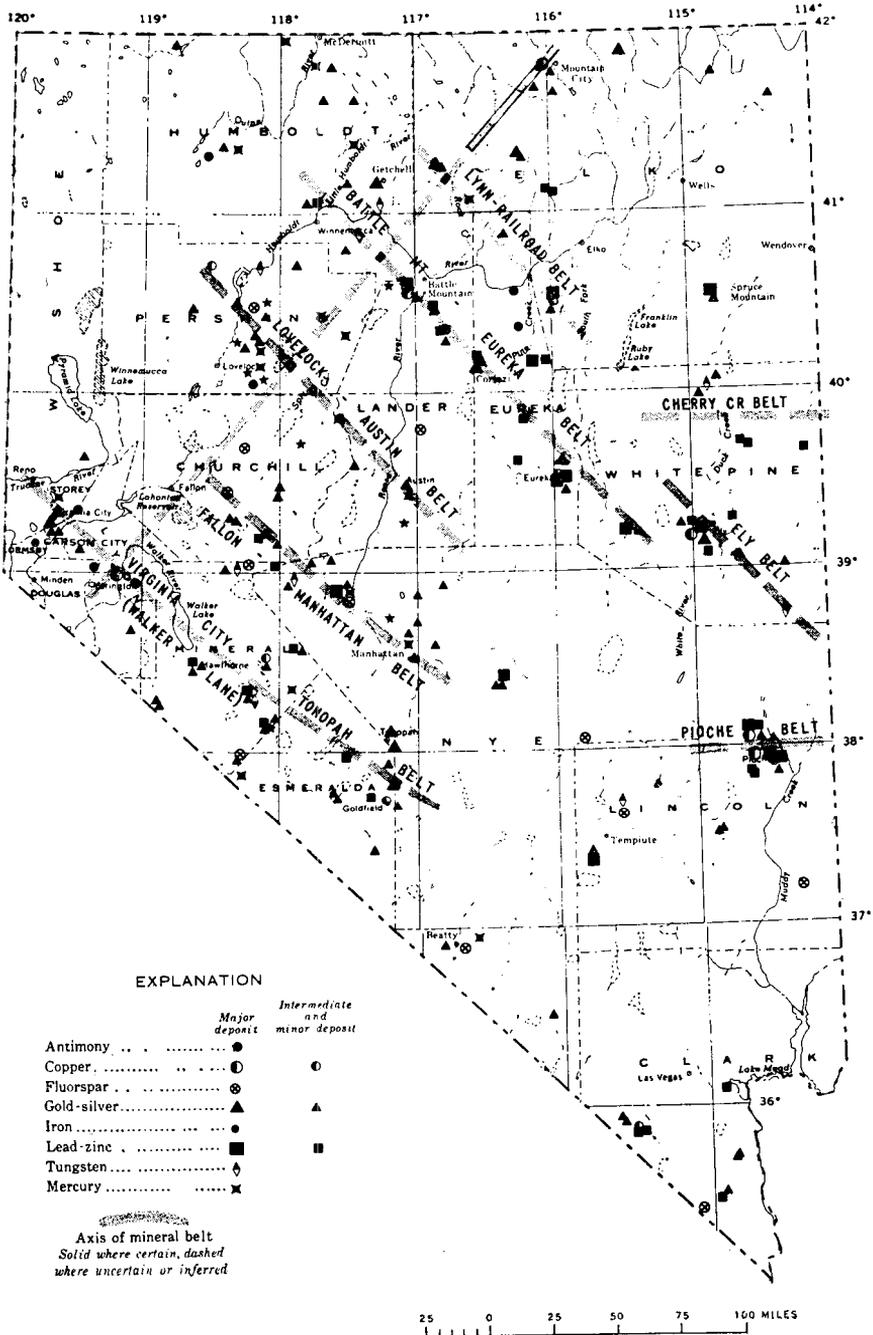


FIGURE 13.—Mineral belts and deposits in Nevada.

Mesozoic siliceous and volcanic rocks and Tertiary volcanic rocks. On the other hand, eastern Nevada is underlain largely by Precambrian metamorphic and sedimentary rocks and Paleozoic carbonate rocks locally covered by Tertiary volcanic rocks (Nolan, 1943, 1962).

These differences in rock types of western and eastern Nevada must reflect fundamental differences within the crust, which are further reflected in the distinctive metal suites of the two areas. Western and eastern Nevada accordingly are two distinct metallogenic provinces (see fig. 12); western Nevada contains the major gold, silver, tungsten, antimony, mercury, and iron deposits thus far discovered (Ferguson, 1944; Nolan, 1950). Eastern Nevada contains the major lead and zinc deposits with associated gold and silver deposits.

The division between the two provinces is not a sharp line, but rather a broad transitional zone that follows along the 117° meridian in southern Nevada, and swings northeastward to the 115° meridian in the northern part of the State (fig. 12). Deposits within the transitional zone include representatives of both provinces; likewise, in eastern Nevada, the base metal deposits are ringed by precious metal and antimony zones. Major copper deposits may be found in both provinces; evidently copper is not so directly related to crustal rock type but may be derived from sources below the crust within the mantle. The sources of metals and their mode of transport upward are yet not clearly understood.

Within the two metallogenic provinces in Nevada, regional structural and lithologic controls were important in localizing districts and ore bodies. On figures 13 and 14 it appears that a number of districts are localized along northwest and northeast trends. These mineral belts in Nevada have been discussed briefly by Roberts (1957, 1960). One extends from Battle Mountain to Eureka; along this belt (Roberts, 1960, p. 18) detailed mapping has shown that the major ore bodies occur in windows of carbonate rocks through the upper plate of the Roberts Mountains thrust and in association with intrusive rocks (fig. 14). The windows represent domal uplifts that began in the Pennsylvanian and were accentuated during intrusive activity in Mesozoic or early Tertiary time. The northwest alignment of windows and associated ore deposits suggests some major structural control for both the domal uplifts and mineral belts. Except for the arching, no displacement is noted along the belt; moreover, the Paleozoic and Mesozoic facies do not seem to be displaced along the belts and it is therefore inferred that the belts are ancient structural features that may be of Precambrian age.

Metallization along the belts varies considerably in type and kind. In the Battle Mountain-Eureka belt, for example, ore deposits in the Osgood Mountains area, 35 miles northwest of Battle Mountain, include gold, mercury, and tungsten deposits; at Battle Mountain, copper, gold, and lead-zinc-silver deposits; at Cortez, silver, lead, and zinc deposits, and at the Buckhorn district, 6 miles east of Cortez, gold deposits (Vanderburg, 1938; H. Masursky, oral communication, 1963). These occurrences may reflect zoning of metals, different metallogenic provinces, metallization at different times, or different levels of erosion. The tungsten and mercury deposits in the Osgood Mountains are characteristic of the western metallogenic province; the silver-lead-zinc deposits at Battle Mountain and Cortez are characteristic

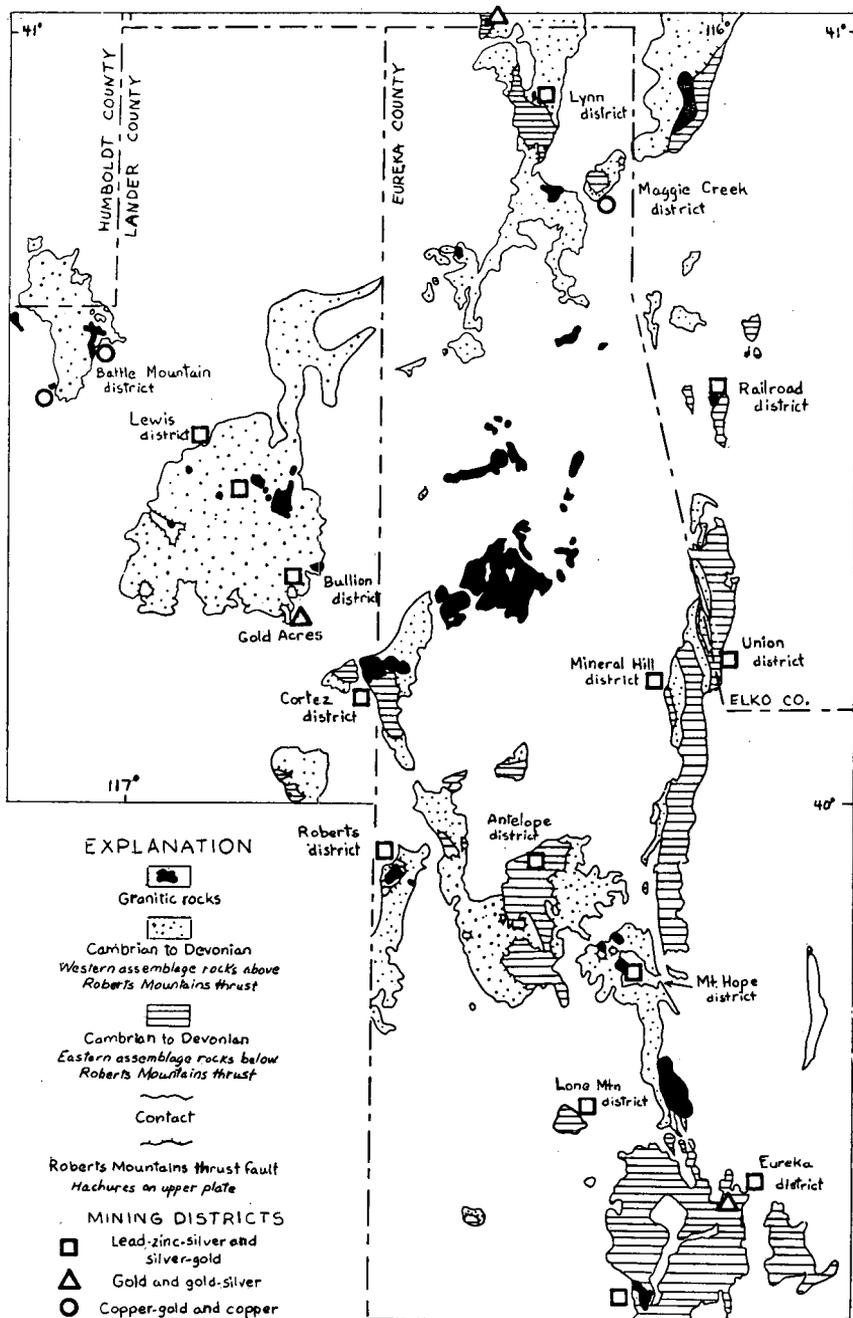


FIGURE 14.—Alinement of mining districts in the Battle Mountain-Eureka and Lynn-Railroad mineral belts.

of the eastern province. The association at Buckhorn of gold peripheral to the Cortez base metal deposits may reflect either zoning of metals, metallization at different times, or a combination of these two factors.

Another major belt is the Virginia City-Tonopah (fig. 13), which contains major gold, silver, and copper districts. This belt has been long recognized as a metallogenic belt (Billingsly and Locke, 1941; Albers, 1963) related to the Walker Lane, a northwest-trending structural feature that has been active for a long time. Districts along the belt include: Goldfield (gold-silver), Tonopah (silver-gold), Aurora (gold-silver), Silver Peak (gold-silver), Candelaria (silver-gold-copper), and Virginia City (silver-gold). The belt probably also extends northwestward into California and may include the copper-gold deposits of the northern Sierra Nevada.

Other possible but less clearly defined, parallel or subparallel, northwest-trending belts (fig. 13) in Nevada that also contain significant ore deposits are the Lynn-Railroad, Lovelock-Austin, Ely, and Fallon-Manhattan. The Lynn-Railroad belt is coincident with the Carlin and Lynn windows; it contains the following districts: Lynn (gold-turquoise), Railroad (silver-lead-copper), Gold Circle (gold), and Carlin (gold). Neither Carlin nor Lynn has yielded significant production to date, but exploratory work was being carried on in both districts in 1962-63 and the outlook for future gold production is promising. The Lovelock-Austin belt includes the following districts: Austin (silver-gold), Unionville, Rochester, and nearby gold-silver districts, the Sutherland and many other antimony deposits in the West Huboldt Range and the Seven Troughs. The Ely belt contains the Robinson district (copper, gold, lead, zinc) and the Minerva district (tungsten). The Fallon-Manhattan belt includes the Rawhide and Gabbs (tungsten), other districts in northwestern Nye County and southern Churchill County, the Manhattan (gold-silver) district, and Tybo district.

Metallogenic belts of other trends have also been noted. A northeast-trending copper belt that extends from Yerington to Mountain City appears to be significant; between these extremities the Antelope, Battle Mountain, and a host of lesser districts have been plotted by Horton and others (1962). Major barite deposits also follow a northeast belt (Horton, 1962), apparently parallel to facies trends in the upper plate of the Roberts Mountains thrust fault. Major iron ore deposits in central Nevada follow a general N. 70° to 75° E. trend from Yerington to Lovelock, thence through the Cortez Mountains (fig. 12). This belt roughly parallels and may be related to the east-west metallogenic belts recognized by Hilpert and Roberts (1964) in Utah. Individual iron deposits near Lovelock appear to be aligned northwest along the Lovelock-Austin belt; iron deposits in the Jackson Mountains lie between the Lovelock-Austin and Battle Mountain-Eureka-belts. Many mercury deposits lie within the belts as shown in figure 12, but Bailey and Phoenix (1944) and Lawrence and Wilson (1962) show that as a group, the mercury deposits tend to lie in a northward-trending belt that parallels the boundary between the eastern and western metallogenic provinces. The manganese deposits belong to several genetic types and do not give a clear-cut pattern. M. D. Crittenden (oral communication, 1964) indicates that the hydrothermal manganese deposits are mostly associated with

base metal deposits in northwest-trending belts, and the syngenetic manganese deposits of northern Nevada in the north-south belt, extending from Winnemucca to Austin, occur mostly in rocks of siliceous and volcanic facies.

Two inferred east-west belts on figure 13 are named the Cherry Creek and Pioche belts. The Cherry Creek contains the Cherry Creek (tungsten, silver), Aurum (gold, lead, copper, zinc), and Granite (gold, copper, lead, zinc) districts. The Cherry Creek belt extends into Utah, where it coincides with the Deep Creek-Tintic mineral belt (Hilpert and Roberts, 1964). The Pioche belt contains the Delamar (gold, silver), Pioche (zinc, lead, silver, manganese), and Tempiute (tungsten); it extends into Utah where it coincides with the southern part of the Wah Wah-Tushar belt.

Deposits within the mineral belts as indicated in figure 13 account for more than 95 percent of the production of copper, lead, zinc, gold, and silver in Nevada. In addition, they also account for most of the molybdenum, largely from copper ore in the Robinson (Ruth) district at Ely; much of the tungsten, principally from the Nevada-Massachusetts, and Osgood districts; almost all the minor metals such as arsenic, bismuth, cadmium, platinum, selenium, and tellurium that are recovered as smelter byproducts; and most of the antimony deposits in western Nevada.

Inasmuch as the mineral belts contain most of the principal mining districts, it seems that the belts should be the best places to look for new ore deposits. In exploration for a certain commodity one should be certain he is in favorable terrain. Nolan (1952) has emphasized that concealed areas adjacent to major districts may be good places to explore. Roberts (1960, 1964) has suggested that geophysical and geochemical methods be used as tools to further pinpoint exploration targets along the mineral belts. Not all geophysical anomalies are associated with ore deposits, but these are generally the best places to start the search. Geochemical sampling in areas of geophysical anomalies may outline favorable areas for further exploration.

### NONMETALLIC DEPOSITS

Nonmetallic deposits including salines, clays, building stone and gravel, diatomite, perlite, limestone, and sulfur have contributed a small but significant production to Nevada's mineral industry. With increasing population and improvements in transportation, deposits of these minerals will play more important roles in the future.

Saline deposits that offer future potential include borate deposits in Clark and Esmeralda Counties (Hewett and others, 1936). These deposits are mostly colemanite (calcium borate) and ulexite (sodium and calcium borate) which cannot compete with borax deposits in California at present, but ultimately may be worked. Sodium carbonate, sulfate, and chloride are in places associated with borax in playas and also occur in bedded deposits of Cenozoic age. Several deposits have been operated on a small scale. The source of the salines was ultimately hot springs associated with volcanism; favorable areas are mainly in southwestern Nevada.

The barite deposits in northern Nevada are of two types, replacements of limy beds in the western siliceous and volcanic facies, and

veins along faults (Ketner, 1963). Some replacement deposits contain significant tonnages and have excellent future potential.

Clay deposits in Nevada are widespread, and include ceramic, filter, and specialty clays. Past production has been small, but reserves in several deposits of kaolinite and bentonite are large and future production may be significant. Diatomite is one of the principal nonmetallic commodities produced in Nevada. The diatomite deposits were formed in fresh-water lakes and many are of high purity.

Dimension stone production in Nevada has been relatively small. Flaggy sandstones have been quarried in southern Nevada, and volcanic tuffs in northern Nevada. These operations are presently hampered by high haulage costs, but as Nevada's population grows, increased local use is likely. Sand and gravel deposits constitute one of Nevada's inexhaustible resources. Gravels along streams in western Nevada and fans in central and eastern Nevada will furnish adequate supplies for future needs.

Fluorspar deposits are scattered throughout western Nevada, but production has been small.

Turquoise is the principal gem mineral found in Nevada. Production from deposits in Esmeralda, Nye, Eureka, and Lander Counties has been significant and at times has dominated the U.S. market. Opal has been produced in northern Nevada from Tertiary beds in the Virgin Valley.

Gypsum production in Nevada during recent years has been significant, and is gradually increasing. Reserves are large, especially in southern Nevada, but production is hampered by high haulage costs.

Refractory silicates produced in Nevada include dumortierite (aluminum borosilicate) and pinite (muscovite and pyrophyllite). During recent years production of these minerals has been small, as cheaper synthetic substitutes have been found.

Reserves of magnesite, which occur as replacement deposits in dolomite near Gabbs, are large. Sedimentary magnesite deposits are also found near Currant and Overton. Limestone for cement and lime is widespread and abundant in Nevada. Dolomite of good quality is also abundant.

Pegmatites in Clark and Elko Counties have been explored for feldspar, mica, and beryl. Feldspar production has been small, the mica is mostly scrap quality; the beryl has been low grade. Deposits of phenacite at Mount Wheeler are potentially significant.

Silica has been mined in Nevada principally for glass and foundry sand. Reserves of high-purity sand are small, but quartzite is widespread and adequate for future silica needs. Sulfur occurs at several localities in western Nevada and in Tertiary beds and in spring deposits; the bodies thus far found have been relatively small, and only a few tons have been mined and shipped. Talc pods in dolomite in southwestern Nevada has been mined on a small scale for many years; the future potential for increased production is not promising. A vermiculite deposit in southern Nevada has been intermittently worked and a small tonnage shipped; others are known but not yet evaluated.

Nevada ranks second in the United States in perlite production. The principal deposits are in Pershing and Lincoln Counties and appear to have ample reserves for the foreseeable future. The outlook is good for increasing use of perlite in deposits near centers of population.

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## MINERAL FUELS

There are no commercial deposits of coal in Nevada, but attempts have been made to mine low-grade deposits associated with Tertiary lake deposits. The oil situation is more promising. Since 1954 exploration has been going on in the Eagle Springs oilfield, Nye County. At the present time 3 wells are active; production to date has been about 717,000 barrels; and the newest well, completed in March 1964, is the largest producer with a flow of over 2,400 barrels per day.

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### COAL

(By R. C. Horton, Nevada Bureau of Mines, Reno, Nev.)

Coal is formed by the burial and consolidation of decaying plant material. Various ranks, or types, of coal are formed depending upon the geological processes involved. These ranks are not sharply divided because the starting material is similar for all coals. In order of increasing rank, coals are classified as lignitic, subbituminous, bituminous, and anthracitic. Coal, like wood and peat, contains carbon, hydrogen, oxygen, nitrogen, sulfur, and other elements in small quantities. The higher rank coals contain more carbon and less volatile elements than do the lower rank coals.

The United States has one-third of the earth's coal reserves. Nearly 80 percent of these reserves, on the basis of heating value per pound, is bituminous or subbituminous. The coal reserves are distributed throughout the United States—about one-third east of the Mississippi River, one-third in the interior, and one-third in the northern Great Plains, Rocky Mountains, and Gulf and Pacific coast areas. At the present rate of consumption these reserves will last for more than 1,200 years.

Coal is extracted from the earth by underground and strip mining. Modern mechanized mining has achieved higher productivity and efficiency, greater safety for miners, and a minimum of hard labor. Coal may be burned for heat in homes or to generate electrical power, gasified for industrial or residential use, or coked for metallurgical purposes. The byproducts of coking—gas, tar, and light oils—can be used as such or processed to serve as raw materials for the chemical industry.

The coal industry reached its peak production of over 630 million tons in 1947. The decline in production since that time is a result of competition from oil and gas in the energy market. The U.S. energy requirements are rapidly expanding, and it is likely that greater amounts of coal will be required in the near future. Many new uses for coal have recently been developed, including the conversion to liquid and gaseous fuels, and it is likely that these new uses will require increased coal production.

There are no commercial deposits of coal in Nevada, although attempts have been made to mine low-grade deposits associated with lake deposits of Tertiary age. As shown on figure 15, deposits of this type are found near Coaldale, Esmeralda County; south of Elko, Elko

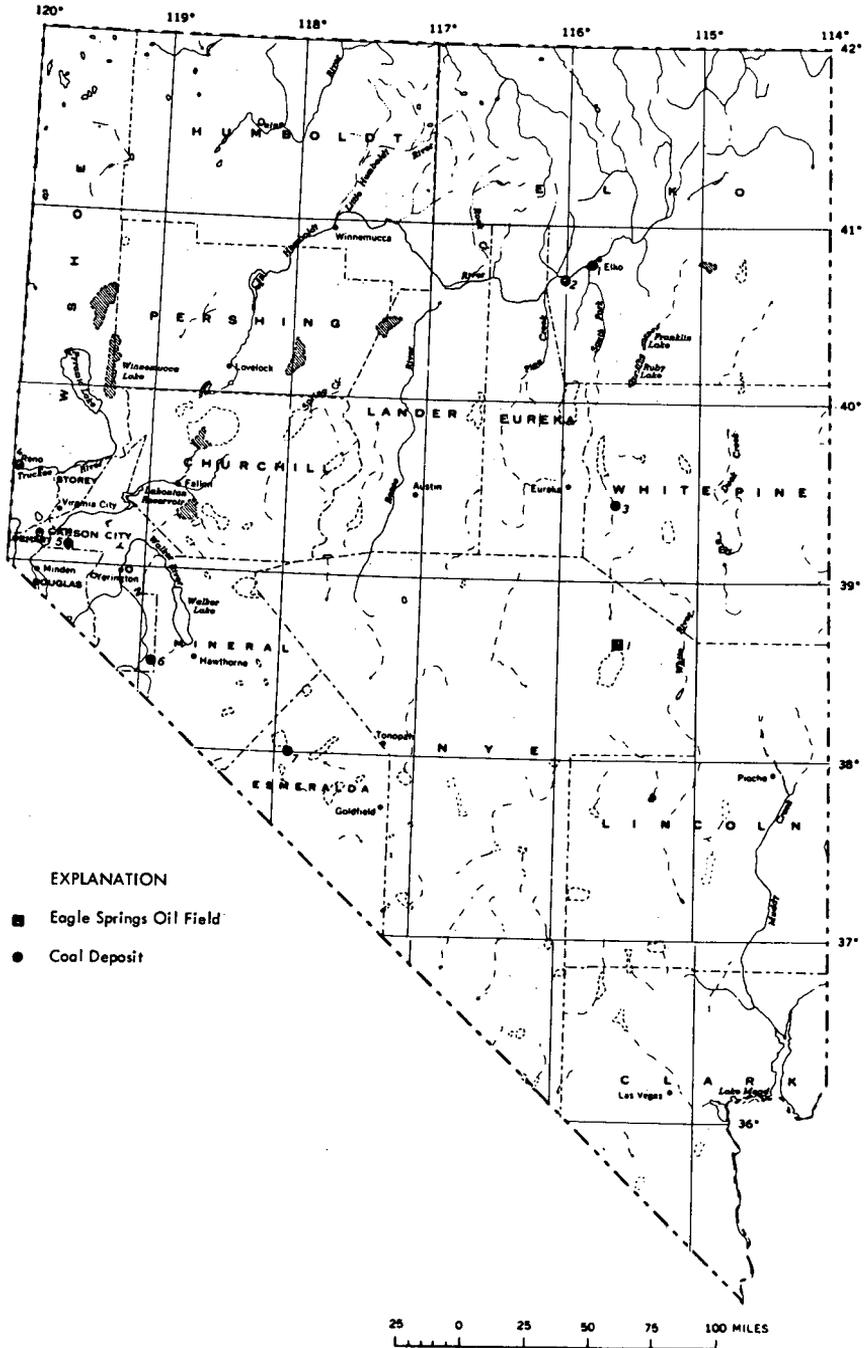


FIGURE 15.—Coal and oil in Nevada (numbers refer to deposits described in text).

County; near Washington, Lyon County; in El Dorado Canyon, Ormsby County; and near Verdi, Washoe County. Deposits in rocks of Paleozoic age occur in Carlin Canyon, Elko County, and in the Pancake Range, White Pine County.

#### ELKO COUNTY

##### *Elko deposit (No. 1, fig. 15)*

Lignite occurs at several horizons in the Humboldt Formation (Miocene and Pliocene?). The lignite is a light-brown loosely bonded material that usually can be crushed in the hands. It has the appearance of slightly compressed plant remains and is markedly laminated. The beds are seldom more than a few inches thick. Numerous cuts have been opened on these beds in the vicinity of Elko during the past 50 years without finding minable deposits.

##### *Carlin Canyon deposit (No. 2)*

A little impure coal occurs west of Molien Canyon, 4½ miles east of Carlin, along the railroad cut in the middle part of a 2,000-foot-thick sedimentary section of Paleozoic age. The coal is in shaly beds at the top of a lower limestone member. This coal was first discovered in 1859, and by 1874 considerable prospecting work had been done. In 1875 the Humboldt Coal Co. was formed to work the coalbeds but made no production. The coal, containing 46 percent carbon, is reported to burn freely, leaving a white ash.

#### ESMERALDA COUNTY

##### *Coaldale deposit (No. 7)*

Coal was first discovered near Coaldale in 1893. Many attempts were made to mine the coal during the early 1900's, none being successful. Four to six zones of bituminous shale and coal, designated as beds A, B, C, and D by Hance (1913), crop out near the base of a rhyolite escarpment and extend northeast-southwest with considerable regularity for about 2 miles. In general, the beds dip steeply northeast from the outcrop. Coarse sandstone, tuff, volcanic ash, siltstone, and shale members comprise the strata above the coal zones; shale, sandstone, and sandy tuff constitute the strata intervening between the beds. Some of the coaly zones have been intruded by rhyolite. Beds of bentonite and shale have been encountered in drilling. These sedimentary deposits are regarded as early Tertiary in age, and they exhibit a great deal of irregularity, both on account of variable depositional conditions and because of subsequent folding, faulting, and igneous intrusions.

The thicknesses of the coal-bearing beds vary, where mined or penetrated by mining. Bed A is about 3 feet thick with a total coal thickness of 10 inches; bed B is 7 feet thick and contains 24 inches of coal; bed C is 9 feet thick with the proportion of coal to total thickness varying from 20 to 80 percent; bed D has a maximum thickness of 7 feet with coal seams constituting 45 percent of the total thickness.

The coal deposits were explored and tested during World War II (Toenges and others) in connection with general investigations of mineral deposits essential to the war effort. Reconnaissance included

secs. 22, 23, 26, 27, 28, 34, 35, and parts of secs. 15, 20, 21, 24, 29, 32, 33, and 36, T. 2N., R. 37 E. The area that appeared most favorable for development included secs. 28, 29, and 33. Diamond drilling failed to disclose any additional coalbeds but did serve to emphasize the structural complexity of the area.

Analyses of the coal showed an ash content ranging from 35 to 85 percent, with an average of 50 percent. Washing tests reduced the ash in the coal tested from about 53 percent to 37 percent with a yield of 33 percent of the mine run material.

Structural complexities, thin beds, low grade coal, and inadequate reserves do not encourage commercial development of the Coaldale coal deposit.

#### LYON COUNTY

##### *Washington (Lewis Coal mine) deposit (No. 6)*

A deposit of low grade coal is located in sec. 36, T. 8 N., R. 27 E. and sec. 1, T. 7 N., R. 27 E., near the mining camp of Washington. The coal occurs in a section of reddish-brown, clay-shales in the upper part of the lower member of the Coal Valley Formation of Axelrod (1956) (Pliocene). The coal has been described as sapropelic. Sapropel is a fluid organic slime originating in swamps as a product of putrefaction. In its chemical composition it contains more hydrocarbon than peat. When dry, it is a lusterless, dull, dark, and extremely hard mass.

In 1919 this coal deposit was developed by the Nevada Coal & Oil Co. during unsuccessful drilling in search of petroleum. The fresh coal is black in color, containing 30 percent volatile hydrocarbons, 40 percent fixed carbon, 16 percent ash, and 14 percent water.

#### ORMSBY COUNTY

##### *El Dorado Canyon deposit (No. 5)*

A deposit of lignite is located in sec. 7, T. 14 N., R. 22 E., on the northeast slope of Bismark Peak and immediately west of the stream in El Dorado Canyon. The deposit was found by English miners soon after the discovery of the Comstock Lode. It is reported that 9,800 tons of coal were mined prior to 1865 and, following formal organization of a mining company in 1872, an additional 31,400 tons were mined. Two shafts were sunk, one 420 feet deep and the other 85 feet deep. The coal bearing formation has been described as follows:

For about 300 feet from the surface the formation consists of alternating layers of marl, soft gray sandstones, shales, fire-clay, carbonized vegetable matter, and beds of weathered lignite. There are three beds of lignite which are, counting from the surface, 16 feet, 15 feet, and 6 to 8 feet in thickness.

The deposit has not been worked for many years. During a recent inspection of the mine area the shafts were caved and the dumps were badly weathered and overgrown with sagebrush. In general, it appears that no work has been done since 1900. As the rocks near the mines are of Tertiary age (Miocene and Pliocene(?)), it is probable that the lignite was deposited under conditions similar to those prevailing at the other Tertiary coal deposits.

## WASHOE COUNTY

*Verdi (Crystal Peak) deposit (No. 4)*

Lignite was discovered northeast of Verdi, in secs. 8 and 9, T. 19 N., R. 18 E., in about 1864. Numerous shafts, adits, and cuts were dug to exploit the deposit. No production is known to have been made. The seams of lignite have been described as varying in thickness from a few inches to 2½ feet, with considerable foreign matter mixed with the lignite. The Nevada Carbon Co. examined the deposit in 1943 and analyses were made of the lignite at that time. A fresh sample contained 38.4 percent volatile matter, 25.2 percent fixed carbon, 23.6 percent ash, and 12.8 percent moisture.

## WHITE PINE COUNTY

*Pancake Summit deposit (No. 3)*

The Pancake coal deposit was discovered sometime prior to 1875. It is in sec. 21, T. 18 N., R. 56 E., about 1 mile south of Pancake Summit on U.S. Highway 50. A shaft was sunk to a depth of at least 480 feet and some coal was mined and shipped to Eureka for use in the lead smelters. The seam mined is reported to have been 2 feet thick. Angel (p. 664) describes the deposit as follows:

A shaft on being sunk 30 feet, found water, and some seams of coal in a vein 4 feet thick. Three distinct veins exist in the locality, which can be traced a distance of 2 miles, and which vary in width from 4 to 6 feet \* \* \*. The veins dip under the mountains to the west at an angle of 40°, and their course is 15° east of south from the point of discovery \* \* \*. The first formation below the vein in which the coal is found is siliceous iron ore; then comes a stratum of limestone, and beneath this sandstone and conglomerate. Above it the formation is bituminous and argillaceous shales; next to the shale, calcareous slate, then red sandstone, conglomerate, and limestone capping the whole formation.

The deposit is located in the area of Paleozoic rocks. If the description by Angel is correct, the coal probably is of Mississippian age. There have been no recent attempts to mine the coal.

## CONCLUSIONS

Without exception the coal deposits of Nevada are too small and too impure to support significant mining, although they might satisfy limited local requirements. The high ash content and low heating value even makes local use questionable as mining costs probably would be greater than the cost of coal delivered from Utah. Some use might be made of these deposits if they could be burned in place and the gases generated from the burning collected. However, the individual beds are so erratic that it might be difficult, if not impossible, to maintain combustion.

## PETROLEUM

(By R. C. Horton, Nevada Bureau of Mines, Reno, Nev.)

Oil and natural gas currently supply more than two-thirds of the total energy requirements of the Nation as well as providing raw material for thousands of other industries. The value of crude oil, natural gas liquids, and natural gas produced in 1962 was \$10,659,097,000. This represents 57.1 percent of the total value of all minerals produced in the United States.

Since the first production of oil in 1859, concern has been expressed regarding the total petroleum reserves in the United States and the likelihood of exhausting these reserves. Few petroleum economists and conservationists now feel concern for this possibility and most believe that much more oil remains to be discovered than has been produced. Statistics on production and reserves are shown in table 3.

TABLE 3.—Oil and gas in the United States<sup>1</sup>

	Crude oil (thousands of barrels)	Natural gas liquids (thousands of barrels)	Total liquid petroleum (thousands of barrels)	Natural gas (million cubic feet)
New reserves found.....	2,180,896	732,549	2,913,445	19,590,353
Production.....	2,550,178	470,128	3,020,306	13,552,420
Net change.....	-369,282	262,421	-106,861	6,037,933

## PRODUCTION AND NEW RESERVES FOUND, ALL TIME TO JANUARY 1963, UNITED STATES

Total reserves.....	102,133,176	12,773,128	114,906,304	483,918,546
Total production.....	70,743,953	5,461,611	72,205,564	210,152,942
Proved reserves.....	31,389,223	7,311,517	38,700,740	272,765,604

<sup>1</sup> The Independent Petroleum Association of America, "The Oil Producing Industry in Your State, 1963."

Proved reserves discovered each year have usually exceeded production. In 1962 fewer barrels of oil were found than were produced, but exploration activity was reduced as compared to previous years. A total of 9,003 wildcat wells were drilled as compared to 9,191 in 1961, 9,635 in 1960, 10,073 in 1959, and 9,588 in 1958. The cost of exploration has increased as deeper wells now are required if a discovery is to be made. The average wildcat well was drilled to a depth of 5,328 feet in 1962 as compared with an average depth of 4,649 feet in 1958.

Interest in Nevada's petroleum dates back to 1907, when wells were drilled in Lyon and Washoe Counties. The first Nevada oil exploration boom occurred in the early 1920's when wells were drilled in a number of counties. The results of the exploration activity, centered in Churchill and White Pine Counties, were not encouraging and interest declined. Current petroleum activity in Nevada began with the drilling of the No. 1 Meridian unit well by the Standard Oil Co. of California and the Continental Oil Co. in the spring of 1950. Other major oil companies became interested in Nevada and on January 11, 1954, the Shell Oil Co. spudded in the No. 1 Eagle Springs

unit well. This well, the first in the Eagle Springs oilfield (fig. 15), was placed on production in June 1954 with an initial rate of 275 barrels per day. Since then four other producing wells have been drilled in the Eagle Springs field. Two of the wells are major producers. Well No. 62-35, placed on production in January 1961, produced over 330,000 barrels through December 1963. In September 1963 the Texota Oil Co. drilled well No. 73-35 in the Eagle Springs field on a farm-out from the Shell Oil Co. This well currently produces 13,000 barrels of oil per month.

In March 1964 the Texota Oil Co. completed a second well, No. 74-35, which was tested at over 100 barrels of oil per hour. Representatives of the company reported that the producing interval extended from 6,725 to 6,800 feet; that the initial marker bed of pyroclastics which was present in the other wells was not found; and that the test produced oil from an entirely new limestone zone not identified with other limestone zones previously drilled in the field. Unlike all previous wells which are produced by pumping, this well flowed oil under considerable pressure. If the producing limestone formation proves to be of Paleozoic age—and such seems likely—then the production potential of at least one Paleozoic formation in eastern Nevada will have been established. The high initial production, equivalent to over 2,400 barrels per day, and the fact that the well is a flowing well, will add impetus to the search for additional productive areas in Nevada.

As of January 1, 1964, the Eagle Springs field had produced 716,765 barrels of oil. The new Texota wells will greatly increase the production during the next few years even if no additional wells are drilled.

Age of the oil at the Eagle Springs field has a direct bearing on further exploration. If it is early Tertiary in age, then additional exploration of similar formations is indicated. If the oil is Mesozoic or Paleozoic in age then the older formations should be explored. Oil at the Eagle Springs field is produced from both Tertiary and Paleozoic age formations and is similar in physical characteristics to the oil produced from early Tertiary sediments in the Uinta Basin of Utah.

A 3,200-foot-thick sequence of nonmarine sedimentary rocks of Eocene age is exposed northeast of the Eagle Springs field, in the South Egan Range. One member in the sequence contains shows of oil and may be the source rock for the Eagle Springs oil. Oil and gas shows in Nevada have also been found in Paleozoic and Mesozoic age rocks. Formations of these ages could also be source rocks for the Eagle Springs oil.

The confusion regarding the source of oil for the Eagle Springs field is not necessarily discouraging, as it appears that Tertiary, Mesozoic, and Paleozoic rocks in Nevada may be productive. Of principal concern in Nevada are the kinds of formations and types of petroleum traps present. There are two basic geologic requirements that must be met if petroleum is to be produced. There must be a source for the petroleum and there must be traps that will contain the oil. Most all geologists agree that petroleum is formed in a sedimentary environment. It is thus pointless to look for petroleum in areas that do not contain sedimentary rocks. Generally, the greater the volume of sedimentary rocks present the greater the likelihood of finding petroleum.

Much of western Nevada is covered by volcanic rocks which overlie plutonic or metamorphic rocks. Petroleum has seldom been discovered in such an environment. The valley basins of western Nevada do contain nonmarine sediments of Tertiary and Quaternary ages but, unless these sediments have petroliferous members, it is unlikely that they will produce petroleum. No petroliferous sediments have been found in rocks of Tertiary or Quaternary ages in western Nevada, and it appears unlikely that any will be found. Small amounts of methane gas have been produced from some of the valley sediments in western Nevada, notably in the Fallon area. It is generally believed that this gas is generated by decomposing vegetation buried in recent lake deposits and that commercial quantities of gas are not likely to be present.

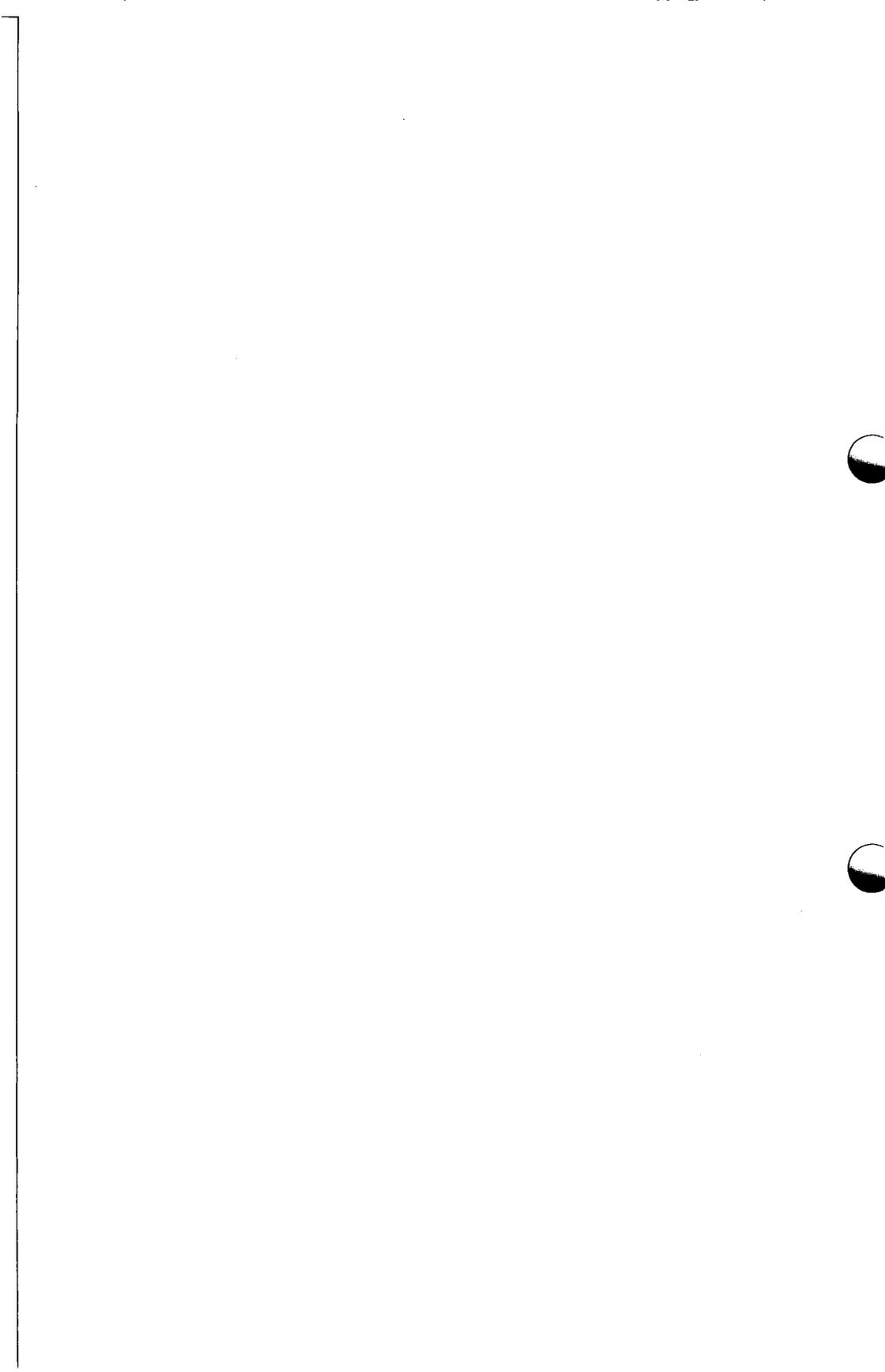
Substantial thicknesses of sedimentary rocks are exposed in Clark County, southern Nevada. Many wells have been drilled in the area without success. However, many of the tests have been shallow and based on limited geologic data. The Shell Oil Co., Bowl of Fire well, found oil shows in rocks of Triassic, Permian, and Mississippian age. These shows are encouraging, and further exploration may prove successful.

The central and northern portions of eastern Nevada appear to offer the best hope for additional discoveries. Thick sections of sedimentary rocks of Paleozoic age are found in the area as well as petroliferous formation of Tertiary age. The presence of oil in this area is no longer questioned. The problem is to find traps in which commercial quantities of oil have accumulated.

The geologic history of eastern Nevada makes finding traps a difficult problem at best. Extensive folding and thrust faulting in the area were followed by normal faulting, dividing the area into mountain and valley blocks. Many geologists believe that any oil once present in the uplifted mountain blocks has escaped. The valley blocks are buried under thousands of feet of Quaternary and Tertiary age rocks, effectively hiding the geology of the potential producing formations. Geophysical techniques can give some information concerning these buried blocks but only drilling can determine the geology with certainty. Additional oilfields will be found in Nevada. The ease with which they are found will depend upon the acquisition and interpretation of geological and geophysical information.

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## METALLIC MINERAL RESOURCES

The mining of metallic minerals has dominated the State's economy for the past 100 years. Production of metals has yielded about \$2.6 billion. Gold and silver production have totaled \$1.2 billion, and copper production has amounted to \$1.1 billion. The balance of roughly \$300 million resulted mainly from the production of lead, zinc, tungsten, iron, mercury, and manganese. In the early days of mining in Nevada, gold and silver were the chief metals produced, but after 1900 copper production became more important and is at present dominant. Large deposits of iron ore have been explored, some very recently, and will doubtless be mined at increasing rates as the market on the Pacific Coast expands. Production of other metals, such as tungsten, will also probably increase in the State when the metal prices become more favorable.

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### ANTIMONY

(By J. H. Schilling, Nevada Bureau of Mines, Reno, Nev.)

Antimony is a brittle, silver-white metal with a melting point of  $630.5^{\circ}$  C. Although antimony is produced in only minor amounts when compared with the base metals, it has many important and diverse uses. There are three major uses: (1) as a stiffener in the lead grids of storage batteries, (2) in tin- and lead-base alloys used as antifriction bearings, and (3) in type metal (lead, tin, antimony) used in printing processes, because of antimony's unique property of expanding upon cooling. Antimony oxide is used as a stabilizer and flame-retardant in various plastics; the sulfide in primers for gun cartridges; and the metal and its compounds as black, white, red, and yellow pigments.

Since 1925 the world production in antimony has averaged 35,000 tons per year with peaks of 90,000 and 59,000 tons during World Wars I and II. China has been the biggest producer and has the largest reserves; Bolivia and Mexico also have been big producers and have large reserves. In recent years the United States has consumed nearly half of the world production while producing less than 4 percent of the ore mined. Over half of the antimony that is consumed in the world is recovered from scrap rather than ore.

Antimony ore has been mined sporadically in Nevada since the 1860's; most production subsequent to 1890 has been during wartime when prices rose because of reduced imports. In 1942, 11 mines in Nevada produced ore containing 305 tons of antimony; in contrast, in 1945, 32 tons were produced from 3 mines. In 1962, typical Nevada ores brought 10 to 12 cents per pound of contained antimony.

Throughout the world antimony most commonly occurs as stibnite,  $\text{Sb}_2\text{S}_3$ , or tetrahedrite  $(\text{Cu}, \text{Fe})_{12}\text{Sb}_4\text{S}_{13}$ , and other sulfantimonides in quartz and calcite fissure veins and replacement bodies in limestone,

calcareous shale, and other rock types. In Nevada, vein deposits predominate and stibnite is the major ore mineral, although some production has come from jamesonite, ( $Pb_4FeSb_6S_{14}$ ), and from antimony oxide minerals, primarily stibiconite and bindheimite. The antimony minerals may occur alone but just as commonly are associated with pyrite, base-metal sulfides, cinnabar, scheelite, gold, silver, and selenium. Antimony mineralization sometimes occurs around the outer margin of gold, tungsten, mercury, and base-metal districts.

Of the 184 occurrences of antimony mineralization that have been described in Nevada (Lawrence, 1963), 41 have produced more than 10 tons of antimony, of which 11 have produced more than a hundred tons and 3 more than a thousand tons of the metal. Most of the more productive deposits are clustered in the Humboldt Range in Pershing County, at the north end of the Clan Alpine Range in Churchill County, and in the Big Creek area of the Toiyabe Range in Lander County forming a northwest-trending belt. Many of the other deposits also occur in clusters and belts. (See table 4 and fig. 16.)

The Sutherland mine (No. 85, fig. 16), just east of Coal Canyon (sec. 15, T. 27 N., R. 33 E.) in the West Humboldt Range, Pershing County, has been the largest producer of antimony in Nevada. An estimated 1,700 tons of antimony (metal) have been produced, mainly during World War I. A 1- to 48-inch-wide vein, striking north and dipping steeply, cuts Upper Triassic shales and interbedded calcareous shale, sandstone, and limestone on the western limb of a northwest-plunging anticline. The vein contains gouge, abundant quartz, stibnite, sporadic pyrite, and yellow and white antimony oxides.

The Bloody Canyon mine (No. 78), on the east slope of the Humboldt Range (sec. 35, T. 31 N., R. 34 E.), Pershing County, has been the second largest producer of antimony ore in Nevada. The mine has produced 1,218 tons of antimony, mainly during 1907, and from 1917 through 1921. Two veins, striking north and dipping steeply in silicified rhyolite flows, average several feet in width and consist of abundant quartz; stibnite as pods, streaks, and single crystals; common pyrite; and rarer chalcopyrite. Locally the stibnite has been oxidized to yellow and white antimony oxides.

The third important antimony mine in the Humboldt Range of Pershing County is the Hollywood mine (No. 86) on the south flank of the range (sec. 2, T. 26 N., R. 34 E.). Ore containing 512 tons of antimony have been mined, mainly during World War I. Several irregular quartz veins containing stibnite, pyrite, calcite, and antimony oxides cut interbedded (Triassic) shale, limestone, and siltstone. The veins vary greatly in thickness and attitude, and are complicated by numerous splits and cross faults. Ore shoots commonly are found at vein intersections. Diabase dikes intrude the country rock near the mine.

The Bray-Beulah mine (No. 46) along Big Creek (secs. 27, 34, and 35, T. 17 N., R. 43 E.) in the Toiyabe Range, Lander County, is the third largest producer in the State. Over 1,000 tons of antimony have been produced, principally during World War I. A 6- to 48-

inch vein, containing quartz, stibnite, and some graphite and pyrite, strikes N. 30° W. and dips 45° to 85° SW. in highly contorted Silurian(?) shale and slate. Quartz stringers parallel the vein and fold axes in the wallrock. The stibnite is partially altered to yellow and white antimony oxides.

Two other antimony mines near the Bray-Beulah mine in the Big Creek mining district of Lander County have produced over a hundred tons of metal. These are the Antimony King mine (secs. 25, 26, and 36, T. 18 N., R. 43 E.) which has yielded more than 500 tons of the metal, and the Dry Canyon mine (sec. 35, T. 18 N., R. 43 E.) with a production of 165 tons. At the Antimony King mine (No. 46) stibnite occurs with pyrite in quartz veinlets and in silicified limestone breccia in a 2- to 9-foot-wide fault zone, striking N. 55° W. and dipping 55° SW., in limestone. At the Dry Canyon mine (No. 46) stibnite, tetrahedrite, sphalerite, and pyrite occur in a 4- to 12-inch-wide quartz vein, striking N. 35° W. and dipping 55° SW. in arenaceous limestone.

The Potosi mine (No. 59) 1 mile west of Candelaria (sec. 5, T. 3 N., R. 35 E.), in Mineral County, has been the fourth largest antimony producer in the State. In contrast to the other major antimony mines described above, which mined stibnite-bearing quartz veins, the estimated 700 tons of antimony from the Potosi mine has been recovered as a byproduct from silver-lead ores. The vein is 8 to 36 inches thick, strikes N. 70° E., dips 45° N., and is offset by several faults striking N. 20° E. It consists of quartz with pods and veinlets of the antimony minerals jamesonite and bindheimite; pyrite; and minor tetrahedrite, galena, and calcite. Ore produced from 1948 through 1952 contained 0.5 to 0.6 ounces of gold and 8 to 12 ounces of silver per ton, 8 to 12 percent lead, 4 to 6 percent antimony, 0.5 percent copper, and 0.5 percent zinc. The bindheimite (a lead-antimony oxide) is an oxidation product of jamesonite, ( $Pb_4FeSb_6S_{14}$ ); brown, yellow, orange, and green banded bindheimite commonly encloses cores of jamesonite. The vein is along the contact between shales of the (Triassic) Candelaria Formation and "grit" of the (Permian) Diablo Formation which forms the footwall. Rhyolite dikes intrude the country rock.

Over 500 tons of antimony have been recovered from silver-lead ore mined in the Arabia mining district (No. 79) in the eastern foothills of the Trinity Range (mainly sec. 21, T. 29 N., R. 32 E.), Pershing County. The Montezuma mine has been the principal producer. Numerous quartz veins up to 6 feet wide and a thousand feet long cut granodiorite and Jurassic(?) hornfels. The veins generally strike north to northeast and dip to the east. They consist of quartz; locally abundant plumbojarosite, bindheimite, and other antimony oxides; and some calcite, arsenopyrite, jamesonite, and cerussite. Most of the jamesonite ( $Pb_4FeSb_6S_{14}$ ) that originally was present has been oxidized to plumbojarosite, bindheimite and other antimony oxides.

TABLE 4.—*Antimony occurrences in Nevada*

[Numbers identify symbols shown in figure 16]

CHURCHILL COUNTY	LYON COUNTY
1. Lake mining district (Green and Hazel mines)	47. DeLongchamps prospect
2. Quick-Tung mine	
3. Bernice Canyon area (includes Antimony King, I.H.X., Lofthouse, Drum, Hoyt, and Arrance mines)	MINERAL COUNTY
4. Caddy mine	48. Reservation Hill prospect
	49. Happy Return mine
CLARK COUNTY	50. Broken Hills mine
	51. Lithia mine
5. Goodsprings (Yellow Pine) mining district	52. Lucky Boy mine and Bismark prospect
6. New Deal and Yarmouth mines	53. Lowman mine
	54. Antimony Blossom, Hartwick, and Julia prospects
DOUGLAS COUNTY	55. Beeler prospect
	56. Volcanic Peak mine
7. Pine Nut Range (includes Danite mine)	57. Pilot Mountain mining district
8. Fullstone prospect	58. Kernick mine
	59. Candalaria mining district (includes Potosi mine)
ELKO COUNTY	NYE COUNTY
9. Blue Ribbon-Boyce mine	60. Milton Canyon mine
10. Mendive and Merritt Mountain prospects	61. Murphy and Teichert mines
11. Island Mountain mining district (includes Gribble Antimony mine)	62. Last Chance and Dollar mines
12. Charleston mining district (includes Prunty Antimony mine)	63. Antimony Lode and Flower mines
13. Valdez prospect	64. White Caps mine
14. Delano mine	65. King Solomon mine
15. Cornucopia mining district	66. Page mine
16. Hyer, Sage, Hen, Snyder prospects	67. Morey mine
17. Good Hope mine	68. Titus prospect
18. Rock Creek mining district	69. Blackbird prospect
19. Tuscarora mining district	70. Lucky Tramp mine
20. Burns Basin and Lost and Found mines, and Birds Eye prospect.	71. Outlook prospect
21. Bootstrap mine	72. Reveille Range (Antimonial and Eaton mines)
22. Hunter prospect	
ESMERALDA COUNTY	PERSHING COUNTY
23. Mickspot mine	73. Antelope and DeSoto mines
24. Gilbert mining district	74. Mill City (Nevada-Massachusetts mine)
25. Cattle Rock prospect	75. Seven Troughs mining district
26. B & B and Red Rock mines	76. Bottomley prospect
27. Florence mine	77. Star mine and Motor prospect
28. Matmueller mine	78. Star mining district (includes Bloody Canyon and Pflum mines)
	79. Arabia mining district (includes Montezuma, Electric, and Jersey mines)
EUREKA COUNTY	80. Panther Canyon (includes Bradley, Panther Canyon, and Oreana mines)
29. Morning Glory mine	81. Black Warrior mine
30. Stafford mining district	82. Johnson-Heizer, Adriene, and Rosal mines
31. Cortez mining district	83. Rochester mining district
32. Mineral Hill mining district	84. Muttelberry Canyon mine
33. Blue Eagle mining district	85. Sutherland Antimony mine
34. Stibnite and Young prospects	86. Antelope Springs mining district (includes Hollywood and Cervantite mines)
	87. St. Anthony mine
HUMBOLDT COUNTY	88. Green Antimony mine
35. Nevada King mine	89. Willow Creek prospect
36. National mining district	90. Antimony Ike mine
37. Juanita group	91. Ore Drag mine
38. Amos prospect	92. Polkinghorne prospect
39. Getchell mine	93. Fence-maker mine
40. Snowdrift mine	
41. Ten-Mile mining district (Pansy-Lee and W.F. mines)	WASHOE COUNTY
	94. Fox Mountains
LANDER COUNTY	95. Angelia prospect
42. Battle Mountain district (includes Cottonwood Canyon, Apex, and Mizpah mines)	96. Dontelli and Sleepy Joe mines
43. North Shoshone Range, (includes Blue Dick mine)	97. Choates mine and Sunset prospect
44. Wildhorse mine	98. Steamboat Springs
45. Reese River (Austin) mining district	
46. Big Creek mining district (includes Bray-Beulah, Dry Canyon, and Antimony King mines)	WHITE PINE COUNTY
	99. Bald Mountain mining district (includes Crown Point and Dees mines)
	100. Cherry Creek mining district
	101. Taylor Creek mining district (Merrimac and Enterprise mines)

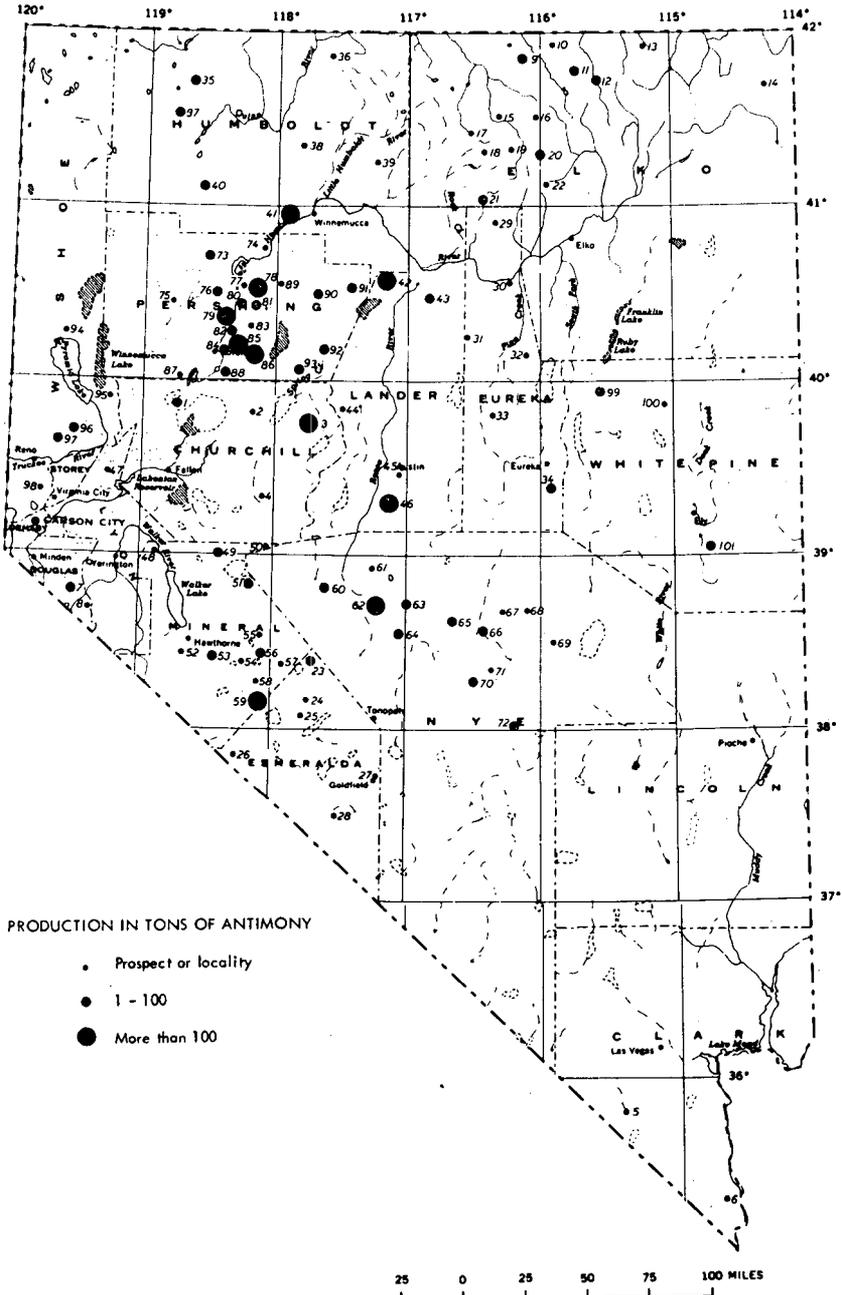


FIGURE 16.—Antimony in Nevada (numbers refer to deposits or districts listed in table 4).

The Pansy-Lee mine (No. 41) in the Krum Hills (secs. 1 and 12, T. 36 N., R. 36 E.), 11 miles northwest of Winnemucca, in Humboldt County, also has produced antimony as a byproduct. However, unlike the Potosi mine and Arabia district above, tetrahedrite is the only primary antimony mineral present. Approximately 200 tons of antimony have been recovered from lead-zinc-copper ores mined from veins that strike N. 20° E. to N. 50° W. and vary from a few inches to several feet in width. They consist mainly of quartz with lesser amounts of calcite, tetrahedrite, sphalerite, galena, pyrite, arsenopyrite, and yellow antimony oxides. Concentrates shipped in 1942 averaged 2 percent antimony, 0.6 ounces of gold and 50 to 60 ounces of silver per ton, in addition to the lead, zinc, and copper. The wallrock is slate.

The Antimony King mine (No. 3) in Bernice Canyon (sec. 23, T. 22 N., R. 37 E.) on the west flank of the Clan Alpine Range in Churchill County produced approximately 175 tons of antimony mainly during both World Wars. A 2- to 48-inch quartz vein, striking N. 10° to 25° E. and dipping 55° W., roughly parallels a highly brecciated latitic (?) sill, in some places following the hanging wall and elsewhere following the footwall. The sill intrudes shale and limestone of the Triassic Star Peak Formation. Pods, blebs, and veinlets of stibnite occur in the quartz vein and in the silicified and sercitized sill. Some arsenopyrite, pyrite, and sphalerite are associated with the stibnite. In the immediate vicinity of the Antimony King mine, the I.H.X. and Ar-rance mines (No. 3) have produced some 50 tons of antimony from quite similar deposits along this sill, and a second parallel sill.

The Last Chance mine (No. 62) on the divide (sec. 17, T. 10 N., R. 42 E.) between Wall and San Pablo Canyons, on the east flank of the Toiyabe Range, Nye County, produced 192 tons of antimony during World War I and II. Several veins, consisting of brecciated wall rock, gouge, some quartz, calcite, stibnite, and pyrite, and minor tetrahedrite, cut highly contorted Permian(?) limestone and shale. The main vein strikes N. 70° E. and dips 45° to 55° NW. Several rhyolite porphyry dikes intrude the sedimentary rocks.

The Cottonwood Canyon mine (No. 42) in Little Cottonwood Canyon, (sec. 35, T. 32 N., R. 43 E. and sec. 2, T. 31 N., R. 43 E.), on the east flank of Antler Peak, in Lander County, has produced 156 tons of antimony. A main vein with several splits strikes N. 15° to 30° E. and dips 45° to 80° W. in a north-trending fault zone cutting Mississippian argillite, shale, quartzite, and chert. A quartz-porphphyry dike intrudes the sediments. East-trending faults offset both the fault zone and vein. The vein is up to 48 inches wide, and contains abundant quartz and gouge, with some calcite, stibnite, and pyrite.

Antimony occurrences that have produced less than a hundred tons are shown on figure 16 and described by Lawrence (1963). Several are of special interest because of unusual features or associations. At the Oreana (Little Tungsten) mine (No. 80), south of Rocky Canyon (sec. 3, T. 29 N., R. 33 E.) on the western flank of the Humboldt Range, Pershing County, rare native antimony is associated with scheelite and beryl in a quartz-oligoclase-albite-phlogopite pegmatite body. At Steamboat Springs (No. 98), 10 miles south of Reno in Washoe County, stibnite and "metastibnite" occur with

chalcedony, quartz, opal, pyrite, cinnabar, and arsenopyrite in the sinter deposits formed by the hot springs. At the Green prospect (No. 1), on the northwest flank of the Mopung Hills (sec. 9, T. 23 N., R. 29 E.), Churchill County, stibnite and antimony oxides occur in large, angular boulders of limestone and rhyolite which lie on limestone and rhyolite bedrock and are cemented by Quaternary Lake Lahontan tufa; the angularity and size of the rubble blocks suggest that they have not been moved any appreciable distance.

A large number of Nevada antimony deposits contain small amounts that add up to an important potential source of the metal; however higher prices are necessary before this material can be profitably mined. Erratic price fluctuations have discouraged exploration and capital investment. Further exploration at some of the deposits could reveal large-enough tonnages of low-grade material to make mass-mining profitable. The chances of finding a commercial selenium deposit in association with antimony in Nevada are poor.

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### ARSENIC

(By B. A. La Heist, U.S. Geological Survey, Washington, D.C.)

Arsenic is produced as a by-product of copper and lead smelting and in the recovery of gold and silver. It is recovered only in the form of arsenious oxide (white arsenic), as no metallic arsenic has been produced in the United States since about 1950. The United States ranked as a major producer and consumer of arsenical products in 1962. Other important producing countries in the non-Communist World include Sweden, Mexico, and France. No domestic ores are mined exclusively for arsenic. Before 1907, arsenic was imported and a considerable amount of white arsenic is still imported chiefly from Canada, Mexico, France, and Sweden. The first recorded production of white arsenic in the United States was in 1901. Arsenic is used for manufacturing calcium and lead arsenate insecticides and herbicides, in chemicals for wood preservation, and is added to lead shot and glass. A small amount is used in alloys with lead and copper to increase the hardness of the former and the resistance of the latter to corrosion and erosion. Many uses of arsenic as a toxic agent have fallen off in recent years with the advent of organic compounds such as DDT.

The most commonly occurring arsenic-bearing minerals are the sulfides arsenopyrite, realgar, and orpiment. The latter two minerals are now manufactured artificially for use in pigments, fireworks, and in dyeing and tanning processes. Native arsenic and the arsenic-bearing minerals proustite, enargite, tennantite, scorodite, annabergite, mimetite, erythrite, cobaltite, niccolite and smaltite are rarer occurrences in the United States. Arsenopyrite, the principal source of white arsenic, is commonly associated in veins with the ores of tin, nickel, cobalt, silver, gold, and lead and with other sulfides such as pyrite, chalcopyrite, and sphalerite. Realgar occurs with the ores of silver and antimony and is usually associated with its alteration product orpiment. Realgar is also found in sublimation deposits from hot springs. Native arsenic is found principally in veins associated with silver, cobalt, and nickel ores.

Arsenic has a widespread occurrence in the ore deposits of Nevada but only in a few districts is the concentration of arsenic-bearing minerals of commercial interest. The Getchell mine in the Potosi district (No. 8, fig. 17), Humboldt County, for example, is one of only a few mines in the United States with considerable resources of arsenic which could be recovered directly from the milling or treating of its precious

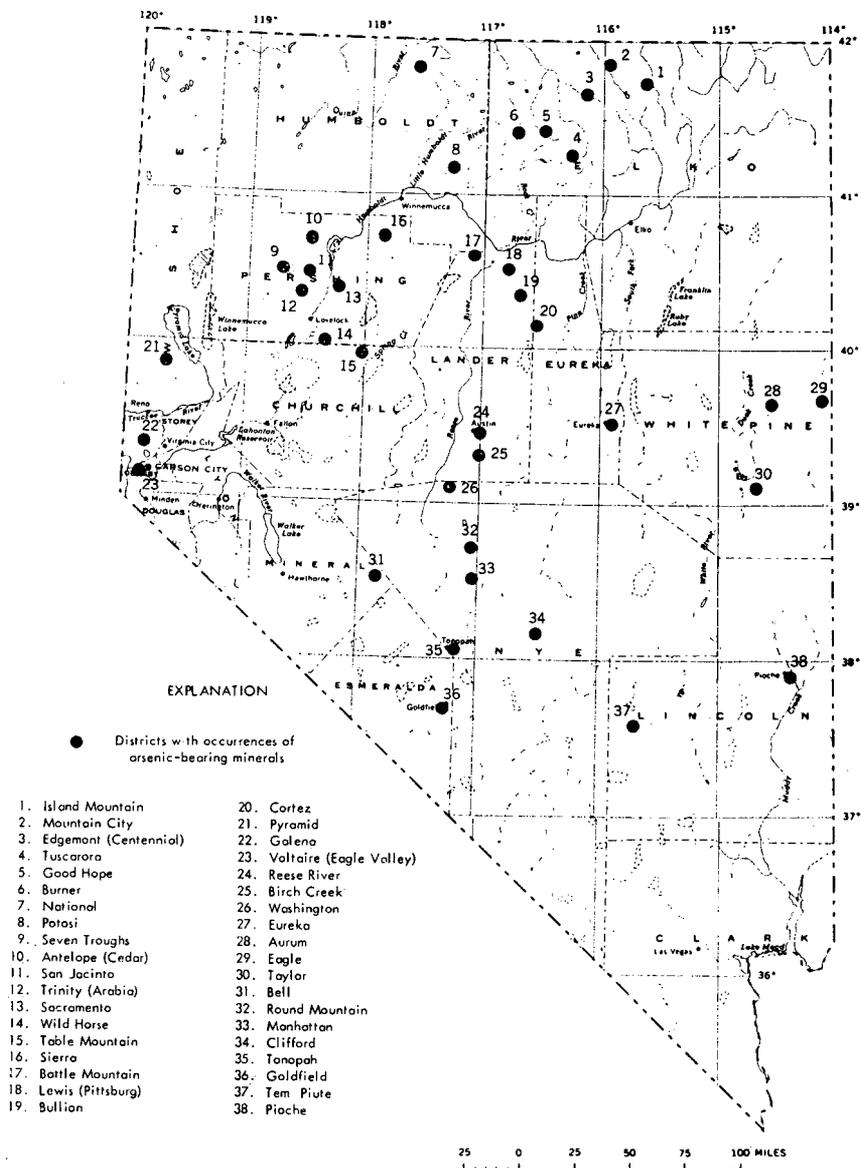


FIGURE 17.—Arsenic in Nevada.

metal ores (McMahon, 1960). Arsenopyrite is the most common arsenic-bearing mineral found in metallic ore deposits in Nevada. It is present in (1) hypothermal deposits such as those found at Majuba Hill (No. 10), Pershing County; (2) mesothermal deposits in the Eureka district (No. 27), Eureka County, and Pioche district (No. 39), Lincoln County; (3) epithermal silver deposits such as those in the National district (No. 7), Humboldt County, Tuscarora district (No. 4), Elko County, Goldfield district (No. 36), Esmeralda County, and the Tonopah district (No. 35), Nye County. Complex silver sulpharsenides are abundant with the arsenopyrite in these districts; (4) the very productive, predominantly silver- and gold-bearing quartz veins associated with granitic intrusives of western Nevada such as in the Reese River district (No. 24), Lander County; (5) contact-metamorphic deposits in west-central Nevada important for tungsten and base metal content such as at the Potosi (Gatchell) district, Humboldt County, and in the Tem Piute district (No. 37), Lincoln County; (6) replacement deposits which are especially important for their silver, lead, and zinc ores in eastern Nevada such as the Eureka and Cortez (No. 20) districts, Eureka County, and the Pioche district, Lincoln County (York and Ferguson, 1944). Realgar is present in the sublimate of the hot springs deposits at Steamboat Springs, Washoe County.

The first mention of arsenic minerals (realgar and orpiment) having been mined in Nevada was in 1919 by the White Caps Mining Co. of Manhattan (No. 33), Nevada. Resources of this material were considered to be substantial. Early in the 1920's, Nevada was a major supplier of arsenical ores from such districts as Battle Mountain (No. 17), Lander County, and from Manhattan, Nye County, and Eureka, Eureka County. A small arsenic plant at Toulon, Pershing County, produced white arsenic in 1923. This plant continued operations for a number of years using ores from the Irish Rose mine, Battle Mountain district, Lander County. In 1941, equipment was installed at the Gatchell mine for roasting gold ore to produce arsenical flue dust. This flue dust was shipped to smelters in Tacoma, Wash., and Murray, Utah, where arsenic was recovered throughout the mid-1940's. In 1949, a new mill designed to treat 1,500 tons of arsenical gold ore per day was completed at the Gatchell mine. Since that time most of the arsenic recovered from Nevada ores has come from this property, although the arsenic concentrates are usually stockpiled. In the following paragraphs arsenic occurrences in Nevada are discussed by county, and numbered as shown on figure 17.

*Churchill County.*—The rare arsenic-bearing minerals annabergite and gersdorffite are thought to occur in association with the nickel, cobalt, copper, gold, lead, silver, and antimony ores of Cottonwood Canyon in the Table Mountain district (No. 15). Ore found in a prospect in this district occurs in fissure veins in andesite at a diorite contact (Lincoln, 1923).

*Elko County.*—In Elko County, arsenopyrite is associated with several gold, silver, lead, and zinc deposits. It is found in fissure veins in the Burner (No. 6), Edgemont (Centennial) (No. 3), and Mountain City districts (No. 2). It is also found in small quartz veins in the Good Hope (No. 5) and Island Mountain (No. 1) districts. These veins occur in andesite, quartzite, granite and metamorphosed limestone and rhyolite (Lincoln, 1923). In the Tuscarora district

(No. 4) arsenopyrite is a minor constituent of the ore, whereas the arsenic-bearing minerals proustite and enargite are common minerals in silver ores (Nolan, 1936).

*Esmeralda County.*—Arsenical famatinite occurs with other base metal sulfides and native gold and tellurides in the Goldfield district (No. 36). This district was the most important gold producer in Nevada during its most active period between 1903–18. The ore deposits are irregular replacement lodes in fractured and altered shales, and Tertiary volcanics and lake sediments (Lincoln, 1923).

*Eureka County.*—Several arsenic-bearing minerals are known to occur in the Eureka district (No. 27). Mimetite is a constituent of the oxidized ores and arsenopyrite occurs in the primary sulfide ores. Scorodite is associated with low-grade gold ore in one part of the district. Old smelter dumps from the Richmond-Eureka mine contain speiss, an artificial arsenide or antimonide resulting from the treatment of various base or ferrous metal ores and 50,000 tons of the dump material, assaying 30 percent arsenic, was shipped to smelters outside Nevada in the early 1920's. The ore deposits at Eureka were among the first large zinc-lead replacement deposits in carbonate rocks to be developed in the West (Nolan, 1962).

Arsenic-bearing minerals have been recognized in the silver, gold, lead, zinc, and copper ores of replacement deposits in the Cortez district (No. 20) (Lincoln, 1923).

*Humboldt County.*—The Getchell mine in the Potosi district (No. 8), as mentioned previously, contains one of the more important deposits of arsenic in Nevada. This district was developed in the 1870's and 1880's. It contains two principal types of ore deposits: (1) contact-metamorphic zones of scheelite ore along monzonite-limestone contacts and (2) a large body of siliceous gold ore in sheared shale. Gold-free realgar and orpiment are found with other low-temperature sulfides in veinlets. Arsenopyrite in this district is gold-bearing (Hardy, 1940).

Arsenopyrite also occurs in veins in volcanic rocks in the National district (No. 7) (Lincoln, 1923).

*Lander County.*—In 1920, the Irish Rose mine in the Battle Mountain district (No. 17) began shipping arsenic ore to the Toulon arsenic plant at Toulon, Pershing County, and continued to do so for several years. The ore deposits in the Battle Mountain district are veins and replacements along fissures or zones of fracturing. In 1921, some ore from the Little Gem mine in the Bullion district (No. 19) was shipped to Toulon. Arsenopyrite and other sulfides occur in fissure veins in quartzites, shales, and limestones, which have been intruded by granodiorite and are capped in places by Tertiary andesite. Minor amounts of realgar and orpiment occur with arsenopyrite in veins in the Reese River district near Austin (No. 24). Arsenical pyrite occurs in the Smokey Valley vein in the Birch Creek district (No. 25), 12 miles south of Austin. Arsenopyrite is also found in the ore of the Lewis (Pittsburg) district (No. 18) (Lincoln, 1923).

*Lincoln County.*—Arsenopyrite and tennantite are known in the Prince mine, Pioche district (No. 38), which was for several years the leading producer in Nevada. Antimony, arsenic, copper, and lead are present in some of the silver ore in the Tem Piute district (No. 37) (Lincoln, 1923).

*Mineral County.*—Minor amounts of pyrite and arsenopyrite occur in the limestone replacement deposits important for their silver, lead and zinc minerals in the Bell district (No. 31) (Lincoln, 1923).

*Nye County.*—Arsenopyrite, realgar, and orpiment are found in the White Caps and East ore bodies of the Manhattan Consolidated mine in the Manhattan district (No. 33). Shipments of realgar from the White Caps mine were made to the smelter at Tacoma, Wash., in 1920. A total of about 335 short tons of contained arsenic had been produced to 1922, when shipments were discontinued (Ferguson, 1924). The ore deposits are veins in Tertiary eruptives and Paleozoic sediments, stockworks in Paleozoic schists, and replacement deposits in Paleozoic limestone. Scorodite occurs in ore from the April Fool mine. A little realgar is found in the primary gold-quartz veins in Tertiary rhyolite in the Round Mountain district (No. 32) (Ferguson, 1922).

Arsenopyrite occurs in the silver-lead ore of the Washington district (No. 26) and in the primary base and precious metal ores in the Tonopah district (No. 35). Arsenical pyrargyrite is also found in the latter district (Nolan, 1935).

*Ormsby County.*—Lenticular bodies of arsenopyrite occur at the Rafetto property in the Voltaire (Eagle Valley) district (No. 23) (Lincoln, 1923).

*Pershing County.*—Arsenopyrite is associated with copper-bearing minerals at the Majuba Hill mine in the Antelope (Cedar) district (No. 10) (Matson, 1948). About 1½ miles from the Majuba mine is an arsenic deposit which was last worked during World War I. Some ore was shipped at this time (Lincoln, 1923, and Vanderburg, 1936).

Arsenopyrite occurs in veins at the Sacramento (No. 13), Sierra (No. 16), Trinity (Arabia (No. 12), and Wild Horse districts (No. 14) (Vanderburg, 1936). Arsenic minerals also are known in the San Jacinto district (No. 11) which has primarily produced silver and lead.

*Washoe County.*—Arsenopyrite is associated with lead, silver, and zinc sulfides in the Galena district (No. 22). Auriferous arsenopyrite occurs at the Rocky Hill mine and some gold was milled from the arsenopyrite ore in 1907. In 1924, after many years of idleness, 66 tons of arsenical ore was shipped from this district to the National Chemical Co. in California where it was roasted and converted to calcium arsenate (Overton, 1947).

Arsenical pyrite occurs in the ores of the Blondin mine in the Pyramid district (No. 21) (Overton, 1947). Native arsenic has been found a few miles south of Pyramid Lake (Lincoln, 1923).

*White Pine County.*—Arsenopyrite is found in the primary ore of the Seigal mine, Aurum district (No. 28). The ore deposits are limestone replacements containing predominantly silver and lead. Enargite is found in the sulfide ores of the Glencoe mine in the Eagle district (No. 29).

There are considerable potential resources of arsenic in Nevada. Previous output has been almost entirely as a smelter byproduct and only minor amounts have been produced, mainly during the early 1920's. Penalties are levied on base metal concentrates that contain high amounts of arsenic, thus arsenic-bearing ores are often discarded or left unmined. The arsenic industry itself has been depressed in

recent years in that supply far exceeds demand, and the use of arsenical insecticides and pesticides has decreased. More arsenic could be produced if new uses were developed and if economic conditions became more favorable.

### BERYLLIUM

(By W. R. Griffiths, U.S. Geological Survey, Denver, Colo.)

Beryllium is a rather rare metal that has a wide variety of uses, both as pure or alloyed metal and in chemical compounds. More than half of all beryllium used is alloyed with copper to make a hard, fatigue-resistant alloy that is much used in springs and other instruments, and in tools that must lack the magnetism and sparking or rusting tendency of steel. Beryllium oxide has long been used as a refractory as it combines high electrical resistance, high thermal conductivity and thermal shock resistance, and a high melting point (4,658° F.). More recent developments are the use of both the metal and the oxide as moderators and reflectors of neutrons in nuclear reactors and as a neutron source in neutron generators. Because of its rigidity beryllium is used in inertial guidance mechanisms of missiles but its brittleness has so far hindered large-scale use as a structural material in missiles and manned aircraft, where its lightness and rigidity would be valuable properties. Beryllium-rich alloys with aluminum were reported in 1963 to have potentially large-scale use in aircraft manufacture. Alloys with alluminum, like those with nickel and magnesium, have already been used on a small scale. Beryllium minerals and compounds are used in the making of special ceramic materials. Speculative uses of the metal include its incorporation in missile fuels and explosives.

The total amount of beryllium used in the United States is not large, as compared with that of other metals. The consumption of ore increased from 1,013 tons in 1946 to an alltime high of only 9,692 tons in 1960. The ninefold increase in consumption, however, is indicative of the increasing industrial importance of the metal.

Adequate and increasing supplies of ore have been obtained by importing the mineral beryl, which contains 10 to 14 percent BeO. This mineral is obtained from pegmatites in South Africa, Brazil, Argentina, India, and elsewhere. Only about 6 percent of our supply is from domestic sources. The low production from domestic pegmatite deposits has caused emphasis in exploration to shift, since 1950, to deposits of other types, some of which are well represented in Nevada.

In general, the pegmatitic deposits of Nevada, though they are of the type that has yielded most of the world's beryl, appear less promising than the nonpegmatitic deposits. No more than a few tons of beryl have been sold from mines in the State. Additional amounts of ore have been extracted during exploration and either stockpiled or used for beneficiation tests.

Beryl has been found in pegmatite deposits in several places in Nevada as listed in table 5 and shown on figure 18. The beryl

deposits in the Ruby Range (No. 1, fig. 18) and the beryl-chrysoberyl deposits of the northern Virgin Mountains (No. 2) have been explored more than those elsewhere and may contain substantial amounts of beryllium (Olson and Hinrichs, 1960, p. 147-173). The rock at both places is rather fine grained, and the minerals will have to be concentrated by flotation.

Beryl has also been reported in pegmatites in the southern Virgin mountains (No. 3) and near Crescent Peak, in Clark County, but apparently in rather small amounts. And a specimen of beryl was received from the Sylvania district, Esmeralda County (No. 7) (Olson and Hinrichs, 1960, pp. 183, 186, 188). Beryl also has been found in pegmatite in the Troy Canyon area, Nye County (No. 6) and in a composite pegmatite-aplite dike in the Strawberry Creek area, White Pine County (No. 8).

Much of central and eastern Nevada is in the largest nonpegmatitic beryllium province in North America, which extends westward from the vicinity of Eureka, Utah, to Austin and Oreana, Nev. Many occurrences of beryllium minerals have been found in this area, of which those of the Mount Wheeler mines and those near Eureka have been extensively explored and probably contain very substantial amounts of beryllium. No beryllium ore has been sold from any of these deposits up to the present, but the probability of future production is good.

A wide variety of beryllium deposits has been found. Hypothermal veins containing beryl, quartz, scheelite or wolframite, muscovite or feldspar, and fluorite or calcite have been found in Pershing, Mineral, Lander, Eureka, and White Pine Counties. Contact metamorphic deposits containing beryllium have been found in Elko and Pershing Counties. Veins of possible mesothermal character contain beryllium in Elko County and veins of mesothermal or epithermal type in altered quartz monzonite contain beryllium in White Pine County. Manganese- and silica-rich hot spring deposits contain beryllium in Mineral and Humboldt Counties. Some of the hypothermal veins have been called pegmatites, but they differ from pegmatites in occurrence, mineralogy, and internal structure.

At the Lakeview mine, Pershing County (No. 15), scheelite and beryl are found in quartz veins and in coarse calcite lenses in limestone near a stock of monzonite. Accompanying minerals are dark blue tourmaline, pyrite, sphalerite, and muscovite (Olson and Hinrichs, 1960, pp. 174-176). Muscovite and white beryl form selvages at the walls of veins of coarse white quartz.

The Oreana mine (No. 16) yielded scheelite from veins in meta-diorite that contain quartz, oligoclase, albite, fluorite, beryl, scheelite, phlogopite, and accessory minerals. The main vein was 1 to 5 feet thick and 2,000 feet long. The minerals were erratically distributed through the vein—in places nearly the entire thickness of the vein was scheelite or fluorite. Beryl forms green prisms one-eighth to one-quarter of an inch across that generally are embedded in white oligoclase, with little or no quartz (Kerr, 1938; Olson and Hinrichs, 1960, pp. 176-177).

TABLE 5.—*Beryllium deposits in Nevada*

[Numbers identify symbols shown in fig. 18]

PEGMATITE DEPOSITS	
1. Ruby Mountains.....	Elko County.
2. Northern Virgin Mountains.....	Clark County.
3. Southern Virgin Mountains.....	Do.
4. Crescent Peak area.....	Do.
5. Eldorado Mountains.....	Do.
6. Troy Canyon.....	Nye County.
7. Sylvania district.....	Esmeralda County.
8. Strawberry Creek.....	White Pine County.
9. Sawmill Canyon.....	Nye County.
TACTITE	
10. Star mine.....	Elko County.
11. Wells area.....	Do.
12. Rose Creek mine.....	Pershing County.
13. Victory mine.....	Nye County.
14. Snake Range.....	White Pine County.
HYPOTHERMAL VEINS	
15. Lakeview mine.....	Pershing County.
16. Oreana mine.....	Do.
17. Lynch Creek.....	Lander County.
18. Eureka district.....	Eureka County.
19. Pine Crow claims.....	Mineral County.
20. Mount Wheeler and Jeppson deposits.....	White Pine County.
MESOTHERMAL VEINS IN TACTITE	
21. Railroad district.....	Elko County.
MESOTHERMAL OR EPITHERMAL DEPOSIT	
22. Cherry Creek Mountains.....	White Pine County.
HOT SPRING DEPOSITS	
23. Golconda area.....	Humboldt County.
24. Sodaville area.....	Mineral County.

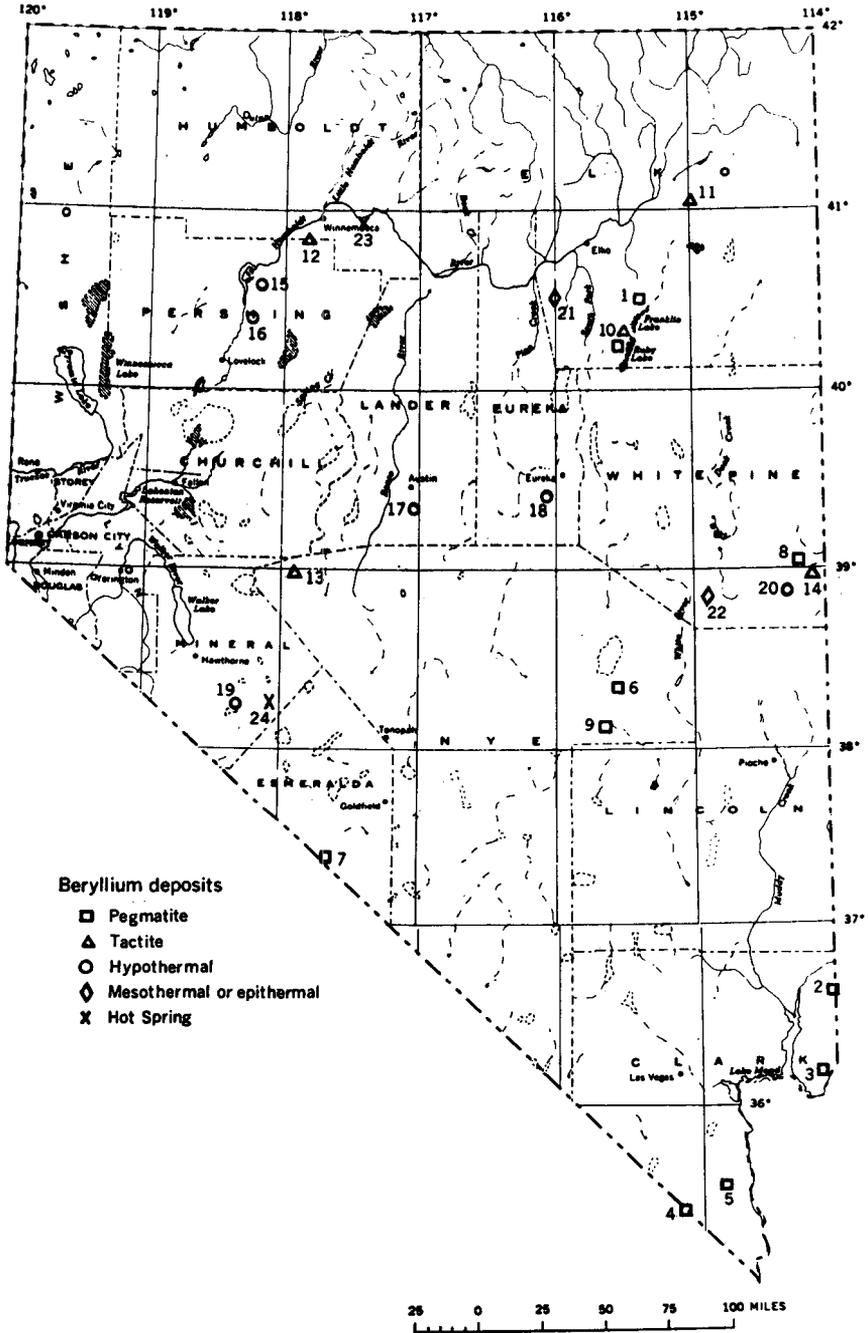


FIGURE 18.—Beryllium in Nevada (numbers refer to deposits or districts listed in table 5).

A vein 1 to 4 feet thick on Lynch Creek, in the Toiyabe Range about 10 miles south of Austin, Lander County (No. 17), consists largely of coarse white quartz. Embedded in the quartz are aggregates about one-tenth of an inch across of greenish muscovite flakes, and calcite and feldspar in masses up to 3 inches in diameter (Hall, 1962). Scheelite grains in quartz and in muscovite are about one-eighth of an inch across and green beryl forms prisms up to one-sixteenth of an inch across and 1 inch long. The vein shows no consistent zoning.

One quartz vein at the Pine Crow wolframite and scheelite prospect at Marietta, Mineral County (No. 19), was found to contain beryl. The beryl is in tiny light blue crystals along the granite footwall of the vein (Olson and Hinrichs, 1960, p. 182).

Deposits of beryllium occurring as phenacite and beryl were found in 1959 at the Mount Wheeler mine and the adjacent Jeppson claims on the west side of the southern Snake Range (No. 20). The beryllium minerals, as well as scheelite and fluorite, are associated with quartz veins in a limestone unit, locally known as the "Wheeler Limestone," in the lower part of the Pioche Shale of Cambrian age. The deposits have been explored more extensively than any other in Nevada. In 1959 and 1960, Beryllium Resources, Inc., explored part of the beryllium deposit by extending the older underground workings and by underground diamond drilling. Later, an extensive exploration and development program was conducted by the Anaconda Co. who purchased the mine in 1962. The deposit in the Mount Wheeler mine has been reported to contain an estimated 100,000 tons or more of ore averaging 0.75 percent BeO (Engineering Mining Journal, 1959). Ore mined during the exploration programs has been stockpiled, but, to date, production has been limited to shipments for milling tests.

The Bisoni brothers have located several beryl-bearing veins about 15 miles southwest of Eureka, Eureka County (No. 18) (Holmes, 1963, p. 13). The veins contain abundant fluorite, a fine-grained pale green micaceous mineral, red hematite, and needle-like prisms of white or yellow beryl, most of which are thinner than one-sixteenth of an inch. Many of the crystals are porous and rather soft. The total amount of beryl in the area appears to be large, although the economic importance of individual concentrations is still in doubt.

As yet, no epithermal beryllium deposits have been found in Nevada that are similar to those in altered dolomitic rhyolite tuff that are being explored at Spor Mountain, Utah. A mass of bleached and altered quartz monzonite in the Cherry Creek Range, White Pine County (No. 22) is reported to yield samples containing at least 0.1 percent BeO and may represent a mesothermal or epithermal type of mineralization.

The manganese-rich hot spring deposits at Sodaville, Mineral County (No. 24), and at Golconda, Humboldt County (No. 23), represent a rather novel type of beryllium concentration. Samples of manganese- and iron-rich material contain as much as 0.016 percent BeO, but no beryllium mineral has been recognized in them. Calcareous sinter at Golconda and chalcedony at Sodaville are not beryllium-rich (Warner and others, 1959, p. 64-65, 69-70). There is little indication that the economic potential of such deposits is important, but they illustrate that beryllium has been deposited at or

very near the earth's surface as well as at the depths represented by hypothermal veins.

Tactites have been found in many places to contain abnormal amounts of beryllium (Warner and others, 1959). Five widely spaced localities which yield tactite samples with at least 0.01 percent BeO are shown on the map. A beryllium-rich mineral has been found in only one Nevada tactite—that in the Railroad district (No. 21). Idocrase was found to be enriched in beryllium in the central Elko County tactite (No. 11) and has been recognized also at the Star mine, farther south in Elko County (No. 10). Granite contains unusual amounts of beryllium near its contact with beryllian tactite at the Victory (No. 13) and Star mines.

Beryllian idocrase is a major constituent of several layers of tactite on the east side of the Snake Range, White Pine County (No. 14). Samples from other tactites in the same area contain interesting amounts of beryllium, but the mineralogy of these deposits has not been determined.

The central part of the Railroad district, Elko County, Nevada (No. 21), has yielded samples with 0.02 percent BeO, as well as over 0.1 percent of yttrium and lanthanum (Ketner and Smith, 1963). The samples are of veins that are in tactite, but which resemble mesothermal veins in other districts more than contact metamorphic deposits. Thus they might reasonably be separated from tactite deposits (Ketner, oral communication, 1963). The rare sodium beryllium phosphate beryllonite has been found in oxidized ore of this district. This is the only known occurrence of this mineral outside of pegmatites and is the only occurrence of a mineral containing beryllium as a major constituent in tactite in Nevada.

Beryl has been found in granite in Sawmill Canyon in southern Nye County (No. 9), but the locality has not been studied.

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## BISMUTH

(By Priscilla Mount, U.S. Geological Survey, Washington, D.C.)

Bismuth is a brittle, silver-white, low-melting-point metal used chiefly in fusible alloys and in pharmaceuticals. It is obtained mainly as a byproduct in the metallurgical treatment of silver, lead, zinc, copper, gold, tungsten, and molybdenum ores. There is no record of production of bismuth in Nevada, principally because byproduct bismuth production is not recorded by source of ores; however, some of the Nevada metalliferous ores are known to contain bismuth.

Bismuth is associated with tungsten deposits in several mining districts in Nevada, including the Tem Piute, Valley View, Rawhide, and Potosi. All of these tungsten deposits are in tactites formed where limestone has been intruded by granitic rocks (Hobbs and Clabaugh, 1946; Geehan and Trengove, 1950). At the Lincoln and Schofield mines in the Tem Piute district, Lincoln County (No. 1, fig. 19), tactite layers and pods in limestone at the contact of a granite stock contains scheelite with associated sphalerite, pyrite, pyrrhotite, and minor galena, chalcopyrite, and fluorite. Bismuth was reported in concentrates obtained during metallurgical testing of this ore (Binyon, Holmes, and Johnson, 1950). The 68.2 percent tungsten

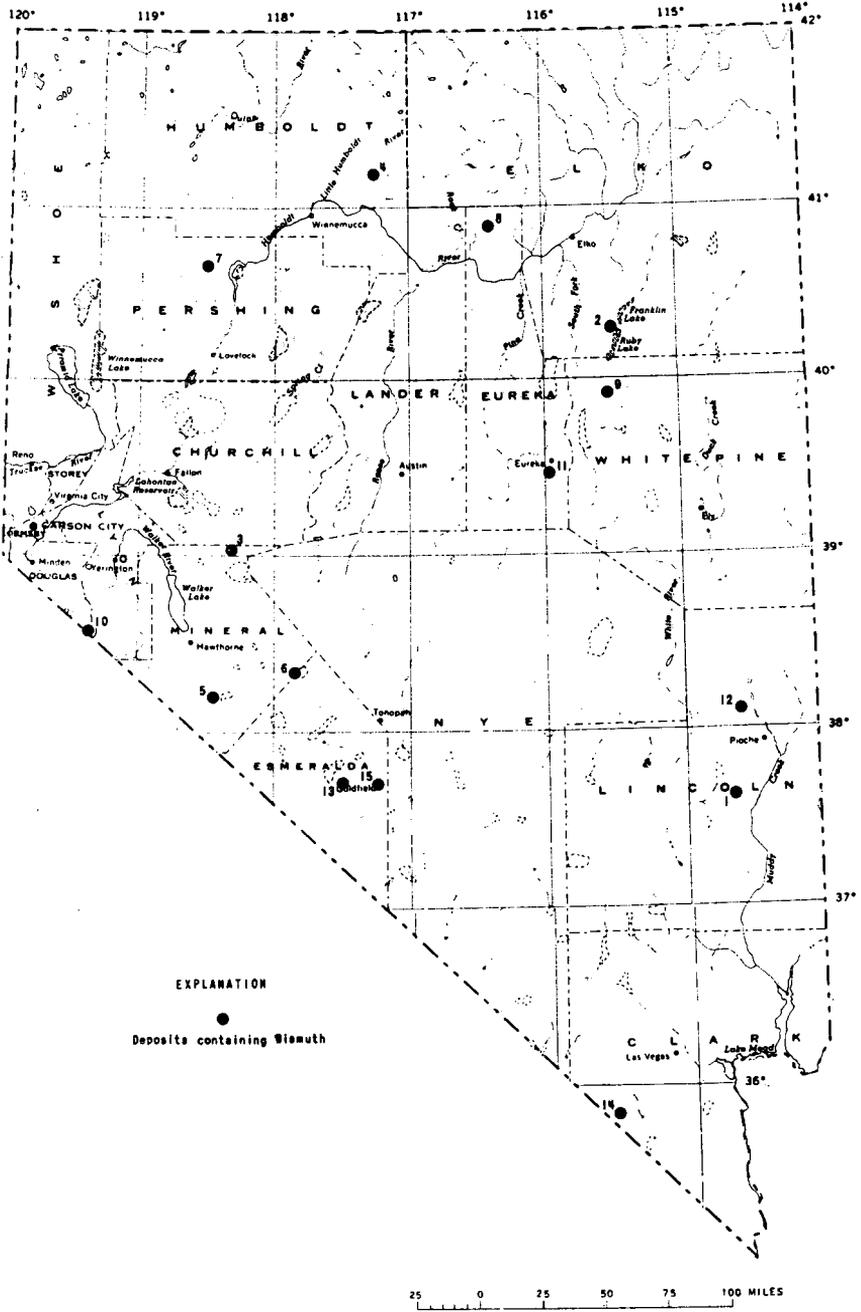


FIGURE 19.—Bismuth in Nevada (number refer to deposits or districts described in text).

concentrate contained 0.92 percent bismuth, a 59.4 percent zinc concentrate contained 0.74 percent bismuth, a zinc-lead concentrate contained 2 percent lead and 3.36 percent bismuth, and an essentially lead-free zinc concentrate, with 0.1 percent lead, contained only 0.06 percent bismuth. The two mines were closed in 1957 and have not been reopened. At the Star tungsten mine (No. 2) in the Valley View (Ruby Valley or Ruby Mountains) district, Elko County, native bismuth and bismuthinite are disseminated in the tactite (Hill, 1916, p. 63). Kaiser, Herring, and Rabbitt (1954, p. 82) determined spectrographically that 0.006 percent  $\text{Bi}_2\text{O}_3$  was present both in tungsten mill heads (scheelite) and in the tungsten tailings (scheelite) from the Star tungsten mill. A sample of scheelite concentrates from this mill contained 0.07 percent  $\text{Bi}_2\text{O}_3$  (spectrographic analysis). The mine closed in the late 1950's, owing to low price of tungsten. In the Regent (Rawhide) district, Mineral County, ores from the Nevada scheelite mine (No. 3) contain some bismuth. Tailings at the Nevada scheelite mill, which processed the Nevada ores, contain 0.01 percent bismuth (Kaiser, Herring, and Rabbitt, 1954, p. 83; Geehan and Trengove, 1950). In the Potosi district, Humboldt County (No. 4), scheelite ores from several deposits that were processed at the Getchell mill contained from 0.001 percent  $\text{Bi}_2\text{O}_3$  in some ores to 0.1 percent  $\text{Bi}_2\text{O}_3$  in copper and iron sulfide concentrates (Kaiser, Herring, and Rabbitt, 1954, p. 82). Other tungsten deposits that contain bismuth minerals include the Pine Crow prospect (No. 5) near Marietta, Mineral County, and the Garnet group (No. 6) on the east side of the Pilot Range, near Mina. Traces of bismuth are present in the copper-tin ores mined at the Majuba Hill mine (No. 7), Pershing County. Bismuth is associated with sulfides deposited along fissures in faulted rhyolites and as replacements of rhyolite and breccia. The bismuth content of materials analyzed spectrographically ranged between 0.001 and 0.1 percent  $\text{Bi}_2\text{O}_3$ . Some 27,000 tons of copper and 350 tons of tin ore were produced at this mine between 1916 and 1949. Most of the copper ore was shipped to the Garfield Smelter, Utah, but it is not known if bismuth was recovered. Trites and Thurston (1958) note that little known mineralized material remains at the mine, and that future production will depend on finding new reserves.

Bismuthinite ( $\text{Bi}_2\text{S}_3$ ) and bismite ( $\text{Bi}_2\text{O}_3$ ) accompany gold in the rich ore and placer material of gold mines in the Lynn district (No. 8), Eureka County. The gold occurs in veins in Tertiary rhyolite cut by porphyritic intrusives (Lincoln, 1923, p. 94).

Native bismuth has been reported in White Pine County (No. 9) by Schrader, Stone, and Sanford (1917, p. 191). No additional information is available.

Overton (1947, p. 33) mentions the occurrence of tetradymite ( $\text{Bi}_2\text{Te}_3$ ) associated with free gold in the Wellington (Silver Glance) district in Douglas County, at the Gold Mint mine (No. 10).

In the Eureka district, Eureka County, complex gold-silver-lead ores of the Lord Byron and Kelly mines (No. 11) contain bismuth. Selected material has analyzed as much as 40 percent  $\text{Bi}_2\text{O}_3$  (Hague, 1892, p. 313). The ore at these mines occurs as pods and irregular replacement bodies in brecciated dolomite of Cambrian age. According to Nolan (1962, p. 68) production from the Lord Byron mine, from

1885 to 1894, amounted to 2,613 tons of ore. It is not known if any bismuth was recovered from this ore.

Cooper (1962) classes the Black Metal (Jackrabbit) mine (No. 12), Pioche district, Lincoln County, as a relatively important bismuth-bearing deposit. The mine has produced principally lead, copper, silver, and manganese from replacement deposits in Cambrian limestone.

Bismuth occurs in the Montezuma district (No. 13) Esmeralda County, associated with silver, gold, lead, and copper veins and replacement bodies in Cambrian sediments cut by intrusives (Cooper, 1962, p. 9).

Bismuth has been found at the Boss mine (No. 14), Yellow Pine district, Clark County. The ore occurs in a roughly elliptical, continuous pipe and in several smaller bodies in Paleozoic limestone near a Tertiary granite porphyry (Cooper, 1962, p. 9). Hewett (1931, p. 114-118) notes that to 1921 about 3,500 tons of ore valued for gold, silver, platinum, palladium, and copper had been produced from the mine. The material richest in gold, platinum, and palladium was determined by W. T. Schaller, U.S. Geological Survey, to be a mixture of 67.3 percent plumbojarosite, 17.2 percent beaverite, 6.9 percent bismutite, and 6.9 percent quartz.

Rich gold-silver ore from the Mohawk mine in the Goldfield district (No. 15) Esmeralda County, is reported by Lindgren (1933, p. 511-512) to have assayed 2 percent gold (541 ounces per ton), 0.25 percent silver, 2.42 percent tellurium, and 0.35 percent bismuth. In the unoxidized ore two bismuth minerals—bismuthinite and goldfieldite—were associated with pyrite, marcasite, famatinite, native gold, tellurides, and dark gray flinty quartz gangue. There is no record of bismuth production from the Goldfield district, although considerable amounts of bismuth were present in the ore.

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## COBALT AND NICKEL

(By L. H. Beal, Nevada Bureau of Mines, Reno, Nev.)

Cobalt and nickel are metals of similar appearance, melting point, density, and other physical properties. They are tough, lustrous, silver-white metals. In nature these elements commonly are associated with iron-bearing minerals. Both metals have remarkable abilities to impart great strength and magnetic qualities to certain alloys.

Cobalt uses include permanent-magnet alloys and high-temperature alloys. Permanent-magnet alloys (Davis, 1956) are widely utilized in motors and generators, control devices, communication equipment, meters and instruments, and mechanical devices. Other important cobalt products (Davis, 1956) include: high-speed and low-cobalt alloy steels, alloy hard-facing tools and armor-piercing projectiles, ground-coat frit for porcelain enamel, pigments, catalysts, electroplating, lacquers, varnishes, paints, inks, stock feed, cobalt-deficient soils, and glazes and decolorizers.

Nickel is used widely in industry; large quantities of it are alloyed with copper, iron, and to a less extent with other metals. There are over 3,000 nickel-alloys used today; these contain from less than a percent to nearly 100 percent nickel. Examples include: coinage,

monel metal, stainless steels, and permanent magnet alloys. Although less efficient, nickel can be used as an alternate for cobalt as a binder in sintered-carbide tools and armor-piercing projectiles, and nickel-base alloys with low cobalt content can be substituted for some cobalt-base high-temperature alloys.

Virtually all cobalt produced is a byproduct or coproduct of other metals, chiefly copper (Davis, 1956). The ore minerals are cobaltite ( $\text{CoAsS}$ ), smaltite ( $\text{CoAs}_2$ ), and a number of sulpharsenide minerals. On the other hand, nickel ores, contain chiefly the following minerals: garnierite— $(\text{Ni}, \text{Mg}) \text{SiO}_3 \cdot n\text{H}_2\text{O}$ ; pentlandite— $(\text{Fe}, \text{Ni})\text{S}$ ; niccolite— $\text{NiAs}$ ; polydymite— $\text{Ni}_3\text{S}_4$ ; violarite— $(\text{Ni}, \text{Fe})_3\text{S}_4$ ; and chloanthite— $(\text{Ni}) \text{As}_2$ . These minerals are commonly associated with pyrrhotite and chalcopyrite and are found in a variety of deposits. These include chiefly deposits resulting from processes of rock decay, massive magmatic bodies, and veins. Sizes of deposits range from narrow high-grade veins containing a few tons of ore minerals to large low-grade bodies having potentials of millions of tons.

The non-Communist world production of cobalt, about 11,000 tons for 1962, was substantially higher than for the previous year. Katanga, Africa, supplied most of the cobalt; only about  $3\frac{1}{2}$  percent of the total metal production was from the United States—the only domestic producer being Pyrites Co., Inc., of Wilmington, Del. The recent use of 7 to 9 percent cobalt in maraging steels suggests that the steel industry may become the major consumer of cobalt (Bilbrey, 1963).

Currently the nickel industry is centered chiefly in the Sudbury district, Ontario, and Thompson district, Manitoba, Canada, but about 10 percent of the world's nickel production comes from Russia, Cuba, and New Caledonia. During the last decade, the United States produced annually from less than 1 to nearly 5 percent of its yearly nickel requirements; the U.S. consumption was 120,000 tons in 1962 (O'Connell, 1963). Current metal prices per pound for large lots of cobalt and nickel metals (Eng. and Mining Jour., April 1964) are, respectively, \$1.50 and \$0.79.

Most of the higher grade nickel sulfide ores in the United States occur in small bodies in widely separated parts of the country. Because of the limited sizes and distribution of these bodies, a smelting industry is not justified. Deposits in this country include: Fredericktown, Mo., Yakobi Island, Alaska, Mouat, Mont., and Riddle, Oreg. The Riddle deposit contains from 1 to 2 percent nickel-silicate ores; the others are low-grade sulfide ores.

During the last several decades, limited tonnages of Nevada nickel and cobalt ores have been shipped, and small quantities of nickel have been recovered as a byproduct from the copper ores of the Ely district, White Pine County (No. 7, fig. 20). Nickel and cobalt in Nevada occur for the most part in sulfide and arsenide hydrothermal deposits. The largest ore bodies have been found in the Bunkerville district (No. 11), Clark County. The Great Eastern and Key West deposits consist of sulfide disseminations and massive pods in dikes of hornblende that intrude Precambrian granite gneiss. The sulfides present are pyrrhotite, pyrite, chalcopyrite, pentlandite, violarite, possibly also polydymite. As a result of exploration during the period 1939–56, it is reported that several tens of thousands of tons of material containing over 1 percent nickel, have been found.

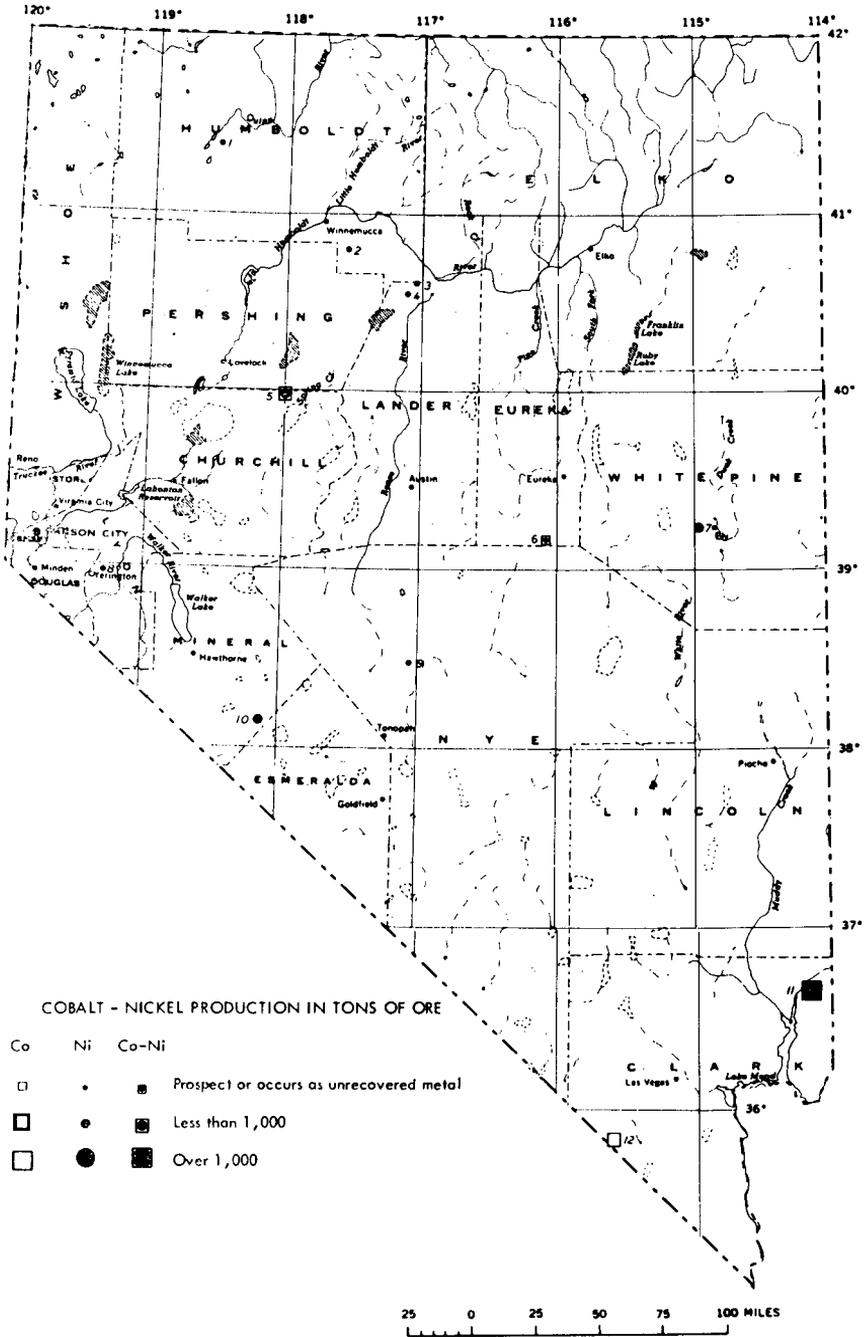


FIGURE 20. Cobalt and nickel in Nevada (numbers refer to deposits or districts described in text).

At Cottonwood Canyon (No. 5), Churchill County, small but unusual nickel-cobalt sulfide and arsenide deposits occur at the Nickel and Lovelock mines. These mines were operated between 1882 and 1908. The deposits, described by Ferguson (1939), consist of discontinuous stringers of cobalt and nickel minerals in altered andesite and aplite, adjacent to an intrusive diorite. The mineralogy of the primary nickel-cobalt ores has not been studied and only niccolite has been identified, but oxidized ores near the surface contain the hydrous nickel arsenate annabergite, and the sulfate morenosite.

An unusual small deposit of manganese oxides containing appreciable amounts of nickel, zinc, vanadium, and cobalt occurs at the Gibellini mine (No. 6), Eureka County. It consists of several small, funnel-shaped ore bodies that occur in Devonian limestone adjacent to vanadiferous shale. The only identified metallic minerals are the manganese oxides psilomelane and pyrolusite, and the nickel, cobalt, zinc, and vanadium apparently occur in them. A representative sample of the ore contains 18.5 percent manganese, 3 percent iron, 1.7 percent nickel, 0.3 percent cobalt, and 3.2 percent zinc (Binyon, 1948). The metals were probably deposited in a hot spring.

Nickel or cobalt have also been found in the following sulfide deposits: Jackson Creek mine (No. 1), Adelaide district (No. 2), Humboldt County, Overlook claims (No. 3), and Plummas mine (No. 4), Lander County, Ludwig claim (No. 8), Lyon County, Red Fox claims (No. 9), just south of the Manhattan district, Nye County, Candelaria district (No. 10), Mineral County, and the Goodsprings district (No. 12), Clark County.

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## COPPER

(By Harold Kirkemo, U.S. Geological Survey, Washington, D.C.)

Few metals possess the versatility of copper in pure metal applications and in alloys. Ancient civilizations used copper for ornaments and coins, and modern man uses it in thousands of applications—even as tiny needles for experiments in outer space. Nearly 55 percent of the copper consumed annually is used in products for the electrical and communications industries, and about 40 percent is used in brass mills.

Copper ranks third after iron and aluminum among the major tonnage metals. Apparent consumption of primary copper in the United States in 1963 was about 1.4 million tons. Consumption is expected to reach 2 million tons annually by 1975.

Nevada ranks fifth among the States in total tonnage of copper mined from earliest record to the end of 1962, with a total of 2,813,338 short tons. In 1962 the State supplied 82,602 tons which was about 7 percent of the national total. From the end of World War II through 1962, Nevada's copper output was about equal to production in Mexico, Japan, or Peru in the same period.

The total value (\$1.1 billion) of copper mined in Nevada from earliest record through 1962 accounts for 36 percent of the total value (\$3 billion) of the State's mineral and metal output. In comparison, gold accounts for 20 percent; silver, 18 percent; zinc and lead, each 3 percent; and all other minerals and metals, 20 percent.

The importance of copper to Nevada's economy is illustrated further by comparison of income from various products since World War II.

In the period 1946-62, the value of copper production represented 51 percent of total income derived from minerals and metals, equaled nearly 77 percent of total agricultural income, and 90 percent of income from livestock and related products. If the value of byproducts from copper production is added, the total for copper and associated metals exceeds income from livestock.

Annual mine production of recoverable copper, value of annual production, and the relative value of copper compared to total mineral production, 1904-62, are shown in figure 21.

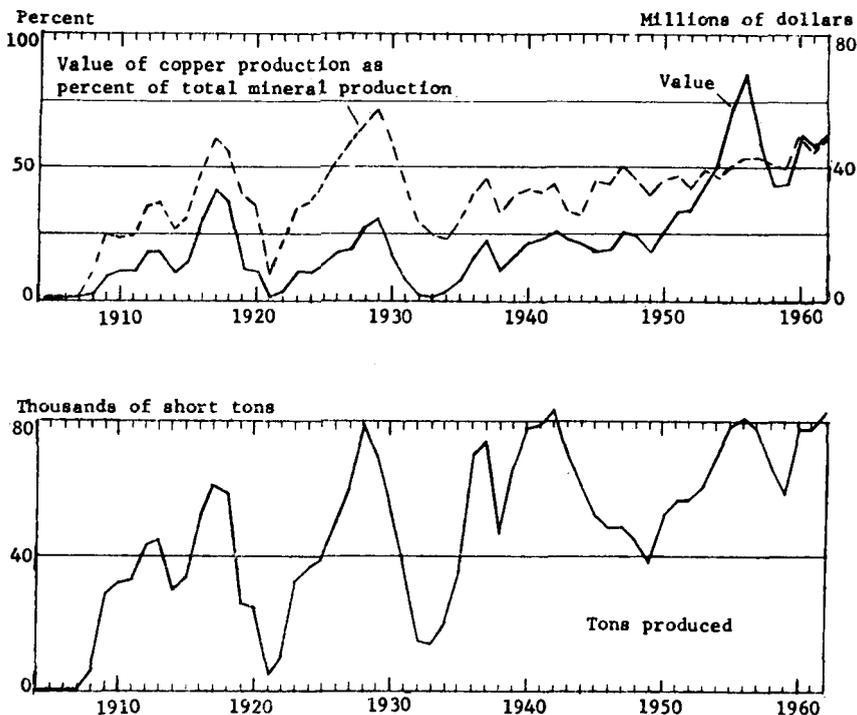


FIGURE 21.—Copper production in Nevada, 1904-62.

Nevada's copper output did not become significant until development in the early 1900's of the flotation process for selective separation of minerals, and adaptation of large-scale, low-cost mining methods that enabled the exploitation of copper deposits formerly uneconomic to mine. Concomitant with copper production has been the by-product recovery of associated minerals containing gold, silver, lead, zinc, molybdenum, and other metals.

Copper production in three counties accounts for 98 percent of the State total as shown in table 6.

TABLE 6.—*Total copper production in Nevada through 1962*

County	Short tons	Percent of State total	Value	
			Millions of dollars	Percent of State total
White Pine.....	2,307,000	82	859.8	78
Lyon.....	340,400	12	203.8	18
Elko.....	105,600	4	25.0	2
Others.....	60,300	2	18.3	2
Total.....	2,813,300		1,106.9	

The interesting relationship of the Lyon and Elko County totals and their percentages of State totals are closely related to the price of copper, and to the period of principal production in the major districts. Production in Lyon County since 1953 benefited from relatively high prices for copper, whereas low prices prevailed during maximum production in Elko County between 1935 and 1947.

In each of the three counties listed above, a single district accounts for most of the copper production—the Ely district (No. 11, fig. 22) with over 2 million tons in White Pine County, the Yerington district (No. 26) with 340,000 tons in Lyon County, and the Mountain City district (No. 3) with 105,000 tons in Elko County. The 38 copper-producing districts with production in excess of 50 tons each are shown in figure 22. Some 134 additional districts have recorded smaller production (Horton and others, 1962; Nolan, 1935, p. 325).

The three major copper districts have had similar histories of development, beginning with exploration and mining of silver and gold. Though copper was present in many of the deposits, its recovery was generally uneconomic. When large-scale copper mining became possible and profitable in the early 1900's many properties were combined and developed by fewer companies with ample financial resources.

Vein and contact metamorphic types of deposits were commonly worked by the early miners of silver and gold. The major copper deposits developed to date in Nevada have been large, disseminated ore bodies, the so-called porphyry deposits, at Ely and Yerington, and the replacement deposit at the Rio Tinto mine in the Mountain City district.

#### ELY DISTRICT

Like many of the mining districts in the West, the Ely district (No. 11) was mainly a gold and silver producer from the late 1860's to the early 1900's. It was not until 1907-08 that its low-grade, disseminated "porphyry" copper ores were first mined and milled on a large scale. Mining and ore beneficiation techniques developed to exploit the low-grade, porphyry copper ores at Bingham, Utah, and Morenci, Ariz., were adapted to the conditions and the ores in the Ely district.

The practice of exploring low-grade copper ores with churn drills was pioneered in the Ely district in 1906 (Spencer, 1917, p. 97). Improvements over the years in mining, concentrating, and smelting have permitted exploitation of lower grade ores. The copper content of ore mined in the district in 1962 was 15.5 pounds per ton as compared with nearly 50 pounds per ton in 1908.

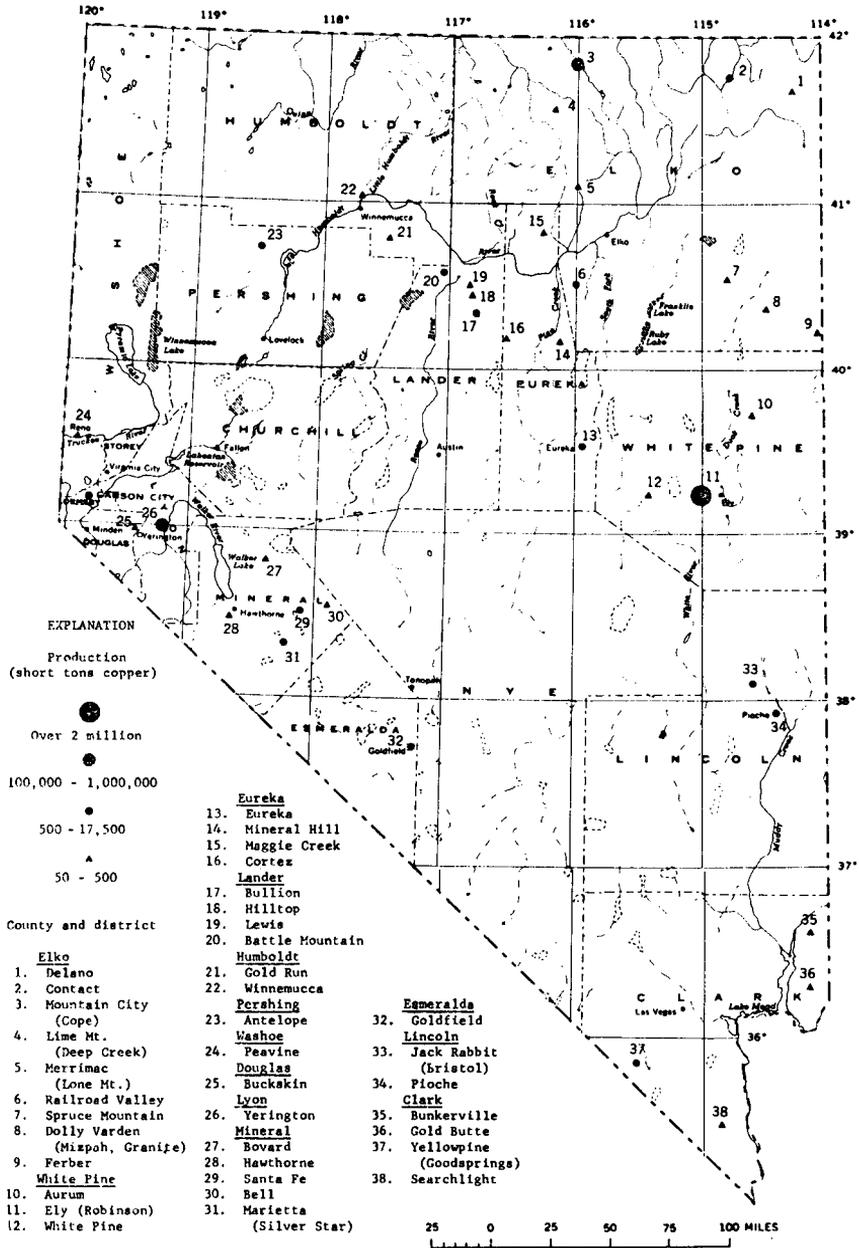


FIGURE 22.—Copper in Nevada.

The Nevada Consolidated Copper Co. (predecessor of Nevada Mines Division of the Kennecott Copper Corp.) and the Consolidated Coppermines Corp. owned and operated the principal mines in the district between 1908 and 1958. In 1958, the Kennecott Corp. purchased Consolidated Coppermines' properties in White Pine County and became the sole ore producer in the district. As formerly, ores are processed at the company's copper concentrator and smelter (Nevada's only copper smelter) at McGill, Nev.

The Ely district has produced nearly 250 million tons of ore yielding over 2,300,000 tons of copper valued at close to \$900 million, and nearly \$80 million in gold, silver, and byproduct platinum metals, lead, zinc, manganese, and molybdenum. About 80 percent of the production has come from open pit mining operations, and the remainder from underground workings. The Liberty Pit deposit accounts for 70 percent of the total district production. The remainder of production through 1962 has been from the Tripp, Ruth, Emma, Veteran, and Kimbley deposits (Bauer and others, 1964).

The six major mineralized areas developed in the Ely district are within a zone 8 miles long and nearly a mile wide lying across the north-trending Egan Range. Within the zone are Paleozoic sedimentary rocks, lower Tertiary or Upper Cretaceous quartz monzonite porphyry, Tertiary volcanic rocks, and Quaternary gravels and alluvium. Sulfide mineralization believed to be genetically related to the porphyry occurs in both the porphyry and in altered portions of the Paleozoic rocks. Disseminated ore in altered porphyry accounts for about 80 percent of the district's production, and disseminated ore in altered sedimentary rocks for most of the remainder.

The principal primary ore mineral is chalcopyrite. Bornite and chalcopyrite are common in portions of the ore bodies. Gold, silver, lead, zinc, manganese, and the platinum metals are present also. Supergene-enriched ore consists mainly of chalcocite with small amounts of covellite coating pyrite and chalcopyrite grains.

Published estimates of ore reserves of the Ely district have consistently assured many years of future operation. Ore reserves in the Ruth and Copper Flat deposits in 1905 were estimated to be 26 million tons. The proved existence of 80 million tons in 1913 included ore already mined (Spencer, 1917). After 25 years of operations during which 80.9 million tons of ore were mined, Bateman (1935) reported district reserves in 1933 at an estimated 100 million tons of ore containing an average of 1.20 percent copper. Trade journals in 1956-58 published estimates of 50 to 75 million tons of reserves. Present reserves are likely still on the order of 75 to 100 million tons.

#### YERINGTON DISTRICT

Yerington (No. 26) has a long history of mining activity but its major production period is relatively recent, dating from 1953. Copper was discovered in the district in 1865, and during the first active period of mining, 1912-30, nearly 60,000 tons was produced. The Anaconda Co. mapped, explored, and sampled the Yerington deposit from 1941 until 1945. It was not until 1952, however, that economic conditions warranted preparation of the property for large-scale, open pit mining, and the construction of ore treatment facilities at nearby Weed Heights.

Anaconda's Yerington project was started in November 1953 and in the following 9 years produced in excess of 250,000 tons of copper—more than four times the total produced in the district in the preceding 90 years. The bulk of production since 1953 was from oxidized copper ore. Sulfide ore, first mined in late 1961, will gradually become the major supply source as the oxide ores are mined out. Copper sulfide ore reserves are adequate for 20 to 25 years at the present rate of production.

Yerington is a disseminated copper deposit geologically similar in many respects to other porphyry copper deposits but with several interesting differences (Wilson, 1963).

Triassic volcanic and sedimentary rocks are the oldest rocks in the district. Intrusive into these are granodiorite and quartz monzonite of probable Cretaceous age. A porphyritic variety of the quartz monzonite is the principal host rock of the ore body. Overlying these rocks is a thick cover of volcanic rocks of Tertiary age, and detrital material.

The ore body conforms in general with the shape of the porphyry intrusive. Not all portions of the intrusive are mineralized, however, and some ore occurs in adjacent rocks. The primary sulfide minerals, pyrite and chalcopyrite, occur as disseminated grains and narrow discontinuous seams in the porphyry.

Unlike most porphyry copper deposits, the Yerington deposit was oxidized, mainly in place, to form economic concentrations of the copper silicate, chrysocolla, without much secondary enrichment. Also, there was an apparent absence of late mineralizing solutions with accompanying sulfide minerals and associated wall rock alteration.

#### MOUNTAIN CITY DISTRICT

The Mountain City district (No. 3) was discovered in 1869 and had produced more than \$1 million in silver by 1881. However, its major period of mining activity occurred more than 60 years later when the Rio Tinto mine was operated. In November 1931, after years of persistent effort under difficult operating conditions and with meager financial resources, a prospector-geologist, Mr. S. F. Hunt, discovered the high-grade Rio Tinto copper ore body. An exploration shaft, driven through 240 feet of barren gossan, encountered ore about at the depth predicted by Mr. Hunt. The International Smelting & Refining Co., subsidiary of the Anaconda Co., purchased the Rio Tinto mine from Mr. Hunt and associates, and developed it for mining under the corporate name of the Mountain City Copper Co. The mine yielded the highest grade copper ore produced in the United States during much of the period it was operated. By 1947 when the deposit was essentially mined out, about 898,500 tons of ore averaging 10.5 percent copper and yielding 94,900 tons of copper had been mined (Granger and others, 1957). Exploration failed to disclose additional ore bodies and the mine closed in September 1947.

The Rio Tinto ore body occurred in metamorphosed sedimentary rocks of Paleozoic age. The oxide zone consisted of a porous mass of quartz and iron oxides about 200 feet thick. The sulfide zone consisted of chalcopyrite, pyrite, and subordinate amounts of bornite enriched by secondary sooty chalcocite, covellite, and massive

chalcocite. Supergene enrichment extended below the oxide zone some 125 feet and locally as much as 175 feet. The intense supergene enrichment accounted for the unusual richness of the ore.

#### OTHER DISTRICTS

Other districts in the State have yielded copper mainly as a by-product or coproduct with lead, silver, zinc, gold, or other metals. The majority of these deposits may be classified as replacement deposits which occur commonly in limestone, sandstone, or shale near intrusive igneous rocks. Copper-bearing veins are not uncommon, and both types of deposits may be present in the same district.

#### FUTURE OUTLOOK

The future yield of copper from these deposits depends more upon production of the main mineral product than upon the copper content. However, possibilities for significant production of copper still exist despite extensive exploitation of known deposits. The histories of the Ely and Yerington districts indicate that their early production was derived from veins and replacement deposits—commonly more valuable for other metals than for copper. Cumulative knowledge of geologic environment, improved exploration techniques, favorable price, and ample capital resulted in recognition of the porphyry deposits. The same circumstances may result in the discovery and development of large deposits of the precious and base metals with which copper may be associated. Copper-bearing iron deposits in the Yerington district also are potential sources of coproduct or byproduct copper.

The fact that industry promptly began investigating clues to possible accumulations of metals of economic value as suggested in studies by Brokaw and others (1962) indicates that maintenance of Nevada's mineral resource base is not being neglected.

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#### GOLD

(By M. H. Bergendahl, U.S. Geological Survey, Denver, Colo.)

Gold was the lure that drew settlers across the wide plains to exploit the mineral-rich mountain ranges of our Western States. Nevada was on one of the main routes to the California gold fields; consequently, many curious gold seekers prospected mineralized parts of the bare, rugged mountain ranges that rose abruptly from the arid flats. Their successes attracted others from the overcrowded California mining areas, and Nevada soon became a major gold and silver producer.

The chief use of gold is in monetary systems as either coinage or as backing for currency. Considerable amounts are used also in the jewelry industry, in plating, binding, lettering, gilding, and interior decoration. Small amounts of gold are used in dentistry, the chemical industry, and glassmaking. In scientific instrumentation gold is used because of its infrared reflective properties and its resistance to corrosion.

Gold occurs in several forms in nature: as the native element associated with quartz or metallic sulfides, alloyed with silver as electrum, or as gold telluride minerals, the most common of which are calaverite, sylvanite, krennerite, and petzite. Gold also is found in rare natural compounds with mercury, bismuth, and chlorine.

The gold deposits of Nevada are related to several periods of igneous activity. The oldest deposits, in the western part of the State, are associated with satellitic bodies of the Sierra Nevada granitic batholith, which had been formerly considered of Late Jurassic age (Ferguson, 1929, p. 117), but more recently is thought to be mostly of Late Cretaceous age (Curtis and others, 1958, p. 10). In the eastern part of the State, gold deposits are related to granitic intrusives of Early Tertiary age along a belt of thrusting and folding. In the central part of the State gold deposits are found near scattered small intrusive masses of granitic rocks of undetermined age. Gold deposits are associated with two distinct periods of Tertiary volcanism—one in Miocene time and one in Pliocene time. Lacustrine beds, known in various localities as the Siebert, Esmeralda, and Truckee formations, separate the two series of volcanic rocks. Where these sedimentary formations are present they provide convenient markers; where they are absent, an unconformity separates the Miocene and Pliocene volcanic rocks (York, 1944, pp. 56, 57).

Distribution of most of the gold-producing areas is shown in figure 23, and production and salient geologic features of the major gold districts of Nevada are summarized in table 7.

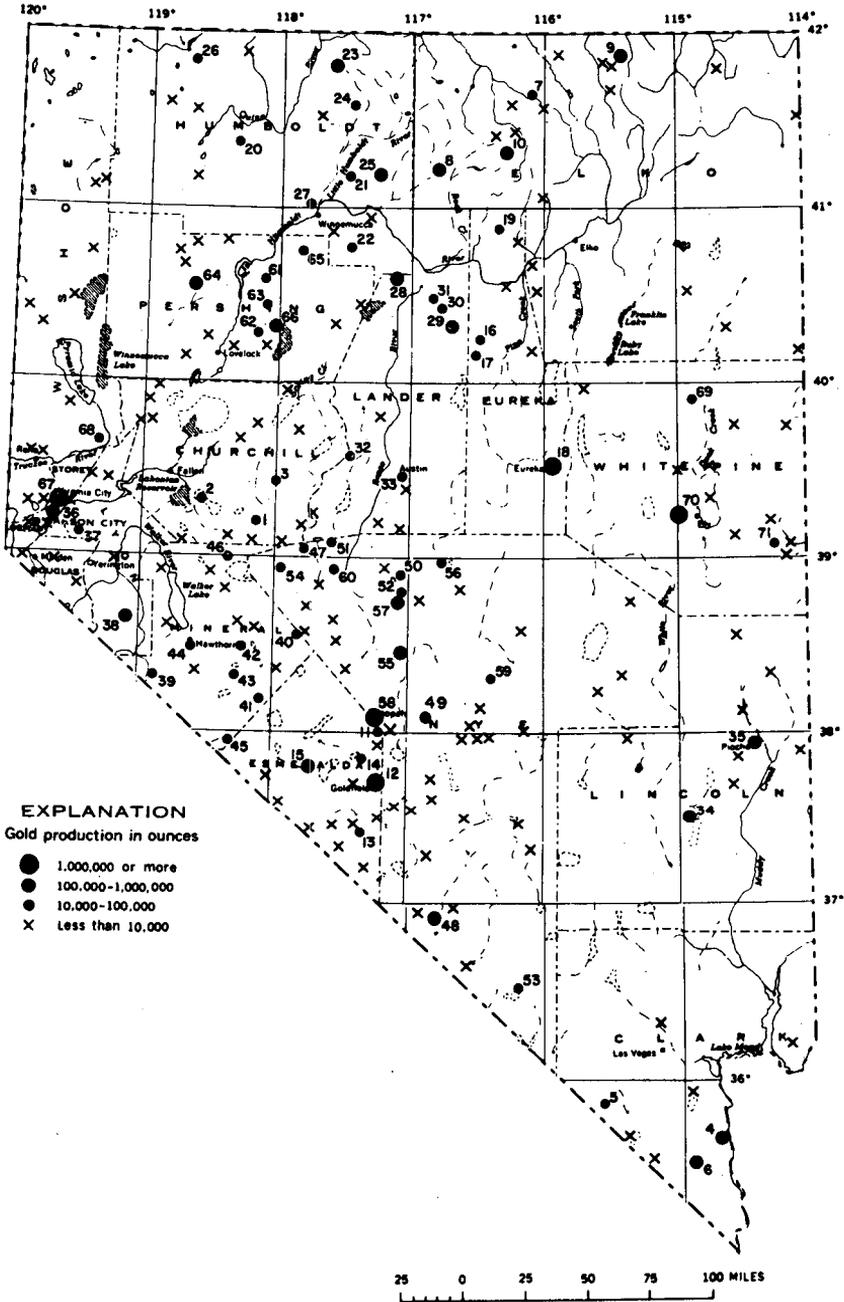


FIGURE 23 — Gold in Nevada (numbers refer to districts listed in table 7).

TABLE 7.—Major gold districts of Nevada

## CHURCHILL COUNTY

Map No. (fig. 23)	District	Manner of occurrence	Gold production in ounces	Remarks	References
1	Fairview.....	Fissure veins in Tertiary andesite.....	53,100 lode.....	Sporadic byproduct gold from silver ores.	Greenan, 1914, pp. 791-793; Vanderburg, 1937, pp. 23, 24.
2	Sand Springs.....	Ore bodies are in silicified zone in schist, limestone, and andesite.	20,875 lode.....	District is inactive, gold was byproduct of silver ores.	Vanderburg, 1937, pp. 40, 41.
3	Wonder.....	Veins in rhyolite in vicinity of dacite intrusive bodies.	73,890 lode.....	Byproduct gold from silver ore. Ratio of gold to silver 1 to 94.	Burgess, 1917, pp. 589-593; Vanderburg, 1937, pp. 54-57.

## CLARK COUNTY

4	Eldorado.....	Small fissure veins in Precambrian(?) schist and gneiss and Tertiary quartz monzonite.	101,729 lode, 168 placer.		Ransome, 1907, pp. 65-79.
5	Goodsprings.....	Pyritic fracture fillings in and near granitic dikes and sills.	58, 815 lode.....	Potosi mine is oldest mine in the State.	Hewett, 1931, pp. 9-90.
6	Searchlight.....	Veins in Precambrian(?) gneiss near contact with Tertiary quartz monzonite body.	246, 997.....	Most production has been from Duplex and Quartette mines.	Callaghan, 1939, pp. 140-165.

## ELKO COUNTY

7	Edgemont.....	Fissure veins in contorted and fractured quartzite.	About 48,500 lode.....	Practically dormant since 1907..	Emmons, 1910, pp. 75, 76.
8	Gold Circle.....	Veins in shear zones in the older of 2 Tertiary rhyolite flows.	109,765 lode, 45 placer.		Rott, 1931.
9	Jarbidge.....	Gold-bearing fissure veins in the older of 2 Tertiary rhyolites.	217,800 lode.....	Most valuable deposits were in veins that strike northwest.	Schrader, 1912, p. 15; 1915, pp. 12-35.
10	Tuscarora.....	Most of the gold came from quartz and adularia fissure fillings and zones of quartz stringers in bedded pyroclastics.	At least 100,000 lode and placer.	High-grade gold ore exhausted by 1886. Low-grade ores mined from 1895-1912.	Nolan, 1936.

## ESMERALDA COUNTY

11	Divide.....	Mineralized fracture zones in Tertiary rhyolite breccia.	26,500 lode.....	Gold is byproduct of silver ores.	Knopf, 1921(a), pp. 148-170.
12	Goldfield.....	Most of the deposits are in silicified zones in Lower Tertiary dacite flows that were warped into a dome and then faulted.	4,195,000 lode.....	Bonanza ore was extremely rich in gold.	Ransome, 1909(a).
13	Hornsilver.....	Veins in calcareous shale near a granite intrusive...	25,000 lode.....	Native gold and silver chloride were main constituents of ore.	Ransome, 1909(b).

14	Lone Mountain.....	Oxidized replacement deposit in limestone near diorite porphyry sheets.	32,000 lode.....	Gold a byproduct of silver ores..	Ball, 1906, pp. 57, 58.
15	Silver Peak.....	Gold-bearing quartz lenses in Paleozoic limestone beds. Deposits are related to an alaskite intrusive of late Jurassic or early Cretaceous age.	568,000 lode.....	First discoveries were silver deposits. Gold deposits were found later and accounted for most of the production.	Nolan, in Hewett, 1936, p. 60; Spurr, 1906.

## EUREKA COUNTY

16	Buckhorn.....	Deposits are along a nearly vertical fault in basalt and interbedded scoria.	39,500 lode.....	Total production of district came principally from Buckhorn mine.	Vanderburg, 1938(a), pp. 19-21
17	Cortez.....	Replacement bodies in limestone of probable Cambrian age and quartzite of probable Ordovician age.	48,700 lode.....	Gold a byproduct of argentiferous lead ore.	Emmons, 1910, pp. 101-104; Vanderburg, 1938(a), pp. 23, 24.
18	Eureka.....	Most production has been from irregularly shaped base metal replacement deposits in Paleozoic dolomite.	1,230,000 lode.....	Large quantities of silver and lead also were produced.	Nolan, 1962.
19	Lynn.....	Gold placers derived from erosion of auriferous quartz stringers in siliceous shale and chert.	9,000 placer.....	Area includes Lynn, Simon, Rodeo, and Sheep Creeks.	Vanderburg, 1936, p. 83; Roberts, 1960, p. 19.

## HUMBOLDT COUNTY

20	Awakening.....	Thin gold-bearing quartz veins in Mesozoic slates in vicinity of a quartz monzonite intrusive.	25,700 lode minimum.....	Jumbo mine, chief mine of district, is characterized by abundant adularia in gangue.	Calkins, 1938, pp. 9-22.
21	Dutch Flat.....	Placers in stream and slope wash gravels. Gold-bearing quartz veins are of minor importance.	About 10,000 placer.....		Willden and Hotz, 1955, pp. 661-668.
22	Gold Run.....	Replacement ore bodies in limestone beds and along fault zones.	24,000 lode, 2,000 placer.....	Gold a byproduct of copper and silver ores.	Vanderburg, 1938(b), p. 24.
23	National.....	Gold- and silver-bearing fissure veins believed to be of Miocene age or younger.	177,000 lode.....	Most veins are valued for silver, but some rich gold ore was worth \$30 per pound.	Lindgren, 1915.
24	Paradise Valley.....	Silver-rich quartz veins in shale, calcareous slate, and porphyry.	73,400 lode.....	Byproduct gold from silver lodes.	Vanderburg, 1938(a), pp. 38-40.
25	Potosi.....	Sheetlike ore bodies rich in gold along north-trending Getchell fault. Abundant realgar and orpiment in ore.	486,000 lode.....	Geochemical anomalies show relationship of arsenic, mercury and tungsten, and these are worthy of exploration for gold (R. L. Erickson, oral communication).	Joralemon, 1951, pp. 267-310; Hotz and Willden, 1961.
26	Warm Springs.....	Gold-bearing quartz veins in granite.....	24,000 lode.....	Ashdown mine chief mine in district.	Vanberg, 1938(b), p. 49.
27	Winnemucca.....	Gold- and silver-bearing veins and replacement deposits in Triassic hornfels, limestone, and slate.	35,000 lode.....		Ferguson and others, 1951; Vanderburg, 1938(b), pp. 51-54.

TABLE 7.—Major gold districts of Nevada—Continued

LANDER COUNTY					
Map No. (fig. 23)	District	Manner of occurrence	Gold production in ounces	Remarks	References
28	Battle Mountain.....	Gold deposits in quartz-pyrite veins with native gold. Gold also occurs in copper sulfide veins. Other deposits are silver-lead fracture fillings and quartz-stibnite veins.	150,280 combined placer and lode minimum production.	Gold was mainly a byproduct of copper and silver ores before 1932. After 1932, copper and silver were chief commodities.	Hill, 1915, pp. 66-76; Vanderburg, 1939, p. 19-20; Roberts, 1951; 1960, p. 19.
29	Bullion.....	Fissure veins in sedimentary rocks, granodiorite, andesite. Goldacres ore body is in a breccia zone along the Roberts Mountains thrust.	146,200 lode, 10,400 placer.	Goldacres open pit mine has been an important gold producer in recent years.	Lincoln, 1923, p. 111; Vanderburg, 1939, p. 39; Roberts, 1960, p. 19.
30	Hilltop.....	Gold-bearing quartz stringers and masses of pyrite and galena containing silver and gold in fractured quartzite cut by porphyry bodies.	17,900 mostly lode.....	Silver, lead, copper are byproducts of gold ore.	Lincoln, 1923, p. 111, 112; Vanderburg, 1939, p. 47.
31	Lewis.....	Fissure veins containing auriferous pyrite in quartzite and granodiorite porphyry. Silver replacement deposits in limestone.	51,000 lode.....	Pittsburg and Morning Star mines chief gold producers.	Emmons, 1910, pp. 122-123 Vanderburg, 1939, p. 59.
32	New Pass.....	Gold-bearing quartz veins in gabbro.....	16,000 lode.....		Lincoln, 1923, p. 114; Vanderburg, 1939, p. 65.
33	Reese River.....	Veins containing silver minerals in joints in lower Tertiary quartz monzonite and along bedding planes in quartzite of tentative Cambrian age.	Probably a minimum of 10,000 lode.	Primarily a silver district with minor byproduct gold.	Ross, 1953; Vanderburg, 1939, p. 69.
LINCOLN COUNTY					
34	Delamar.....	Deposits are: (1) quartzite breccia containing comb quartz, sulfides, and gold, (2) small veins containing gold and sulfides, (3) bedded quartzite containing gold in small fractures and along bedding planes.	217,200 lode.....	Delamar mine has been one of the major gold mines in the state.	Callaghan, 1937.
35	Pioche.....	Deposits are: (1) silver-bearing fissure veins in Cambrian quartzite, (2) lenses and pods of silver minerals in granite porphyry dikes, (3) sulfide replacement deposits in limestone and dolomite of Cambrian age.	105,000 lode minimum.	Gold has been a byproduct of silver-lead-zinc-copper ores.	Westgate and Knopf, 1932; Young, 1950, pp. 111-120.

LYON COUNTY

36	Silver City.....	Gold and silver ores in veins in a shear zone of late Tertiary age.	143,500 lode, 46,500 placer.	Veins are southern extension of Comstock Lode.	Stoddard and Carpenter, 1950, p. 81; Couch and Carpenter, 1943, pp. 93, 94; Gianella, 1936, Vanderburg, 1936, p. 12.
37	Como.....	Quartz veins containing gold, silver, and copper in Tertiary volcanic rocks.	10,000-15,000 lode.....		Stoddard and Carpenter, 1950, pp. 76, 77.
38	Wilson.....	Lenses of quartz and pyrite containing gold and silver in a crushed zone in quartz monzonite.	408,000 lode.....		Hill, 1915, pp. 134-136; Stoddard and Carpenter, 1950, p. 96.

MINERAL COUNTY

39	Aurora.....	Gold- and silver-bearing quartz veins in biotite-quartz latite and andesite.	93,600 lode minimum.....	Early production records incomplete.	Hill, 1915, pp. 141-150; Vanderburg, 1937(b), pp. 14, 15.
40	Bell.....	Gold-bearing quartz veins in rhyolite and Triassic sedimentary rocks.	34,000 lode.....	Silver-lead ores also mined in district.	Knopf, 1921, pp. 377-381; Ross, 1961, table 6.1; Vanderburg, 1937(b), p. 19.
41	Candelaria.....	Mineralized fault zones with silver- and gold-bearing sulfides. Ore mined in early days was oxidized.	13,000 lode minimum. Early production may have been much greater.	Gold a minor byproduct of rich silver ores.	Knopf, 1922, pp. 1-22; Page, 1959.
42	Garfield.....	Quartz veins in volcanic rocks of Permian and possible Triassic age, and in limestone of Triassic age.	10,000-50,000 lode.....	Early production data was in value of combined silver and gold.	Ross, 1961, p. 82; Vanderburg, 1937(b), p. 33.
43	Gold Range.....	Veins of Pliocene age that branch out from 2 major faults. Deposits are in Triassic and Jurassic sedimentary rocks and Tertiary rhyolite.	97,000 lode.....	Tungsten and silver produced from some deposits.	Ferguson and others, 1954(a).
44	Hawthorne.....	Sulfide veins in granodiorite intrusive and contact metamorphosed invaded limestone.	10,000 lode, but early output was probably several times this amount.	Gold is byproduct of silver ores mostly from Pamlico and La Panta mines.	Hill, 1915, pp. 151-157 Vanderburg, 1937(b), pp. 36-38.
45	Mount Montgomery and Oneota.	Quartz veins containing gold and silver in Tertiary volcanic rocks.	At least 10,000 from lodes—possibly several times this amount.	Large amounts of silver were produced from this district.	Ross, 1961, pp. 65, 80; Vanderburg, 1937(b), pp. 47-49.
46	Rawhide.....	Deposits are in network of veinlets in rhyolite, dacite, and andesite. Kaolinized rhyolite seems to be most strongly mineralized.	51,000 lode, 2,000 placer.		Vanderburg, 1936, pp. 120-121; Vanderburg, 1937(b), pp. 58-64.

NYE COUNTY

47	Bruner.....	Gold- and silver-bearing quartz veins in Tertiary volcanic rocks.	17,200 lode.....	Penelas mine chief producer.....	Kral, 1951, p. 26.
48	Bullfrog (Rhyolite)...	Crustified gold-bearing quartz-pyrite veins in Tertiary rhyolite.	120,400 lode.....	Considerable silver produced as a byproduct.	Kral, 1951, p. 29; Ransome, Emmons, and Garrey, 1910.

TABLE 7.—Major gold districts of Nevada—Continued

## NYE COUNTY—Continued

Map No. (fig. 23)	District	Manner of occurrence	Gold production in ounces	Remarks	References
49	Ellendale.....	Irregular veins filled with gold-bearing iron-stained quartz in rhyolite near its contact with andesite porphyry.	Roughly 8,000-20,000 lode.		Kral, 1951, p. 56; Ferguson, 1917, pp. 122-123.
50	Gold Hill.....	Gold-bearing quartz vein in rhyolite.....	At least 25,000 lode....		Couch and Carpenter, 1943, p. 120; Ferguson and Cathcart, 1954.
51	Jackson.....	Quartz-sulfide veins in metaandesite of Carboniferous (?) age.	Roughly 24,000-48,000 lode.	Production data largely estimated.	Kral, 1951, p. 76.
52	Jefferson Canyon.....	Sulfide vein along contact of Ordovician limestone and Tertiary porphyry.	No reliable production data, probably 20,000-25,000 lode.	Both gold and silver were important products.	Lincoln, 1923, p. 171; Kral, 1951, pp. 80-81.
53	Johnnie.....	Gold-bearing quartz veins in Cambrian quartzite, shale, limestone, and conglomerate.	40,000	Johnnie mine chief producer.....	Nolan, in Hewett and others, 1936, p. 69; Kral, 1951, pp 86, 87.
54	Lodi.....	Lead-silver replacement deposits in Triassic limestone, mineralized fault fissures.	Production records are incomplete; production probably 10,000-20,000 ounces.	Gold is byproduct of silver-lead ores. Some tungsten and talc have been produced.	Kral, 1951, pp. 93-96; Couch and Carpenter, 1943, p. 113.
55	Manhattan.....	Ore bodies are in Cambrian limestone and quartzose schist in hanging wall of thrust. Placers are in gravels in Manhattan Gulch.	280,000 lode, 206,000 placer.	Primarily a gold district with silver as byproduct.	Ferguson, 1924; Ferguson and Cathcart, 1954.
56	Northumberland.....	Deposits are in a carbonaceous shale bed 60-70 feet thick in vicinity of roof of monzonite intrusive.	35,400 lode.....	Most gold came from open pit mining from 1939-42.	Kral, 1951, pp. 135-136.
57	Round Mountain.....	Complex gold-bearing fissure veins of Tertiary age.	About 390,000 lode, 150,000 placer.	Large-scale placer operations, 1950-59.	Kral, 1951, p. 144; Ferguson and Cathcart, 1954; Ferguson, 1922, pp. 383-406.
58	Tonopah.....	Replacement veins in faults in Tertiary volcanic rocks.	1,880,000 lode.....	Primarily a silver district.....	Nolan, 1935; Lincoln, 1923, p. 186.
59	Tybo.....	Tabular replacement bodies in dikes of quartz latite porphyry along a major fault.	27,300 lode.....	Gold is a byproduct of lead-silver ores.	Kral, 1951, p. 189; Ferguson, 1933.
60	Union.....	Veins in Tertiary volcanic rocks and Carboniferous metaandesite.	At least 10,000 lode before 1900.	District produced mainly mercury after 1907.	Lincoln, 1923, p. 196; Kral, 1951, pp. 196-200.

## PERSHING COUNTY

61	Humboldt.....	Gold- and silver-bearing quartz vein in shale, quartzite, and limestone of probable Triassic age.	35,500 lode.....	Considerable silver produced from district.	Ransome, 1909(b), p. 46; Vandenburg, 1936, pp. 16, 17.
62	Rochester.....	Silver-bearing quartz veins, silver-bearing stockworks, gold-bearing veins, all in Triassic volcanic rocks.	70,000 lode, 4,500-50,000 placer.	Lode gold byproduct of silver ores. Gold placers in Limerich and American Canyons were productive before 1900.	Ransome, 1909(b), p. 12; Knopf, 1924.

63	Rye Patch.....	Irregular fissures in Triassic limestone filled with brecciated wall rock, quartz, calcite, and ore minerals.	About 10,000 lode.....	Primarily a silver district.....	Lincoln, 1923, p. 204; Vanderburg, 1936(a), p. 33.
64	Seven Troughs.....	Mineralized breccia zones and fissures in Tertiary volcanic rocks.	160, 200 lode.....		Ransome, 1909(c), pp. 16-25.
65	Sierra.....	Gold-bearing quartz-sulfide veins that are associated with diabase dikes in volcanic rocks.	194,000 placer, 47,000 lode.	Placers were productive in 1880's and 1890's.	Vanderburg, 1936, pp. 39, 156; Ransome, 1909(c), pp. 50-51.
66	Spring Valley.....	Lodes have had insignificant production.....	534,000 placer.....	Placers in American and Limerick Canyons and Spring Valley were productive before 1900.	Vanderburg, 1936(a); p. 42; Ransome, 1909(c), p. 12.
STOREY COUNTY					
67	Comstock.....	Mineralized shear zone several hundred feet wide, Y-shaped in cross section and 13,000 feet long. Country rock consists of Triassic sedimentary and volcanic rocks, Jurassic quartz monzonite, Tertiary volcanic rocks.	8,560,000 lode; unrecorded amount of placer gold in 1850's.	Primarily silver district; large-scale mining of low-grade ores after World War II.	Smith, 1943; Lincoln, 1923, pp. 223-226; Stoddard and Carpenter, 1950, pp. 22-30, 55-73; Coats, 1956, pp. 532-534; Giannella, 1936; Becker, 1882.
WASHOE COUNTY					
68	Olinghouse.....	Zones of altered Tertiary andesite adjacent to intrusive rhyolite.	36,000 lode.....		Hill, 1910, pp. 103-105; Vanderburg, 1936, pp. 164-166; Lincoln, 1923, p. 240; Overton, 1947, pp. 71-72.
WHITE PINE COUNTY					
69	Cherry Creek.....	Veins in Cambrian quartzite near small quartz monzonite and diabase intrusives.	36,200 lode.....	Gold a byproduct of silver-lead ores. Tungsten has been produced in 1950's.	Lincoln, 1923, p. 243.
70	Ely.....	Blanketlike masses of supergene enriched pyritized monzonite porphyry.	1,960,000 lode.....	Silver lead-gold ores were mined before 1906. After 1908 copper with byproduct gold was mined from porphyry ores.	Spencer, 1917.
71	Osceola.....	Mineralized sheeted zones and shattered zones in Cambrian quartzite.	91,600 placer, 40,100 lode.	Bulk of placer and lode output occurred before 1907.	Weeks, 1908.

The gold deposits may be classified in a general fashion as (1) veins, replacement deposits, and disseminated deposits in volcanic rocks; (2) veins and replacement deposits in carbonate rocks; (3) deposits in intrusive rocks; (4) contact metamorphic deposits; and (5) placers.

Large quantities of gold are extracted as a byproduct from many veins, replacement deposits, and contact metamorphic deposits mined for silver, lead, zinc, and copper. In western Nevada, for example, many silver veins yield considerable gold, whereas in the eastern part of the State, lead-zinc-silver replacement deposits have been the main source of gold. Large-scale operations in the disseminated copper deposits of the Ely district, also in eastern Nevada, have contributed sufficient byproduct gold to make this district a major gold producer since World War II.

### DEPOSITS IN VOLCANIC ROCKS

Typical of deposits in volcanic rocks are the epithermal-type veins of Comstock (No. 67, table 7, fig. 23), Goldfield (No. 12), Tonopah (No. 58), and Round Mountain (No. 57).

The ore minerals were deposited from hydrothermal solutions penetrating fractures, faults, or shear zones in volcanic rocks of Miocene or Pliocene age. Some veins are characterized by crustified, banded, and comb textures—criteria of open-space fillings; in other veins considerable replacement of the wall rock with ore and gangue minerals occurred. The typical ore mineralogy of these deposits consists of stibnite, argentite, cinnabar, realgar, orpiment, silver sulfarsenides and sulfantimonides, native gold, pyrite, galena, sphalerite, and chalcopyrite. Gangue minerals are chalcedonic quartz, rhodochrosite, adularia, calcite, dolomite, barite, and fluorite.

Shallow fissure veins in volcanic rocks in the Goldfield district have yielded more than 4 million ounces of gold. According to Ransome (1909, pp. 32-74), the oldest rocks in the district are dark flinty shale and quartzite of Cambrian age, into which were intruded masses of alaskite and granite of probable Early Cretaceous age. These rocks are overlain unconformably by a section of volcanic rocks including latite, rhyolite, andesite, dacite, and basalt. A series of lacustrine sedimentary rocks called the Siebert Tuff overlies the volcanic sequence unconformably and is in turn overlain by welded ash flows and basalt. The gold deposits were formed prior to deposition of the Siebert Tuff. Most deposits are in topographically prominent silicified zones of small intersecting, ramifying shears in the dacite. Other deposits occur in andesite, and a few are in rhyolite (Ransome, 1909, pp. 150-155). The ores are complex sulfides consisting of pyrite, bismuthinite, goldfieldite, and a mineral resembling famatinitite in a dark-gray flinty quartz gangue. Alunite is a common gangue in some ore. Native gold, commonly very fine grained, is associated with these minerals. Characteristic of the ore is its concentric banded texture, its extreme richness, and the erratic behavior of the ore shoots (Ransome, 1909, pp. 165-167).

## VEINS AND REPLACEMENT DEPOSITS IN CARBONATE ROCKS

Widespread and, in places, significant ore bodies of gold-bearing sulfides have been formed by the selective replacement of limestone and dolomite beds by upward migrating hydrothermal solutions. These ore bodies are irregularly shaped masses of sulfides that extend outward from fractures along bedding planes or along subsidiary fractures in the country rock. Common ore minerals are silver-bearing galena, pyrite, sphalerite, chalcopyrite, pyrrhotite, stibnite, tetrahedrite, argentite, tennantite, enargite, and bornite. Gold is usually extremely fine grained in these deposits, and most of it occurs in the pyrite. Gangue minerals are dolomite, cherty quartz, calcite, barite, and clay minerals. The richest ore is in the oxidized zone, where the gold and silver have been concentrated by weathering, and the primary sulfides have been transformed to sulfates and carbonates. In many deposits a zone of supergene sulfide enrichment occurs at the base of the oxidized zone. In such places, rich ore bodies of chalcocite, bornite, covellite, argentite, and silver sulfarsenides and sulfantimonides are formed.

Small quantities of gold have come from veins and replacement deposits in carbonate rocks from numerous districts; the most productive of which have been those in the Eureka (No. 18), Pioche (No. 35), Silver Peak (No. 15), and Manhattan (No. 55) districts. Replacement deposits in the Eureka district have yielded more than 1,200,000 ounces of gold from ores that were mined mainly for silver and lead. The district is underlain by a thick section of sedimentary rocks consisting of quartzite, limestone, and shale of Paleozoic age, overlain unconformably by scattered outcrops of Lower Cretaceous sedimentary rocks. Igneous rocks in the district range in age from Cretaceous to Quaternary and consist of quartz diorite, quartz porphyry, hornblende andesite, rhyolite, rhyolite tuff, andesite, and basalt (Nolan, 1962, pp. 9-17). The district has been interpreted as a series of structural blocks separated from one another by faults of large displacements. Nearly all of the ore bodies of the district are within the north-trending Prospect Ridge block, which is bounded on the east by the Hoosac fault and on the west by the Dugout Tunnel thrust, and the Spring Valley, Sharp, and Cave Canyon faults. Recognized within the Prospect Ridge block are three thrust zones, two normal fault zones, and a transverse fault (Nolan, 1962, pp. 18-29). The greater part of the deformation is thought to have occurred in the late Mesozoic, though the older structures were formed in Paleozoic time, and movement of some faults took place in Pleistocene or Recent time (Nolan, 1962, pp. 27-29).

Ore bodies at Eureka are grouped into five geographic groups or clusters, the most productive of which has been the Ruby Hill cluster. Most of the ore has been mined from irregular replacement deposits in dolomite. Such deposits consist of irregularly shaped masses of fine-grained anglesite, cerussite, plumbojarosite, mimetite, and galena, with minor wulfenite, pyrite, arsenopyrite, hematite, sphalerite, calamine, smithsonite, calcite, aragonite, siderite, quartz, clay minerals, azurite, and malachite. Cerargyrite and native gold are present in small quantities. Gold ore from the Windfall mine is distinctive in that textures of the replaced dolomite have been preserved, and the dolomitic gangue has been converted to a "sand" by the mineralizing

solutions. The Windfall ore is further characterized by relative absence of sulfides and their oxidation products (Nolan, 1962, pp. 30-47).

#### DEPOSITS IN INTRUSIVE ROCKS

In the Reese River district (No. 33) a pluton of quartz monzonite of early Tertiary age cuts Cambrian quartzite and is overlain by Tertiary dacite flows and welded tuffs. The ore deposits are veins in joints in the quartz monzonite and along bedding planes in the quartzite (Ross, 1953, p. 23). The district produced large amounts of silver, but relatively small quantities of gold.

The Wilson district (No. 38), which produced more than 400,000 ounces of gold, is underlain by quartz monzonite very similar to the Sierra Nevada batholith (Hill, 1915, pp. 134 and 135). The ore consists of lenses of quartz and pyrite in a shear zone in the monzonite.

The Ely district (No. 70), having produced about 2 million ounces of gold, is the most important of this class of deposits. Complexly faulted and folded Paleozoic sedimentary rocks were intruded by bodies of monzonite porphyry. After a long period of erosion the rocks were covered with upper Tertiary rhyolite flows, tuff, and agglomerate (Spencer, 1917, pp. 23-130). The ore bodies are blanketlike masses of supergene-enriched pyritized monzonite porphyry; the chief ore mineral is chalcocite.

#### CONTACT METASOMATIC DEPOSITS

Sedimentary rocks adjacent to the intrusive usually show some degree of alteration due to replacement and thermal effects of the igneous body. This alteration ranges from a relatively inconspicuous baking or hardening to a thorough transformation of the original rock to masses of hornfels, skarn, or quartzite, depending upon the original composition of the rock. In places hydrothermal solutions have formed ore bodies in these altered rocks by the deposition of metallic sulfides and oxides.

The contact metasomatic deposits of Nevada are not important sources of gold. In the Hawthorne district (No. 44), small amounts of gold were produced as a byproduct of a silver-rich galena-tetrahedrite-pyrite vein in a skarn of garnet, tremolite, diopside, quartz, and calcite adjacent to a grandodiorite mass. The vein cut both the skarn and intrusive (Hill, 1915, pp. 151 and 152).

In the Olinghouse district (No. 68), native gold, silver chloride, chalcopyrite, pyrite, calcite, and quartz occur in altered andesite adjacent to intrusives of porphyritic rhyolite and later andesite (Hill, 1911, pp. 104 and 105; Overton, 1947, p. 71).

#### PLACERS

Gold-bearing placers occur in stream gravels, where the gold has been separated and concentrated through the action of moving water. In general, the placers of Nevada have been of relatively minor economic importance; however, those in the Spring Valley district (No. 66) produced more than 500,000 ounces, and others at Manhattan (No. 55) and Round Mountain (No. 57) yielded 200,000 and 100,000 ounces, respectively.

## PRODUCTION AND OUTLOOK

Nevada is the fifth largest gold-producing State, with a total output of 27,057,000 ounces from 1859 to 1962. The State ranked seventh in production in 1962, when only 62,863 ounces were mined.

The gold mining industry in Nevada exemplifies the general trend of gold production in the United States, which has steadily declined from a high of more than 4.5 million ounces in 1940 to 1.5 million ounces in 1962 (U.S. Bureau of Mines preliminary data), the lowest peacetime output since 1884. This may be contrasted with the world gold production of 50 million ounces in 1962, a record high. Factors responsible for diminishing production of gold in the United States are the gradual depletion of high-grade deposits and constantly increasing costs under a fixed selling price of \$35 per ounce. As a result of this situation, a steadily increasing portion of domestic gold output is a byproduct of base metal mines.

Figure 24 shows Nevada's gold-mining history since 1880 in terms of annual production. Most of the bonanza production of the Comstock (No. 67, fig. 23) occurred before systematic annual records were kept; consequently, the impact of this district cannot be shown. The high production from 1906 to 1916 is due mainly to the tremendous output of Goldfield (No. 12) during this period. After the decline of Goldfield, gold mining generally waned in the 1920's and early 1930's, but during this period there occurred a marked transition in the source of gold from predominantly gold-bearing lodes to byproduct gold, mainly from the copper ores of Ely (No. 70). With the increase in the price of gold from \$20.67 to \$35 per ounce in 1934, interest in gold mining was renewed, and many lode districts were reopened. The large output of the Getchell mine in Potosi district (No. 25) is reflected in the peak of almost 400,000 ounces in 1940. The post-World War II period has been one of general diminishing activity, marked by short-lived spurts of production due to large-scale placer operations at Round Mountain (No. 57), large-scale open pit mining at the Goldacres pit in the Bullion district (No. 29), and at the Getchell mine (No. 25), in addition to significant sustained amounts of byproduct gold from Ely.

Under current high costs, plus the fixed price of gold, a revival of gold mining in Nevada comparable to the 1906-16 era hardly seems likely. The known rich bonanza ore bodies are, for the most part, exhausted. Any significant increase in gold output will probably be either from byproduct gold or from large-scale mining of low-grade lode or placer gold deposits. Rejuvenation of silver and silver-lead mining in such districts as Comstock, Tonopah, and Eureka, or a sharp increase in copper output at Ely would most certainly boost gold production to several times its current rate.

The closing of the Goldacres open pit mine in 1961 marked the end of significant production from lode gold mines in Nevada; however, the recent resumption of activity at the Getchell mine in the Potosi district may very well herald a new approach to gold mining wherein high costs are combated by bold and imaginative planning and a willingness to invest in and develop techniques for mining large low-grade ore bodies, for extracting gold and all useful byproducts from complex ores, and for exploring for concealed ore bodies.

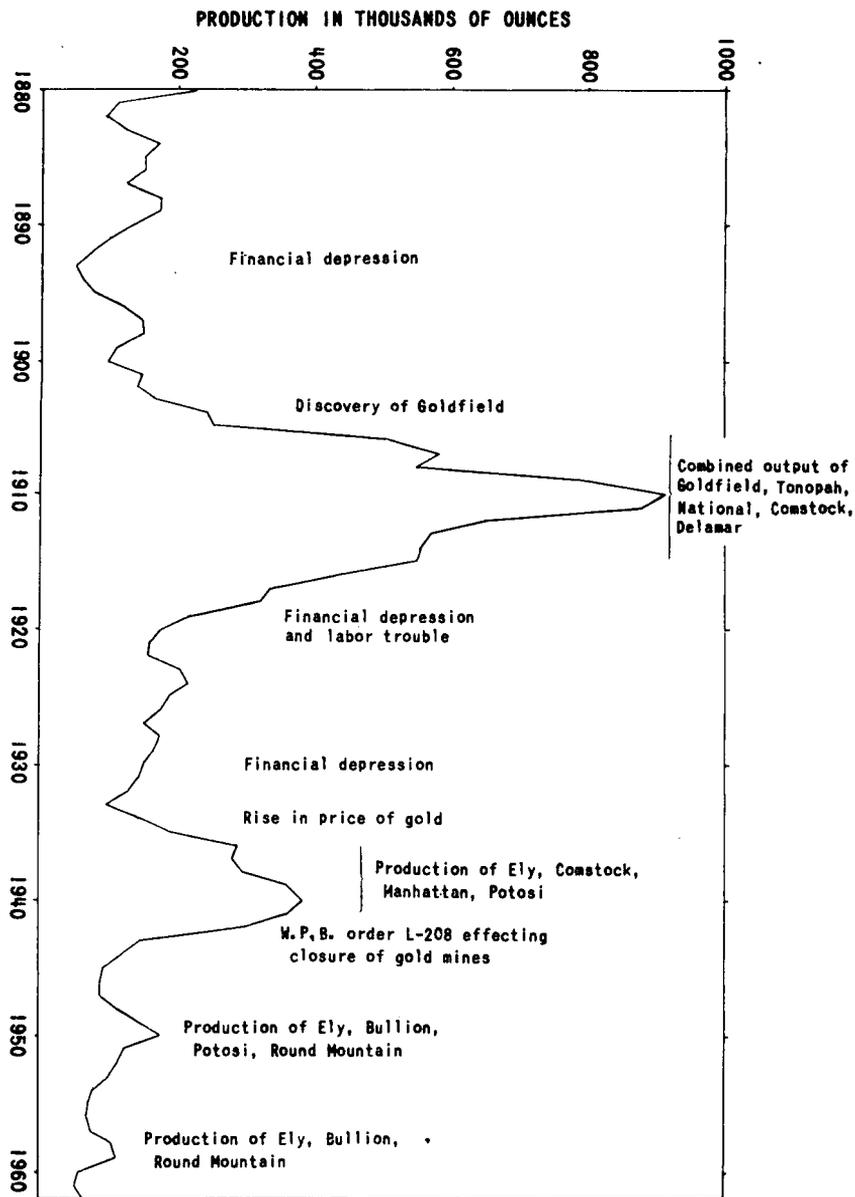


FIGURE 24.—Gold production in Nevada, 1880–1962.

## IRON

(By R. G. Reeves, U.S. Geological Survey, Washington, D.C.)

Iron ore is one of the essential raw materials for the production of the iron and steel on which modern industrial economies are based. The vast quantities of iron and steel produced annually in the United States require large amounts of iron ore, coal (of coking quality), and water, and lesser amounts of limestone and other mineral raw materials. Because of this need for large quantities of raw materials, which in 1962 amounted to more than 94 million tons of iron ore and almost 47 million tons of coke, the iron and steel industries are centered in areas where iron ore, coal, or both are located, or where they can be brought together easily and inexpensively. The principal centers of iron and steel production in the United States are in the States bordering the Great Lakes or along the Middle Atlantic seaboard. The two largest centers of production in the Western United States are at Fontana, Calif., 50 miles east of Los Angeles and near Provo, Utah, 30 miles south of Salt Lake City.

Intensive worldwide search following World War II resulted in the discovery of enormous quantities of high-grade iron ore in Canada, Africa, South America, and Australia. A number of deposits are being mined and others are being developed; this, along with the rapid increase in beneficiation of low-grade ores into premium quality blast furnace feed, has brought about a temporary oversupply of iron ore and intense competition among ore suppliers. Moreover, locations of existing centers of iron ore consumption are not particularly favorable for the utilization of Nevada iron ore. Although Nevada iron-ore deposits are within economical rail transport distance of the western steel production centers they have not as yet been drawn upon appreciably, because adequate sources of ore are available closer at hand. Most of Nevada iron ore has been shipped abroad to Japan; a smaller but sizable amount has been shipped to the Central and Eastern United States.

Past development of known Nevada iron-ore deposits has been limited in part by their small size and in part by their geographical location and has depended on special economic and political conditions. Several of them were readily available sources of iron ore for the limited wartime demand and later for export to Japan during the Korean war, owing to their proximity to the two transcontinental rail lines that cross Nevada, which provide economical transportation to Pacific coast ports.

In recent years the possibility of expansion of iron- and steel-making facilities on the Pacific coast has led to intensive exploration for iron ore in Nevada. This exploration, using airborne and ground magnetic surveys coupled with regional and local geologic mapping, has resulted in significant discoveries. Chief among them are hidden deposits in the valleys surrounding the Buena Vista Hills (No. 6, fig. 25, and table 8), Churchill-Pershing Counties, and in the foothills of the Wassuk Range east of Yerington (No. 22), Lyon County. Beneficiation studies indicate that low-grade, high sulfur- or copper-bearing material can be used to produce a competitive blast furnace feed. Resources are estimated at one-half to 1 billion tons of material averaging 40 percent or more iron.

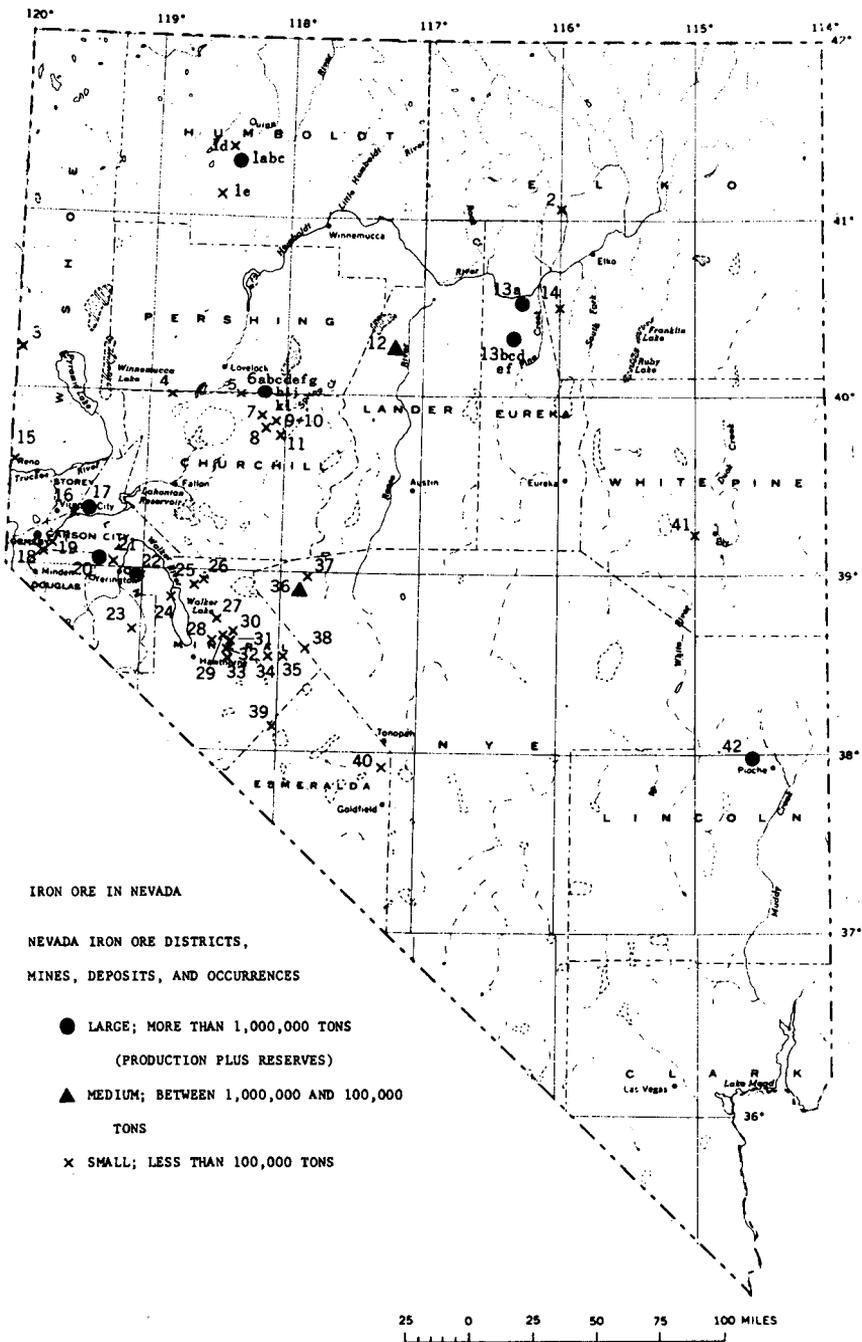


FIGURE 25.—Iron in Nevada (numbers refer to deposits or districts listed in table 8).

TABLE 8.—Iron ore districts, mines, deposits, and prospects in Nevada

Map No. (fig. 25)	District, mine, deposit, or prospect	County	Type of deposit	Production	Reference
1	Jackson Mountains	Humboldt	Magnetite and some hematite replacement bodies in metavolcanic rock.	Large	Shawe, Reeves, and Kral, 1962, pp. 103-110.
a	Iron King mine.				
b	Redbird mine.				
c	Black Jack mine.				
d	Jackson-Iron King prospect.				
e	Low prospect.				
2	Iron Hood prospect	Elko	Pyrometamorphic (contact metamorphic) magnetite deposit in limestone.	None	Emmons, 1910, p. 86; Horton, 1962.
3	Black Hawk prospect	Washoe	Magnetite veins in metavolcanic rock.	do	
4	Basalt prospect	Churchill-Pershing	Pyrometamorphic magnetite deposit in limestone.	do	Shawe, Reeves, and Kral, 1962, pp. 116-117.
5	Piute prospect	Pershing		do	Horton, 1962.
6	Buena Vista Hills	Churchill-Pershing	Replacement and vein deposits of magnetite in altered diorite and metavolcanic rock.	Large	Reeves and Kral, 1955; Kral, 1947a, 1947b.
a	Thomas mine.				
b	American Ore-Parker mine.				
c	Iron King-Ford mine.				
d	Beacon Hill prospect.				
e	Seegerstrom-Heizer mine.				
f	American Ore Mine.				
g	Buena Vista mine.				
h	Young Anomaly prospect.				
i	Consolidated Minerals mines.				
j	Iron Castle mine.				
k	Iron Hat mine.				
l	Phoenix group mine.				
7	Black Joe prospect	Churchill	Magnetite-calcite veins in greenstone.	None	Shawe, Reeves, and Kral, 1962, p. 118.
8	Coppereid prospect	do	Lenses of specularite and pyrite along shear zones in sedimentary rocks.	Small	Shawe, Reeves, and Kral, 1962, p. 121.
9	Emery-Fish prospect	do	Magnetite-apatite veins in metavolcanic rock.	do	
10	Ute prospect	do		None	Horton, 1962.
11	White Rock prospect	do	Siliceous magnetite-hematite veins in metavolcanic rocks.	do	Shaw, Reeves, and Kral, 1962, pp. 125-126.
12	McCoy district	Lander	Magnetite replacement bodies in limestone.	Medium	Shawe, Reeves, and Kral, 1962, pp. 110-116; Schrader, 1934; Kral, 1947d.
a	Uhalde-New World mine.				
b	Hancock mine.				
13	Cortez Mountains	Eureka	Hematite and minor magnetite replacement deposits in volcanic rock.	Large	Shawe, Reeves, and Kral, 1962, pp. 86-103; Jones, 1913; Kral, 1947e.
a	Barth mine.				
b	Modarelli mine.				
c	Imperial prospect.				
d	Jackson prospect.				
e	Frenchie Creek prospect.				
f	Big Pole Creek prospect.				

TABLE 8.—Iron ore districts, mines, deposits, and prospects in Nevada—Continued

Map No. (fig. 25)	District, mine, deposit, or prospect	County	Type of deposit	Production	Reference
14	Bullion district prospect	Elko	Replacement bodies of hematite in limestone.	None	Shawe, Reeves, and Kral, 1962, p. 121.
15	Peavine prospect	Washoe	Magnetite lenses along fault zones in metavolcanic rock.	do	Shawe, Reeves, and Kral, 1962, p. 125.
16	Iron Blossom prospect	Storey	Magnetite veinlets in shaly limestone.	Small	Reeves, Shawe, and Kral, 1958, pp. 71-73.
17	Dayton iron deposit	Lyon-Storey	Hematite and magnetite bodies in limestone.	None	Harder, 1959; Butler, 1945; Geehan, 1949; Reeves, Shawe, and Kral, 1958, pp. 56-61.
18	Capitol prospect	Ormsby	En-echelon veins and lenses of magnetite and hematite in hornblende diorite near its contact with limestone.	Small	Reeves, Shawe, and Kral, 1958, p. 66.
19	Bessemer prospect	do	Small ore bodies and veins of siliceous magnetite in volcanic rock.	do	Reeves, Shawe, and Kral, 1958, pp. 61-62.
20	Minnesota mine	Douglas	Pyrometasomatic magnetite bodies in limestone.	Large	Reeves, Shawe, and Kral, 1958, pp. 45-56.
21	Easter prospect	Lyon	Small magnetite veinlike body in grandiorite.	Small	Reeves, Shawe, and Kral, 1958, p. 68.
22	Lyon prospect	do	Four large pyrometasomatic magnetite bodies in limestone.	None	Sargis, S. G., written communication; Horton, 1962.
23	Owen prospect	do	Magnetite veins in metavolcanic rock.	Small	Reeves, Shawe, and Kral, 1958, pp. 76-77.
24	Walker Lake prospect	Mineral	Magnetite disseminated in epidotized metavolcanic rock.	do	Reeves, Shawe, and Kral, 1958, p. 78.
25	Centipede prospect	do			Horton, 1962.
26	Foster prospect	do	Pyrometasomatic magnetite deposit in limestone.	Small	Reeves, Shawe, and Kral, 1958, pp. 68-69.
27	Crews prospect	do	Pyrometasomatic magnetite in limestone.	None	Horton, 1962.
28	Black Butte prospect	do	Pyrometasomatic magnetite deposit in limestone.	do	Reeves, Shawe, and Kral, 1958, pp. 62-63.
29	Last Chance prospect	do	do	do	Reeves, Shawe, and Kral, 1958, p. 76.
30	Gillis prospect	do	do	do	Reeves, Shawe, and Kral, 1958, pp. 69-70.
31	Black Horse prospect	do	Magnetite replacement in sedimentary rocks.	do	Reeves, Shawe, and Kral, 1958, pp. 63-64.
32	Iron Crown mine	do	Pyrometasomatic magnetite deposit in limestone.	Small	Reeves, Shawe, and Kral, 1958, pp. 73-75.
33	King David prospect	do	Pyrometasomatic magnetite, hematite, and some copper and iron sulfides in limestone.		Reeves, Shawe, and Kral, 1958, pp. 75-76.
34	Iron Gate mine	do	Replacement bodies and narrow veins of hematite in dolomite.	Small	Reeves, Shawe, and Kral, 1958, p. 75.

35	Iron Butte.....	do.....	Pyrometasomatic magnetite and some hematite deposits in limestone.	None.....	Reeves, Shawe, and Kral, 1958, p. 73.
36	Phelps-Stokes mine.....	Nye.....	Replacement body along fault that forms contact between limestone and metavolcanic rock.	Medium.....	Reeves, Shawe, and Kral, 1962, pp. 38-44; Kral, 1947c.
37	Engle-Stouder prospect.....	do.....	Magnetite along shear zones in meta-volcanic rock.	None.....	Reeves, Shawe, and Kral, 1958, p. 68.
38	Maddelena prospect.....	Mineral.....	Magnetite veins at granite, limestone contact; pyrometasomatic deposits in limestone.	do.....	Horton, 1962.
39	Boak prospect.....	Esmeralda.....	Hematite and some magnetite in shear zones and replacement bodies in dolomite and conglomerate.	do.....	Reeves, Shawe, and Kral, 1958, pp. 64-66.
40	Klondike prospect.....	do.....	Pyrometasomatic deposit and veins of magnetite in granite and limestone.	do.....	Horton, 1962.
41	Pilot Knob prospect.....	White Pine.....	Pyrometasomatic and replacement deposits of magnetite and hematite in limestone.	do.....	Do.
42	Fioche district.....	Lincoln.....	Manganosiderite in limestone.....	Medium.....	Westgate and Knopf, 1932, pp. 60-66, 71-72; Hewett and others, 1934, pp. 86-87.

These recently reported discoveries, and the continued population and industrial growth in the Western United States, could lead to a substantial expansion of iron and steel production, including construction of additional facilities and thereby lead to an increase in output of Nevada iron ore.

Iron ore was first mined in Nevada in 1893-94, when a 535-ton trial shipment was made to the Union Iron Works in San Francisco from deposits in the Buena Vista Hills (No. 6). In 1903 the Barth (West) iron mine (No. 13a), Eureka County, belonging to the Central Pacific Railroad Co. (now Southern Pacific Railroad Co. and Southern Pacific Land Co.), was leased to and operated by the American Smelting & Refining Co. to furnish iron ore for its Murray, Utah, smelter. Following cessation of that operation in 1918, no significant amount of iron ore was mined in Nevada until 1943, when ore was again produced from the Buena Vista Hills deposits. Production during World War II was over 60,000 long tons, chiefly from Buena Vista Hills mines; most was used as concrete aggregate for permanent ballast in ships constructed in the San Francisco area, but some was used to augment or replace scrap in Pacific coast steel furnaces.

Following the end of World War II, annual output of Nevada iron ore dropped sharply. In 1951, the Korean war and coincident rebirth of the Japanese steel industry created a demand for iron ore. The Korean war also resulted in a large increase in U.S. steel production and accentuated a shortage of hard lump openhearth ore, a type contained in many Nevada deposits. Production of Nevada iron ore to help fulfill these needs rose to a peak of over 900,000 tons in 1952; most of this was blast furnace feed destined for Japan. In 1951 several producers started shipments of hard lump open hearth ore, and by 1954 these accounted for nearly one-third of the ore shipped from Nevada. Over 90 percent of this hard lump open hearth ore was shipped to Central and Eastern United States steel producers; the remainder went to small steel furnaces on the Pacific coast.

Nevada iron-ore production dropped sharply following cessation of hostilities in Korea, in part the result of development of sources closer and thus less costly to Japan, in part of the opening of new sources of hard lump open-hearth ore closer to the Eastern and Central United States markets, and in part the result of a worldwide drop in steel production. Production increased in 1956 and has since remained at a relatively high level. Estimated Nevada production in 1963 was 785,000 long tons with a value of about \$4 million. Most of the production in recent years, after the mid-1950's has been exported to Japan; domestic shipments have accounted for only 10 to 20 percent of the total.

The revolution in the iron-ore industry occasioned by the highly successful use of beneficiated ore, particularly pellets, contributed to the lessened demand for Nevada iron ore. Attempts to regain lost markets have led to the installation of beneficiation plants, ranging from simple screening and ore-grading installations to complete beneficiation plants at several of the Nevada mines and plans to install similar plants at several other deposits.

Including the estimated 1963 production, almost 10 million tons of iron ore has been mined in Nevada; most of this has been since 1950. Nevada iron-ore production is shown in figure 26.

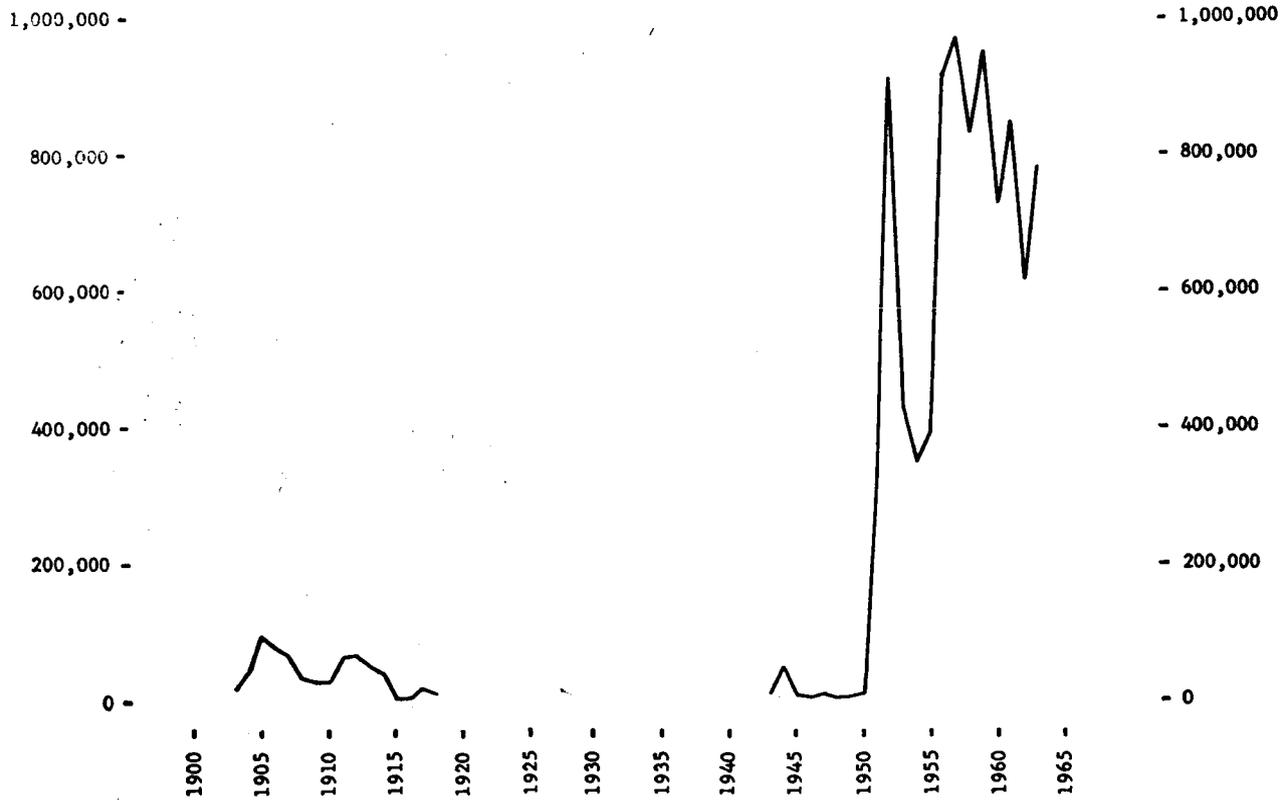


FIGURE 36.—Iron production (long tons) in Nevada, 1903-63.

Iron-ore deposits are widely scattered throughout northern and central Nevada, but none are known in the extreme southern part of the State. The Buena Vista Hills (No. 6), on the Pershing-Churchill County line southeast of Lovelock, the Cortez Mountains (No. 13) in northern Eureka County, and the Jackson Mountains (No. 1a, b, c) in west-central Humboldt County contain sizable deposits. Several important deposits and a number of smaller deposits or prospects occur in the west-central part of the State; chief among these are the Minnesota mine (No. 20) in Douglas County, the Dayton deposit (No. 17) in Lyon and Storey Counties, and the Phelps-Stokes mine (No. 36) in Nye County. Several small deposits in the McCoy district (No. 12) of Lander County have had some production.

All of the known deposits are of igneous affiliation. These include pyrometamorphic (contact metamorphic) deposits of magnetite in limestone surrounding igneous intrusive bodies; magnetite vein and high-temperature replacement bodies in the intrusive bodies; and low temperature replacement bodies of hematite and magnetite in volcanic rocks or limestone. Extensive manganosiderite deposits of hydrothermal origin in limestone occur in the Pioche area (No. 2), Lincoln County.

Distribution of all known districts, mines, deposits, and prospects are shown in figure 25, where they are classed in terms of production plus reserves as large, intermediate, and small. Large districts or deposits are those of over 1 million long tons; intermediate, from 100,000 to 1 million long tons; and small, of less than 100,000 long tons. Summary information on the deposits is presented in table 8, and the principal deposits are described below.

The Buena Vista Hills are a north-trending spur of the Stillwater Range. The hills and adjacent parts of the Buena Vista Valley to the north and northeast, and the Carson Sink to the west are underlain principally by Mesozoic or older metadiorite and metavolcanic rocks.

The Buena Vista Hills iron-ore deposits are magnetite replacement bodies and veins in the metadiorite and, to a lesser extent, in the metavolcanic rocks. The ore bodies are localized mainly along north-east- and north-trending faults; some have been broken into isolated or semidetached blocks by postore faulting. They range from bodies of almost pure magnetite with an average grade of about 65 percent iron to lower-grade disseminations of magnetite in chloritized diorite and metavolcanic rock. The iron-ore deposits extend from the southern part of the main Buena Vista Hills to a group of low hills north of the main hills, a distance of 9 miles. Several of the deposits are in the soil and rock-covered valleys that surround the hills; the first of these was discovered by careful prospecting that disclosed inconspicuous magnetite outcrops and subsequent ones were found by magnetometer surveys. The deposits were explored by the U.S. Bureau of Mines (Kral, 1947a and 1947b) and studied jointly by the U.S. Geological Survey and Nevada Bureau of Mines (Reeves and Kral, 1955).

Production from the Buena Vista Hills deposits commenced in 1943 and has continued without interruption to the time of this report; through 1962, the last year for which data are available, 3.5 million long tons of ore were produced. Mines with recorded production and their ownership are: the Buena Vista (United States Steel Corp.); Segerstrom-Heizer and Thomas mines (Southern Pacific Land Corp.,

leased to Nevada Barth Corp.); Iron Horse-Ford, American Ore, American Ore-Parker, and Consolidated Minerals, section 16 and section 22; Iron Castle, Iron Hat, and Phoenix group (Nevada Barth Corp.). The Nevada Barth Corp., the major producer in the district, in 1963 installed a magnetic concentrator in order to produce a more competitive, higher grade, and more uniform product.

At the Buena Vista mine (No. 6g), an east-trending area 2,000 feet long and 500 feet wide contains individual ore bodies from 50 to 150 feet wide and up to 500 feet long. These have been cut in diamond drill holes at a maximum depth of 250 feet below the original surface. They are localized along faults that brecciated the diorite. Magnetite is the principal ore mineral; chlorite, calcite, and quartz are the main gangue minerals, accompanied by minor amounts of apatite and sphene. The ore ranges from almost exclusively massive magnetite to magnetite disseminated in chloritized diorite. Where the bodies are not bounded by faults, the contact between ore and altered diorite is usually gradational. The bodies are mostly highly irregular in shape owing to the unevenness of replacement, but some are tabular or lenticular.

The Segerstrom-Heizer and American Ore mines (Nos. 6 e and f) are along a northeast-trending fault that partly forms the northern border of the hills. The Segerstrom-Heizer deposit consists of an ore zone about 700 feet long and up to 300 feet wide and cut in a diamond drill hole 275 feet below the original outcrop, that contains a main ore body and several smaller bodies to the southeast. The main ore body is bounded on both east and west by steeply dipping faults, and is cut into two almost equal parts by a north-trending fault of small displacement. The ore body at the American Ore mine is about half a mile northeast of the Segerstrom-Heizer main ore body; it is about 50 feet wide and 150 feet long.

Both the Segerstrom-Heizer and American Ore ore bodies consist of massive magnetite accompanied by very minor amounts of chlorite, calcite, tremolite-actinolite, and apatite.

The Thomas and American Ore-Parker mines (Nos. 6 a and b) consist of several ore bodies in an ore zone in metavolcanic rocks that extends for 2,000 feet along a north-trending fault system. Only about 800 feet of the northern part of the ore zone is wide enough to mine. The main ore bodies are at the intersections of north-northwest-trending faults with the main north-south fault system; one follows the north-northwest-trending faults, and others are in the main fault system north and south of the intersection. The ore bodies are from 30 to 50 feet wide, 200 to 400 feet long, and dip steeply east. The ore is massive magnetite, much of which has been oxidized to martite; it grades into disseminated magnetite in chloritized metavolcanic rock.

The Iron Horse-Ford mine (No. 6c) is in the Carson Sink Valley west of the Buena Vista Hills. The deposit consists of separate ore bodies up to several hundred feet long and 100 feet wide in a northwest-trending ore zone in metadiorite. The ore zone follows, and has replaced the areas between, several northwest-trending en echelon faults. The ore is magnetite.

The Cortez Mountains in northern Eureka County are an east-tilted fault block range, composed chiefly of moderately folded and faulted older volcanic rocks overlain by relatively undisturbed mostly silicic

younger volcanic rocks. The older volcanic rocks are cut by intrusive bodies of predominantly diorite, granodiorite, and quartz monzonite. The iron-ore deposits are hydrothermal replacement bodies in the older volcanic rocks, generally near diorite or quartz-monzonite intrusive bodies. The two principal mines are the Barth (No. 13a), at the north end of the range on the southern bank of the Humboldt River, and the Modarelli (No. 13b), 15 miles to the south. The geology and iron-ore deposits of the Cortez Mountains were jointly studied by the U.S. Geological Survey and the Nevada Bureau of Mines (Shawe, Reeves, and Kral, 1962).

The Barth iron mine (No. 13a), which belongs to the Southern Pacific Land Co., was leased to and operated by the American Smelting & Refining Co. from 1903 to 1918 to provide iron ore for use as flux in their Murray, Utah, lead smelter. It was studied by Jones (1913) during its first period of operation, and was explored in 1954 by the Southern Pacific Land Co. by magnetic survey and diamond drilling (K. N. Meador, unpublished report). It was leased again, this time to the Nevada Barth Corp. who reopened it in 1960. The 1954 exploration disclosed that the body extends northwest under the Humboldt River channel and flood plain, and a new channel was dug by the Nevada Barth Corp. to divert the river so that the pit could be extended to the part below the river.

The deposit consists of hematite and some magnetite that replaced the older volcanic rock. It is about 1,000 feet long and up to 200 feet wide in its upper part. The footwall dips  $45^{\circ}$  NE; the hanging wall is vertical to  $45^{\circ}$  NE., and the deposit tapers to a thickness of 50 to 100 feet about 200 feet below the surface. The southeastern end of the deposit crops out, forming part of the bluffs along the southern bank of the river; unconsolidated sediments of the Humboldt River flood plain, from 20 to nearly 100 feet deep, and unreplaced volcanic rock up to 20 feet thick covers the northwestern part of the deposit.

The Modarelli mine (No. 13b) is owned by the J. R. Simplot Co. of Pocatello, Idaho, who operated it in 1951-52, 1955-56, and 1959. The Modarelli deposit was explored by the U.S. Bureau of Mines during World War II (Kral, 1947c). The ore body is localized at the intersection of northwest- and east-trending fault systems. It forms part of a larger hydrothermally altered zone about 2,000 feet long and 1,000 feet wide. The ore body is triangular in plan; the northwest-trending side of the ore body is about 1,000 feet long and dips steeply northeast, and the south and west legs are about 700 feet long. The ore is mostly fine-grained red hematite, accompanied by minor amounts of quartz and calcite, that replaced older volcanic rock. Apatite is widely scattered throughout the ore.

Other deposits in the Cortez Mountains west of the Modarelli mine are the Imperial, Jackson, Frenchie Creek, and Big Pole Creek prospects (Nos. 13c, d, e, f). All are veins or small replacement bodies of hematite and generally subordinate magnetite in the older volcanic rocks. The Frenchie Creek prospect is the largest; it consists of magnetite-hematite lenses and hematite-cemented breccia along shear zones

The Jackson Mountains are in west-central Humboldt County, 40 miles west of Winnemucca and 85 miles north of Lovelock. The principal iron ore deposits (Nos. 1a, b, c) are in the northeastern part of the mountains, in an area of folded and faulted metavolcanic and

interbedded nonmarine sedimentary rocks that are intruded by diorite, granodiorite, and other igneous rocks. The Jackson Mountains have been studied by Willden (1958; in press) and the iron ore deposits were studied by Shawe, Reeves, and Kral (1962). The deposits are replacement bodies of magnetite in the metavolcanic rock, surrounding and believed related to diorite intrusive bodies.

The largest deposit is the Iron King (No. 1a), held by location by the DeLong brothers. It was leased to W. G. Austin and Tom Beko who operated it from 1952, first as an open pit and later as an underground mine. It consists of three main and several smaller ore bodies along a north-trending fault zone in metavolcanic rock near the contact between it and diorite. The northernmost of the three main ore bodies is 250 feet long and 30 feet wide, the central is 150 feet long and 40 feet wide, and the southernmost is 350 feet long and up to 200 feet wide. The southernmost body was cut in a diamond drill hole more than 200 feet below its highest outcrop. The ore is massive magnetite with few, if any, gangue minerals and low impurities.

Two other nearby deposits (Nos. 1b. and 1c) the Red Bird and Black Jack, were operated in conjunction with the Iron King mine. The ore bodies are smaller but otherwise similar to that of the Iron King deposit.

The Minnesota mine (No. 20) is in the eastern tip of Douglas County, 11 miles northwest of Yerington. It was first worked as a copper mine, before and during World War I; a small amount of iron ore was mined in 1943-45. The Standard Slag Co., of Youngstown, Ohio, commenced large-scale production from the mine in 1952. A 3,000-long-ton-per-day magnetic concentrator that produces a 62-to 63.5-percent sinter-grade concentrate was installed in the spring of 1963. The concentrate is shipped to Japanese steel mills (Huttl, 1963).

The iron ore at the Minnesota mine is magnetite that replaced dolomitized limestone. The main ore body is on the northern slope near the top of Minnesota Hill. It is 400 feet long east to west and over 100 feet wide with several south-trending apophyses up to 200 feet long along the south side of the ore body. Magnetic data and diamond drilling indicate that the main body dips westward more steeply than the dolomitized limestone. The magnetic anomaly trends south, suggesting that the entire northern part of the hill may be underlain by ore, and that the outcrop on the eastern side of the hill just below the top is a protrusion of the top of the ore body.

The Phelps-Stokes iron ore deposit (No. 36) is 5 miles east of Gabbs, Nye County. Approximately 400,000 tons of ore were produced (Reeves, Shawe, and Kral, 1959) from 1949 to 1954, by the Standard Slag Co., to provide iron ore for use in the basic refractory industry at Gabbs and for shipment to Japan. The deposit, a replacement in dolomite, is dumbbell shaped in plan, about 950 feet long and from 25 to 250 feet wide; it was mined by open pit to a depth of 250 feet. The ore is magnetite with minor amounts of hematite that in the upper part of the deposit was low in sulfur and phosphorous, but ore below the present level of mining, cut in drill holes during U.S. Bureau of Mines exploration (Kral, 1947d) is high in sulfur-bearing pyrrhotite and pyrite.

The Dayton deposit (No. 17) is on the Storey-Lyon county line 25 miles northeast of Carson City. It is on patented mining claims

owned by Robert C. Giles and Mortimer Fleischhacker of San Francisco and land belonging to the Southern Pacific Land Co.; the entire property was leased to the Utah Mining & Construction Co.

The deposit was described by Harder (1909), and was studied and explored during World War II by the U.S. Geological Survey (Butler, 1945) and U.S. Bureau of Mines (Geehan, 1949), and later described by Reeves, Shawe, and Kral (1958). The deposit consists of hematite-magnetite replacement bodies in folded metasedimentary rocks. Several bodies are exposed at the surface or were cut during the World War II exploration. The main body is 800 feet long, 40 to 180 feet thick, and was penetrated by diamond drill holes to a maximum depth of 370 feet.

The material is mostly magnetite associated with epidote, garnet, quartz, chlorite, mica, calcite, and feldspars. The pyrite content ranges from 1 to 10 percent, but is usually between 5 and 6 percent. It is generally too low grade (average grade, 45 to 47 percent iron) and contains too much sulfur to be used directly.

Several small iron ore deposits (No. 12) occur along the south side of the now abandoned gold mining camp of McCoy in northwestern Lander County, 27 miles southwest of Battle Mountain. Several of the deposits were mined in 1943, from 1951 to 1953, and again in 1961. The McCoy district was studied by the U.S. Geological Survey (Schrader, 1934) and the iron ore deposits were explored by the U.S. Bureau of Mines (Kral, 1947c) and jointly studied by the U.S. Geological Survey and Nevada Bureau of Mines, (Shawe, Reeves, and Kral, 1961). Some of these deposits are being mined (in 1964) by the ARD Equipment Co.

Magnetite and some hematite replace dolomite and limestone of the Osobb Formation of Late Triassic age. The Osobb and associated sedimentary formations have been intruded by diorite and granodiorite that crops out south and west of the iron ore deposits. The iron ore occurs in bands, lenses, and irregularly shaped pods; it is exposed over a distance of slightly more than a mile along the north slope of a hill south of the camp of McCoy, but only at three places is it thick enough to have been mined. The ore bodies are conformable with the sedimentary rocks, which dip from 10° to 20° south into the hill. The largest body, at the west end of the exposed belt of Osobb Formation, is 800 feet long and 10 feet thick, and was mined 75 feet down the dip. Two smaller bodies to the east are 400 feet long and 15 feet thick and 100 feet long and 10 feet thick, respectively. An isolated deposit at the Hancock mine, 1 mile south of the main belt of exposures, is about 80 feet long and nearly 50 feet thick, and appears to dip gently southwest into the hill.

A very large, newly discovered magnetite deposit, the Lyon prospect (No. 22), is in Lyon County, on the west flank of the Wassuk Range east of Yerington. This deposit was discovered in 1962 by Columbia-Geneva Steel Division of the United States Steel Corp. as a result of regional geological studies and airborne and ground magnetic surveys (S. G. Sargis, written communication). It is a pyrometasomatic deposit in limestone, similar to but much larger than the many exposed pyrometasomatic deposits in west-central Nevada. Diamond drilling disclosed at least four large ore bodies.

## LITHIUM

(By W. R. Griffitts, U.S. Geological Survey, Denver, Colo.)

Lithium is a very light alkali metal that has had rapidly increasing use during the last 20 years. The raw material is largely converted to a variety of lithium chemicals. Lithium stearate is extensively used in lubricating greases, especially those used at high temperatures or in contact with water. Lithium carbonate, and also some lithium minerals are used in ceramics and glass. Lithium halides are used in industrial air conditioners and in fluxes for welding and brazing. The metal itself is alloyed in self-fluxing brazing rods and used as a degasifier and deoxidizer of metals.

Most lithium is obtained from the minerals spodumene and lepidolite, which are mined from pegmatite deposits. Much also is obtained from the brine of Searles Lake, Calif. The United States has substantial reserves of lithium minerals and produces about two-thirds of its requirements. The other third is obtained mainly from South Africa and Canada.

There is no record of lithium production in Nevada, but several occurrences of lithium minerals and lithium-bearing playas are known and more probably will be found. Dry lithium-bearing clays have been found in basins in Arizona, and similar clays, as well as brines, may be found in Nevada.

Lepidolite, a lithium mica, has been found in small amounts in pegmatite near the head of Corral Creek, in the Ruby Mountains, Elko County, where it is accompanied by beryl (Olson and Hinrichs, 1960, p. 171). Lepidolite also was found, apparently in somewhat larger amounts, in pegmatite in the Mineral Ridge area, Esmeralda County (Olson and Hinrichs, 1960, p. 183). Though not reported, beryl might be expected to accompany the lepidolite.

The playa deposits are more promising as potential sources of lithium than are the pegmatites. The subsurface brine of Clayton Valley, near Silver Peak, Esmeralda County, has been explored and found to have possible resources of 275,000 tons of  $\text{Li}_2\text{O}$  and about 2,800,000 tons of  $\text{K}_2\text{O}$  (Anonymous, 1961, p. 293, 295). Comparable material may well be in other closed basins.

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MANGANESE

(By M. D. Crittenden, Jr., U.S. Geological Survey, Menlo Park, Calif.)

Manganese is essential to a modern industrial economy. About 17 pounds of manganese metal (40 pounds of ore) are required for the production of each ton of steel (De Huff, 1956, p. 502), and small but essential amounts are required for the manufacture of dry cell batteries and industrial chemicals. The United States now consumes about 2 million tons of ore per year, more than 95 percent of which is used by the steel industry in the form of ferromanganese. For this function, i.e., to scavenge sulfur and oxygen from the melt, no substitute is known. Recovery of the manganese now lost in open-hearth slags is capable of reducing the annual requirement by perhaps one-third, but this recovery is more costly than the use of ores now available.

Although the United States is the world's largest consumer of manganese ores, it has very limited supplies of the high-grade ores (plus 40 percent manganese) required for the production of ferromanganese. Domestic production, therefore, has seldom exceeded 10 percent of consumption, and has often dropped to zero. Foreign supplies, on the other hand, are abundant, readily available, and comparatively cheap during peacetime. As a result there has been no economic incentive to develop the large resources of very low grade refractory materials that are available in this country. During each national emergency, however, the supplies of ore from foreign sources have been curtailed or threatened; manganese has therefore remained high on the list of strategic materials, and has been the subject of emergency measures and artificially high prices during each World War and the Korean conflict.

The production of manganese ore in Nevada (excluding fluxing ores from which no manganese was recovered) (table 9) shows the effect of these fluctuations in price and other stimuli, exceeding 20,000 long tons in 1918, 26,000 long tons in 1944, and 100,000 long tons per year from 1956 through 1958, when production stimulated in 1952 reached its peak. The total output from Nevada mines from 1917 to date is about 800,000 long tons with an approximate value of \$50 million.

TABLE 9.—*Production of manganese ores in Nevada*<sup>1</sup>

Year	Grade manganese (in percent)		Total production <sup>2</sup> (in long tons)	Year	Grade manganese (in percent)		Total production (in long tons)
	+35	10-35			+35	10-35	
1917.....	3,450		3,450	1944.....	19,463	6,689	26,152
1918.....	19,872	258	20,130	1945.....	857	1,975	2,832
1919.....	78	6,225	6,303	1946.....	950	11,132	12,082
1920.....	1,240		1,240	1947.....	59	11,712	11,771
1921.....				1948.....		7,774	7,774
1922.....				1949.....		4,432	4,432
1923.....				1950.....		7,984	7,984
1924.....	1,310	2,591	3,901	1951.....	52	1,116	1,168
1925.....	850	6,659	7,509	1952.....	621	7,095	7,716
1926.....	1,607	12,205	13,812	1953.....	18,313	27,536	45,849
1927.....	1,357	3,310	4,667	1954.....			
1928.....				1955.....	93,465	1,120	94,585
1929.....		2,407	2,407	1956.....	109,012	2,805	111,817
1930.....	1,489	3,363	4,852	1957.....	115,324	3,968	119,292
1931.....				1958.....	113,679	1,585	115,264
1937.....		533	533	1959.....	50,545	179	50,724
1938.....				1960.....	43,818		43,818
1939.....				1961.....	25,511		25,511
1940.....	210	4,613	4,823	1962.....			
1941.....	2,622	7,958	10,580				
1942.....	5,457	2,449	7,906	Total.....	640,542	155,372	795,914
1943.....	9,331	5,699	15,030				

<sup>1</sup> Compiled from U.S. Bureau of Mines Mineral Yearbook.

<sup>2</sup> Excludes fluxing ores mined between 1915 and 1925 from which no manganese was recovered.

The largest single producer is the Three Kids mine (table 10 and fig. 27, No. 3) in Clark County, which has yielded more than 600,000 long tons of concentrates averaging about 45 percent manganese. This was obtained by milling more than 2,225,000 long tons of crude ore averaging about 18 percent manganese. The Black Diablo mine (No. 44) in Pershing County has yielded over 100,000 tons of material which averaged 25 to 35 percent manganese (Tren Grove, 1959, fig. 1). The Caselton and Pioche Nos. 1 and 2 mines of the Combined Metals Reduction Co. have also produced more than 100,000 tons.

This included both mine-run ore averaging 11 to 25 percent manganese and concentrates containing more than 50 percent manganese. Part of this production was converted to ferromanganese by the Pioche Manganese Co. in a plant at Henderson, Nev. (Huttl, 1952). The Nevada district (No. 50), including the Steptoe and Essex groups of claims, near Ely in White Pine County, has yielded about 30,000 tons of ore, much of which has averaged 35 to 40 percent manganese. The remaining production has come from some 70 deposits many of which have shipped less than 1,000 tons.

A plant for the production of synthetic battery-grade manganese oxide by the electrolytic process was operated at Henderson, Clark County, from 1951 to 1955 by the Western Electrochemical Corp. (Schrier and Hoffman, 1954). The operation was continued from 1955 into 1957 by the American Potash & Chemical Corp. Though some of the ores utilized came from Nevada, most of the raw material used was comparatively high-grade oxide ore from Mexico.

The operation and history of the Three Kids mine (No. 3) has been described in the literature and will be only briefly reviewed here (Hunt, McKelvey, and Wiese, 1942; Huttl, 1955; and Van Gilder, 1959). High-grade surface outcrops of manganese ore were first discovered on the original Three Kids property in 1917, and by 1920 had yielded between 15,000 and 20,000 tons of ore averaging about 40 percent manganese (Pardee and Jones, 1920). Little ore was mined between then and World War II, but the probability of a considerable underground extension of the ore led first to diamond drilling by the owners (Hewett and Webber, 1931), and in 1940, to a cooperative project to explore the entire deposit by the U.S. Bureau of Mines and the U.S. Geological Survey. This work (Hunt, McKelvey, and Wiese, 1942; Johnson and Trengrove, 1956) demonstrated the existence of ore reserves in excess of 5 million tons averaging about 10 percent manganese. Recent mining has removed all that is accessible to open-pit mining.

Pilot plant studies indicated in 1941 that the low-grade ores could be treated by leaching with  $\text{SO}_2$  and acid solutions, and a plant to handle several thousand tons per day was constructed by the Manganese Ore Co. in 1942. A large open pit was developed in the easternmost block of ore, and some 285,000 tons of ore averaging about 20 percent manganese were mined and stockpiled. Technical difficulties with the leaching and calcining process coupled with the end of hostilities led to abandonment of this operation in 1944.

In 1950 the plant was acquired by Manganese, Inc., and was converted to flotation, using oil emulsion reagent and  $\text{SO}_2$  as an activator. At the same time, the mining was completed in the original open pit, and two new ones were developed which together yielded most of the 1,800,000 tons of ore mined from 1950 to 1961.

The Three Kids deposit is typical of several in the Lake Mead area except that it is larger and higher in grade (McKelvey, Wiese, and Johnson, 1949). Only the Boulder City deposit (No. 7) contains resources large enough (1 million tons averaging 7.5 percent, or 15 million tons averaging 3 percent) to make operation feasible at some time in the future.

The largest remaining resources of manganese in Nevada are in the Pioche district (No. 33), Lincoln County, where they occur as bedding replacement deposits that form halos or extensions around the base metal ore bodies. These are typical hydrothermal deposits, containing small amounts of zinc, lead, silver, and gold. The primary material consists mainly of manganoan siderite (a carbonate of manganese and iron) mixed with small amounts of sulfides and gangue. This material is amenable to treatment by selective flotation for recovery of both the base and precious metals as well as the manganese. Resources of this material probably exceed 4 million tons averaging 10 percent manganese. A somewhat larger amount of oxidized material is present, and although it presents a more difficult metallurgical problem, manganese could be recovered from it in an emergency.

TABLE 10.—*Manganese deposits in Nevada*

[Numbers identify symbols shown in fig. 27]

CHURCHILL COUNTY		LANDER COUNTY	
1. Black Joe prospect		26. Black Rock mine	
	CLARK COUNTY	27. Black Eagle mine	
2. Virgin River deposit		28. Blackbird mine	
3. Three Kids mining district		29. Black Devil mine	
4. Fannie Ryan deposit		30. Peterson mine	
5. Little Tom prospect		31. Last Chance mine	
6. Ebony Queen prospect		LINCOLN COUNTY	
7. Boulder City deposit		32. Jack Rabbit district	
	DOUGLAS COUNTY	33. Pioche district	
8. Danite mine		34. Southpaw mine	
		35. Culverwell prospect	
	ELKO COUNTY	MINERAL COUNTY	
9. Indian prospect		36. Bullion mine	
10. Wicker mine		37. Ballbearing prospect	
11. Nevada mine		38. Black Jack prospect	
12. Maggie Summit prospect		NYE COUNTY	
13. Darcy mine		39. Butte prospect	
14. Spruce Mountain mining district		40. Surprise prospect	
15. Berning prospect		41. Victory prospect	
	ESMERALDA COUNTY	42. Lydon prospect	
16. Black Rock prospect		PERSHING COUNTY	
17. Dunnigan prospect		43. Victory Lode prospect	
18. Gaillac prospect		44. Black Diablo mine	
	EUREKA COUNTY	45. Black Beauty prospect	
19. Gibellini mine		WASHOE COUNTY	
	HUMBOLDT COUNTY	46. Peponis prospect	
20. Gibson prospect		47. Scarboli prospect	
21. Golconda deposit		WHITE PINE COUNTY	
22. Topsy mine		48. Siegel mine	
23. Major prospect		49. Ely district	
24. Black Hawk prospect		50. Nevada district	
25. O'Leary prospect			
Black Diamond mine			

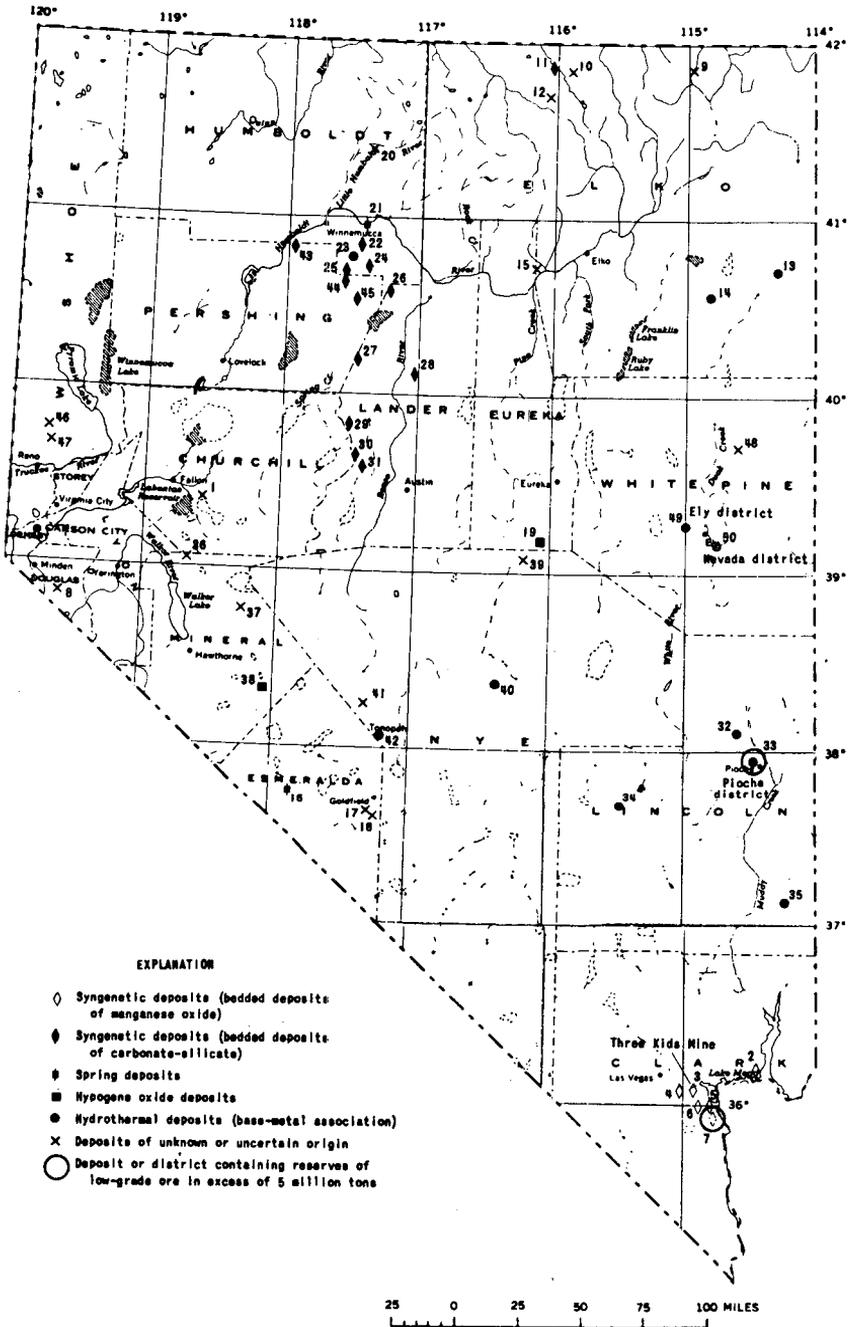


FIGURE 27.—Manganese in Nevada (numbers refer to deposits or districts listed in table 10).

Other deposits of manganese in Nevada are diverse in character and widely distributed, and most are too small to warrant the installation of complex milling equipment.

Manganese deposits may be most readily understood by the prospector or developer if they are grouped according to the way they were formed, with particular emphasis on the source of the manganese. Two large groups are recognized: those called syngenetic in which the manganese was formed at the same time as the enclosing rocks; and those called epigenetic in which the manganese was introduced after the formation of the enclosing rocks. Deposits of the first type are typically beds or lenses; those of the second type are typically veins or pipelike bodies.

The most important deposits of the syngenetic type are those of the Lake Mead area, which include the Three Kids mine, already described, and a number of smaller deposits nearby. All are bedded deposits of manganese oxide in the Muddy Creek Formation of Pliocene age. These are believed to have formed in arid basins much like the desert basins of today, in which sediments and volcanic ash were accumulating probably in shallow lakes. Manganese is believed to have been carried into the basin by voluminous hot springs, probably rising along marginal faults. Evaporation and oxidation resulted in the accumulation of beds of oxide, intermixed with the sediments and ash. Such beds range in thickness from a few inches to 50 feet thick (McKelvey, Wiese, and Johnson, 1949, p. 91), and in manganese content from a percent or 2 to as much as 25 percent. Some beds are traceable along the strike for a distance of several miles.

A second group of syngenetic deposits occurs in central Nevada in Lander and Pershing Counties (Nos. 24-31). These are ancient deposits enclosed in marine rocks of Carboniferous and Permian age (220 to 250 million years ago) and are associated with thin-bedded chert (fine-grained silica) and greenstone (submarine volcanics). The largest deposit of this type was the Black Diablo (No. 44) which, before mining, was a massive lens of the dense black mineral (braunite,  $MnOMnSiO_3$ ) and silica. Several similar but smaller deposits are known nearby (Nos. 24, 31, and 43-45).

The second type of deposit, the epigenetic type, formed later than the enclosing rocks by introduction of manganese from an outside source. These include the typical vein deposits that have yielded much of the mineral wealth of Nevada. The largest deposits of this type in the United States are closely associated with the copper deposits of Butte, Mont. Similar association of manganese carbonate (rhodochrosite,  $MnCO_3$ ) with sulfide ores is recognized in mining districts throughout the West. The largest in Nevada are those in the Pioche district (No. 33). Smaller amounts of manganese carbonate, generally oxidized in shallow workings, are known in a number of other mining camps in the State. The ease with which such ores and their associated sulfides can be concentrated by flotation makes any large deposits of manganese carbonate a valuable potential resource.

A second group of epigenetic deposits, which consist entirely of veins of manganese oxide of primary origin (Hewett and Fleischer, 1960), are represented by only one or two known examples in Nevada. The Gibellini mine (No. 19) (Binyon, 1948) is a unique pipelike deposit of waddy manganese oxide that cuts limestone country rock. The light weight and vesicular character of the ore, the rapid down-

ward decrease in size, together with the unique chemical composition (typically, 18 percent manganese, 1.7 percent nickel, 0.3 percent cobalt, 3.2 percent copper, 0.11 percent molybdenum, 0.88 percent  $V_2O_5$ ) suggest strongly that the Gibellini deposit is the eroded root of a hot spring of very unusual character, probably associated with nearby volcanism.

A final group of epigenetic deposits that are the result of recent or active hot springs include another of unusual composition (No. 21), the Golconda deposit, in Humboldt County, which was actually mined for its tungsten content (Kerr, 1940).

*Future outlook.*—The known resources of manganiferous material in Nevada are sufficient to yield at least twice the past production, or about 2 million tons of high-grade concentrates. All of it would require beneficiation in order to produce a usable product; some of it by both chemical and ore-dressing methods. As a result, the costs of producing such material will be at least twice that of the ore now available from foreign sources.

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## MERCURY

(By E. H. Bailey, U.S. Geological Survey, Menlo Park, Calif.)

Mercury, or quicksilver as it is often called, is a metal that at normal room temperature is a liquid rather than a solid like all other metals. It is perhaps most widely known as the material that forms little silver-colored droplets or balls when a fever thermometer is broken. Its use in silver alloy dental fillings and mercury vapor lights is also widely known, but less well known is its much larger use in electrical apparatus, in bactericides and fungicides, in medicines, and in antifouling paint for ship bottoms. Although generally only a small amount is required for a single piece of equipment or application, in mercury boilers and caustic soda plants a large quantity is used in each installation. Despite the fact that mercury has at least a thousand different identifiable uses the U.S. economy normally requires only about 2,000 tons of mercury each year. The metal is marketed in steel flasks, about the size of half-gallon milk bottles, containing a standard 76 pounds of mercury, and the worldwide units of trade are these standard flasks. The annual U.S. consumption in recent years has been about 55,000 flasks. Domestic mines have in the last few years yielded annually a production of about 30,000 flasks, or a little more than half of the domestic consumption. The other half comes chiefly from the Almaden mine in Spain and several mines in Italy. Because these can produce mercury in large amounts and at lower costs than can our domestic mines, the world price of mercury is largely controlled by their asking price.

The recovery from the ore of the final product—metallic mercury—is more readily and cheaply done for this metal than for any other, except perhaps free gold. For this reason it is possible to produce the final product at the mine, or in a few cases at the recovery plant of a nearby mercury mine. Nearly pure mercury is obtained directly from the ore by the simple process of heating the rock hot enough to convert the mercury minerals to mercury vapor, and then moving the vapor to a place where it cools enough to condense to the liquid metal. The mercury in the ore is generally in the form of a sulfide which is

dissociated to mercury and sulfur at a low red heat (about 1,000° F). To prevent these elements from recombining on cooling the sulfur must be combined with oxygen from the air or with some other substance. Two basic types of equipment are used for heating the ore—retorts and furnaces. They differ fundamentally in that in retorts the gases from the fuel do not mix with the mercury vapor, whereas in furnaces they do. Most retorts process a batch and must be unloaded and recharged, but furnaces generally are operated continuously. Quite effective retorts may be made simply and inexpensively from a section of 12-inch pipe that is placed over a small firebox, equipped with a seal at each end, and provided with a long exhaust pipe that serves as a condenser. Furnaces are much larger in size, capacity, and cost. They may be either rotary, like a cement kiln, or multiple hearth, like the Herreshoff furnace. In either case, the quantity of gases passing through them, including mercury vapor, air, and products of combustion, is so large that elaborate condensing systems are required.

Nevada mercury mines have produced altogether about 145,000 flasks of mercury, which is only about 4 percent of the total U.S. production of nearly 3,300,000 flasks. However, in the last 10 years (1953-62) Nevada mines have accounted for nearly one-fourth (23 percent) of the domestic production, and the Cordero mine, in northern Nevada, has ranked as either the largest or second largest producer in the United States during much of this period. Nevada also contains more than 100 other mercury mines for which some production has been recorded, but none of these others has been one-tenth as productive as the Cordero mine. The mines are distributed among about 30 districts, nearly all of which lie west of a meridian drawn through the center of the State (see fig. 28).

The first discovery of cinnabar in Nevada was made by Indians who used the bright red mineral for body paint. When mercury minerals were first recognized in Nevada by white men is not definitely known, but by the late 1870's a small amount of mercury was being recovered from the cinnabar deposit at Steamboat Springs. For the next 30 years, however, little mercury was recovered in Nevada in spite of other discoveries. In 1907 two deposits were discovered near Ione in the central part of the State, and by the end of 1919 these two together yielded about 10,000 flasks. Their success, coupled with the high wartime price of mercury, stimulated prospecting and led to the finding of deposits in the Goldbanks, Pilot Mountains, Imlay, and Antelope Springs districts. In spite of these discoveries low postwar prices led to near cessation of production, but with an increased price in 1927 these and other districts were reactivated. Production again dwindled to about nothing by 1932 when the price dropped abruptly, and it remained at a low level until just after the marked increase in price in 1939 brought about by war in Europe. Throughout the World War II period, and continuing until 1963, the annual production has generally been between 4,000 and 8,000 flasks. During the war years the production came from many mines, but following a postwar price decline all of the major mines, except Cordero were shut down.

Cinnabar, which is a bright red sulfide of mercury (HgS), is the source of practically all the production in Nevada; however, in a few deposits other mercury minerals are of some economic importance.

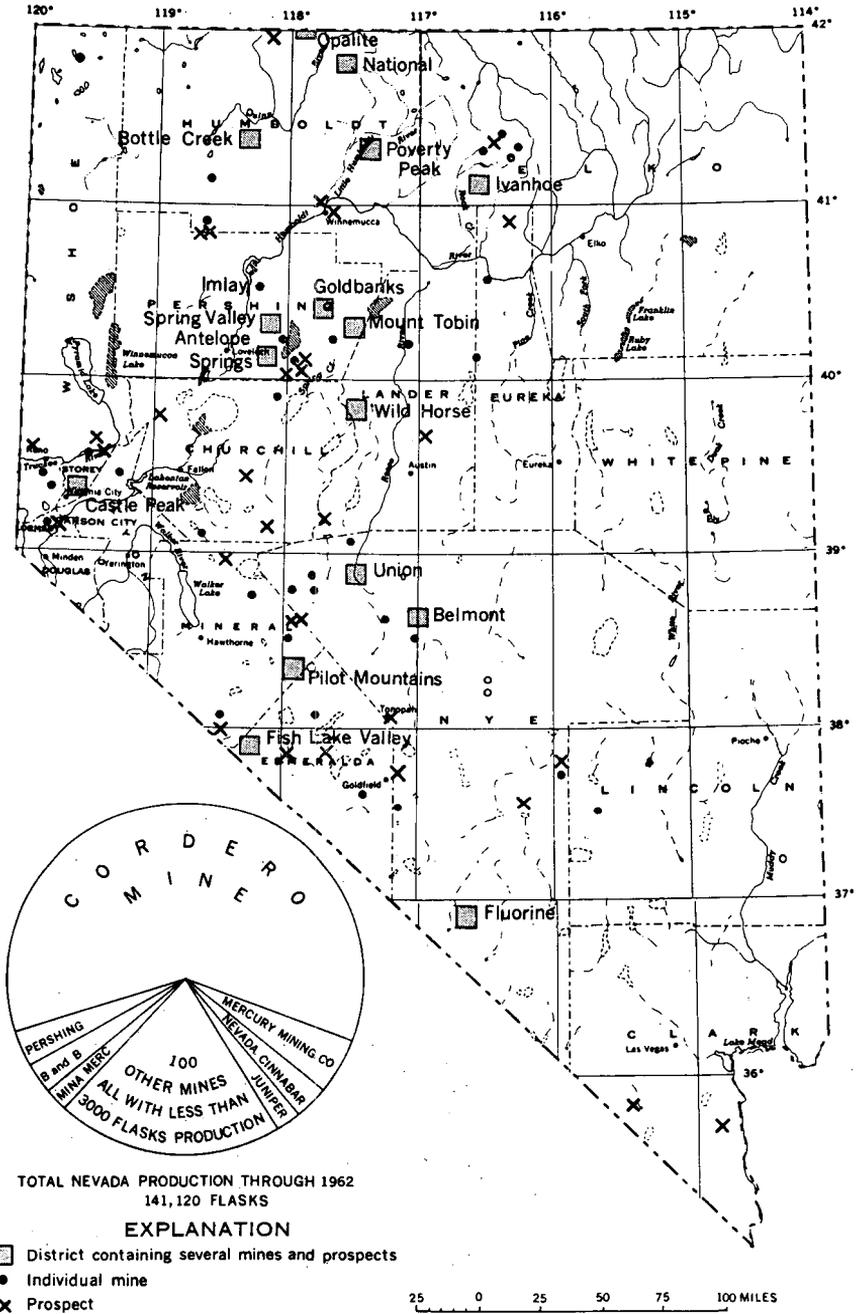


FIGURE 28.—Mercury in Nevada.

Metacinnabar, which is chemically like cinnabar but has a jetblack color, is as abundant as cinnabar in a few small mines. Metallic mercury occurs as droplets in some ores, and locally it is accompanied by the mercury chloride, calomel, or the strange mercury oxychlorides, terlinguaite and eglestonite that quickly turn black on exposure to sunlight. A new mercury sulfate was first found in Nevada deposits and named schuetteite in 1959 (Bailey and others, 1959).

Mercury deposits are formed by the deposition of the ore minerals from aqueous solutions at shallow depths in the earth and at temperatures that are lower than for most other metallic ores. Their close relation to hot springs is indicated by occurrences at Steamboat Springs, 11 miles south of Reno, where mercury is present in the escaping steam and in the muds brought up in the hot springs, and cinnabar is present in siliceous sinter deposited about recently active vents (White, 1955, pp. 112-113). The maximum known depth of cinnabar deposition in Nevada is 1,200 feet in the White Caps gold mine, but this is probably not the true limit as cinnabar has been found to extend downward to about twice this depth in the New Almaden mercury mine in California.

Mercury ore deposits have been found in Nevada in many different kinds of sedimentary and igneous rocks. The size and character of the ore bodies is different in different host rocks, but throughout the State ores developed in the same kind of rock are surprisingly uniform. The characteristics of each of these kinds of deposits have been described elsewhere (Bailey and Phoenix, 1944), and only those of greatest significance will be reviewed here.

Mines in andesitic and rhyolitic lava flows and breccias have yielded about three-fourths of the mercury recovered in Nevada. A typical example is provided by the highly productive deep ore bodies of the Cordero mine. The ores are formed by concentrations of cinnabar that may occur in small veins, veinlets, or tiny crystals disseminated in volcanic rocks that have been partly altered to clay minerals. Pyrite and marcasite are generally present, and quartz and calcite generally accompany the sulfides in veins. Typically the ores are either in or near a steep fault, but are generally not closely restricted by geologic structures. In the better deposits the grade of the ore over a minable width is about 1 percent. The largest ore body in the Cordero mine was 250 feet long, 50 feet wide, and has been mined through a vertical range of about 400 feet to a depth of about 700 feet. The ore bodies mined in the two larger mines near Ione in the Union district were smaller, but they might have a greater vertical extent than is now known.

Ore bodies found in thick beds of limestone in Nevada have been exceptionally rich, locally containing ores with as much as 50-percent cinnabar, but they also have been relatively small. In these ore bodies cinnabar replacing limestone predominates over cinnabar filling fractures, and small amounts of metallic mercury and mercury chloride may also be present. Gangue minerals are largely carbonates, and the antimony sulfide stibnite may be locally abundant. The ores in limestone are generally sharply bounded and confined to structural traps formed by faults or by a fault and a "capping" of shale. Good examples of this kind of ore body were exploited at

the Juniper mine in the Antelope Springs district and the Mina Mercury mine in the Pilot Mountains district, each of which yielded about 3,000 flasks. The ores found in this kind of deposit are so rich that they can be profitably mined under the lowest mercury prices conceivable, but they are so small and sharply bounded that it is not uncommon for all the profits realized on the first ore body to be spent in the search for another.

A third kind of mercury ore body occurs in a rock that is formed by silicification of rhyolite tuff and is widely known as "opalite." The type example of an ore body in this kind of rock was exploited at the Opalite mine, which is in the Oregon part of the Opalite district that straddles the Nevada-Oregon boundary. (See fig. 28.) However, Nevada contains many more deposits in opalite than does any other state. All the mines of the Ivanhoe district are in opalite, as is also the B. & B. mine in the Fish Lake Valley district, the Goldbanks mine in the Goldbanks district, and the Buckskin Peak mine in the National district. In addition, the exploitation of the opalite ores found at the surface at the highly productive Cordero mine led to the deeper exploration that revealed large ore bodies of a different character lying at greater depth.

Because the hydrothermal alteration of rhyolite tuffs to opalite has generally taken place in flat-lying beds near the surface, opalite occurs as nearly flat blankets at the surface or beneath less than 100 feet of cover. Such blankets vary in size, but are commonly less than 1,000 feet in diameter and only 30 to 50 feet thick. Some contain opal, but most opalite, in spite of its name, consists of chalcedony or fine-grained quartz. Cinnabar may be disseminated through much of the opalite, concentrated along favorable beds, or less commonly occur only along faults that cut the opalite. Metallic mercury, and mercury chloride or oxychlorides, occur in many opalite deposits but only in small amounts. Pyrite is rare in opalite ores, though it has been commonly found in the altered volcanic rocks beneath them. Opalite ores are generally low in grade, averaging only a few pounds of mercury to the ton, but because of their size and near-surface occurrence they are especially amenable to large-scale, open-cut or glory-hole mining. Only small parts of a few opalite deposits have been found to contain ore rich enough to be retorted profitably. Although most opalite deposits cropped out, most remained unrecognized until the mid-1920's because the pink color of opalite ore is rapidly changed on the surface to a nondescript blue black by the action of sunlight.

Other kinds of mercury ore bodies have been profitably exploited in Nevada at times of high prices, but those that have been described above have accounted for most of the production. The historical pattern of discovery suggests new deposits will be found, and additional ore bodies will be discovered in mines now regarded as worked out. Nevada contains a small reserve of marginal ore that can be treated at a profit when the price of mercury is unusually high, but the long-term continuation of mercury mining will require a more aggressive search for new ore bodies than appears justified by the prices that prevailed in 1963, especially when these are considered along with the uncertain level of future prices.

## MOLYBDENUM

(By J. H. Schilling, Nevada Bureau of Mines, Reno, Nev.)

Molybdenum is a silvery-gray metal having a higher melting point than all other metals except rhenium, tungsten, and tantalum. It is one of the most versatile alloying elements, and is used extensively in iron and steel to increase hardness, strength, and corrosion resistance, particularly at elevated temperatures. Molybdenum metal has similar properties, and has a small but rapidly increasing use in electronic applications, jets, and missiles. Molybdenum compounds are used as catalysts, lubricants, pigments, fertilizers, and chemical reagents.

The United States produces over 80 percent of world output and has the largest reserves. World production has increased from 1 million pounds in 1925 to over 80 million pounds in 1958; over the same period the price of a pound of molybdenum contained in concentrates increased from 70 cents to \$1.25. Only three mining districts in Nevada have produced molybdenum, and most of it has been recovered from copper ores mined in the Robinson district, White Pine County.

Molybdenum occurs most commonly as molybdenite ( $\text{MoS}_2$ ), a soft metallic-gray, platy mineral. Other important molybdenum minerals are wulfenite ( $\text{PbMoO}_4$ ), powellite ( $\text{CaMoO}_4$ ), and the oxides, ferrimolybdate and ilsemanite. Only the larger and the more interesting molybdenum deposits are described individually below; the name and location of all known occurrences in the State are listed in table 11 and shown on figure 29. For descriptions and references of nearly all these occurrences see Schilling (1962).

## PORPHYRY-COPPER DEPOSITS

The most important sources of molybdenum are the porphyry-copper deposits of the United States, Chile, U.S.S.R., and Peru. These deposits presently supply over half of the total world output as a byproduct of copper mining. In these deposits primary copper minerals and molybdenite occur as disseminated grains and in stockworks of crisscrossing quartz veinlets in hydrothermally altered granitic intrusive bodies and the intruded country rock. Oxidation generally has taken place at the surface, and the copper commonly has migrated to a zone of enrichment while the molybdenum usually has remained in place after being converted to an oxide. The deposits presently being exploited contain from 0.5 to 2 percent copper and 0.1 to 0.01 percent molybdenum.

Molybdenite concentrates worth about \$4 million have been recovered by Kennecott Copper Corp. from the porphyry-copper deposits (No. 97, fig. 29) in the Robinson (Ruth) mining district near Ely, White Pine County. Over 4 billion pounds of copper, 2 million ounces of gold, and 7 million ounces of silver also have been produced from the large open pit and underground mines. The porphyry-copper deposits occur along an east-west zone, mainly in hydrothermally altered monzonite porphyry intrusive bodies and to a lesser extent in adjacent sedimentary rocks. The monzonite intrusive

bodies and the hydrothermal alteration also are concentrated along the same east-west zone. Both faults and fractures have helped to control the locations of the ore bodies. Pyrite and chalcopyrite occur as disseminated grains and veinlets and as blebs in quartz veinlets. Coatings and flakes of molybdenite occur erratically along fractures. The ore bodies have been oxidized to depths ranging from 100 to more than 400 feet, and the copper minerals removed by leaching. A zone of supergene enrichment generally occurs below the zone of oxidation; here chalcocite replaces both the pyrite and chalcopyrite as coatings on the sulfide grains.

Duval Sulphur & Potash Co. is doing extensive exploratory drilling of porphyry-copper deposits in the Copper Canyon-Copper Basin area of the Battle Mountain mining district (No. 42), Lander County, in an attempt to find orebodies suitable for open-pit mining. In the past considerable copper-gold ore was produced by the underground Copper Canyon mine (sec. 27, T. 31 N., R. 44 E.) from richer portions of these deposits. Molybdenite occurs with quartz, chalcopyrite, and pyrite, some arsenopyrite and pyrrhotite, and minor galena, sphalerite, and scheelite in veins and as disseminations.

At the Copper Mountain mine (No. 63), Mineral County, in section 2, T. 11 N., R. 31 E., the richer portions of a porphyry-copper deposit were mined from 6,000 feet of workings developed through three shafts and several adits. Irregular masses and dikes of quartz monzonite porphyry intrude Jurassic and Triassic limestone. Chalcopyrite, cupriferous pyrite, chalcocite, and molybdenite are disseminated as grains and streaks in altered quartz monzonite porphyry, and occur as disseminations and large masses in contact-metasomatized (garnetized) limestone in contact with the quartz monzonite.

Core from a diamond-drill hole in section 21, T. 16 N., R. 57 E. (No. 96), in the White Pine (Hamilton) mining district, White Pine County, contains pyrite and chalcopyrite in quartz veins and as disseminations in quartz monzonite of the Monte Cristo stock and adjacent country rock. Molybdenite is present locally in the veins.

At Red Hill (No. 18) along U.S. Highway 95, 11 miles north of Coaldale Junction (sec. 34, T. 4 N., R. 36 E), in Esmeralda County, molybdenite occurs along the margins of small, irregular quartz-pyrite-chalcopyrite veinlets forming a stockwork in sericitized and silicified granodiorite. Smaller amounts of molybdenite and pyrite, and rare chalcopyrite, also are disseminated through the country rock. Younger, through-going quartz-feldspar "dikes" containing fluorite cut the granodiorite, surrounding sedimentary rocks, and mineralization. Ferrimolybdate and "limonite" fill boxworks and coat fractures. The deposit apparently is small and low grade.

In the Oddie Tunnel (No. 94) in the Bald Mountain mining district (sec. 22, T. 24 N., R. 57 E.), White Pine County, a little disseminated molybdenite and pyrite, small barren quartz veinlets, and some copper carbonate occur in a highly sericitized and calcitized quartz monzonite dike within a stock of granite porphyry.

TABLE 11.—*Molybdenum occurrences in Nevada*

[Numbers identify symbols shown in fig. 29]

CHURCHILL COUNTY	
1. Scott prospect	46. Cortez mining district
2. Nevada Wonder mine	47. Reese River (Austin) mining district
3. Chalk Mountain mining district	48. Birch Creek mining district
	49. Linka mine
CLARK COUNTY	
4. Goodsprings (Yellow Pine) district, (including Shenandoah mine)	LINCOLN COUNTY
5. Crescent mining district	50. Patterson mining district
6. Searchlight mining district	51. Tem Piute mining district
	52. Totten prospect
DOUGLAS COUNTY	
7. Risue Canyon	LYON COUNTY
	53. Silver City mining district
ELKO COUNTY	
8. Montrose prospect	54. Old Soldier mine
9. Mountain City mining district	55. Yerington mining district
10. Tennessee Mountain	56. Benway mining district
11. Batholith mine	57. McCoy prospect
12. Robinette mine	58. W. & P. mine
13. Contact mining district	59. Cowboy mine
14. Fox Creek Ranch	60. Sweetwater
15. Lucin mining district	
16. Spruce Mountain mining district	MINERAL COUNTY
17. Dolly Varden mining district	61. Nevada Scheelite (Leonard) mine
	62. Broken Hill mine
ESMERALDA COUNTY	
18. Red Hill (Redlich)	63. Copper Mountain mine
19. Carrie mine	64. Rand and Bovard mines
20. Black Horse mine	65. Cory Canyon
21. Lone Mountain	66. Lucky Boy area
22. Tonopah Divide mine	67. Dawson Powellite mine
23. Goldfield	68. Douglas prospect
24. Sylvania mine	69. Marietta
25. Cucomunga deposit (and small nearby occurrences)	70. Silver Dyke mine
26. Bullfrog-George prospect	71. Pine Tree prospect
27. Redemption mine	72. Pilot Mountains
	73. Queens
EUREKA COUNTY	
28. Mineral Hill mining district	NYE COUNTY
29. Eureka mining district	74. Downeyville mine
30. Antelope mine	75. Superior prospect
31. Gibellini mine	76. Round Mountain mining district
	77. Barcelona mine (Perkins and War- ren prospects)
HUMBOLDT COUNTY	
32. Ashdown mine and Vicksburg Canyon.	78. Manhattan mining district
33. Desert View prospect	79. Belmont mining district
34. Bartlett Creek	80. Hall property
35. Amos	81. Tonopah
36. Bloody Run mine	82. Oak Springs mining district
37. Osgood Mountains (including Get- chell mine)	PERSHING COUNTY
38. Winnemucca	83. Empire mining district
39. Sonoma Mountain mining district	84. Majuba Hill
40. Golconda mining district	85. Fifty-Six mine
41. Molly prospect	86. Mill City (Nevada-Massachusetts mine)
	87. Rose Creek mine
LANDER COUNTY	
42. Battle Mountain mining district	88. Garfield Force mine
43. Lewis mining district	STOREY COUNTY
44. Indian Creek	89. Comstock Lode
45. Violet shaft	WASHOE COUNTY
	90. Guanomi mine
	91. Hill-Johnson prospect
	92. Verdi
	93. Steamboat Springs

WHITE PINE COUNTY

- 94. Bald Mountain mining district
- 95. McMurry prospect
- 96. Monte Cristo stock

- 97. Ely (Robinson, Ruth) mining district
- 98. Minerva group

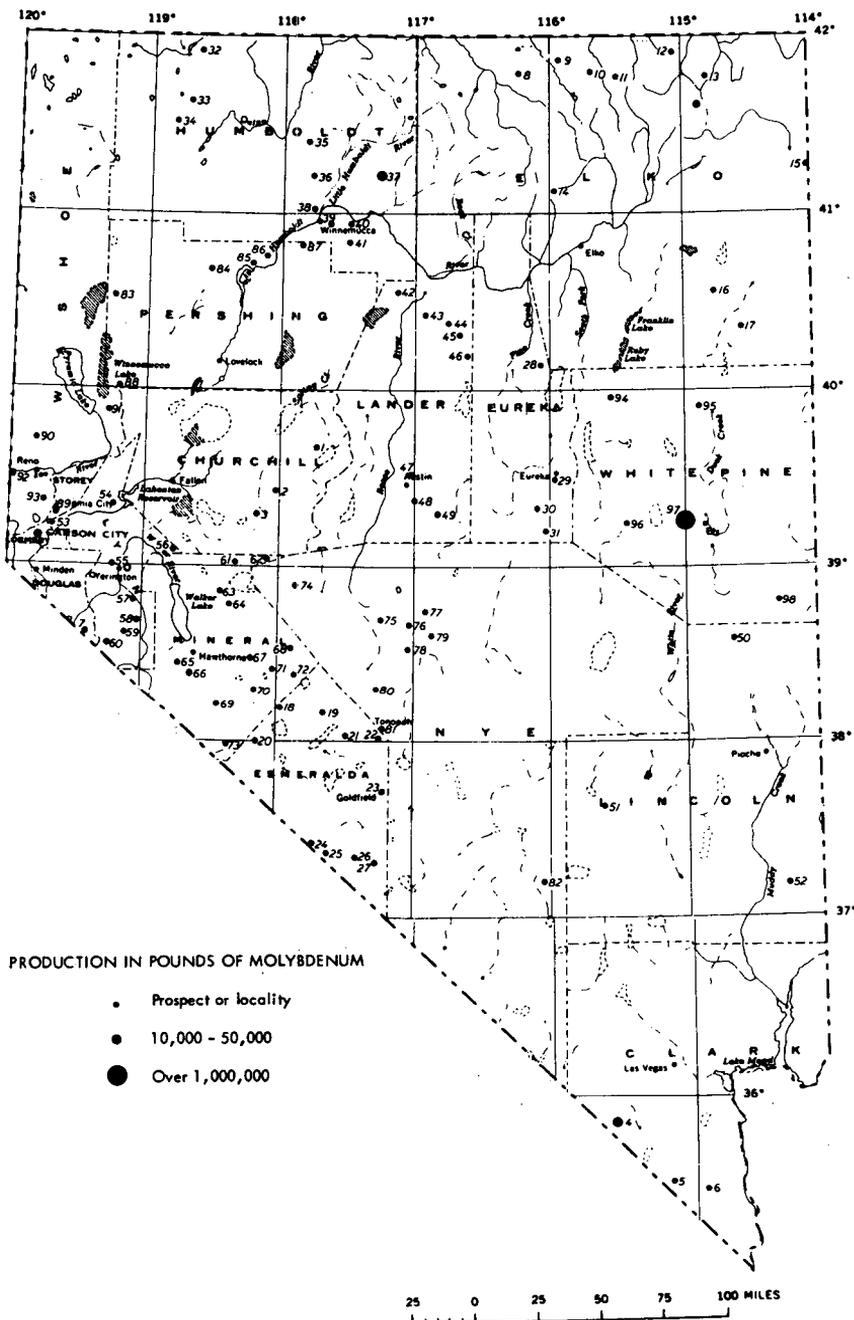


FIGURE 29.—Molybdenum in Nevada (numbers refer to deposits or districts listed in table 11).

## PORPHYRY-MOLYBDENUM DEPOSITS

The porphyry-molybdenum deposits differ from the porphyry-copper deposits (above) principally in containing little or no copper, and from the quartz veins (below) in consisting of stockworks rather than distinct, throughgoing veins. One deposit of this type, the Climax mine in Colorado, has produced half of the total world output of molybdenum. The Climax mine presently exploits ore containing 0.4 percent molybdenite.

At the Hall property (No. 80) in Nye County, 18 miles north-northwest of Tonopah, over 4,400 feet of underground work and extensive diamond drilling have been done while exploring for molybdenum. Until recent years, most of the exploration was concentrated on a high-grade portion of a porphyry-molybdenum deposit. Here molybdenite, pyrite, and minor chalcopyrite occurred in quartz veins and pods which form a tabular ore body 50 to 75 feet wide and 1,500 feet in length. The ore body and many of the veins that form the ore body roughly parallel the quartz monzonite-schist contact and the foliation of the schist. Ferrimolybdate and "limonite" are common in the zone of oxidation which extends to a depth of 95 to 150 feet. Powellite is erratically distributed in the vicinity of the ore body. Ilsemannite(?) was found at one spot near the workings. Since 1957, the Anaconda Co. has done extensive exploratory drilling on the entire deposit which consists of a stockwork of molybdenite-bearing quartz veinlets and masses that form an irregular halo around the margins of the quartz monzonite body and intruded rocks. The rocks in the halo have been silicified, sericitized, and argillized.

The Cucomunga deposit (No. 25) southwest of Lida in the Magruder Mountains (secs. 2 and 3, T. 7 S., R. 39 E.) of Esmeralda County has been explored by the 900-foot Roper adit and extensive drilling mainly by Bear Creek Mining Co. A northwest-trending zone, a thousand feet wide and several miles long, occurs in "Cottonwood" quartz monzonite along the contact with a wedge of metasediments which separate the quartz monzonite from older quartz monzonite porphyry to the southwest. The rocks within the zone have been silicified, sericitized, and argillized. Flakes and rosettes of molybdenite are disseminated through the silicified and sericitized Cottonwood quartz monzonite and along the edges of quartz veinlets that form a stockwork in the altered Cottonwood quartz monzonite. Pyrite also is common, but copper minerals are almost completely absent. Limonite, iron sulfate, jarosite, and other oxidation products are abundant at the surface but molybdenite and pyrite also are found. Yellow ferrimolybdate is present but difficult to distinguish from the other yellow secondary minerals. Abundant dark blue ilsemannite is forming on the dump of the Roper adit, and occurs along a fault zone in the altered area. The water from Poison Springs and from the Roper adit contains appreciable amounts of molybdenum.

In the Goldfield mining district (No. 23), Esmeralda County, pyrite-bearing quartz veinlets and disseminated flakes of molybdenite occur in argillized and sericitized alaskite exposed in the bottom and on the 1,100-foot level of the Silver Pick shaft (SE $\frac{1}{4}$  sec. 35, T. 2 S., R. 42 E.). The alaskite is older than the overlying Tertiary volcanic rocks in the district.

## QUARTZ VEINS

Molybdenite commonly occurs in distinct, throughgoing quartz veins with or without other sulfide minerals. The largest molybdenum mine of this type, the Questa mine, New Mexico, produced over 18 million pounds of molybdenite from quartz veins containing 1 to over 20 percent of the mineral. At present this type deposit is not an important source of molybdenum.

In the Contact mining district, (No. 13), Elko County, molybdenite occurs with chalcopyrite and bornite in numerous quartz fissure veins cutting a granodiorite body and to a limited extent the intruded Carboniferous sedimentary rocks. Many of the veins are in or associated with alaskite dikes that cut the other rocks. Molybdenite-bearing quartz veins containing copper minerals but no lead or zinc also occur at the Nevada Wonder mine (No. 2), Churchill County; with niccolite (NiAs) at the Montrose prospect (No. 8), Elko County; in the Winnemucca mining district (No. 38), Humboldt County, and with scheelite at the Molly prospect (No. 41), Humboldt County; in the Birch Creek mining district (No. 48), Lander County; in the Benway mining district (No. 56) and at the W. & P. mine (No. 58), Lyon County; at the Bovard mine (No. 64), Mineral County; and with barite at the Superior prospect (No. 75), Nye County.

Molybdenite-bearing quartz veins containing lead and zinc, as well as copper minerals, are found in Esmeralda County at the Bullfrog-George prospect (No. 26) where they also contain fluorite and at the Carrie mine (No. 19) where they contain stibnite and scheelite; in the Mineral Hill mining district (No. 28), Eureka County; in the Reese River mining district (No. 47), Lander County; and at the Broken Hill mine (No. 62), Mineral County.

Molybdenite-bearing quartz veins containing little or no copper, lead, or zinc are found in the Mountain City mining district (No. 9) and near the Fox Creek Ranch (No. 14), Elko County; at several localities near the Cucomunga deposit (No. 25), Esmeralda County; near Amos, Humboldt County; in the Silver City mining district, Lyon County; at the Douglas prospect, Mineral County; in the Empire mining district, Pershing County; and at the McMurry prospect, near Cherry Creek, White Pine County. Many of these occurrences also contain secondary molybdenum oxides; at the Hill-Johnson prospect (No. 91) north of Reno in Washoe County the blue oxide, ilsemannite, stains quartz veins in which there are no other visible molybdenum minerals.

An interesting occurrence of what apparently is an oxidized molybdenite-bearing quartz vein is in the Divide mining district a few miles south of Goldfield in Esmeralda County. In the district, silver-bearing veins, trending north and dipping vertically, follow shear zones in rhyolite breccia. The primary vein material consists of quartz and pyrite; supergene enrichment has resulted in the concentration of silver as argentite, which subsequently has been almost completely converted to cerargyrite. A considerable amount of bright yellow ferrimolybdate occurs on the 165-foot level of the Tonopah Divide mine (No. 22), Esmeralda County. The ferrimolybdate disappears with depth, and at the corresponding position on the next lower level there is abundant well-crystallized powellite. No molybdenite has been reported in the district.

## TUNGSTEN CONTACT DEPOSITS

Molybdenite and powellite commonly occur in tungsten (scheelite)-bearing contact deposits (tactites or skarns) developed in lime-rich rocks near granitic intrusive bodies (see Tungsten, p. 258). The scheelite ( $\text{CaWO}_4$ ) in some of these deposits contains up to several percent molybdenum in place of part of the tungsten (W). Pyrite and copper minerals commonly are associated with the molybdenite. In most cases the molybdenum minerals are present in such small amounts that they can be recovered only as byproducts. The Pine Creek mine, California, is the only important producer of this type.

Production of 1,900 pounds of flotation concentrates containing 45 percent molybdenum were obtained in 1958 from molybdenite-bearing tactite at the Gatchell mine (sec. 33, T. 39 N., R. 42 E.) in the Osgood Mountains (No. 37), Humboldt County. These concentrates reportedly were made during mill tests run to determine the feasibility of exploiting this occurrence. The molybdenite occurs with scheelite, chalcopyrite, and pyrite in tactitized limestone along the northeast edge of a granodiorite body.

At the Nevada-Massachusetts mine (No. 86), Pershing County, the largest tungsten mine in Nevada, molybdenite is widely distributed in fractures which cut garnet, epidote, and scheelite in tactite. At the Barcelona mine (No. 77), 6 miles northwest of Belmont in Nye County, molybdenite occurs disseminated through tactite containing only minor scheelite adjacent to an "alaskite" granite body; at the Perkins prospect, which is the southwesternmost exposure at this occurrence, molybdenite is in massive pyrite-pyrrhotite replacing contact-metamorphosed hornfels, while to the northeast at the Warren prospect, molybdenite and pyrite are scattered through garnetized limestone. Molybdenite also occurs in the following tungsten-bearing deposits: in Risue Canyon (No. 7), Douglas County; at Tennessee Mountain (No. 10), at the Batholith mine (No. 11), and at the Robinette mine (No. 12), Elko County; at the Black Horse mine (No. 20) and in the Goldfield mining district (No. 23), Esmeralda County; at the Desert View prospect (No. 33), along Bartlett Creek (No. 34), and at the Bloody Run mine (No. 38), Humboldt County; at Indian Creek (No. 44) and the Linka mine (No. 49), Lander County; at the Nevada Scheelite mine (No. 61) and near Queens (No. 73), Mineral County; and at the Rose Creek mine (No. 87), and at the Garfield Force mine (No. 88) in the Nightingale district, Pershing County. Many of these occurrences also contain powellite, commonly replacing molybdenite.

A few tungsten-bearing contact deposits in Nevada contain powellite but no molybdenite. These include: some of the tungsten mines in the Osgood Mountains (No. 37) and deposits in the Sonoma mining district (No. 39), Humboldt County; the Lincoln mine in the Tem Piute mining district (No. 51), Lincoln County; and the Dawson powellite mine (No. 67), Mineral County.

Several contact deposits contain molybdenian scheelite (which contains one-half to 5 percent molybdenum and fluoresces pale yellow) rather than the much-more-common molybdenum-poor scheelite (which fluoresces pale blue-white). At the Lincoln mine in the Tem Piute mining district (No. 51), Lincoln County, and near Marietta (No. 69) and at the Silver Dyke mine (No. 70), Mineral County, only

the molybdenian variety of scheelite is present; no other molybdenum minerals have been reported from the latter two occurrences. At the Rose Creek mine (No. 87), Pershing County, two varieties of scheelite occur either separately or as irregular intergrowths in the same crystal: one variety fluoresces bluish-white and contains about 0.05 percent molybdenum; the other variety fluoresces light yellow and contains about 1.8 percent molybdenum.

In contrast to the many molybdenum-bearing contact deposits that contain scheelite, in the Contact mining district (No. 13), Elko County, molybdenite occurs with quartz, chalcopyrite, bornite, and specularite in scheelite-barren contact-metasomatized limestone adjacent to a granodiorite intrusive body.

### LEAD-ZINC DEPOSITS

Wulfenite is present in the oxidized portions of many lead-zinc deposits. Before World War I this was the most important source of molybdenum, but at present little or no molybdenum is recovered from this type deposit.

At the Shenandoah mine (sec. 35, T. 24 S., R. 57 E.) in the Good-springs (Yellow Pine) mining district (No. 4), Clark County, wulfenite concentrates containing approximately 20 tons of molybdenum were produced in 1935(?) from 5,000 tons of ore. Here and at many of the other lead-zinc deposits in the district, wulfenite is common as tabular, orange to wax-brown crystals lining drusy cavities. The lead-zinc mineralization forms bodies replacing Mississippian limestone and dolomite where brecciated fault zones and fractures cut these rocks. The bodies consist mainly of quartz, galena, cerussite, hydrozincite, calamine, some anglesite, smithsonite, and sphalerite, and locally some chalcopyrite, chrysocolla, malachite, and azurite. Oxidation extends below the deepest workings.

Wulfenite is relatively abundant and widespread in the oxidized lead-silver ore of the Eureka mining district (No. 29), Eureka County. Many excellent specimens have been found. Molybdenite also is present in the ore, but only in a few spots, and in small amounts. The mineral deposits of the district are replacement chimneys, irregular bodies, veins, cavern linings, and bedded deposits associated with fissures, mainly in Cambrian limestone. Galena, pyrite, arsenopyrite, and sphalerite are common below the zone of oxidization. Galena, cerussite, anglesite, and mimetite occur in the oxidized zone which extends to a depth of 1,200 feet. Molybdenum is present in appreciable amounts in the slag and other waste products resulting from the smelting of the Eureka ores.

Wulfenite also occurs in lead-zinc deposits of the Chalk Mountain mining district (No. 3), Churchill County; of the Crescent (No. 5) and Searchlight (No. 6) mining districts, Clark County; of the Lucin (No. 15), Spruce Mountain (No. 16), and Dolly Varden (No. 17) mining districts, Elko County; at the Redemption mine (No. 27), Esmeralda County; at the Rand mine (No. 64), Mineral County; and at the Downeyville mine (No. 74) and in the Round Mountain (No. 76), Belmont (No. 79), and Tonopah (No. 81) mining districts, Nye County. At 3 (Nos. 3, 64, 79) out of 12 of these occurrences, molybdenite is known to occur in the unoxidized portions of the same deposits that contain the wulfenite; in some of the other occurrences

only oxidized mineralization has been exposed by the workings. Vanadinite and copper minerals also are present in many of the above occurrences.

#### OTHER OCCURRENCES

At the Gibellini mine (No. 31) in section 35, T. 16 N., R. 52 E., Eureka County, manganese ore has been mined from open cuts and underground workings. The manganese minerals, psilomelane and pyrolusite, occur as pipe-shaped bodies in Paleozoic limestone. The ore contains appreciable zinc, nickel, and vanadium, and a little cobalt, molybdenum (0.1 percent), and copper.

At Steamboat Springs (No. 93), 10 miles south of Reno in Washoe County, blue stains of ilsemannite coat the walls of a pit in basalt that has been altered by hot spring activity.

#### FUTURE POTENTIAL

Nevada is a potentially important source of molybdenum. Several deposits are being explored with encouraging results, and the geologic environment in the State is favorable for the discovery of other mineable deposits of the porphyry-molybdenum, porphyry-copper, and contact-tungsten types.

The possibility of recovering molybdenum oxides, which currently are being wasted, should not be overlooked. If mass mining of tungsten becomes profitable in the future, recovery of byproduct molybdenite and other mineral materials might be feasible.

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#### PLATINUM

(By L. H. Beal, Nevada Bureau of Mines, Reno, Nev.)

The platinum group of metals includes platinum, palladium, iridium, osmium, rhodium, and ruthenium. The element platinum is a heavy, grayish-white, noncorroding precious metallic element, malleable and ductile but fusible with difficulty, and resistant to most chemicals. Other members of this group have similar chemical properties, but several are brittle, different in density, and have a silver or whitish color. As pure metals, combined, clad, or alloyed with certain other metals, the platinum metals are used for jewelry, in the glass industries, in the chemical and electrical industries, in dentistry, and for a number of miscellaneous uses (Ryan and McBreen, 1960).

Platinum metals are found in nature in the uncombined form, associated with each other and frequently with gold, copper, nickel, iron, and chromium ores. The U.S. supply of platinum metals comes mostly from Canada, but domestic placers, byproduct metals, and secondary refining yield about 22 percent of this country's requirements (Engelhard, 1963). Estimated domestic consumption for 9 months of 1962 was 602,400 ounces. Current market prices per troy ounce (Eng. and Mining Jour., April 1964) are: platinum, \$87 to \$90; palladium, \$28 to \$30; iridium, \$70 to \$75; osmium, \$60 to \$70; rhodium, \$142 to \$145; and ruthenium, \$55 to \$60.

In Nevada limited platinum metals have been recovered from the copper-nickel-cobalt ores of the Bunkerville district and the copper-gold ores and gold-platinum ores of the Yellow Pine district, Clark County. Also minute amounts have been recovered from the copper ores of the Ely district, White Pine County. During the last few years no record of platinum production in Nevada has been published.

## RHENIUM

(By J. H. Schilling, Nevada Bureau of Mines, Reno, Nev.)

Rhenium is a rare metal with the second highest melting point (3,180° C.) and fourth highest density (21 gm/cc) of all the metals. About 100 pounds of rhenium are consumed annually in the United States; rhenium powder sells for \$680 a pound. It presently is used in thermocouples and in filaments for mass spectrographs and ion gages, but most of the metal is consumed in research aimed at discovering commercial applications. Many potential new uses have been found, particularly in electrical contacts, electronics, and in corrosion-resistant and high-temperature alloys.

There are no known rhenium minerals; however, trace amounts of the metal are found in many minerals. Rhenium is particularly abundant in the molybdenum mineral, molybdenite, which contains up to 0.4 percent. The rhenium content of molybdenite from producing porphyry copper-molybdenum deposits is 2 to over 30 times greater than that of molybdenite from any other type of occurrence. Essentially all the rhenium now being produced is recovered from flue gas and dust resulting from the roasting of molybdenite concentrates from such porphyry-copper deposits. It is estimated that some 15 tons a year of rhenium could be recovered from molybdenite concentrates now being produced in the United States, more than the rest of the world combined.

Little is known about the occurrence of rhenium in Nevada. At present the only significant potential sources are the molybdenite deposits of the State (described under Molybdenum, p. 124-132), particularly those of the rhenium-rich porphyry-copper type. Rhenium has been extracted by the Kennecott Copper Corp. from molybdenite concentrates from their porphyry-copper open-pit mines in the Western United States including the Ely (Ruth), Nev., deposits; molybdenite from Ely reportedly contains 0.1 to 0.3 percent rhenium. In contrast, molybdenite from the Hall property, Nye County, and the Cucamonga deposit, Esmeralda County, contain only several hundredths of a percent rhenium.

The porphyry-copper deposits of Nevada are an important potential source of rhenium. However new specialized uses that warrant the high cost of the metal will have to be developed before this source is fully utilized.

## SELENIUM AND TELLURIUM

(By D. F. Davidson, U.S. Geological Survey, Denver, Colo.)

Essentially all selenium and tellurium of commerce produced in the United States are byproducts. Selenium is recovered from anode slimes produced during electrolytic refining of copper, and tellurium comes from the same sources, and from lead refining. The elements are semimetals, and both fall in group VI of the periodic table of elements.

The largest use of selenium at present is in rectifiers and photoelectric cells, and the largest potential use of tellurium may be in the construction of thermoelectric devices. Both elements are used as alloying materials in ferrous and nonferrous metallurgy, and in the rubber industry as vulcanizing agents. There are many other varied uses of both elements.

The world production and U.S. production and prices of selenium and tellurium in 1962 are shown in table 12. U.S. production accounted for about 47 percent of the non-Communist world selenium production, and approximately 66 percent of tellurium production.

TABLE 12.—*Production and prices of selenium and tellurium, 1962*<sup>1</sup>

	Selenium		Tellurium	
	Production in pounds	Price per pound	Production in pounds	Price per pound
North America:				
Canada.....	506,015		61,211	
Mexico.....	6,953			
United States.....	999,000	\$5.76-\$6.25	264,000	\$6.00
South America: Peru.....	18,382		50,742	
Europe:				
Belgium-Luxembourg.....	* 30,900			
Finland.....	11,797			
Sweden.....	* 200,000			
Asia: Japan.....	309,314		22,297	
Africa: Rhodesia and Nyasaland, Federation of Northern Rhodesia.....	40,526			
Oceania: Australia.....	* 3,000			
Total.....	2,126,000		398,000	

<sup>1</sup> Data from Shelton (1963).

\* Estimates.

So far as the writer is aware, there is no production of either selenium or tellurium from ores from Nevada at the present time. Little is known of the resources of tellurium—there are published descriptions of tellurium occurrences in only two places, the Delamar district in Lincoln County (Palache and others, 1944) and the Goldfield district in Esmeralda County (Ransome, 1909). Tellurium is associated with gold at both places and occurs as the native element at Delamar, and in telluride minerals at Goldfield. Tellurium is also known to occur in telluride minerals in the Ward district, and in the Robinson district, White Pine County.

Resources of selenium in Nevada are probably quite large. The element occurs in several different types of mineral deposits as shown on figure 30. It is known to be a part of the silver deposits of the Jarbidge district, Elko County (Schrader, 1923); the Tonopah district, Nye County (Basten and Laney, 1918); the Aurora district, Mineral County (Hill, 1915); and the Comstock district, Storey County (Becker, 1882; Coats, 1936).

The selenium of the Jarbidge district is, in part, present in the silver selenide mineral "naumannite," and part of the selenium of the Comstock district is present in the silver-selenium-sulfur mineral "aguilarite." The nature of the selenium occurrences in the other districts is not known to the writer, although it does occur with the silver.

Lindgren (1915) has described a selenium occurrence in the vicinity of mercury deposits in the national district, Humboldt County. The selenium is presumed to be in elemental form. No evidence other than juxtaposition of deposits is available to link the selenium with mercury.

Spencer (1917) mentions occurrence of selenium in the copper deposits of the Robinson (Ely) district, White Pine County. The mineralogic occurrence of selenium in these deposits is not known to the writer.

Davidson (1960) lists partial analyses for 52 antimony ore samples from 22 localities in Churchill, Elko, Humboldt, Lander, Mineral, Nye, Pershing, and Storey Counties. Selenium contents of the samples ranges from a trace to 1.06 percent. Fourteen of the localities are shown on figure 30, and listed in table 13. Work, so far unpublished, seems to demonstrate that except when oxidation has freed it, as elemental selenium, the selenium of these deposits is directly associated with the antimony mineral, and may in fact be substituting for sulfur in stibnite.

Davidson and Lakin (1961, 1962) present selenium analyses for samples of carbonaceous marine shales from localities in White Pine, Eureka, Humboldt, Elko, and Nye Counties. Localities are listed in table 13, and shown on figure 30. Selenium contents of the samples ranged from  $<1$  to 290 ppm. The selenium of the shales is at least partly in sulfide minerals, and might be recoverable if the shales are worked for their other valuable constituents (see section on vanadium, p. 165).

TABLE 13.—*List of localities, areas and districts containing occurrences or deposits of tellurium, selenium, and vanadium in Nevada.*

[Numbers identify symbols shown in fig. 30]

## Tellurium:

1. Goldfield, Ransome, 1909.
2. Delamar, Palache, and others, 1944.

## Selenium with mercury:

3. Buckskin Peak mine, National district. Lindgren, 1915.

## Selenium with copper:

4. Several mines, Ely district. Spencer, 1917.

## Selenium with precious metals:

5. Long Hike mine, Jarbidge district. Schrader, 1923.
6. Several mines, Tonopah district. Bastin and Laney, 1918.
7. Durant mine, Aurora district. Hill, 1915.
8. Comstock district. Becker, 1882; Coats, 1936.

## Selenium with antimony:

9. Near Fallon. Davidson, 1960.
10. 65 miles north of Elko. Davidson, 1960.
11. Near Elko. Davidson, 1960.
12. Tuscarora. Davidson, 1960.
13. Near Wells. Davidson, 1960.
14. Near Winnemucca. Davidson, 1960.
15. National. Davidson, 1960.
16. Near Battle Mountain. Davidson, 1960.
17. Near Austin. Davidson, 1960.
18. Near Hot Creek. Davidson, 1960.
19. Near Tonopah. Davidson, 1960.
20. Near Manhattan. Davidson, 1960.
21. Near Lovelock. Davidson, 1960.
22. Near Reno. Davidson, 1960.

## Selenium with vanadium:

23. Goose Creek Valley. Davidson and Lakin, 1962.
24. Taylor Canyon. Davidson and Lakin, 1962.
25. Edna Mountains. Davidson and Lakin, 1961.
26. Scheel Creek Range. Davidson and Lakin, 1961.
27. Fish Creek Range. Davidson and Lakin, 1961.
28. Toquina Range. Davidson and Lakin, 1962.

## Vanadium with asphaltite:

29. Pine Creek area. Schilling, 1962.

## Vanadium with iron ores:

30. Buena Vista Hills district. Reeves and Kral, 1955.

## Vanadium with uranium:

31. Virgin Valley district. Butler and others, 1962.
32. Chalk Mountains. Schilling, 1962.
33. Atlanta mine. Butler and others, 1962.
34. Sloan district. Hewett, 1923.
35. Sutor area. Hewett, 1923.

## Vanadate minerals:

36. Cave Valley mine, Patterson district. Schrader, 1931.
37. Prince mine, Pioche district. Westgate and Knopf, 1932.
38. Republic mine, Chief district. Callaghan, 1936.
39. Many mines, Goodsprings district. Hewett, 1931; Dorner, 1923.
40. Searchlight district. A. V. Heyl, written communication, 1961.

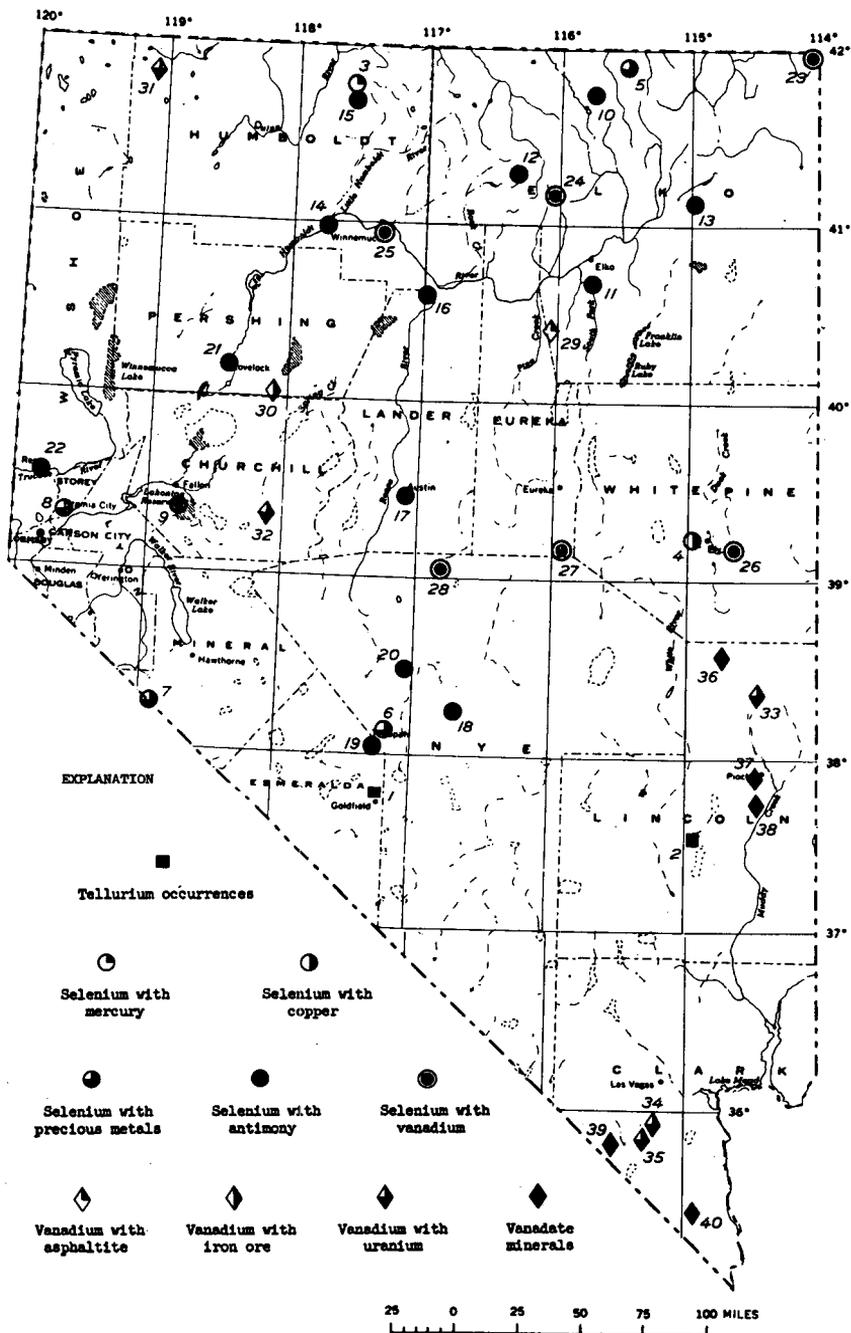


FIGURE 30.—Selenium, tellurium, and vanadium in Nevada (numbers refer to deposits or districts listed in table 13).

## SILVER, LEAD AND ZINC

(By F. J. Kleinhampl, U.S. Geological Survey, Menlo Park, Calif.)

Nevada has at least 267 scattered districts that have produced silver, lead, or zinc; about one-third have had important, if not major, production and are shown on figures 31 and 32, listed in table 14 and described in this report. Horton and others (1962 a, b, and c) classify districts by commodity and into seven categories by magnitude of production. A modification of this classification is used in table 14, and figures 31, 32, and is as follows:

District rank	Silver production (troy ounces)	District rank	Lead or zinc production (short tons)
1.....	100,000,000 or more.....	A	50,000 or more.
2.....	10,000,000 to 100,000,000.....	B	500 to 50,000.
3.....	1,000,000 to 10,000,000.....	C	Less than 500.
4.....	100,000 to 1,000,000.....		
5.....	Less than 100,000.....		

This usage is in preference to the classifications developed by McKnight, Newman, and Heyl (1962a and 1962b) and McKnight and others (1962) because the latter utilize not only production, but reserves, which are difficult to obtain and to evaluate. The interested reader is referred to these publications because the inclusion of reserves alters the classification of some districts; also, geologic descriptions of districts in table 14, modified in some cases, are primarily from these sources. Production and consumption data has come primarily from the minerals yearbooks (U.S. Bureau of Mines, 1933-63), "Mineral Facts and Problems" (U.S. Bureau of Mines, 1960), and Knoerr and Eigo (1961).

Silver has been valued since prehistoric times for ornamentation and as a medium of exchange. The myriad uses of the metal make it one of the most versatile known to man, with industrial applications having become increasingly important in modern times because of the metal's special alloying properties, excellent heat and electrical conductance, and sensitivity of some silver salts to light. In the United States for 1959, consumption in photography took about 30 million ounces, solder and brazing about 25 million, electrical contacts about 19 million, and batteries and ceramics about 1 to 2 million each. Industrial consumption of silver for the United States compared to that of the rest of the free world was in the ratio of 2 to 1 from 1949 to 1953; from 1954 to 1962 the ratio was about 1 to 1. During the 1950-62 period, total free world industrial consumption had increased from about 130 to 240 million ounces. Silver consumed in total world coinage from 1950 to 1962 ranged from about 44 to 127 million ounces, and was about double the U.S. coinage need.

Nevada produced 316,558,354 ounces of silver with a value of \$217,529,000 from 1904 through 1962. This output is 10.6 percent of the total U.S. production, by weight, for that period. Annual output since 1943, however, has scarcely exceeded a million ounces and has not approached the 10.6-percent figure given above.

TABLE 14.—*Significant silver, lead, and zinc districts in Nevada*<sup>1</sup>

Locality No.		District	County	Rank <sup>1</sup>			Manner of occurrence	References
Silver map (fig. 31)	Lead-zinc map (fig. 32)			Silver	Lead	Zinc		
1		Wonder	Churchill	3	C		Veins in Tertiary rhyolite, partly along contact with intrusive dacite.	Vanderburg, 1940.
2		Sand Springs		3			Veins in schist, limestone, and andesite	Do.
3	1	Fairview		3	B		Fissure veins in Tertiary andesite	Do.
	2	Las Vegas	Clark	5	B	C	Sedimentary deposit in tuffaceous sandstone of Pliocene(?) lake. Recovered as byproduct from manganese production.	Hunt and others, 1942; McKelvey and others, 1949.
4	3	Yellow Pine		3	B	A	Replacement deposits along fracture zones parallel and subparallel to bedding mainly in Mississippian limestone.	Hewett, 1931; Longwell and others (in press).
5		Eldorado		3	C	C	Fissure veins in Tertiary quartz monzonite and in Precambrian gneiss and schist.	Lincoln, 1923; Longwell and others (in press).
6	4	Searchlight		4	B		Breccia veins in andesite of early Tertiary(?) age near contact with intrusive quartz monzonite.	Callaghan, 1939; Ransome, 1907.
7		Mountain City	Elko	3	C		Fissure veins in quartz monzonite and metamorphosed limestone; byproduct of copper in secondary enriched ore.	Emmons, 1910; Granger and others, 1957.
8		Jarbridge		3			Fissure veins in Tertiary rhyolite	Schrader, 1912, 1923; Granger and others, 1957.
9		Aura		3	C		Fissure veins and bedded replacements in limestone adjacent to granodiorite stock, and veins in the granodiorite.	Emmons, 1910; Granger and others, 1957.
10	5	Delano	Elko	3	B	C	Replacement bodies along bedding in brecciated Paleozoic carbonate rock.	Granger and others, 1957.
11		Cornucopia		4	C		Lodes in altered intrusive Tertiary andesite	Do.
12		Gold Circle		3	C		Replacement and fissure veins and lodes in rhyolite and along shattered contact between rhyolite and andesite.	Granger and others, 1957; Emmons, 1910.
13		Tuscarora		3	C		Stockworks and lodes in Tertiary rhyolite and intrusive andesite; minor placer deposits.	Emmons, 1910; Nolan, 1936; Granger and others, 1957.
	6	Tecoma		5	B		Replacement bodies along fissures on low anticline in Devonian limestone.	Granger and others, 1957.
14	7	Merrimac		4	B	B	Veins and bedding replacement deposits along faults bordering contact of porphyry with Mississippian limestone; some contact metamorphic deposits.	Do.
	8	Loray		5	B		Opaline quartz veins in Paleozoic carbonate rocks.	Granger and others, 1957; Hill, 1916.

See footnotes at end of table, p. 143.

TABLE 14.—*Significant silver, lead, and zinc districts in Nevada*<sup>1</sup>—Continued

Locality No.		District	County	Rank <sup>1</sup>			Manner of occurrence	References
Silver map (fig. 31)	Lead-zinc map (fig. 32)			Silver	Lead	Zinc		
15	9	Railroad.....		3	B	C	Replacement bodies at fracture intersections in limestone. Some contact metamorphic deposits.	Granger and others, 1957.
16	10	Spruce Mountain.....		3	B	B	Bedding replacements and veins along fractures and faults in Paleozoic limestone, partly at contact with porphyry dikes.	Granger and others, 1957; Schrader, 1931.
17		Good Hope.....	Elko.....	5			Lodes along shear zones in rhyolite flow breccia.....	Emmons, 1910; Granger and others, 1957.
18	11	Lone Mountain.....	Esmeralda.....	4	B	C	Replacement bodies in Cambrian limestone along contact with porphyry dike or with granite intrusive.	Ball, 1907, p. 51-55.
19		Divide.....		3	C		Veins along shear zones in upper Tertiary pyroclastic rocks.	Knopf, 1921a; Hewett and others, 1936.
20		Klondike.....		4	C		Replacement bodies in Cambrian sedimentary rocks.	Lincoln, 1923; Spurr, 1906; Albers, oral communication, 1964.
21		Silver Peak (Mineral Ridge).....		3	C	C	Veins in Tertiary volcanics and in Precambrian(?) Wyman Formation.	Lincoln, 1923; J. P. Albers, oral communication, 1964.
22	12	Montezuma.....		4	B(?)		Veins and replacement bodies in Cambrian carbonates.	Lincoln, 1923; J. P. Albers, oral communication, 1964.
23		Goldfield.....		3	C		Veinlike irregular bodies in Tertiary dacite and other volcanic rocks. Recovered as byproduct from gold mining.	Lincoln, 1923; J. P. Albers, oral communication, 1964; Ransome, 1907 and 1909a; Searles, 1948.
24		Lida.....		4	C		Veins and replacement bodies in Cambrian rocks.....	Lincoln, 1923; J. P. Albers, oral communication, 1964.
25		Hornsilver.....		4	C	C	Veins in Paleozoic sediments near borders of granite intrusives.	Ransome, 1909b; Hewett and others, 1936.
26		Safford.....	Eureka.....	4	C		Veins in andesite.....	Vanderburg, 1938b.
27	13	Cortez.....		2	B	C	Replacement bodies in Cambrian dolomite and Ordovician quartzite, partly within sheeted zones parallel to porphyry dikes.	Vanderburg, 1938b; Emmons, 1910; Roberts and others (in press).
28		Buckhorn.....	Eureka.....	4			Veins along fault in kaolinized brecciated Tertiary(?) andesite and siliceous shale.	Vanderburg, 1938(a); Emmons, 1910; Roberts and others (in press).
29	14	Mineral Hill.....		4	B	C	Replacement bodies in Devonian limestone adjacent to thrust fault.	Vanderburg, 1938(a); Roberts and others (in press).
	15	Union.....		4	B(?)		Replacement bodies in Devonian limestone.....	Vanderburg, 1938(b); Roberts and others (in press).
	16	Lone Mountain.....		5	C	B	Probably irregular replacement bodies adjacent to faults in carbonate rocks.	C. W. Merriam, oral communication, 1964.

30	17	Eureka.....		3	A	B	Irregular and bedded replacement deposits, associated with fissures and faults, in Cambrian carbonate rocks; minor disseminated deposits.	Nolan, 1962.
	17A	Mount Hope.....		5	C	B	Replacement bodies in Permian(?) limestone roof pendants in alaskite stock.	Roberts and others (in press), Matson, 1946.
31		National.....	Humboldt.....	4	C		Veins in Tertiary volcanic rocks.....	Vanderburg, 1933(b); Compton <i>in</i> Willden (in press).
32		Rebel Creek.....		4(?)	C		Veins(?) in fractured Upper Triassic quartzite.....	Compton <i>in</i> Willden (in press).
33		Paradise Valley.....		3	C		Fissure veins in calcareous slate.....	Vanderburg, 1933(b).
34	18	Winnemucca.....		4	B	C	Veins along shear zones in Upper Triassic siltstone, shale, slate, hornfels, and sandstone.	Vanderburg, 1938(b); Willden (in press).
35		Sulphur.....		4			Veinlets in a postvolcanic(?) cemented conglomerate.	Do.
36		Gold Run.....		4	C	C	Veins in limestone, quartzite, shale, and schist.....	Vanderburg, 1933(b).
37	19	Battle Mountain.....	Lander.....	3	B	C	Veins and replacement bodies along faults in Cambrian and Pennsylvanian hornfels, conglomerate, and quartzite.	Roberts, 1951.
37A	20	Lewis.....		3	B		Veins in granodiorite and in Carboniferous quartzite, limestone, and slate, in part with replacement.	Vanderburg, 1939.
38		Hilltop.....		4	C		Veins in brecciated quartzite.....	Do.
39	21	Bullion.....		4	B	C	Fissure veins and sheeted lodes in Carboniferous limestone, quartzite and shale and in andesite and granodiorite.	Vanderburg, 1939; Emmons, 1910.
40		Reese River.....		2	C		Veins in Jurassic(?) or Tertiary(?) quartz monzonite and Paleozoic schistose quartzite.	Vanderburg, 1939; Hill, 1915; Ross, 1953.
41	22	Jackrabbit (Bristol).....	Lincoln.....	3	B	B	Replacement bodies along intersections of fissures in Cambrian carbonate rocks.	Westgate and Knopf, 1932; Tschanz and Pampeyan (in press).
42	23	Pioche.....		2	A	A	Replacement veins and bedded deposits along fissures in Cambrian limestone; veins in quartzite.	Do.
43	24	Comet.....		4	B	B	Bedded replacement bodies in Cambrian limestone; veins in Cambrian quartzite.	Do.
44		Tempiute.....		4	C	C	Veins and replacement along breccia zones in Silurian and Devonian carbonate rocks.	Tschanz and Pampeyan (in press).
45		Delamar.....		3	C(?)		Disseminated ore and veinlets in shattered Cambrian quartzite.	Tschanz and Pampeyan (in press); Callaghan, 1937.
46	25	Groom.....		3	B	C	Replacement bodies along bedding and fissures in Cambrian limestone.	Humphrey, 1945.
47		Silver City.....	Lyon.....	3	C		Veins along faults in Tertiary andesite and rhyolite with best ore commonly at vein intersections.	Stoddard and Carpenter, 1950; Gianella, 1936.
48		Palmyra (Como).....		4			Veins in Tertiary volcanic rocks, chiefly andesite.	Stoddard and Carpenter, 1950.
49		Pine Grove (Wilson).....		4	C		Stringers and lenses along crushed zones in quartz monzonite.	Stoddard and Carpenter, 1950; Hill, 1915.
50		Yerington.....		(?)	(?)	(?)	Disseminated deposits in quartz monzonite; contact metamorphic deposits in bordering limestone. Byproduct of copper mining.	Stoddard and Carpenter, 1950; Knopf, 1918.
51	26	Broken Hills.....	Mineral.....	4	B	C	Quartz-filled fissure veins and stock-work lenses in post-Esmeralda volcanic rocks.	Vanderburg, 1937; Ross, 1961.
52		Rawhide.....		4	C		Quartz veins in altered pre-Esmeralda Tertiary volcanic rocks.	Do.
53		Bovard.....		4	C		Veins in Tertiary rhyolite and latite.....	Do.

See footnotes at end of table, p. 143.

TABLE 14.—Significant silver, lead, and zinc districts in Nevada<sup>1</sup>—Continued

Locality No.		District	County	Rank <sup>2</sup>			Manner of occurrence	References
Silver map (fig. 31)	Lead-zinc map (fig. 32)			Silver	Lead	Zinc		
54	27	Hawthorne		3	B	C	Veins in Mesozoic limestones and volcanic rocks, one important vein along or near contact with intrusive granodiorite.	Vanderburg, 1937; Ross, 1961; Hill, 1915.
55		Sante Fe		4	C	C	Contact metamorphic deposits; replacement bodies and veins along faults in limestone and vein in altered quartz monzonite.	Vanderburg, 1937; Ross, 1961; Hill, 1915; Clark, 1922.
56		Garfield		4	C		Veins in limestone and volcanic rocks.	Vanderburg, 1937; Ross, 1961.
	28	Bell	Mineral	5	B	C	Replacement bodies in Triassic limestone along sides of alaskite porphyry dike; veins in Tertiary volcanic rocks.	Vanderburg, 1937; Ross, 1961; Knopf, 1921b.
57	29	Silver Star (includes Marietta, Mina, and Silver Dyke).		4	B	C	Veins in Triassic volcanic and sedimentary rocks, and in Tertiary volcanic rocks.	Vanderburg, 1937; Hill, 1915; Kerr, 1936; Ross, 1961.
58		Aurora		3	C		Veins along fissures in Tertiary latite and andesite.	Vanderburg, 1937; Hill, 1915; Ross, 1961.
59	30	Candelaria		2	B	C	Veins in Mesozoic shale and argillite along faults with most production from most intensely altered and disrupted rocks.	Vanderburg, 1937; Knopf, 1922; Page, 1959; Ross, 1961.
60		Twin River	Nye	4	C	C	Vein in slate.	Kral, 1951.
61		Lodi		4	C		Veins in Triassic limestone and limy shale at contact with intrusive granodiorite.	Do.
62	31	Union		4	C	B	Replacement bodies in Triassic limestone; veins in Permian(?) meta-andesite, Triassic sediments and in Tertiary andesite.	Ferguson and Muller, 1949; Kral, 1951.
63		Jefferson Canyon		4			Veins with silver along contact of Tertiary rhyolite with Cambrian and Ordovician schist; veins in rhyolite yielded gold with some silver.	Lincoln, 1923; Ferguson and Cathcart, 1954.
64		Round Mountain		4			Fissure veins in Tertiary rhyolite; byproduct of gold mining.	Ferguson, 1921; Ferguson and Cathcart, 1954; Kral, 1951.
65		Belmont	Nye	3	C		Veins and lenses in Ordovician limestone and shale near contact with granitic intrusive.	Kral, 1951.
66		Manhattan		4	C	C	Replacement veins and stockworks in Cambrian rocks along basal zone of major thrust plate; insignificant production from veins in Tertiary volcanics.	Ferguson, 1924; Ferguson and Cathcart, 1954; Kral, 1951.
67		Morey		4	C		Veins in quartz latite.	Kral, 1951.
68	32	Tybo		3	B	C	Replacement of quartz latite porphyry dikes along faults cutting Cambrian and Ordovician limestones.	Ferguson, 1933; Kral, 1951.
69		San Antone		4	C		Veins in Permian volcanic rocks and in Ordovician limestone.	Kral, 1951.
70		Tonopah		1	C	C	Replacement veins in Tertiary rhyolitic rocks and altered andesite.	Nolan, 1935; Hewett and others, 1936; Kral, 1951.

71		Bellehelen		4	C		Fissure veins in rhyolitic ash flows.	Kral, 1951; Kleinhampl, unpublished data, 1964.
72	33	Reveille		4	C	B	Veins and stringers in Ordovician quartzite adjacent to Tertiary rhyolitic ash flows.	Do.
73		Silverbow		4			Veins in altered Tertiary rhyolitic welded to non-welded tuffs.	Hewett and others, 1936; Kral, 1951; Cornwall, oral communication, 1964.
74		Bullfrog		4	C		Fissure-filled zones along faults in Tertiary rhyolitic lavas and ash flows with deposits concentrated near margins of caldera subsidence structures.	Ransome, 1907; Ransome and others, 1910; Cornwall and Kleinhampl (in press).
75		Antelope	Pershing	4	C	C	Replacement bodies in limestone; also byproduct of copper in fissure in tourmalinized rhyolite.	Vanderburg, 1936b.
76		Seven Troughs		4	C	C	Veins along basalt dikes cutting Tertiary volcanic rocks.	Do.
77		Rye Patch		4			Fissure veins in shattered Triassic limestone.	Do.
78		Unionville		3	C		Veins in Triassic limestone and rhyolite.	Lincoln, 1923; Vanderburg, 1936b; Tatlock, oral communication, 1964.
79		Kennedy		4	C		Veins in granitic intrusive rocks and in metasediments and volcanics.	Vanderburg, 1936b; Tatlock, oral communication, 1964.
80		Rochester		3	C		Replacement veins and stringers in Triassic rhyolite.	Vanderburg, 1936b.
81		Comstock	Storey	1	C	C	Lodes and veins in upper Tertiary igneous rocks, ranging from diorite to andesite.	Becker, 1882; Bastin, 1922; Gianella, 1936.
82		Peavine	Washoe	4	C		Veins and replacement bodies in schist, Cretaceous quartz monzonite, and Tertiary andesite.	Overton, 1947.
83		Wedekind		4			Veins in hydrothermally altered andesite.	Hill(?), 1915.
84		Leadville		4(?)	C(?)	C(?)	Veins in diorite porphyry dike and in Tertiary andesite.	Overton, 1947.
85		Cherry Creek	White Pine	3	C	C(?)	Veins in Cambrian quartzite and in Cretaceous(?) quartz monzonite.	Schrader, 1931.
86	34	Aurum		4	B(?)	B(?)	Replacement bodies along faults and bedding in Cambrian limestone; minor replacement in quartzite; minor contact metamorphic deposits.	Hill, 1916.
	35	Eagle		5	B	C	Veins in granite(?) and in Paleozoic(?) sedimentary rocks close to the granite(?).	Do.
87		Newark		4	C	C	Vein in limestone.	Lincoln, 1923.
88	36	White Pine		2(?)	A	C	Replacement bodies along veins and bedding in Ordovician dolomite; saddle reefs in Devonian limestone below shale.	Hague, 1870; Humphrey, 1960.
89	37	Ely		3	B	B	Replacement bodies along veins and bedding, and contact metamorphic deposits in limestone; disseminated deposits in Jurassic(?) monzonite porphyry stocks as byproduct of copper mining.	Spencer, 1917; Bauer and others, 1960.
	38	Duck Creek		5	B	C	Replacement bodies along bedding fissures in Ordovician limestone.	Hill, 1916.
90	39	Ward		4	B	C	Veins and replacement bodies along contact of quartz monzonite porphyry dikes with Pennsylvanian limestone.	Do.
91		Taylor	White Pine	3	C	C	Breccia filling and replacement bodies in brecciated Ordovician(?) limestone.	Lincoln, 1923.
92		Osceola		4	C		Lodes along fracture zones in Cambrian sedimentary rocks.	Lincoln, 1923; Vander

<sup>1</sup> Modified from Horton, Bonham, and Longwill (1962 a, b, and c), McKnight and others (1962, 1962 a and b).

<sup>2</sup> See text for classification of rank.

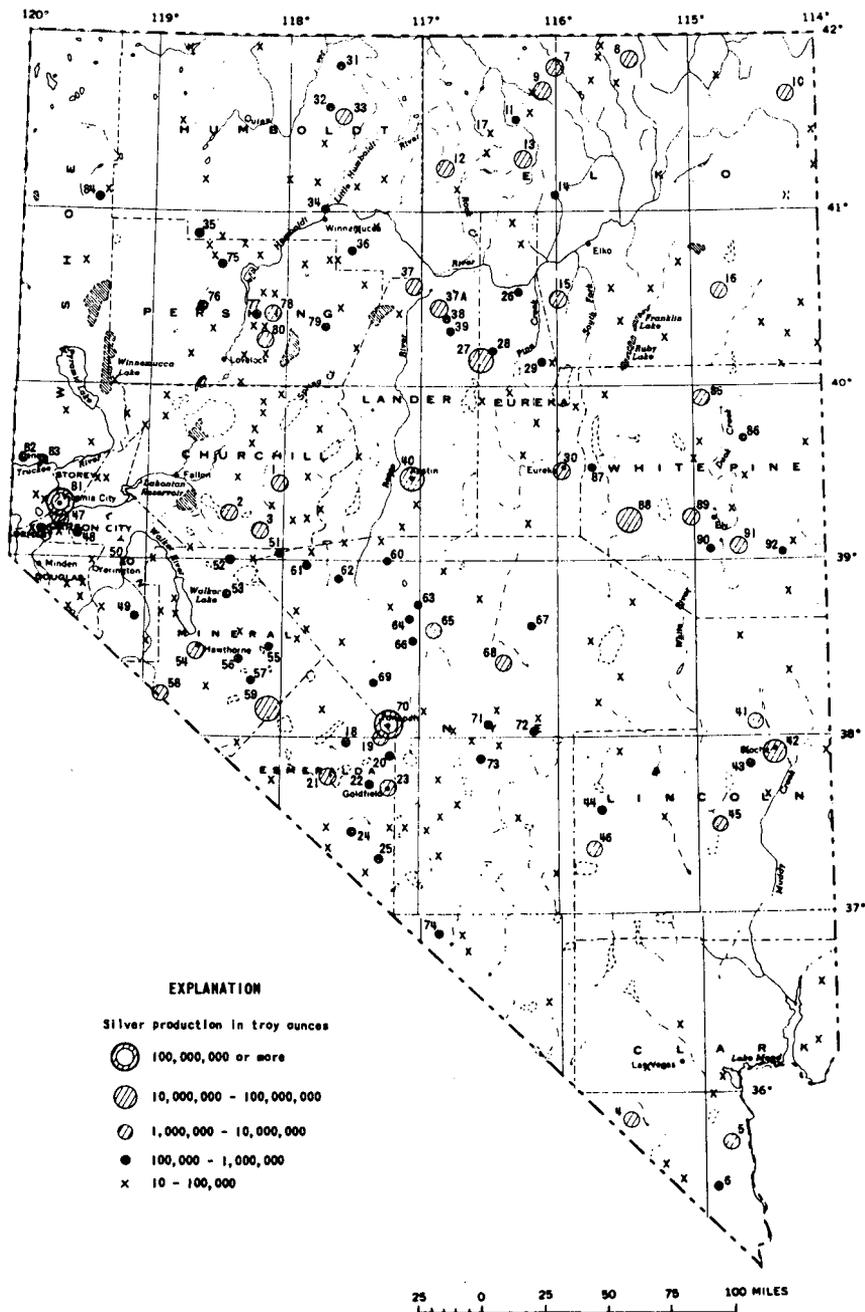


FIGURE 31.—Silver in Nevada (numbers refer to districts listed in table 14).

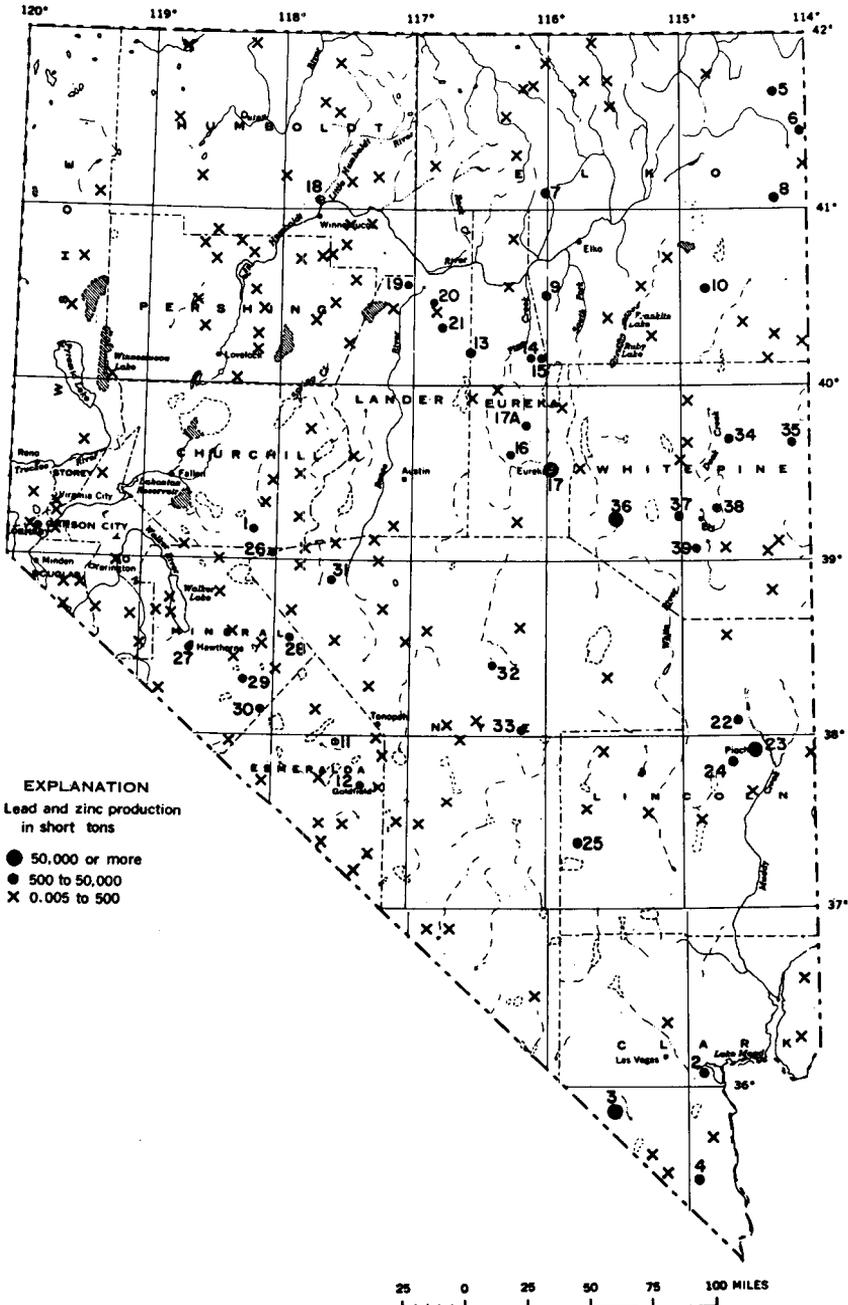


FIGURE 32.—Lead and zinc in Nevada (numbers refer to districts listed in table 14).

Lead has found use in the arts and industry for thousands of years; modern usage has shifted principally to applications unknown prior to the industrial revolution. Consumption in storage batteries and antiknock compounds for gasoline accounted for about one-half of all lead consumed in the United States in 1962. The rest of consumption was divided among about a score of products, the most important of which are pigments, caking lead, solder, cable coverings, and ammunition.

Total lead production of Nevada from 1904 through 1962 has been 392,421 short tons, with a value of \$62,430,000. Prior to 1904 and extending back to 1871, Lincoln (1923, pp. 274-275) tallies a production of about 220,000 short tons. During the period 1871-81, Nevada's share of the total U.S. production was approximately 22 percent; thereafter, Nevada produced 6 percent or less of the U.S. total. In more recent years, 1949-62, Nevada's share of U.S. production did not exceed 2 percent, and had declined to about 0.3 percent in 1962.

Zinc is one of the four quantitatively most important metals of industrialized societies, after iron, aluminum, and copper. Its primary uses are in galvanizing, die casting, and zinc-base alloys (brass and bronze).

Total zinc production of Nevada from 1904 through 1962 has been 483,354 short tons, with a value of \$93,488,000. From 1906 to 1922, Nevada's share of total U.S. zinc production has ranged from 0.01 to 2.3 percent and averaged 1.2 percent (Lincoln, 1923, p. 289). Since 1949, and including 1962, Nevada's share of total U.S. production has not changed much, and has not exceeded 0.10 percent of the U.S. total from 1958 to 1962. As in the case of lead, production is not expected to be significantly different for 1963.

Most of the deposits are spatially and thought to be genetically related to Mesozoic or Tertiary intrusive igneous rocks of intermediate to acidic composition. Ore bodies in some districts are considered to be related to unseen intrusives at depth. Where known, the intrusives are commonly dikes or pluglike bodies that are considered as apical parts (cupolas) of deeper and larger stocks and small batholiths. Hydrothermal alteration of the host rocks adjacent to ore bodies is common, and many important districts have areas of intense rock alteration, as at Candelaria (No. 59, fig. 31) and Tonopah (No. 70, fig. 31).

Most silver-lead-zinc deposits of Nevada exhibit near-surface enrichment, with enriched oxidized and sulfide zones extending downward from a leached zone at the surface and grading farther downward into a primary unenriched sulfide deposit. These enriched shallow zones, especially the oxide zone, have yielded the greatest amounts of ore, and production commonly ceased or was sharply curtailed upon their exhaustion because of the low grade of the deeper, primary part of the deposits.

There is a great diversity in the geologic occurrence of silver, as might be suspected from its association with many other metals, notably lead, zinc, copper, and gold. Silver occurs in economically recoverable quantities in base metal (sulfides of lead, zinc, and copper) and precious metal (gold) deposits. In the former, much silver is found in lead sulfide bodies ("argentiferous galena") as small inclusions of argentite (silver sulfide) and complex sulfides like tetrahedrite (McKnight and others, 1962, p. 1). Silver in the large porphyry

copper deposits comes in part from disseminated zones, and in part from veins. Silver is alloyed with gold as the native metal and also exists as complex sulfides in many primary precious metal deposits. Oxidized bodies yield many of the same minerals found in primary deposits and have formed exceedingly rich ore (Tonopah, No. 70, fig. 31). Some very rich oxidized bonanza deposits (White Pine, No. 88, fig. 31, and Tonopah, No. 70, fig. 31) have occurred at or very near the surface, where the ores consisted principally of secondary minerals, such as cerargyrite (hornsilver) lodyrite and embolite.

Lead in primary unoxidized ore is found as the sulfide galena and occurs in many districts, including the important ones of Yellow Pine (No. 3, fig. 32), Pioche (No. 23, fig. 32), and Eureka (No. 17, fig. 32). However, most of the lead ore of the major districts has come from oxidized deposits consisting of the carbonate, cerussite, and the sulfate anglesite, and, locally, plumbojarosite, a sulfo-salt of lead and iron, along with a residuum of the primary unoxidized sulfide galena. Oxidized minerals of other metals, such as zinc, silver, and copper may occur along with the lead, but because of greater mobility of zinc during oxidation, the zinc commonly forms deposits separate from the lead and silver. The mode of occurrence of lead is similar for nearly all the other important districts in Nevada. An unusual exception is in the Las Vegas district (No. 2, fig. 32), where lead was recovered as a byproduct from a sedimentary manganese deposit of moderate size.

Zinc production has come from both primary and enriched oxidized ore bodies. Where unoxidized, the primary zinc mineral is the sulfide sphalerite; where oxidized, the main zinc minerals are the carbonates smithsonite and hydrozincite. The silicate, calamine (hemimorphite) is also present in some deposits.

Ores in which silver and gold as native metals and complex sulfides are associated with abundant sulfides of base metals copper, lead, and zinc form important replacement deposits in carbonate rocks in eastern Nevada. Another type of ore, the so-called dry and siliceous ore, in which silver and gold appear with siliceous gangue, and with only minor base metal sulfides, commonly occurs in veins in western Nevada (Ferguson, 1944, pp. 77-105). It would appear, moreover, that the latter type of deposit is most common in volcanic and intrusive rocks of Tertiary age and in rocks that are spatially related to the intrusives satellitic to the Sierra Nevada batholith (Ferguson, 1944, p. 77).

Deposits within intrusive igneous bodies occur as veins and disseminations (Ely district, No. 89, fig. 31), as veins (Reese River district, No. 40, fig. 31), and as replacements of dikes (Tybo, No. 68, fig. 31). More commonly, ore deposits border the intrusives in faulted host rock of volcanic or sedimentary origin and of lowest Paleozoic to Tertiary age. These deposits occur chiefly as bedded replacements adjacent to faults or fractures and as fissure fillings or replacements of breccia or wallrock along fault zones or fractures. In many districts (e.g., Eureka, No. 30, fig. 31; Cortez, No. 27, fig. 31; and Yellow Pine, No. 4, fig. 31) dolomite is the principal host rock; in others, it is limestone (Belmont, No. 65, fig. 31; Groom, No. 46, fig. 31; and Tecoma, No. 6, fig. 32) or quartzite (Reveille, No. 72, fig. 31, and Delamar, No. 45, fig. 31) and, more rarely, shale or argillaceous rocks (Candelaria, No. 59, fig. 31). Volcanic host rocks are commonly Triassic or Tertiary lavas and tuffaceous rocks of andesitic

to rhyolitic composition, and gold-silver predominate in these deposits rather than base metals (Bullfrog, No. 74, fig. 31; Jarbidge, No. 8, fig. 31; Rawhide, No. 52, fig. 31; Round Mountain, No. 64, fig. 31; Rochester, No. 80, fig. 31; and Silver City, No. 47, fig. 31). Some silver deposits in young Tertiary volcanics, however, contain fairly abundant base metal sulfides (Comstock, No. 81, fig. 31).

### SILVER

Of the 91 silver districts scattered throughout Nevada, about one-third of them have been important producers of lead or zinc. Some have also yielded considerable copper (Mountain City, No. 7, fig. 31; Pioche, No. 42, fig. 31; and Eureka, No. 30, fig. 31) and manganese (Pioche, No. 42, fig. 31). Another common associate of silver is gold, and many of the deposits in Nevada have had sizable gold production (Aurora, No. 58, fig. 31; Jarbidge, No. 8, fig. 31; and Battle Mountain, No. 19, fig. 32). The value of these other metals from some districts has been so great that they might just as aptly be classed with respect to one of the other important constituents.

Deposits with substantial amounts of silver have been classified into seven major groups by McKnight and others, 1962, pages 2-3. Five groups have contributed significantly to Nevada's silver production and include (1) deposits in intrusive igneous rocks, (2) deposits in older rocks adjacent to intrusive rocks, (3) deposits in igneous dikes, (4) deposits in predominantly volcanic rocks, and (5) deposits along fault contacts between intrusive and igneous rocks.

The Comstock (No. 81, fig. 31) and Tonopah (No. 70, fig. 31), with silver production valued at about \$220 million and \$100 million, respectively, are the outstanding silver districts of Nevada (Lincoln, 1923, pp. 186, 226; Nolan, 1935, p. 41). The Comstock lode, a prominent fault-fissure zone 2.5 miles long, dips about 45° east and lies entirely in Tertiary rocks. The footwall of the lode is diorite, and the hanging wall is Tertiary andesite; wall rocks are extensively altered (Gianella, 1936, pp. 89, 97; Smith, 1943, p. 72). Rich bonanzas of ore, 16 in all and scattered in the form of lenses within barren quartzose vein material, were located in crushed zones of the lode, mostly close to the hanging wall and mostly within 600 feet of the surface (Smith, 1943, p. 76). The principal ore minerals were silver sulfides and native gold. The zone of enrichment, with secondary native silver, generally did not extend much below a depth of about 500 feet, and much of the rich bonanza ore throughout the Comstock, mined to depths of several thousand feet below the present surface, has been proved primary in origin (Bastin, 1922, pp. 43-54).

At Tonopah, a series of westward-dipping Tertiary volcanic rocks is cut by a recumbent curved fault that is convex upward. Nolan (1935, pp. 10-12) suggests that an intrusive may have caused the uplift along the fault and supports this suggestion by noting that a quartz-adularia-sericite alteration underlies the central part of the district with a chlorite-carbonate alteration on the periphery. Ore deposits occur as replacement veins along the great curving fault and other faults that branch from it. Ore shoots are restricted to a zone 600 to 1,000 feet thick that generally conforms in shape with the zone of quartz-adularia-sericite alteration (Nolan, 1935, pp. 12, 41-43).

## LEAD

The 191 districts in Nevada from which lead has been produced are widely scattered; most of the 36 important ones are in the eastern part of the State (fig. 32). Of the 36, only 3 can be considered as really major districts: Eureka (No. 17, fig. 32), Pioche (No. 23, fig. 32), and White Pine (No. 36, fig. 32), each having produced more than 50,000 tons of lead. The Yellow Pine district (No. 3, fig. 32) has nearly reached this amount, and probably should be classed as a major lead deposit. Of the four districts mentioned above, two—Pioche and Yellow Pine—are also major zinc districts, and all four have been relatively important silver producers. Pioche and Eureka have recorded sizable gold production.

Lead deposits are found commonly at some distance from the igneous intrusives that they border. Faults and fissures served as channels for the mineralizing solutions, and the deposits occur chiefly as veins along faults, shear zones, and fractures, and as replacement deposits. The latter, especially in breccia and in limestone and dolomite, have had the largest production. Disseminated and contact-metasomatic deposits occur as well, but are not very important economically.

## ZINC

There are at least 82 districts in Nevada that have some recorded zinc production, but only 14, with a production of 500 tons or more, are considered important enough to be described (table 14) and almost all are in the eastern half of the State. Of the 14, 2 have been important only for zinc; 9 for zinc, lead, and silver; and 3 others for zinc and either lead or silver. The majority of deposits occur as veins and replacement bodies in rocks known or thought to border intrusives. Most of the deposits are believed to range from Cretaceous to Tertiary in age. The host rocks of the important districts are chiefly sedimentary and range in age from Cambrian to Triassic. Rarely, Tertiary volcanics serve as host. The Pioche (No. 23, fig. 32) and Yellow Pine (No. 3, fig. 32) districts have been the chief sources of zinc in Nevada.

The outstanding lead-zinc district of Nevada is Pioche (No. 23 fig. 32). Here and at the neighboring districts of Jackrabbit (No. 22 fig. 32) and Comet (No. 24, fig. 32), the major production has come from replacement fissure and bedded deposits in Cambrian limestone and dolomite. The important fissure deposits are oxidized and commonly highly manganeseiferous and limonitic (Westgate and Knopf, 1932, pp. 45-75). The bedded deposits lie at several horizons and extend laterally along favored beds from commonly inconspicuous steeply dipping crosscutting fissures. Major production from bedded replacement bodies at Pioche has come from the Combined Metals and Prince mines (Westgate and Knopf, 1932, pp. 50-51). At the former, the ore is unoxidized and extends along a 50-foot-thick limestone unit within a shale sequence. At the Prince mine, the ore is both oxidized and unoxidized, and production has come from several horizons in the carbonate rocks.

## RESOURCE APPRAISAL

Total world consumption of silver in recent years has exceeded output; demand in the last few years caused the price of silver to rise from a fairly stable level of \$0.85 to \$0.90 per troy ounce fine for the past decade to about \$1.29 in June 1964. The higher 1963 prices for silver have already stimulated exploration and development at many of the known districts. Some, such as the Rochester (No. 80, fig. 31), Silver Peak (No. 21, fig. 31), and Ward (No. 90, fig. 31) have been reactivated (Knoerr and Peterson, 1963, pp. 77, 79) with production or development now started. The price for silver may remain high for some time to come because of shortage of the metal. Most present-day silver is obtained as a byproduct or coproduct from base metal ores and output of silver therefor is inextricably tied to the economy of these base metals. The Bingham district, Utah, for example, is one of the country's largest silver producers; yet is mined primarily for copper. Ely (No. 89, fig. 31), also primarily a copper district, produces significant amounts of silver. Yerington (No. 50, fig. 31), another copper district, should in time yield byproduct silver, now that primary sulfide ore is being treated by flotation. The new large iron discovery by the United States Steel Corp. near Yerington may provide a sizable future supply of silver as a byproduct. Barring the discovery of another silver-gold bonanza, such as Comstock or Tonopah, this interdependence of metal prices and production shall probably continue to strongly influence the future output of silver, lead, zinc, and copper in Nevada.

Future major lead-zinc production probably will continue to come from the Pioche (No. 23, fig. 32) and Yellow Pine (No. 3, fig. 32) districts, as well as several others like Spruce Mountain (No. 10, fig. 32) and Lone Mountain (No. 16, fig. 32), where considerable oxidized ore is believed to occur (T. H. Kiilsgaard, written communications, 1962, 1964). That Eureka (No. 17, fig. 32) will be at least a moderately large producer seems assured because of the presence of large sulfide bodies discovered at depth (Nolan, 1962, pp. 41-48, 52, 56-59, 66, and especially p. 43); McKnight and others, 1962b). Reports on the Ely district (No. 37, fig. 32) barely mention zinc, but considerable reserves may be present (Allen Heyl, written communication, 1964).

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**THORIUM AND THE RARE EARTHS**

(By M. H. Staatz, U.S. Geological Survey, Denver, Colo.)

Thorium and the rare-earth metals are treated together in this report as they are commonly associated in nature and are closely interrelated economically. Thorium has a number of industrial uses and has a considerable potential as an atomic fuel. Present thorium requirements are, however, relatively small compared to many other metals, and in 1961 only 121 tons of ThO<sub>2</sub> were consumed (Baker and Tucker, 1962, p. 1210). Over 90 percent of this was used in thorium-magnesium alloys and gas mantles. Minor amounts of thorium are also used in refractories, polishing compounds, chemicals, drugs, and electronic products.

Thorium is the only natural radioactive element other than uranium that is a potential source of atomic power. Although thorium metal

cannot be used directly in nuclear reactions, it can be converted to a fissionable uranium isotope by neutron capture. The use of thorium for nuclear energy is, however, in the experimental stage and it is in competition with relatively cheap, abundant uranium (Kelly, 1962, p. 25). In 1961, however, the U.S. Atomic Energy Commission had built or committed for construction five different types of reactors to study the use of thorium as a nuclear fuel (Baker and Tucker, 1962, p. 1211).

The rare-earth metals comprise the 15 elements having atomic numbers 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tu), ytterbium (Yb), and lutetium (Lu). One of these, promethium, is not known to occur in nature. Yttrium (Y), with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so-called because cerium is their most abundant member. The remaining eight elements (Gd through Lu) together with yttrium are called the yttrium group. The two groups are also referred to respectively as the "light" and "heavy" rare earths. The properties of the members of the two groups are sufficiently distinct to cause one group to predominate over the other in most rare-earth minerals, even though all or nearly all are ordinarily present (Olson and Adams, 1962).

Domestic consumption of the rare earths in 1962 was 2,386 tons of rare-earth oxides (Parker, 1963, p. 2). The rare earths have many industrial applications such as in the steel industry, nonferrous alloys, glass manufacture and glass polishing, sparking alloys, and carbon electrodes for arc lights and projection lamps. The rare-earth industry is developed almost entirely around the cerium group elements, primarily cerium, lanthanum, praseodymium, and neodymium. Although considerable research is being directed to finding uses for yttrium and the heavy rare-earth elements the current demand for these is small.

The marketing of ores of thorium and the rare earths is difficult as there is no established market comparable to those of the more widely used metals, and prices of their ores are generally determined by negotiation between buyer and seller. Detailed information on the economic factors of thorium and rare earths is given in a recent publication of the U.S. Bureau of Mines (Kelly, 1962).

Thorium and the rare earths are found in a large number of minerals, but only a few of these have been found in sufficient concentration to be used as ores. The most important source mineral for thorium is monazite, a phosphate of the cerium group rare earths. The thorium content of this mineral is variable, but commercial monazite commonly contains between 3 to 10 percent thoria ( $\text{ThO}_2$ ) and 55 to 60 percent combined rare-earth oxides (Kelly, 1962, p. 5). Other potential sources of thorium are thorite and thorogummite, and multiple-oxide minerals such as euxenite, samarskite, and fergusonite.

Monazite is also the principal ore mineral of the rare earths, but important deposits of bastnaesite, a rare-earth fluorocarbonate, are currently being mined at Mountain Pass, Calif. Both monazite and

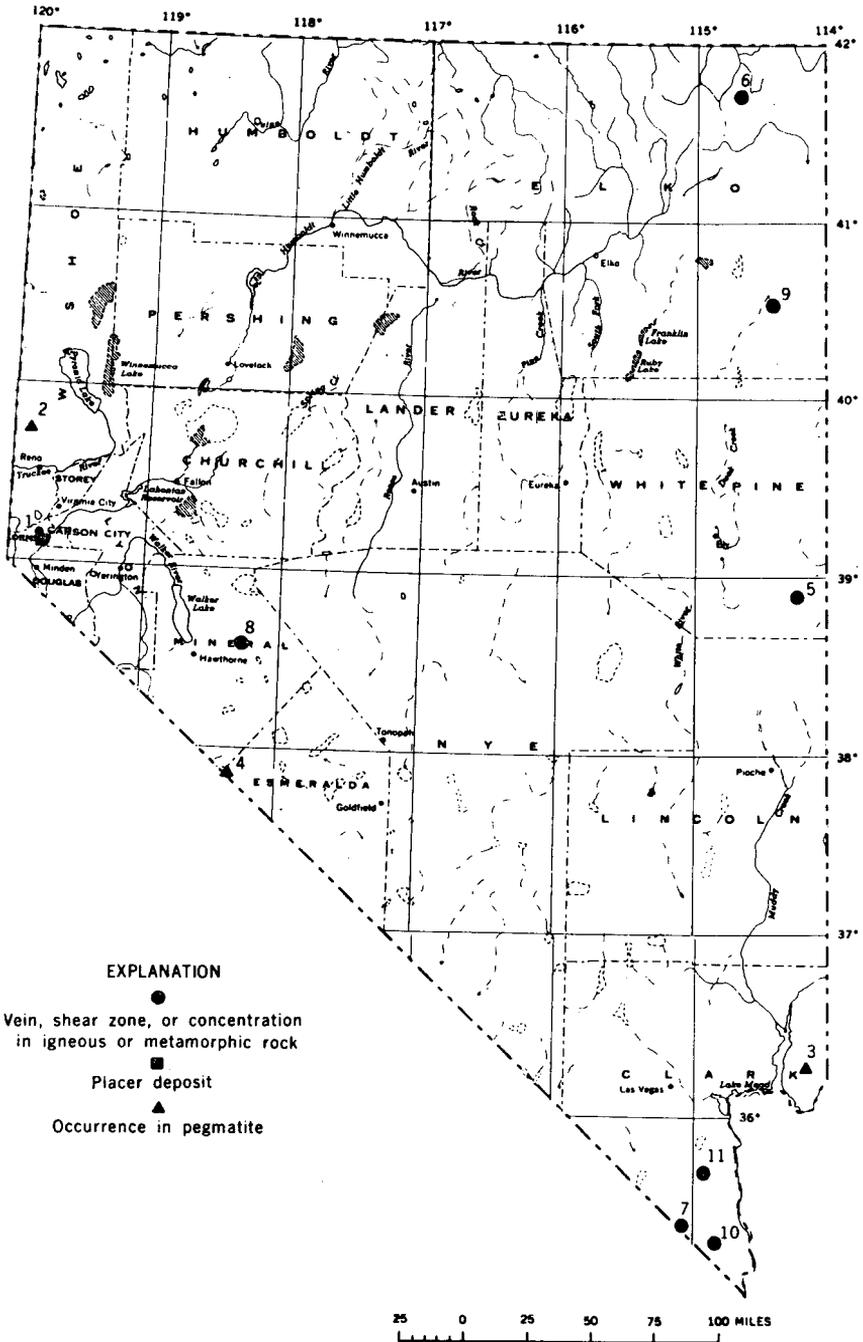


FIGURE 33.—Thorium and rare earths in Nevada (numbers refer to deposits or districts described in text).

bastnaesite contain dominantly cerium group elements. Minerals in which the yttrium group predominates include xenotime, a yttrium phosphate, and euxenite.

Most of the thorium and rare-earth minerals occur sparsely in pegmatites, granites, syenites, carbonatites, schists, and gneisses. Occurrences are shown in figure 33. Those thorium and rare-earth minerals that are not easily weathered are concentrated in stream and beach placers. Monazite, being both one of the most common of the thorium and rare-earth minerals and resistant to weathering and erosion, is hence commonly concentrated in placers. Monazite is found in stream placers near Carson City, Ormsby County (No. 1, fig. 33) (Day and Richards, 1906, pp. 1204-1205). In one sample of sand 12 pounds per ton of heavy black sand concentrate was obtained. The black sand was principally magnetite, but in two concentrates monazite made up 5 and 29 pounds per ton.

Thorium and rare-earth minerals are found in pegmatites in three areas. Allanite occurs in narrow fine-grained perthite-albite-quartz pegmatites about 10 miles south of Red Rock (No. 2) (Volborth, 1962, pp. 209-213; Olson and Hinrichs, 1960, p. 180). Allanite is a minor accessory in some small irregular pegmatites in the Gold Butte district (No. 3) (Volborth, 1962, p. 214). In the same district some zoned feldspar-quartz-biotite pegmatites contain sparse monazite and samarskite (Lovering, 1954, p. 80). Euxenite or samarskite were tentatively identified in a meta-igneous rock believed to be pegmatite on the Lucky Susan No. 1 prospect in westernmost Esmeralda County (No. 4). These pegmatites occur in widely scattered lenses generally less than an inch thick in hornblende schist (Olson and Adams, 1962, p. 8).

Allanite has also been noted as a minor accessory mineral in the porphyritic granites in the Gold Butte district (No. 3) (Volborth, 1962, p. 213), in quartz monzonite on Mount Wheeler (No. 5) (Lee and Bastron, 1962, pp. 1327-1328), in the contact zone between granodiorite and limestone in the Contact district (No. 6) (Schrader, 1912, p. 113), and in dikes in the Crescent Butte area (No. 7) (Volborth, 1962, p. 214). These dikes, which also contain xenotime and monazite, are fine grained, partly brecciated, and as much as 5 feet wide.

In the Crescent Butte area a second type of deposit is found on the Thor claims. Here an oval area in sheared gneissic granite is altered and mineralized. Monazite, apatite, zircon, and bastnaesite(?) are reported (Olson and Adams, 1962, p. 8). A grab sample of the altered rock contained 0.15 percent thorium and 1.54 percent total rare earths (J. W. Adams, oral communication, 1963).

In two other areas thorium has been reported along shear zones: the Fitting district (No. 8), where uranothorite, huttonite, and extremely minor amounts of autunite occur along iron-stained fault planes (Olson and Adams, 1962, p. 8), and the Dolly Varden district (No. 9), where radioactivity occurs along fractures in pegmatites, quartz monzonite, and rhyolite (Davis, 1954, p. 17). Material from a fracture in pegmatite assayed 5.95 percent thorium and 0.35 percent total rare earth.

Thorium is reported on the Superfluous No. 1 claim (No. 10) in Clark County along a contact between granite and Precambrian metasediments (Olson and Adams, 1962, p. 8). A select sample, how-

ever, contained only 0.25 percent thoria. A similar type occurrence is found 37 miles north of the Superfluous on the M. and E. claims in the Eldorado mining district (No. 11).

There has been no production of thorium or rare-earth minerals in Nevada to date. Several of the Nevada deposits were discovered, through their radioactivity, during the intensive search for uranium, but their thorium and rare-earth potential has not been developed further. The small size and general low tenor of the known deposits, however, together with much larger resources and higher grade of unworked deposits in Idaho, Montana, Colorado, North Carolina, and South Carolina suggest that little if any will be produced in the near future unless larger deposits are developed.

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### TITANIUM

(By L. H. Beal, Nevada Bureau of Mines, Reno, Nev.)

The demand for titanium, a light strong metal which resists corrosion at high temperatures, has increased sharply during 1962 and the current outlook is bright (Eigo, 1963). Although titanium mill products reached an alltime high last year of about 6,500 tons, the composite mill product price of \$1.32 a pound was the lowest in the history of the industry, owing to advances in metallurgy and technology. High production cost is the major obstacle in the widespread use of titanium metal products. Titanium metal and alloy uses include: aircraft, jet engines, space probes, missiles, corrosion-resistant apparatus in the processing industries, heat exchangers, and reactors. Titanium oxide, a brilliant white substance, is widely used as pigment (in paint, paper, rubber, etc.), as welding-rod coatings, in ceramics, and in fiberglass.

Although titanium is the fourth most plentiful structural metal (Cservenyak and Tumin, 1959) in the crust of the earth, elemental titanium does not exist in nature. Ilmenite ( $\text{FeTiO}_3$ ) and rutile ( $\text{TiO}_2$ ) are the important ore minerals of titanium but some sphene ( $\text{CaTiSiO}_5$ ) and perovskite ( $\text{CaTiO}_3$ ) have been mined. Titanium ores are found throughout the world, in metamorphic and basic igneous rocks, and also in beach and alluvial sands and gravels. Nearly a third of the world's ilmenite production (Stamper, 1961) comes from rock deposits in the eastern part of the United States; Canada, India, Norway, and Australia produce the greater share of the remaining tonnage. About 90 percent of the rutile concentrates are mined from Australian placer deposits, of which nearly a quarter is exported to the United States.

No ore deposits of titanium minerals have been found in Nevada, but rock and placer deposits containing subcommercial amounts of titanium minerals have been reported in 11 counties within the State (Beal, 1963). Titanium sponge is commercially produced by three plants in the United States, but Titanium Metals Corp. of America, which manufactures titanium ingots, is the only producer in the West.

## TUNGSTEN

(By J. H. Schilling, Nevada Bureau of Mines, Reno, Nev.)

Tungsten is a ductile, white metal with a melting point of  $3,410^{\circ}$  C.—higher than any other metal. Tungsten steels and carbides are extensively used in machine tools, jet and rocket engines, and other applications where their structural strength, extreme hardness, and resistance to wear, especially at elevated temperatures, is needed. Tungsten metal is used in lamp filaments, electrical contacts, and other electrical and electronic applications because of its high melting point, low vapor pressure, and noncorrosion and structural strength at high temperatures.

Although tungsten deposits are widely distributed in the world, China has been by far the largest producer (28 percent) and has the largest reserves. The United States has been the second largest producer (13 percent), but until 1951 consumed more than it produced. Premium prices in 1951-57 stimulated domestic production to a rate greater than consumption and intensive exploration led to the discovery of large reserves. Much lower prices since 1957 have resulted in the closing of most tungsten mines in the United States except a few that produce ores containing other marketable minerals. Nevada and California have been the largest tungsten-producing States, each having produced about 30 percent of the total.

Tungsten occurs principally as scheelite ( $\text{CaWO}_4$ , which forms an isomorphous series with powellite, the calcium molybdate) in contact deposits developed in lime-rich rocks by granitic intrusions, and as scheelite and minerals of the wolframite group (wolframite,  $(\text{Fe}, \text{Mn})\text{WO}_4$ ; huebnerite,  $\text{MnWO}_4$ ; and ferberite,  $\text{FeWO}_4$ ) in quartz veins. Contact deposits have supplied the major portion of U.S. and Nevada production, although for the world as a whole they are less important than the veins. Vein deposits predominate in eastern Nevada.

In the China-Burma belt and in Bolivia, tin minerals occur with the tungsten. In the United States and elsewhere tungsten commonly is associated with molybdenum and/or copper, or less commonly with manganese, beryllium, or antimony and/or mercury. Most of the tungsten deposits of the Western United States are related spatially to granitic intrusive bodies.

## CONTACT DEPOSITS

The Nevada-Massachusetts property (secs. 27 and 34, T. 34 N., R. 34 E.) at Tungsten (table 15 and No. 70, fig. 34) in the Eugene Mountains, Pershing County, has been one of the two largest, possibly the largest, tungsten producers in the United States. Some  $1\frac{1}{2}$  million units (20 pounds in a unit) of  $\text{WO}_3$  have been produced from open pit and underground workings extending to a depth of over 1,400 feet. Fine-grained scheelite is disseminated in steeply dipping 1- to 25-foot silicated limestone (tactite) beds, widely spaced in hornfels, intruded by a granodiorite stock; some scheelite also is present in quartz veins that fill tension fractures in the tactite and surrounding hornfels (Kerr, 1934 and 1946, pp. 182-188). The ore mined contains 0.3 to 2 percent  $\text{WO}_3$ . Some pyrite and molybdenite, and traces of pyrrhotite, chalcopyrite, stibnite, and bismuthinite(?)

also are disseminated through the tactite. The tactite consists mainly of garnet, epidote, quartz, and calcite.

In the northern half of the Osgood Range (No. 29), Humboldt County, scheelite occurs around the margins of a large granodiorite body in silicated limestone that is interbedded with argillite (Clabaugh and Hobbs, 1946). An estimated half million units of  $WO_3$  have been mined at the Getchell, Riley, Richmond, Kirby, Valley View, and Granite Creek mines from ore containing 0.3 to over 0.8 percent  $WO_3$ . Powellite, some molybdenite, and minor pyrite, sphalerite, chalcopyrite, galena, silver, and bismuth occur disseminated in the tactite bodies and in quartz veins cutting the bodies and surrounding rocks.

The Lincoln mine (No. 34) in the Tem Piute mining district, Lincoln County, has produced over 300,000 units of  $WO_3$  from underground workings extending to a depth of over 400 feet. Scheelite-bearing garnet-tactite occurs in limestone along the west side of a granite intrusive body. The tactite, which contains 0.2 to 1 percent  $WO_3$ , forms a 15- to 100-foot band directly at the contact and also is present as irregular masses extending up to 450 feet away from the granite. Some higher grade ore was found in small calcite-fluorite-scheelite-sphalerite masses along minor faults in marbleized limestone adjoining tactite. Powellite, some pyrite, chalcopyrite, and pyrrhotite, and minor molybdenite and bismuthinite(?) also are present in the tactite. To the north tactite bodies also are exposed along the west side of a second granite body but are too narrow, discontinuous, and lowgrade to be economically significant. (Wyant and Lemmon, 1951.)

At the Nevada Scheelite (Leonard) mine (No. 39) in sec. 1, T. 13 N., R. 32 E., Mineral County, 278,000 units of  $WO_3$  have been mined from underground workings extending to a depth of over 400 feet. The ore contained 0.6 to 1.5 percent  $WO_3$ . Scheelite occurs around the margins of a small granodiorite body in tactitic limestone. Locally small fingers of tactite extend outward from the main granodiorite body along bedding planes, dikes, and sills. The tactite consists mainly of garnet, epidote, and diopside. Abundant pyrite, some chalcopyrite and molybdenite, but no powellite, are associated with the scheelite. (Geehan and Trengove, 1950.)

Contact deposits of scheelite in tactite also have been mined at the St. Anthony (No. 1) and Tungsten Mountain (No. 3) mines, and in the Sand Springs Range (Nos. 4 and 5), Churchill County; in the Gardnerville (No. 7) and Topaz Lake (No. 8) areas, Douglas County; at the Garnet (No. 9), Coon Creek (No. 10), Batholith (No. 10), Robinette (No. 11), Tunnel (No. 12), Star (No. 18), and Valley View (No. 18) mines, Elko County; at the Black Horse mine (No. 21) and Sylvania mining district (No. 22), Esmeralda County; at the Defense (No. 24), Ashdown (No. 24), Lakin (No. 31), Linka (No. 32), Conquest (No. 32), Birch Creek (No. 33), and Lynch Creek (No. 33) mines, Lander County; at Tungsten Flat (No. 36) and the Cowboy mine (No. 37), Lyon County; at the Lemr mine (No. 43), and in the Garfield Hills (No. 45), Santa Fe mining district (No. 46), and Pilot Mountains (No. 50), Mineral County; at the Tungsten King mine (No. 56), Ophir group (No. 57), Peg Leg mine (No. 64), North Star mine (No. 64), and Oak Springs mining district (No. 67), Nye County; at the Kings Canyon mine (No. 68), Ormsby County; in the Nightin-

gale mining district (No. 83), and at the Rose Creek (No. 71), Stormy Day (No. 72), Holiday (No. 74), Esther (No. 75), Star (No. 77), Ragged Top (No. 84), and Long Lease (No. 85) mines, Pershing County; at the Nash (No. 86) and Derby (No. 87) mines, Washoe County; and at the Monte Cristo mine (No. 96), White Pine County.

### QUARTZ VEINS

At the Scheelite Chief, Silver Bell, Oriole, Everit, and other mines in the Minerva mining district (No. 102) in sections 16, 21, and 28, T. 11 N., R. 68 E. on the west edge of the Snake Range, White Pine County, some 100,000 units of  $WO_3$  have been produced from underground and surface workings. Scheelite, and minor tetrahedrite, galena, silver haloids, powellite, and cuprodesclousite occur as shoots in east-striking, northdipping quartz veins up to 30 feet wide that cut Cambrian limestone. The shoots, which contain 0.7 to 1.7 percent  $WO_3$ , rake gently westward, roughly paralleling the bedding in the adjacent limestone. Subsequent faulting has offset the veins. (Newman, Geehan, and Trengove, 1950.)

The Silver Dyke mine (No. 48) in the Excelsior Mountains (sec. 10, T. 5 N., R. 34 E.), Mineral County, was the largest tungsten producer in Nevada during World War I. The Silver Dyke vein system consists of several remarkably persistent parallel fracture fillings of quartz forming a continuous zone extending more than 6 miles east-west in both Triassic(?) andesite and a diorite body that has intruded the volcanic rock. Scheelite is concentrated in the portion of the vein system in contact with the diorite body that has intruded the volcanic rock. The scheelite which contains a half percent molybdenum fluoresces pale yellow. (Kerr, 1936 and 1946, p. 176.)

TABLE 15.—*Tungsten mines in Nevada*

[Numbers identify symbols shown in fig. 34]

CHURCHILL COUNTY	ELKO COUNTY—continued
1. St. Anthony mine and other small nearby mines	13. Lone Wolf and Open Pit mines
2. Quick-Tung mine	14. Diablo mine
3. Tungsten Mountain (Hilltop) mine	15. Battle Creek mine
4. North Sand Springs Range	16. Monarch mine
5. South Sand Springs Range	17. Great Western mine
CLARK COUNTY	18. Star, Valley View (Owl), and Campbell mines
6. Tri State mine	19. Phalen mine
DOUGLAS COUNTY	ESMERALDA COUNTY
7. Gardnerville	20. Rock Hill placer mine
8. Topaz Lake	21. Black Horse mine
ELKO COUNTY	22. Sylvania mining district
9. Garnet (Tennessee Mountain) and Star Metal mines	23. Copper King mine
10. Coon Creek and Batholith mines	HUMBOLDT COUNTY
11. Robinette (Pyramid) mine	24. Defense and Ashdown mines
12. Tunnel mine	25. Saddle mine
	26. Paradise mine
	27. Johnson mine

TABLE 15.—*Tungsten mines in Nevada*—Continued

HUMBOLDT COUNTY—continued		NYE COUNTY—continued	
28. Bloody Run mine		62. Van Ness mine	
29. Osgood Mountains (includes Getchell, Riley, Richmond, Kirby, Valley View, and Granite Creek mines)		63. Wolframite mine	
30. Golconda mine		64. Peg Leg and North Star mines	
		65. Old Reveille mine	
		66. Terrell and Nye mines	
		67. Oak Springs mining district	
LANDER COUNTY		ORMSBY COUNTY	
31. Lakin (Gold Acre) mine		68. Kings Canyon mine	
32. Linka and Conquest mines		69. Valley View mine	
33. Birch Creek and Lynch Creek mines			
LINCOLN COUNTY		PERSHING COUNTY	
34. Tempiute (Lincoln) mine		70. Mill City (Tungsten; Nevada-Massachusetts mines)	
35. Comet mine		71. Rose Creek mine	
		72. Stormy Day (Thrasher) mine	
		73. Sage Hen mine	
		74. Holiday mine	
		75. Esther (Black Canyon) mine	
		76. Imlay, Lakeview, and Starlite mines	
		77. Gamble and Star mines	
		78. Ryepatch and Orea (Little Tungsten) mines	
		79. Arizona mine	
		80. Limestone mine	
		81. Ore Drag mine	
		82. True American mine	
		83. Nightingale mining district	
		84. Ragged Top mine	
		85. Long Lease mine	
LYON COUNTY		WASHOE COUNTY	
36. Tungsten Flat		86. Nash mine	
37. Cowboy mine		87. Derby (Wadsworth) mine	
		88. Peavine mining district	
MINERAL COUNTY		WHITE PINE COUNTY	
38. Howard mine		89. Bald Mountain mining district	
39. Nevada Scheelite (Leonard) mine and other small nearby mines		90. Cherry Creek mining district	
40. Slim Pickens mine		91. White Horse mine	
41. Lucky Four mine		92. Antelope mine	
42. Hefler mine		93. Tungstonia mine	
43. Lemr and Lucky Boy mines		94. Bay State mine	
44. Dry Gulch mine		95. Valley View mine	
45. Poor Boy, Windup, Bataan, and Copper King mines		96. Monte Cristo mine	
46. Eagle, Western Metals, and York mines		97. Sacramento Pass	
47. Defender mine		98. Osceola mining district	
48. Silver Dyke mines		99. Hub and Mt. Wheeler mines	
49. Black Jack (Sodaville) mine		100. Bonita mine	
50. Gunmetal (Linsay) mine and other nearby small mines		101. St. Lawrence mine	
51. Cedar Chest, Cedar Summit, and Blue Bird mines		102. Minerva mining district	
52. Queens mine		103. Deer Trail mine	
NYE COUNTY			
53. Victory mine			
54. El Capitan mine			
55. Commodore mine			
56. Tungsten King mine			
57. Ophir group			
58. Big Top (Baxter) and White Diamond mines			
59. Silver Palace mine			
60. Jett mine			
61. Round Mountain mining district			

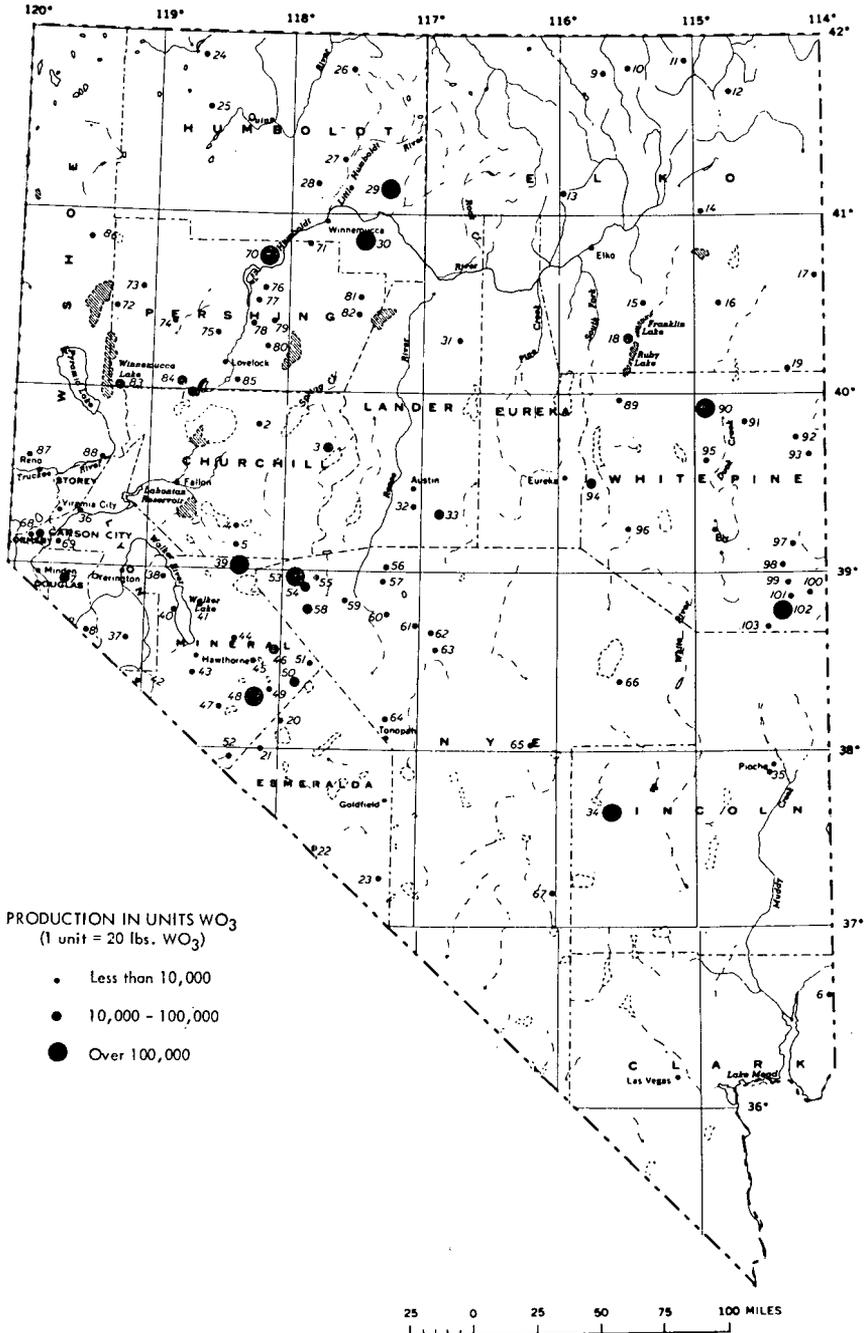


FIGURE 34.—Tungsten in Nevada (numbers refer to deposits or districts listed in table 15).

Scheelite also has been mined from quartz veins at the Tri State mine (No. 6), Clark County; at the Battle Creek mine (No. 15), Elko County; at the Bloody Run mine (No. 28), Humboldt County; at the Arizona mine (No. 79), Pershing County; and at the Antelope mine (No. 92), Bay State (No. 94) at Sacramento Pass (No. 97), in the Osceola mining district (No. 98), and at the Bonita mine (No. 100), White Pine County. Beryllium minerals occur with the scheelite in a few localities. At the Pole Canyon adit of the Mount Wheeler mine (No. 99), White Pine County, scheelite, phenacite, bertrandite, beryl, pyrite, and fluorite form veinlets in limestone (Stager, 1960). And at the Oreana (No. 78) and Lakeview (No. 76) mines in the Humboldt Range, Pershing County, scheelite has been mined from pegmatitic (feldspar-quartz-mica) veins containing beryl and fluorite (Kerr, 1938).

Huebnerite-bearing quartz veins have been mined in the Sylvania mining district (No. 22), Esmeralda County; in the Round Mountain mining district (No. 61); and at the Tungstonia (No. 93), and Hub (No. 99) mines, White Pine County.

Both huebnerite and scheelite occur in quartz veins at Ellsworth (near No. 55) in the Paradise Range, northeast of Gabbs, in Nye County, which is the type locality for huebnerite; and in the Cherry Creek mining district (No. 90) and Deer Trail mine (No. 103), White Pine County.

Wolframite has been mined from quartz veins at the Comet mine (No. 35), Lincoln County, that also contain galena, sphalerite, and pyrite; and at the Wolframite mine (No. 63), Nye County.

#### OTHER OCCURRENCES

At the Victory (No. 53) and adjacent mines in Nye County north of Gabbs, 100,000 units of  $WO_3$  have been produced from an unusual deposit containing scheelite, fluorite, and minor quartz disseminated along cracks in crushed and feldspathized granodiorite. A stockwork of quartz veinlets cut the scheelite-fluorite mineralization (Humphrey and Wyatt, 1958).

The Ticup, Chance, Only Chance, Scheelite King, Last Chance, Gypsy, Calcite, Happy, and other smaller mines in the Cherry Creek mining district (No. 90), White Pine County, have produced over 100,000 units of  $WO_3$ , mainly from irregular pipelike bodies of scheelite, calcite, and quartz in brecciated and silicified limestone along the main northeast-trending fault zones in the district. The bodies are also controlled by bedding and cross fractures. Scheelite, and more rarely huebnerite, also are found in the silver- and gold-base metal veins which occur in the northeast-trending faults (Holmes, 1950, and Adair, 1961).

At Golconda (No. 30), Humboldt County, 105,000 units of  $WO_3$  were produced from tungsten-bearing iron and manganese oxides deposited by Pleistocene hot springs as fissure veins and blankets cementing gravel beds (Kerr, 1940). The higher grade portions of the ore bodies contained up to 7 percent  $WO_3$ ; material containing less than 0.8 percent  $WO_3$  could not be treated profitably because of the high cost of the chemical treatment used to recover the tungsten. The Black Jack mine (No. 49) at Sodaville, Mineral County, has produced a small amount of tungsten from a similar deposit.

Scheelite has been recovered from placers at the Rock Hill mine (No. 20), north of Coaldale Junction, Esmeralda County; and at the Three Sisters mine (No. 98) in the Osceola mining district, White Pine County.

#### FUTURE POTENTIAL

Nevada remains an important potential source of tungsten, and the long-term outlook for tungsten mining is good. However, higher prices and/or improved technology are essential to restore the tungsten mining industry. With improved economic incentives, exploration can be expected to substantially increase the already large resources, both by extending known deposits and by the discovery of new deposits. Significant reductions in costs of production can be achieved through research toward mass mining methods, improved metallurgical recoveries, and the recovery of byproducts such as molybdenum and copper.

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#### URANIUM

(By A. P. Butler, Jr., U.S. Geological Survey, Denver, Colo.)

Uranium is a mixture of three isotopes, mainly  $U^{238}$ , and  $U^{235}$ , and a vanishingly small amount of  $U^{234}$ . The  $U^{235}$  isotope, which makes up only 0.7 percent of natural uranium, fissions (splits) readily under neutron bombardment. The  $U^{238}$  isotope which makes up 99.3 percent of natural uranium is not easily fissionable but can be converted in a nuclear reactor to a plutonium isotope,  $Pu^{239}$ , which is readily fissionable. Fissioning of  $U^{235}$  and  $Pu^{239}$  yields a large amount of energy. In an uncontrolled chain reaction the release of energy is explosive; in a controlled reaction the release of energy can be used as a source of heat.

Since 1942 uranium has been used mainly for atomic weapons and to a smaller extent as a fuel in nuclear reactors for generation of power. A little is also used, as it has been in the past, in the ceramic, chemical, and electrical industries.

For 20 years the United States has been the principal consumer of uranium. In the 5 years through 1962 the United States acquired from 26,400 to 34,000 short tons of  $U_3O_8$  annually (Baker and Tucker, 1963, table 4). In the year ended June 30, 1962, 59 percent of the uranium acquired was mined in this country, and by the end of 1962 a total of 108,000 tons of  $U_3O_8$  had been produced from about 40 million tons of ore mined in the United States.

Deposits in continental sedimentary rocks are the principal source of uranium mined in the United States. The largest and most numerous deposits are in sandstones in which uranium minerals coat the grains and partly fill the pore spaces of the rock. Deposits of lesser importance are in limestone and coaly carbonaceous rocks interbedded with continental clastic sedimentary rocks. Vein and related types of fracture-controlled deposits are also a source of uranium but are distinctly subordinate in importance to the deposits in continental sedimentary rocks. Uranium is also abundant in extensive, low-grade concentrations in some marine black shales and in marine phosphorites such as the Phosphoria Formation in Idaho and some adjoining States. Some uranium has been recovered from phosphate rock

mined in Florida (Baker and Tucker, 1961, p. 1274). Uranium minerals are present in some pegmatites but are generally too sparse to be recovered economically. Uranium minerals or uranium-bearing minerals are minor accessory components of many granitic rocks and some of these rocks may be a source of uranium in the future.

Only a relatively small amount of ore has been mined in Nevada. Total production has been about 26,000 tons of ore<sup>1</sup> ranging in grade from 0.1 to 0.7 percent  $U_3O_8$  and having an estimated value of about \$470,000. Most of this was mined from 1955 to 1961. No ore was mined in 1962 (Davis, Ashizawa, and Giorgetti, 1963, p. 687).

Uranium minerals were first noted in Nevada shortly after 1920 (Hewett, 1923), and uranium in veins was found between 1942 and 1949 at Majuba Hill, the Green Monster mine, and the Stalin's Present prospect (Lovering, 1954, pp. 77, 94, and 95). Veins and related types of fracture-controlled deposits are the most abundant type of deposit in Nevada, are widely distributed (fig. 35), and have been the chief source of ore mined in the State. The larger number of veins are in fractures or fracture zones cutting metamorphic, igneous, or sedimentary rocks of pre-Tertiary age. Veins in rocks of Tertiary age are somewhat less numerous but nearly as widespread as those in the older rocks. The deposits in the older rocks range from simple mineralized fractures to complex zones of fracturing in metamorphic rocks at the margin of intrusive granitic rocks as at the Early Day and Low Boy mines (Nos. 12 and 13). Some deposits in the Tertiary rocks, the Moonlight and Red Bluff mines (Nos. 3 and 5), for example, are in well-defined faults. Some, like the Buckhorn deposit (No. 7), are in groups of ill-defined fractures or, like the Lowary deposit (No. 5) in narrow fracture zones which exhibit little or no displacement.

Most deposits are known only in the zone of weathering and oxidation, and the uranium minerals in them are brightly colored yellow and green secondary minerals. Either uraninite or its varietal form pitchblende, two of the principal primary minerals of uranium, have been recognized, however, at the Moonlight, Early Day, and Bluebird mines (Nos. 3, 12, and 14). Introduced vein minerals other than uranium minerals and pyrite are sparse in many deposits and in most of those that have been mined, but sulfides of base metals are present in some deposits.

Although the largest number of productive deposits is represented by veins in Tertiary rocks, more than half the ore mined in the State has come from the deposit in older rocks at the Early Day mine (No. 12). No more than a few hundred tons of ore has been mined from any one vein in the Tertiary rocks, and production from all of them is only a little more than 1,000 tons of ore.

Deposits of uranium in continental sedimentary rocks are widespread in the State but less abundant than veins. The most numerous and all the productive deposits consist of uranium minerals in the interstices of arkosic or tuffaceous sandstone and water laid tuff of Tertiary age. The uranium is commonly in beds that contain carbonized fragments of plants.

Many of the deposits such as those near Mountain City (Nos. 1 and 2) and the Go Getter and Divide prospects in Washoe County near Nos. 5 and 6 are at or near the base of a rock sequence composed

<sup>1</sup> Compiled from information made available by the U.S. Atomic Energy Commission.

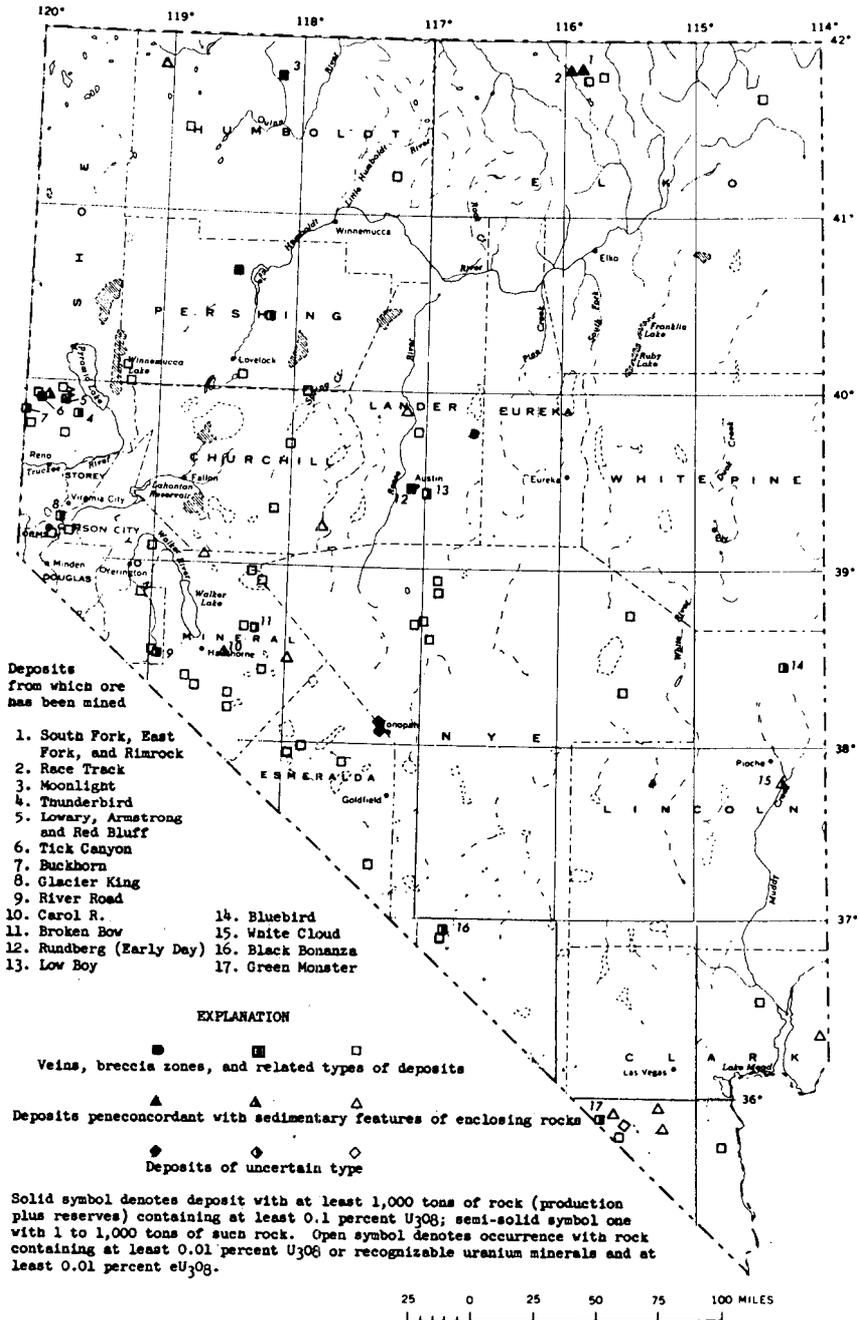


FIGURE 35.—Uranium in Nevada.

mainly of intermediate to felsic volcanic tuffs and flows. Some like the Carol R (No. 10) (Davis and Hetland, 1956, p. 458) and mineralized beds near Penaca (No. 15) (Davis and Hetland, 1956, p. 358) are somewhere within or high in the sequence of Tertiary rocks respectively. Deposits in older continental sedimentary rocks are represented by weakly mineralized sandstone in Clark County (Hewett, 1923).

The deposits near Mountain City have yielded a few thousands of tons of ore.

Uranium-bearing opalized tuff of Tertiary age in the Virgin Valley area, Humboldt County (Staatz and Bauer, 1954b) and uranium-bearing fine-grained tuffaceous rocks in Esmeralda and Nye Counties west of Tonopah (Davis and Hetland, 1956, pp. 353-355) are deposits in continental sedimentary rocks in which identifiable uranium minerals are sparse or lacking and thus differ from deposits generally characteristic of those rocks elsewhere. The deposits near Tonopah are locally extensive (Davis and Hetland, 1956, p. 355), but have not been mined.

Low-grade concentrations of uranium in coaly rocks at the Gamma group, Churchill County (Staatz and Bauer, 1954a), represent the only reported deposit of this kind in Nevada.

The outlook for uranium mining in Nevada depends on future demand for uranium and cost of mining it. The search for uranium in the United States in the decade between 1948 and 1958 was so successful that uranium is no longer in short supply. So much was found that the Atomic Energy Commission, the sole purchaser, had to limit the amount it would buy. Commencing April 1, 1962, an allocation system of uranium purchase supplanted the graduated price schedule for ore in effect before then. Under this system annual quotas in pounds of  $U_3O_8$  were assigned to individual mines and companies. Until the end of 1966, and under some circumstances until the end of 1968, the price is \$8 per pound for  $U_3O_8$  in concentrates produced from reserves discovered prior to November 28, 1958. In 1969 and 1970 the maximum price will be \$6.70 per pound for  $U_3O_8$  in concentrates from properties qualified by the deferring of a portion of the pre-1967 allocation to 1967 and 1968 (Baker and Tucker, 1962, p. 1274). It now appears that any increase in price for uranium will depend on the extent to which demand may be stimulated by an increase in use of nuclear reactors to generate electricity.

Reserves of uranium ore in Nevada consist of several tens of thousands of tons which the U.S. Atomic Energy Commission (written communication, 1962) considers available (minable) under the purchase price in effect through 1961, and a slightly smaller amount which is considered unavailable, because of tenor, size, location, or character of deposit. At prices comparable to those in force before 1962 the known deposits might supply a few thousand tons of ore annually. Additional deposits might also be found under such conditions, but a large increase in production seems unlikely from the kinds of deposits now known.

Most of the vein deposits in Nevada are small, and the uranium is irregularly distributed in them. Moreover, veins in general are only a relatively small source of uranium in the United States.

The known bedded deposits in the stream-laid sedimentary rocks interbedded in the lower part of local sequences of volcanic rocks are

also mostly too small or too lean to be a source of much uranium even under conditions as favorable as those prior to 1962. Places favorable for the occurrence of similar and perhaps larger deposits, however, may be concealed beneath a widespread cover of volcanic rocks and in downfaulted, alluvial filled basins. If aggressive exploration for uranium were favored by prices somewhat higher than in the past, some concealed deposits of this kind might be found. Under similar conditions deposits in fine-grained tuffaceous rocks like those near Tonopah might also become a usable resource of uranium.

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## VANADIUM

(By R. P. Fischer, U.S. Geological Survey, Denver, Colo.)

About 2,000 short tons of vanadium have been consumed annually in the United States in recent years. Three-quarters of this has gone into special engineering, structural, and tool steels, where it is used as an alloy to control grain size, impart toughness, and inhibit fatigue. The other principal domestic uses have been in nonferrous alloys and chemicals (U.S. Bureau of Mines, 1960; Busch, 1961).

The bulk of domestic supplies of vanadium, and about half of the world supplies, has come from deposits of vanadium- and uranium-bearing sandstone in southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico. The other principal sources of vanadium have been a deposit of vanadium-bearing asphaltite in Peru, vanadate minerals from the oxidized zones of some base metal deposits in Africa, and vanadium-bearing iron deposits in Europe and Africa. These iron deposits and similar ones in many parts of the world contain very large resources of vanadium. Probably they will become increasingly important as sources of vanadium in the future.

In Nevada, vanadium occurrences representing all four geologic types of commercial vanadium deposits are known, but none of them known at present is judged to be of significant commercial potential. On the other hand, still another type of vanadium deposit—vanadiferous shale—occurs in Nevada and might ultimately be of commercial value. Reported vanadium occurrences of these geologic types are shown on figure 30.

Crystals of vanadates of lead, zinc, or copper are common in the oxidized zones of base metal deposits in areas of arid or semiarid climates in many parts of the world. Generally these crystals are irregularly scattered in the oxidized zones, though in places they are concentrated in patches or bodies from which some material of commercial grade can be obtained by selective mining. Vanadate minerals occur in many deposits in Southwestern United States, but only a few of these deposits have yielded commercial vanadium ore. In southern Nevada, vanadate minerals have been observed in the oxidized zones of base metal deposits in several mining districts (fig. 30), but shipments of vanadium ore are reported only from the Goodsprings district. These reported shipments total only a few thousand tons of ore and average about 1 percent  $V_2O_5$ ; most of this was purchased and stockpiled by the Government during World War II. It is unlikely that a significant production of vanadium will be made from this type of ore in Nevada.

The mineral carnotite, a vanadium and uranium ore mineral in southwestern Colorado and adjoining States, has been identified in beds of sandstone in various places in Nevada. Although a few of these deposits have yielded a little uranium ore, the vanadium content of the known occurrences is too low for the material to be used as vanadium ore. In general the host rocks are not judged to be favorable for the accumulation of much vanadium.

Clarke (1924, p. 723) reports the ash from an asphalt from Nevada contains nearly 30 percent  $V_2O_5$ ; although seemingly high, this content is not uncommon in some types of asphaltic material. Clarke gives no locality, and he makes no resource appraisal. Schilling (1962) shows a vanadium-bearing asphaltite prospect in Elko County. The reported occurrences of asphalt in Nevada are small, however, so the vanadium potential of this type of deposit is judged to be of little or no significance in the State.

Reeves and Kral (1955, p. 21) report about 0.3 percent  $V_2O_5$  in iron ores from the Buena Vista Hills district, Churchill and Pershing Counties. Under present conditions in the iron and steel industry, this vanadium content is too small to permit the profitable recovery of vanadium from this iron ore.

Beds of carbonaceous shale containing more than average amounts of vanadium, selenium, and other metals occur in the Comus Formation of Ordovician age, the Chainman shale of Mississippian age, and one or more other formations of Paleozoic age in central and north-eastern Nevada. (See chapter on "Selenium," p. 134, and fig. 30, this report; see also Davidson and Lakin, 1961, 1962.)

J. D. Vine (written communication, 1964) of the Geological Survey states that:

Black shale beds that occur in the western and transitional (eugeosynclinal) facies of the lower Paleozoic in Nevada commonly contain unusually high concentrations of some minor elements. In particular, the beds of black shale in the Ordovician, Silurian, and Devonian commonly contain as much as 0.2 to 0.7 percent each of barium and vanadium, other metals are less common, although several deposits contain about equal amounts of vanadium and zinc. Other metals that are sometimes present in unusual concentration include molybdenum, nickel, lead, and silver.

One of the larger deposits of this type that has been commercially explored includes the Gibellini and Bissoni brothers claims in the Fish Creek Range, about 20 miles south of Eureka, Eureka County. The rocks in this area, mapped by C. W. Merriam (U.S. Geological Survey) as a western facies of the Devonian, are rich in vanadium, zinc, and molybdenum and extend for a distance of at least 6 miles along a zone as much as half a mile wide. There may be as much as 10 million tons of metal-rich rock, but the average grade is not known.

A second deposit that has been commercially explored is located in an outcrop of the Comus Formation about a mile north of U.S. Highway 40, on the east side of Golconda Summit, Humboldt County. This deposit of black shale is rich in vanadium and zinc, but also contains unusual concentrations of copper, silver, nickel, and barium. The highest concentrations of metal occur in a stratigraphic zone about 35 feet thick that has been traced for a distance of about 1,000 feet along strike in beds that dip about  $35^\circ$  to the northwest. From this, I estimate about a million tons would be available within 500 feet of the surface.

The samples obtained from these and other deposits in recent years are probably not adequate to give a quantitative estimate of the tonnage and grade of  $V_2O_5$ , but the indications are that the deposits are of too low grade for commercial exploitation at the present time.

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## NONMETALLIC MINERAL RESOURCES

Resources of the nonmetallic minerals are widely distributed throughout the State, and in recent years production of these materials has become increasingly important. In 1942 production of non-metallic minerals first exceeded \$5 million and has gradually increased to \$25 million in 1962. During World War II the production of magnesite at Gabbs, Nye County, was temporarily greatly expanded. In general, however, production of sand and gravel has been the most important, and the output of other nonmetallics has been substantially smaller. Nevada has large resources in some nonmetallic materials, as will become apparent in the following sections. New uses found for them or expansion of established uses could lead to significant production of any of these materials. Clays, diatomite, gypsum, and perlite are examples of such materials.

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### BARITE

(By R. C. Horton, Nevada Bureau of Mines, Reno, Nev.)

Barite is a white, heavy, relatively soft crystalline mineral with the composition,  $\text{BaSO}_4$ . Most Nevada barite, particularly in replacement deposits, is gray in color and resembles the limestone which it replaces. Its high specific gravity, about 4.5 for pure barite, distinguishes it from most other nonmetallic minerals. There are many uses for barite in the chemical and ceramic industries, but the major use is as a weighting agent in oil well drilling muds.

Production of barite in the United States in recent years has varied from 700,000 tons to 1 million tons annually. Imports of barite have increased markedly since 1952, and the United States presently imports about the same quantity of barite as is produced domestically. Canada and Mexico are the largest foreign suppliers.

Measured and indicated reserves of barite in the United States are estimated at 46 million tons, with another 67 million tons of inferred reserves. The United States thus has enough reserves to be self-sufficient, if need be, for many years.

Barite production began in Nevada in 1907 when a small amount of barite was mined at the American Barite mine (No. 55, fig. 36) in Esmeralda County. The Yerington mine (No. 39) in Ormsby County is mentioned as having produced barite in 1909. The Crystal mine (No. 44) in Mineral County was an active producer from 1916 through 1919, and again during the 1920's and early 1930's. The development of the present Nevada barite industry began during the late 1930's. Nevada barite mines have produced over 1,400,000 short tons of barite with a value in excess of \$9,500,000. Most of this production has come from replacement type deposits in the Battle Mountain-Carlin area of Lander, Eureka, and Elko Counties. A total of 137,727 tons of barite, with a value of \$954,000, were produced in Nevada in 1962.

Most of the Nevada barite is used in oil well drilling in California, with the exception of the barite produced by the Inorganic Chemical Division of the FMC Corp. That company operates the Mountain Springs mine (No. 28) and the Pleasant View mine (No. 24) in Lander County and ships most of the production to their chemical plant at Modesto, Calif.

The principal specification of barite for use in drilling fluids is that it have a specific gravity of at least 4.2; it also should be clean and relatively free of iron. The specifications for use in rubber and dark paints are about the same as for drilling; for light-colored paint, white barite is needed; and for glass, a relatively pure barite is required. Manufacturers of barium chemicals generally require barite that contains at least 90 percent barium sulfate, and no more than about 0.7 percent iron oxide.

Only barite to be crushed and ground has been purchased from independent miners for use in California in recent years. The prices paid for such material depend on the buyers and sellers involved, on the grade, and on the ability of the seller to sustain an ore supply. Prices paid for barite mined in Nevada, f.o.b. north-central rail points, range from about \$5.50 to \$8 per short ton. The actual cost delivered to northern California processing plants ranges from \$14 to \$18 per ton, and from \$18 to \$22 delivered to southern California facilities.

TABLE 16.—*Barite occurrences in Nevada*

[Numbers identify symbols in fig. 36]

1. Seventy-Six Creek prospect	31. Pine Mountain mine
2. Prunty prospect	32. Snow White prospect
3. Wildcat Barium mine	33. Unnamed prospect
4. Jungo Group	34. Unnamed prospect
5. Anacabe prospect	35. Bear mine
6. Joan Laura prospect	36. Bald Mountain prospect
7. Gaylord prospect	37. Alpha
8. Rytting prospect	38. Laurent mine
9. Esterbrook mine	39. Yerington mine
10. Tomlinson-Mullinix prospect	40. Highland Group
11. Rossi mine	41. Summit Creek mine
12. Jones Marvel mine	42. Northumberland prospect
13. Big Three prospect	43. Gravity mine
14. Heavy Spar prospect	44. Crystal Barite mine
15. Sander's mine	45. Cowden-Knowles prospect
16. Maggie Creek mine	46. Annett Group
17. Sugar Loaf prospect	47. Noquez Barium mine
18. Unnamed prospect	48. Candelaria prospect
19. Shelton Baryte No. 1 mine	49. Little Mountain prospect
20. Argenta mine	50. Little Summit mine
21. Small prospect	51. Barite King and Queen Group
22. Unnamed prospect	52. B and L mine
23. Bateman Canyon mine	53. Warm Springs mine
24. Pleasant View mine	54. Jumbo mine
25. Lancaster-Caudle Group	55. American Barite mine
26. Starr Grove prospect	56. Congress prospect
27. White Rock mine	57. Lucky Boy prospect
28. Mountain Springs mine	58. Lagarto prospect
29. King Gulch prospect	59. Klinger prospect
30. Greystone mine	60. Goodsprings district

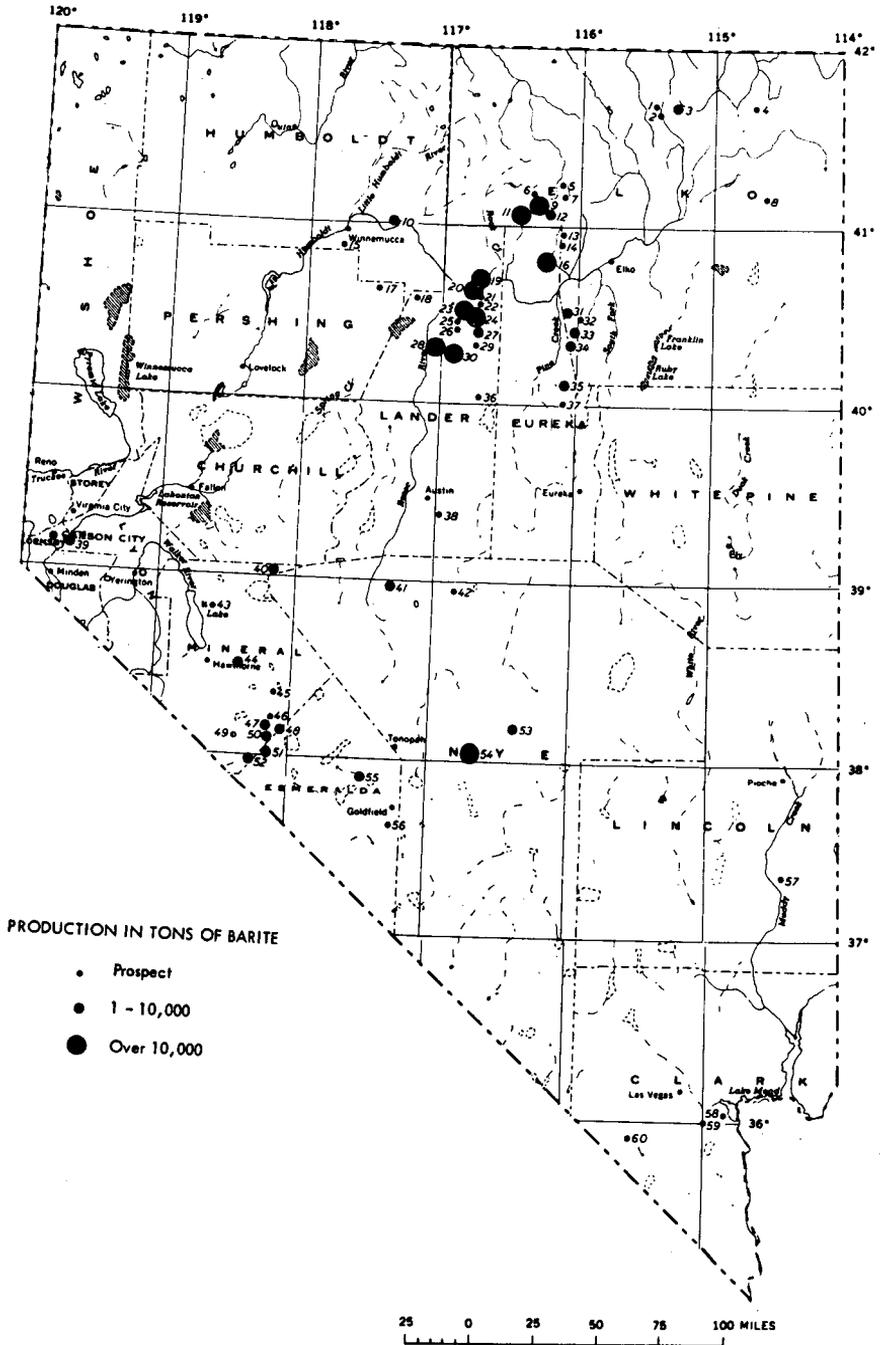


FIGURE 36.—Barite in Nevada (numbers refer to deposits or districts listed in table 16).

Barite occurs in fissure veins in all types of rocks and in replacement bodies in reactive rocks, usually limestone or dolomite. Residual deposits formed by the weathering of barite replacement deposits are of importance in Missouri, Tennessee, Georgia, and other Southern States. Residual deposits have not been found in Nevada, but both fissure vein and replacement deposits have been mined.

Most of the barite deposits in Nevada are within a belt some 50 to 75 miles wide extending northeast-southwest across the center of the State, as shown on figure 36. The "barite belt" coincides with the Antler orogenic belt as described by Roberts and others (1958, pp. 2813-2857). Although the reason for this coincidence is not presently known, it is of definite value as a guide to future exploration.

The deposits in the southwestern portion of the belt are generally limited to fissure vein types. Substantial amounts of barite from this area have been mined and shipped to southern California. Deposits in the northeastern half of the belt include both fissure vein and replacement type deposits, with the replacement type having been by far the most productive. These deposits were probably formed by barium-rich solutions that originated at depth. In many instances the replacement is so subtle that it is difficult to recognize the difference between the barite and the unreplaced limestone without hefting a specimen to estimate its specific gravity. The absence of accessory minerals, such as pyrite and galena, common in many barite deposits, and the absence of visible alteration effects, has led some observers to conclude that the barite is of sedimentary origin. Detailed geologic mapping may answer the question of origin, but it presently appears that the barite occurs in formations of widely differing ages, suggesting a replacement origin. In addition, the presence of fissure veins further suggests that the barite deposits were formed from barium-rich solutions introduced after the rock was consolidated.

There are three large barite mines in Nevada; the Rossi mine (No. 11) operated by the Baroid Division, National Lead Co.; the Mountain Springs mine (No. 28) operated by the Inorganic Minerals Division, FMC Corp.; and the Greystone mine (No. 30) operated by the Magnet Cove Barium Corp. This latter company also operates a barite mill at Battle Mountain. All of these are open pit mines. The deposits are formed by the replacement of limestone. At the Mountain Spring mine the barite replaces thin-bedded limestones interbedded with chert, siliceous argillite, and argillite of the Pumpernickel Formation (Pennsylvanian?). The geology of the Greystone mine is similar.

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### BORATES

(By W. C. Smith, U.S. Geological Survey, Menlo Park, Calif.)

Nevada supplied most of the borate mineral raw material consumed in the United States in 1872-92, when the domestic borax industry was in its infancy. It also produced some borates in 1921-28, and a little in 1939 (about 200 tons  $B_2O_3$ ). The largest resources of borate known in Nevada are in deposits of colemanite in Clark County. These, like the much larger colemanite deposits in California, have not been profitable to mine since 1927, the year when the Kramer district and Searles Lake, Calif., attained their large production, which

thereafter fully supplied the industry and brought it to maturity (Ver Planck, 1956).

The United States leads the world in production and consumption of boron compounds, and has large reserves on which to draw for many years. In 1961, the U.S. consumption was equivalent to 333,357 short tons of  $B_2O_3$ . This was very near the average annual consumption for the period 1957-61. Exports in 1961 were equivalent to 269,271 short tons of  $B_2O_3$ , mostly to industrial centers in Europe (Stipp and Schreck, 1962). Turkey, Italy, Chile, and Argentina produce significant quantities, but the United States supplies nearly 90 percent of the free world's requirement.

The most important commodities produced from borate minerals are borax ( $Na_2B_4O_7 \cdot 10 H_2O$ ), anhydrous borax ( $Na_2B_4O_7$ ), and boric acid ( $H_3BO_3$ ), but the borax industry also produces many other boron compounds, and it ships small quantities of crushed or partly processed borate minerals. The commercially important borate minerals are listed below for convenient references. Borax is the most easily processed because it is readily soluble.

Name	Formula	$B_2O_3$ Percent
Borax.....	$Na_2B_4O_7 \cdot 10H_2O$ .....	36.5
Kernite.....	$Na_2B_4O_7 \cdot 4H_2O$ .....	50.9
Ulexite.....	$NaCaB_5O_9 \cdot 8H_2O$ .....	42.9
Colemanite.....	$Ca_2B_4O_{11} \cdot 5H_2O$ .....	50.8

The use of borax and boric acid in household pharmaceuticals, soaps, and detergents makes their names familiar, but industrial uses, which account for most of the consumption, are much less widely known. Few realize, for example, that the heat-resistant glass in kitchen utensils and automobile headlights contains about 13 percent of borax. In making these and other products, the glass industry consumes about a fourth of the borax output. Equally large is the use in porcelain enamels and ceramic glazes. In general, the established industrial uses of boron compounds are so numerous that consumption follows rather closely variations in total industrial activity, and, furthermore, consumption tends to rise as population grows and as living standards improve. In addition, new uses are vigorously sought by industrial laboratories. This activity is well shown in the extensive reviews of new developments in the industry which appear in the annual chapters on boron in the Minerals Yearbook. (See Stipp and Schreck, 1962, and earlier volumes.)

All the known domestic borate deposits are in California, southern Oregon, and western Nevada (Smith, 1962). The accompanying map (fig. 37) shows the distribution of deposits in Nevada. Since borates, like other evaporate minerals, accumulate in arid basins, their absence in basins of eastern Nevada requires a geologic explanation. The probability is that boron was brought to the surface of the earth only in the western area, that transport was mostly by thermal waters, and these were moving upward most vigorously during volcanic activity such as that which characterized mid-Tertiary time. The transport is still continuing—boron is found in many springs west of central Nevada, but in few to the east.

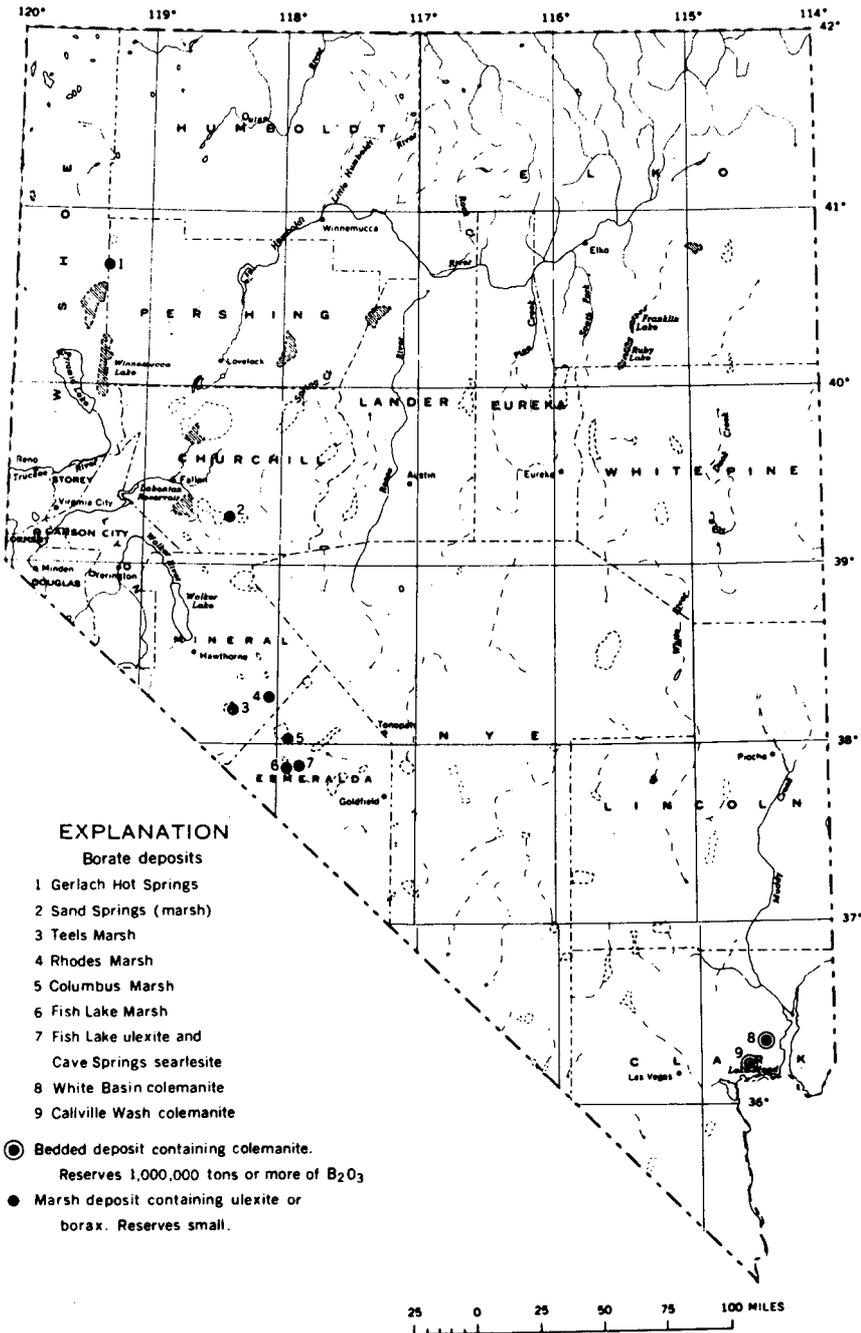


FIGURE 37.—Porates.

Because the domestic and world borax industry is so largely supplied by the two major deposits in California, brief notes on them provide useful background for an appraisal of deposits in Nevada. Though quite different in character, both deposits are very large and both are worked by large-scale, efficient methods (Smith, 1960; Garrett, 1960). Among other borate deposits of either historic interest or potential commercial value in the United States, some have moderately large reserves, but only certain minor deposits in California have been worked at all regularly in recent years, and the tonnages mined from these have been small (Smith, 1960).

About two-thirds of U.S. production of boron compounds is from the Kramer district (Gale, 1946; Obert and Long, 1962). Its ore is bedded crystalline borax interlayered with shale, evidently a deposit that formed in a lake during the Tertiary period. The ore contains much kernite (also known as rasorite), in crystals that cross bedding and plainly are secondary to the bedded borax, which is the preponderant mineral. The borax-bearing series of lake beds are slightly tilted and faulted, and buried by younger sediments. The ore body lies 150 to 1,000 feet deep; found by drilling, it was mined by underground methods from 1927 to 1957 and since then by open pit. The ore being mined contains 20 to 25 percent  $B_2O_3$ , it extends under 500 acres, more or less, and is about 200 feet thick. The reserves are estimated to be about 100 million tons, enough to sustain mining at the current rate at least 50 years.

Searles Lake is a salt pan in a desert basin. Its hard flat surface of common salt is underlain by mixed evaporate minerals in two layers, locally called crystal bodies, with thicknesses of 70 to 90 feet for the upper layer and 25 to 40 feet for the lower. Some of the common salt at the surface has been mined, but the other solid minerals have not. Borax and other saline products are extracted from brine that is pumped out of pores, or voids, in the crystal bodies. The brine is a complex mixture, 35 percent total solids, containing 1 to 1.2 percent  $B_2O_3$ . Pore space of the crystal bodies is estimated at about 45 percent and the bodies extend for nearly 40 square miles, thus the volume of brine is very large. The brine available should sustain operations at recent rates for about 25 years. Two companies are operating at Searles Lake and they account for almost a third of domestic production of boron compounds (Garrett, 1960).

When Nevada was the principal source of U.S. borax minerals, between 1872 and 1892, the main deposits being mined were at Teels Marsh and Rhodes Marsh in Mineral County, and at Columbus Marsh and Fish Lake Valley in Esmeralda County. Teels Marsh was the most productive, and its production is recorded as valued at \$929,743 (Ferguson, Muller, and Cathcart, 1954). Records are lacking for the others, but their combined total probably did not exceed the Teels Marsh production.

Teels Marsh is a salt-encrusted playa about 8 square miles in extent. The mining, mostly at the east end, consisted of scraping off the powdery saline surface crust, which may have been several inches thick. The crust contains the mineral borax mixed with sodium chloride, sulfate, and carbonate minerals. The crust that was mined may have been in part the residue of salts left on evaporation of a lake of unknown depth, but the present crust, and probably the surficial part of the crust that was worked, developed by evaporation of water that

rises by capillary action, bringing salts from underlying saturated muds.

Rhodes Marsh also yielded some borax mineral, but ulexite was more important (Vanderburg, 1937), p. 64-66. The ulexite occurred, characteristically as nodules in wet, soft mud underlying the playa surface. These nodules, which were handpicked, are called cotton ball because the fibrous ulexite is softly felted together in a rounded mass. A Columbus Marsh, also, cotton ball was mined. It forms thin layers 1 to 6 inches below the surface, in mud, silt, and sand in irregular areas around the margin of the extensive playa (area 13 square miles). The layers are so thin and their distribution is so patchy, that this raw material gives a strong impression of being very lean, yet at Columbus Marsh there are remnants of no less than nine borate treatment plants. At Fish Lake, there were two plants, at which borax was extracted from ulexite found in salty ground along the east margin of the Lake (Spurr, 1906, p. 158-165).

Sand Springs, Churchill County, may have been the first marsh deposit found. It was small; the total production was about a ton, in 1870-72 (Hanks, 1883). At Gerlach, Washoe County, ulexite was found in the apron of hot springs. No published record of the amount produced has been found, but an unpublished memorandum, by H. S. Gale says that 3,000 tons of borax were shipped in the 1890's.

The ulexite that was mined in Fish Lake Valley during 1939 came from bedded deposits in the low hills 3 miles east of the marsh deposit of Fish Lake (Albers, oral communication). The ulexite beds are part of an upturned sequence of lake sediments and volcanic rocks of Tertiary age. It is worth noting here this example of ulexite originally accumulated in a marsh or lake, and how erosion of this older bedded deposit supplies boron to the new marsh deposit. This surface geochemical cycle probably began when springs associated with the Tertiary volcanism brought boron up from where it had been stored within the earth, in rocks involved in a subsurface part of the boron cycle, and fed it into a Tertiary marsh.

The Tertiary rocks 2 miles south of the bedded ulexite contain the mineral searlesite ( $\text{NaBSi}_2\text{O}_6 \cdot \text{H}_2\text{O}$ ). This is the Cave Spring locality well known to mineralogists (Foshag, 1934). The searlesite is in very thin veinlets only and the deposit has no commercial value.

In Clark County, Nev., colemanite was mined from bedded deposits in steep-dipping Tertiary rocks in White Basin and at Callville Wash. (Gale, 1921; Callaghan and Rubey, 1936). Geologically, these deposits are one step further removed from a marsh deposit, for colemanite is typically a mineral formed from ulexite upon loss of sodium and water. The colemanite is relatively insoluble and, therefore, hard to process; this, added to the difficulties of mining underground on steep beds less than 15 feet thick, made extraction costs high in these districts. The Callville Wash (Anniversary Mine) production was equivalent to 25,000 tons of  $\text{B}_2\text{O}_3$ . White Basin production is unrecorded and probably was small.

The known borate resources of Nevada are mostly in the two districts in Clark County, which are estimated to total about 2 million tons, the larger part at Callville Wash. The resources of bedded ulexite at Fish Lake are unknown, but are probably small. The marshes have only thin surficial deposits that seem unworkable in the foreseeable future.

## CLAYS

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

No single definition of the term "clay" is acceptable to all workers, but most agree that clay is a natural, earthy, fine-grained material composed largely of hydrous aluminum silicate minerals which are plastic when wet. Clays are secondary minerals that are derived from the alteration of many types of rocks, and are widely distributed over the earth's surface. They vary widely in chemical composition. Although there are countless different types of clay, the principal industrial clays are kaolin, ball clay, fire clay, bentonite, fuller's earth, and miscellaneous clays.

Approximately two-thirds of all the industrial clay produced is used for the manufacture of formed and fired ceramic products, and the remainder goes to varied nonceramic applications. Miscellaneous clay, for instance, is produced in every State except Rhode Island and Alaska. Kaolin is used for whitewares, paper fillers and coaters, rubber fillers, in specialty cements, and many other products. Ball clay and fire clay are used almost exclusively for ceramic products. Bentonite and fuller's earth have similar uses, such as oil clarifiers and catalysts, binders for foundry sands, insecticides, drilling muds, and many other nonceramic applications. Miscellaneous clay is used for heavy clay products, cement, and lightweight aggregate.

The testing of clays is complex and requires thorough knowledge of industrial uses and specifications as well as an array of highly specialized and expensive equipment. For these reasons the ordinary assay laboratory can seldom produce definitive results concerning the economic potential of a clay. It is far more desirable to submit samples to potential consumers or to one of the various governmental agencies equipped to perform such testing. The U.S. Bureau of Mines and the Nevada Bureau of Mines have been engaged for several years in a cooperative testing program on clay deposits in Nevada, to assist in development of new deposits or possibly the reopening of some old ones.

The clay minerals are generally divided into three broad categories: the kaolin group, composed chiefly of the minerals kaolin, halloysite, or other similar clay minerals; the montmorillonite group to which the bentonites belong; and the illite group.

The kaolin clays are formed as hydrothermal alteration products, as residual weathering deposits, and as sedimentary deposits; any one of these can be a commercial deposit. The sedimentary kaolin clays (Cretaceous) of South Carolina and Georgia constitute by far the most extensive deposits and dominate the U.S. kaolin industry.

Although bentonite clay is extremely common, particularly in the Western States, it is the sodium montmorillonite member of the montmorillonite group which is most desirable; the only large supply of this material comes from Cretaceous beds in Wyoming and South Dakota. Although bentonite deposits can be formed in several days, their most common origin is thought to be the low-temperature alteration of volcanic glass.

Almost all illite deposits are sedimentary in origin, although there are some hydrothermal and residual deposits; but no pure deposits are known. For the most part illite clays have no special uses other than in structural clay products such as brick and tile.

Almost 48 million short tons of clay were sold or used in the United States in 1962 for a gross value of about \$163 million. The value of the finished products manufactured from this amount of clay far exceeds the value quoted for the crude ore. The United States is self-sufficient with regard to clay deposits. No possible substitution of other material for the major uses of clay is expected in the near future and therefore the clay industry of the United States should continue its steady growth. However, near-surface supplies of high-grade clays, such as the superduty refractory kaolins, are diminishing and the future may see a relative increase in the underground mining of such clays.

Production figures for Nevada clay are confidential and cannot be disclosed by the U.S. Bureau of Mines, but it may be safely stated that clay presently is one of the lesser industrial mineral industries of Nevada. Nevertheless, the State is in a favorable position with respect to several large market areas for certain specialty clays, which, if found in Nevada, could be mined profitably even at relatively long distances from railroads.

Nevada's known clay deposits are essentially of two types, kaolins and bentonites. They are shown on figure 38.

#### KAOLIN CLAYS

The Stoker kaolin deposit (No. K-1, fig. 38), Pershing County, probably is the largest known kaolin deposit in Nevada. It may be traced for at least one-half mile along the base of the western flank of the Stillwater Range immediately north of New York Canyon. The body probably is on the order of a few hundred feet across. Bulldozed trenches have shown that it is as much as 25 feet deep. The kaolin is thought to have been formed by hydrothermal alteration of a Mesozoic(?) phyllite. Although deep red staining by iron oxides probably has rendered this material unusable for the paper industry, the clay might have ceramic applications.

Kaolinite is present along the White Horse fault zone in the Cortez district near Mount Tenabo (No. K-2), Lander County. It is found in fairly large bodies associated with turquoise deposits occurring in an east-west trend. The clay probably was derived by hydrothermal alteration of lower Paleozoic siliceous rocks.

A large deposit of halloysite occurs in the Bullion (Railroad) mining district (No. K-3), Elko County, which originally was developed for silver, lead, copper, and gold in 1869. At the intersection of two large dikes of quartz porphyry on the north face of Bunker Hill the porphyry has been almost entirely converted by hydrothermal processes to halloysite and other clays. The exact extent of the clay is unknown, but one adit which cuts the dike at an approximate angle of  $45^\circ$  is in clay for 350 feet (Johnson, 1962). This halloysite is reported to have potential value as a catalytic agent. The property, formerly known as Alladin mines, is presently operated by John H. Uhalde and associates.

A deposit of halloysite has been encountered in the Liberty copper pit (No. K-4) near Ely, White Pine County, operated by the Kennecott Copper Corp. The deposit is near the old Emma shaft headframe at the northwestern corner of the pit. This is superduty refractory clay, but as presently known the deposit is quite small (less

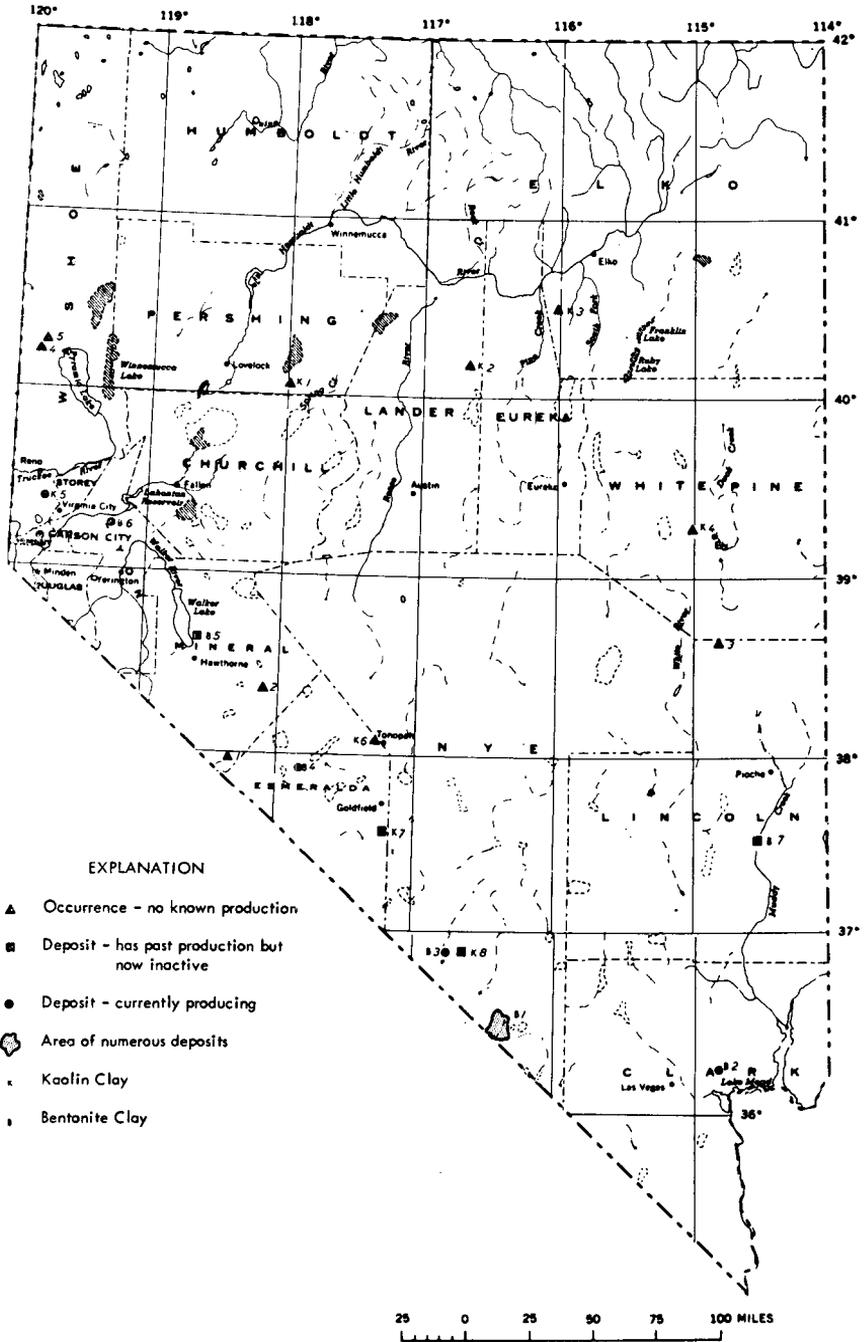


FIGURE 38.—Clays in Nevada (number refer to districts or deposits discussed in text).

than 100,000 tons), is far from present markets, and would have to be mined so as not to interfere with the extraction of copper ore.

Clay formed by the hydrothermal alteration of early(?) Tertiary volcanic flow rocks to the east and west of Steamboat Springs (No. K-5), Washoe County, has been used by the Reno Press Brick Co. for the manufacture of building brick. Although the writer knows of no definitive mineralogical work having been done on the deposit, it is likely that these clays belong to the kaolin group.

West of Tonopah (No. K-6) in Esmeralda County kaolinite occurs as thin beds, generally less than 2 feet thick, in the Siebert lake beds of late Tertiary age. The clay apparently formed by the alteration of tuffaceous strata. The beds are too thin, areally limited, and too far from rail transportation to make their utilization likely in the near future.

At the old mining district of Cuprite (No. K-7) Esmeralda County clay derived from altered tuffs once was shipped to Los Angeles as china clay for the manufacture of sanitary porcelain. Although the clay has not been identified mineralogically the use to which it was put strongly indicates that it was kaolin clay.

The Bond and Marks clay deposit lies about 6 miles east of Beatty on the north slope of Bare Mountain (No. K-8) Nye County. This irregularly shaped pod of kaolinite clay and alunite probably was formed by the hydrothermal alteration of argillaceous beds in an Upper Silurian carbonate sequence. The clay is contaminated by intense staining of iron and manganese oxides, which undoubtedly led to its early abandonment.

Undoubtedly there are many other occurrences of kaolin clays in Nevada which are not yet known or have been misidentified in the past.

#### BENTONITE

The best known bentonite deposit in Nevada, and the one with greatest production, is the Ash Meadows deposit (No. B-1) Nye County, which actually includes many deposits within one large district. These clay deposits are calcium and magnesium montmorillonites derived from the alteration of tuffaceous lakebeds of probable Pleistocene age. Recorded past production has been almost \$3 million (Kral, 1951), but local residents who worked on these deposits over 30 years ago claim that the gross value of all production is many times this amount. The primary use of this clay was for filtering and clarifying mineral oils and as an absorbent. Some major oil companies still retain mineral rights in portions of the district, although production has been practically at a standstill since the 1930's. The K-B Mining Corp. recently built a plant in the northern portion of the district for the upgrading and beneficiation of bentonite clay.

The R. T. Vanderbilt Co., Inc., mines intermittently from three montmorillonite deposits in Nevada (Nos. B-2, Clark County, B-3, Nye County, B-4, Esmeralda County) for use in their line of Veegum products. This company has many other deposits in the Western United States from which they mine similar material. After careful testing, the various clays are blended into mixtures and processed at their plant in Connecticut for use in cosmetics, pharmaceuticals, and other such high-value uses.

Along the southwestern flank of the Muddy Mountains east of Las Vegas (No. B-2) Clark County a 3- to 4-foot thick tuffaceous bed of probable Cretaceous age is strip mined. Tonnages taken from this deposit are relatively small.

The Beatty area (No. B-3), Nye County, has many stony ash-flow tuff units in which pure montmorillonite clays with well-developed thixotropic properties have been formed, presumably by the combination of hydrothermal alteration and weathering. Although the crude ore may contain considerably less than 50 percent clay by volume, it is of such high value that underground mining commonly is employed. Lovelite Cosmetics, Inc., of Las Vegas uses Beatty clay in their products.

The clay deposit along the eastern flank of the Silver Peak Range (No. B-4), Esmeralda County, is megascopically similar to the Beatty clay deposits. It probably was formed by the hydrothermal alteration of ash-flow tuff of the Esmeralda Formation, possibly along a range front fault.

Large amounts of bentonite were mined from the Chiatovich clay deposit along the eastern shore of Walker Lake north of Hawthorne (No. B-5), Mineral County, but the property is now inactive.

The Jupiter bentonite deposit, presumably formed by hydrothermal alteration of volcanic flow rock, is located south of the Carson River near Fort Churchill (No. B-6), Lyon County. This clay is cut by abundant selenite seams and veinlets. It is intermittently mined and shipped to the San Francisco area, presumably without beneficiation of any sort.

Large amounts of clay, presumably bentonite, have been mined from a deposit high on the eastern wall of Rainbow Canyon north of Boyd siding on the Union Pacific Railroad (No. B-7), Lincoln County. The clay and abundant siliceous alunite have been formed by the hydrothermal alteration of what apparently was tuffaceous rhyolite (Moore, 1936). The deposit and its workings are extensive. A tramway was built to transport the ore to the bottom of the canyon, but operations ceased about 1930 and have not been resumed.

#### OTHER DEPOSITS

Many clay deposits noted in the geologic literature are not described here. Vandenburg (1937) notes two bentonite deposits in Mineral County (Nos. 1 and 2). Schrader (1931) briefly describes a large clay deposit in Cave Valley (No. 3), Lincoln County. Overton (1947) notes a high alumina clay (No. 4) and a fuller's earth deposit (No. 5), both in Washoe County.

In summary, although Nevada has not been a large clay producer in the past, if large deposits of the right type of clay can be found, it is in an excellent position to serve Western United States market areas. The abundance of various types of known clay deposits in Nevada leads the writer to believe that additional specialty clays can be found in the State.

## DIATOMITE

(R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Diatomite is a siliceous sedimentary rock that consists mainly of the fossilized remains of diatoms, forms of microscopic unicellular organisms. Diatomaceous earth and kieselguhr are synonymous with diatomite. Many sedimentary rocks contain diatom remains, but the term "diatomite" is restricted to material of a quality and purity suitable for commercial uses. Pure diatomite is composed of opaline or hydrous silica and in addition most deposits contain unusually high amounts of free water. Diatomite is characterized by its generally light colors and extreme lightness of weight. The density of natural diatomite varies from 20 to 40 pounds per cubic foot, but after processing it is considerably less. It is easily confused with the purer varieties of volcanic ash, but these are generally somewhat darker (more toward light gray than white) and have a distinctly different texture that commonly can be detected with an ordinary hand lens. Diatomite is particularly susceptible to diagenetic changes caused by leaching and redeposition as opal, chert, or porcelaneous silica. After such changes have occurred the deposits can rarely be considered as commercial.

Almost all of the uses for diatomite are based upon its unique natural microscopic cellular structure, but because of wide variations in origin, geologic history, and content of impurities, any single deposit may have only a limited or nonexistent value and not necessarily be competitive with nearby deposits. Testing and evaluation of diatomite samples is a highly developed and fairly complicated process which is usually practiced only by diatomite producers; such services are not generally available through commercial assaying firms. There are literally hundreds of uses for diatomite and product specifications for these uses are extremely complicated and exacting. The industrial uses include filtration, mineral filler or extender, insulation, absorbent, mild abrasive, process applications such as brick, admixture or pozzolan for cementitious mixtures, conditioning agent in preventing caking, and numerous miscellaneous uses.

There are two main types of diatomite deposits; those deposited in marine waters, and those formed in fresh water; both types form as bottom accumulations of the shells of diatoms. All Nevada deposits of diatomite were formed in fresh water. These organisms have the ability to extract silica from the water in which they live and biologically precipitate it to form their valves or shells. Such accumulations formed at the bottoms of oceans or lakes range in thickness from a few feet to as much as 1,000 feet or more, as at Lompoc, Calif. The important diatomite deposits of the world are quite young geologically, having formed in either the Tertiary or Quaternary periods, and the economically important U.S. deposits, all of which are in the Western States, are further restricted to the latest part of the Tertiary. The large diatomite deposits of the world are invariably associated with volcanic formations and most workers believe that some such source of soluble silica is necessary over long periods of time in order to form diatomite beds of significant thickness. The commercial value and industrial applications of marine and fresh-water diatomite are essentially the same.

Although occurrences of diatomite, many of them large, are known in many parts of the world, those deposits of commercial interest are much less numerous. The United States is presently the world's leading producer of diatomite and the remaining production is essentially confined to Europe and Africa. The United States exports a substantial amount of its diatomite production (exact figures are not available), and imports are generally either extremely small or non-existent. Clearly, the diatomite reserves in this country are adequate for an indefinite period in the future. In recent years approximately 500,000 short tons have been produced annually with an average value per ton of about \$50. California in recent years has produced approximately three-fourths of the U.S. production, with Nevada, Oregon, and Washington following in the order of importance.

Tonnages and values of diatomite production for individual States are not available because, at the producer's request, they are included by the U.S. Bureau of Mines in a single undisclosed category with many other mineral commodities. Nevertheless, California has long been and is likely to remain the principal diatomite producer in the United States, whereas Nevada has been and is likely to remain the second most important diatomite producer.

Three firms are currently producing diatomite products in Nevada at four plants as shown on figure 39. The Eagle-Picher Co. produces filter grade material at a relatively new plant north of Lovelock, Pershing County, and also produces diatomite for uses other than filtration at a plant at Clark siding, Storey County, about 20 miles east of Reno. The Aquafil Co. processes diatomite for uses other than filtration at its plant in Fernley, Lyon County, as does the Great Lakes Carbon Corp. at its plant near Basalt Junction, Mineral County.

It is difficult to describe the diatomite resources of Nevada as individual deposits due to the extent and thickness of diatomaceous strata. Relatively small deposits in northeastern and southeastern Nevada can be considered as individual deposits; but for the large area in the northwestern portion of the State, in which all the important and presently operating deposits are found, diatomite occurrences must be considered as occupying large basins rather than be considered as individual deposits.

All of the diatomite deposits of Nevada are assumed to be late Tertiary in age, probably either late Miocene or Pliocene. The diatomite deposits to be described below are in the Truckee, Humboldt, Esmeralda, Siebert, and Panaca Formations, which in a general sense are all roughly correlative and taken altogether bridge only a small part of Tertiary time.

The Tri-o-Lite Co. formerly operated a deposit (No. 1, fig. 39) near Carlin, Elko County. The mill, now abandoned but still standing, is at Vivian siding along the Southern Pacific Railroad tracks and the deposit is about 1 mile north of the mill. The diatomite occurs as a mass 15 feet thick, tilted 35° to the southeast (Eardley-Wilmot, 1928) and cut by numerous local faults. About 2,000 tons were being mined annually at the time of Eardley-Wilmot's investigation, most of it for insulation purposes. Other deposits are known west of Carlin in Eureka County, and in the large basin filled with late Tertiary deposits in the vicinity of Carlin between the Tuscarora Mountains and the Independence Mountains, but to the writer's knowledge these have not yet been developed and exploited.

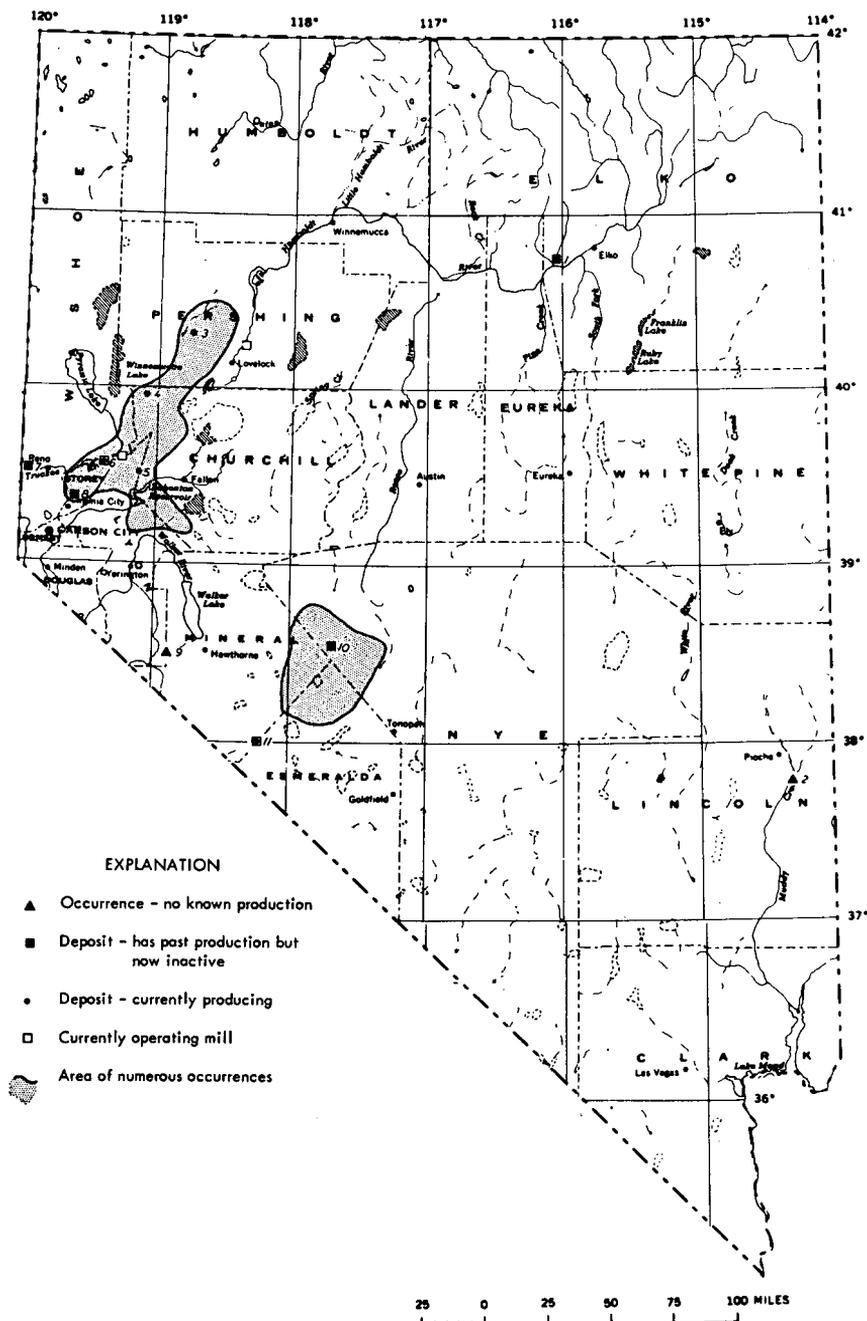


FIGURE 39.—Diatomite in Nevada. (Numbers refer to deposits or districts discussed in text.)

Diatomite is present in a basin centered around Panaca in the Meadow Valley Wash drainage of Lincoln County. The main exposures lie about 1 mile east of Panaca immediately north of the Panaca-Modena highway (No. 2). The main bed ranges up to 10 feet in thickness, but is covered with a substantial thickness of overburden. Several adits and cuts have been made at this deposit, but there is no record of production.

Except for these two isolated occurrences, significant diatomite deposits are restricted to the western part of the State. On the map (fig. 39) deposits now operating are shown along with some which have produced in the past; but this cannot give an accurate picture of diatomite resources because such sequences have a sedimentary basin aspect and are spread out over large areas. Therefore two large areas are delineated in which many diatomite occurrences are known, but are too numerous to pinpoint in the usual manner. Within these large areas, however, diatomite outcrops constitute only a very small percentage of the total area, and neither area should be considered as a single sedimentary basin. The diatomite beds generally crop out in intermontane basins or low on the flanks of ranges, but were originally deposited in larger continuous basins before the present mountain ranges formed. The present configuration of valleys and diatomite occurrences has little relationship to the original basin or basins in which the diatomaceous strata were deposited.

The Eagle-Picher Co. is mining filter-grade diatomite from an area along the western flank of the Trinity Range northwest of Lovelock (No. 3), Pershing County. Significant thicknesses of diatomite with relatively minor contamination by interbeds of volcanic tuff is being strip-mined and trucked about 25 miles to the mill at Colado siding on the Southern Pacific Railroad. The processed diatomite has high value as a filtration aid and substantial quantities are shipped abroad. There is no other production of filter grade diatomite in Nevada at the present time.

The Aquafil Co. operates a diatomite mill at Fernley along the main line of the Southern Pacific Railroad and procures diatomite from two general areas. A deposit southeast of Nightingale along the Bradys Hot Springs-Nightingale road (No. 4), Pershing County, is mined seasonally and another deposit southwest of Hazen (No. 5), Lyon County, is mined to supplement the production from the Nightingale deposit.

The Eagle-Picher Co. mines diatomite along the southern wall of the Truckee River Canyon (No. 6) Storey County, and trucks it a few miles west to a mill at Clark siding on the Southern Pacific Railroad about 20 miles east of Reno. This large deposit can be seen easily from U.S. Highway 40. The strata here dip more steeply than most of the western Nevada diatomite deposits.

A diatomaceous earth deposit near Verdi (No. 7), Washoe County, was mined in the 1920's and used for flooring and interior finishing products, but the operation failed because of the differential wearing away of portions of the softer diatomaceous earth aggregate in these products (Overton, 1947).

The Electro-Silicon Co. of New York City mined diatomite for use as silver polish from a deposit about 6 miles northeast of Virginia City (No. 8), Storey County, as late as 1930. Diatomite and diatomaceous

shales are interbedded in a tuffaceous sequence which has been tilted as much as 80°, presumably by block-faulting.

Diatomaceous shales have been described by Axelrod (1956) in the vicinity of Aldrich Grade along the western flank of the Wassuk Range (No. 9), Lyon and Mineral Counties. The valleys to the north and south of this locality contain great thicknesses of pedimented late Tertiary sedimentary strata, but no pure diatomite has been described from this general area.

In the 1920's The Nature Products Co. mined and shipped three carloads of diatomite to Reno from a property east of the Cedar Mountains (No. 10), Nye County. The material was used in the production of toothpowder and dental cream. Much of this diatomite is reputed to be of good quality, and the area has received some attention since its last known production about 1925.

The Great Lakes Carbon Corp. is currently strip-mining a deposit near Basalt Junction (No. 11), Mineral County, which is about one-half mile wide and at least 3 miles long. Their mill is east of the deposit, and the processed diatomite is trucked to Mina for shipment on the Southern Pacific Railroad.

This brief report cannot begin to mention all of the localities of diatomite deposits in northwestern Nevada, but most of the major ones have been described.

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#### DIMENSION STONE

(By R. C. Horton and R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

The stone industry generally is divided into two main branches—dimension stone and crushed and broken stone. Dimension stone is used as building blocks, while crushed and broken stone is used as concrete aggregate, railroad ballast, and in highway construction. Because Nevada's production of crushed and broken stone has uses similar to those for sand and gravel, it is discussed under the chapter "Sand and Gravel".

The term "dimension stone" is applied to natural blocks or slabs of rock cut or sawn to definite shapes and sizes. These are used for building stone, monumental stone, paving stone, curbing, and flagging. The principal use undoubtedly is as building stone, but monumental stone has the highest unit value.

Dimension stone deposits are of many types, for quarrying operations can be developed in numerous kinds of sedimentary, metamorphic, or igneous rocks. Sandstone, limestone, quartzite, marble, volcanic flow rock, and granites and related rocks are commonly quarried for dimension stone. Deposits of suitable rock should be large enough to allow room for a sizable quarry and there should be little or no overburden. The type of rock is not nearly as important as is color, durability, texture, freedom from flaws, and esthetic appeal. Certain mineral constituents in weathering may stain or, by their alteration, weaken the rock in time. Such deleterious factors are difficult to test for but study of weathered outcrops will usually indicate the rock's durability.

The dimension stone industry in the United States has remained fairly static over the past decade with respect to tonnage and value of products sold or used per year. In 1962 approximately 2,700,000

short tons of dimension stone having a value of about \$91 million were sold or used in the United States. This country is self-sufficient in dimension stone for many decades to come, but domestic producers have difficulty in satisfying the public demand for variety. Many types of marble and granite produced in other nations seem to have no satisfactory counterpart in the United States, and as a consequence special varieties of building and ornamental stones are imported, chiefly from Europe.

Statistical figures for the dimension stone industry in Nevada are not available due to their consolidation with figures for other commodities, but such production probably is valued at less than \$1 million per year. If deposits can be found that would supply demands for rare types of dimension stone for the west coast population centers, Nevada is favorably located with respect to transportation costs. Most of Nevada's dimension stone production is hauled by truck to consuming centers, but some is sold f.o.b. quarry.

In Virgin Valley (No. 1, fig. 40) west of Denio, Humboldt County, the Wegman brothers of Winnemucca are operating a quarry in late Tertiary tuffaceous sandstone. The rock is cable sawn in the quarry into large blocks which are moved to a bank of gangaws that cut the rock into various thicknesses and widths of facing stone. Appropriate lengths then are cut with a hydraulic guillotine. The resulting facing stone is sold under the trade name "Owyhee Rose Stone." Most is sold in the Pacific Northwest, but some is marketed and used in Nevada.

Star Dust Mines, Inc. operates a quarry on the east flank of the Snake Range, White Pine County, in Tps. 14 and 15 N., R. 70 E. (No. 2). The quarried material is a schistose quartzite (Cambrian) having an exposed thickness in excess of 1,200 feet. About 20 small quarries have been opened in the quartzite and, in 1963, 150 tons of building stone were mined and sold from these quarries.

Along the northwest flank of the Muddy Mountains in the general vicinity of Buffington Pockets (No. 3), Clark County, the Aztec sandstone (Jurassic?) has been quarried for rough building stone intermittently over a long period of time. The sandstone is exposed in the basal block of the Muddy Mountain overthrust fault. Two general quarry areas have been developed within a couple of miles of each other. Freshly split rock has been stockpiled in recent years near the mouth of the canyon containing the American Borax Road, indicating that these properties remain active.

Sporadic attempts have been made to procure flagstone rock from low-lying cuestas of the Virgin limestone member of the Moenkopi formation (Triassic) along the eastern flank of Frenchman Mountain east of Las Vegas (No. 4), Clark County, but these operations have met with little success. To the writer's knowledge blasting and quarrying methods have not been used; rather the smooth-surfaced flaggy float blocks have been gathered and loaded by hand into trucks. The problem in such operations is to obtain clean surfaces at a minimum of cost. Although this uniformly thin-bedded limestone holds up well in its natural desert environment, it presumably would behave less satisfactorily in areas of moister climates.

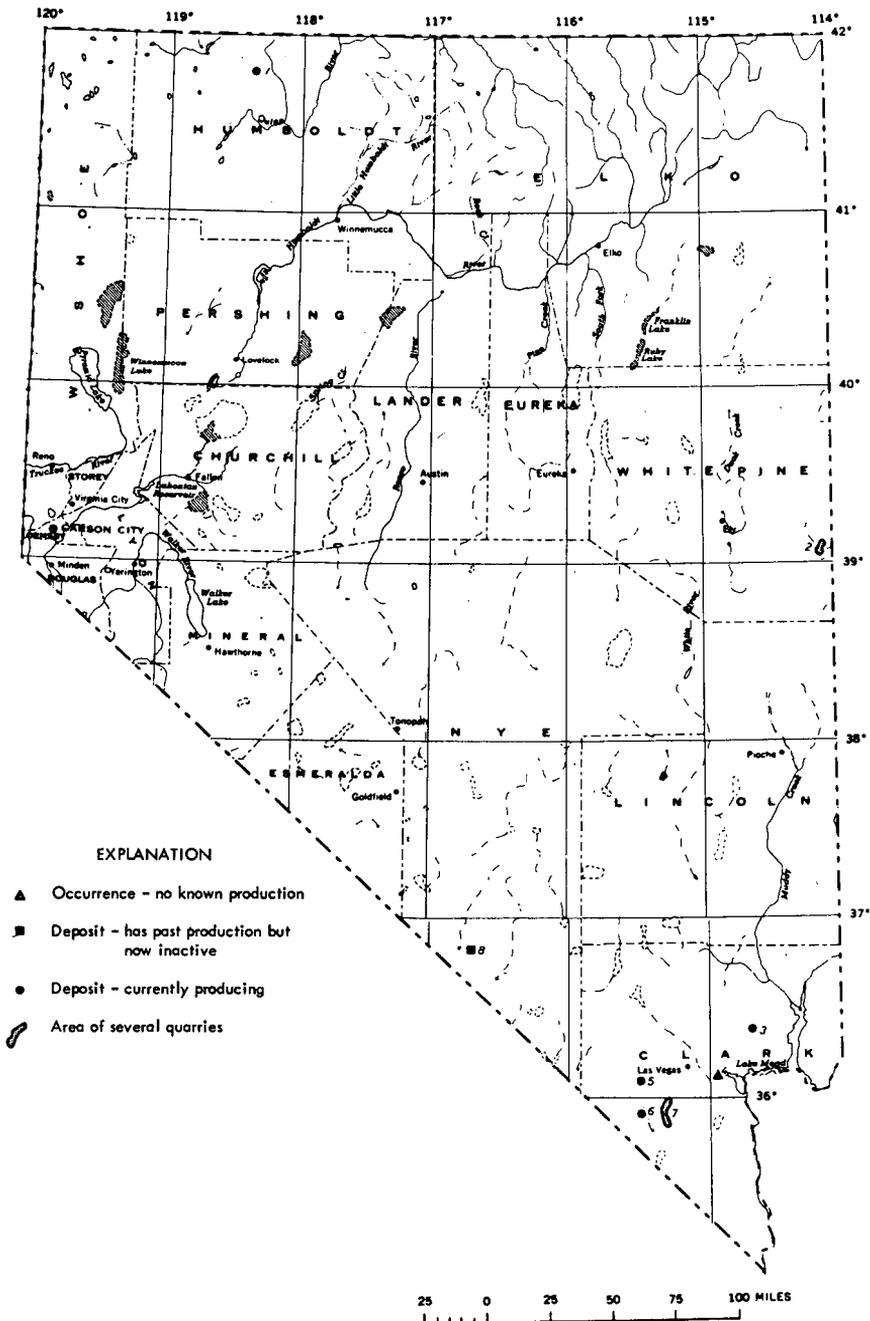


FIGURE 40.—Dimension stone in Nevada (numbers refer to localities discussed in text).

Blocky sandstone beds near the top of the Chinle formation (Triassic) along the foot of the steep eastern wall of the Spring Mountains north of Blue Diamond Village (No. 5), Clark County, are being quarried for rough building stone by Mr. T. P. Rhea of North Las Vegas. After quarrying, the sandstone is split with a guillotine and trucked to markets. The geology of this deposit is not fully understood but the hill from which the sandstone is being quarried presumably has slumped from its natural position and has overridden the soft red shales of the underlying portions of the Chinle formation.

Several rock quarries in the Aztec sandstone (Jurassic) have been developed in two low-lying ridges along the base of the eastern flank of the Spring Mountains approximately 7 miles north of Goodsprings (No. 6), Clark County. The rock is split into rough building stone at Goodsprings and trucked to markets. The principal quarries were operated until recently by Mr. P. A. Simon of Jean and are known locally as the Simon or Rainbow quarries.

Numerous rock quarries have operated sporadically along a 10-mile-long belt on the eastern side of the Bird Springs Range to the west of Sloan siding on the Union Pacific Railroad (No. 7), Clark County. These are undifferentiated red beds near the base of the Permian sequence, and are unusual for Nevada stone operations in that locally some of the mining was performed underground by numerous small and shallow adits. Some of this production may have been used as silica sand, but this has not been verified. Local pockets of dark iron-stained sandstone are quarried by hand from time to time in the central portion of this area for use as ornamental rock, in the construction of fireplace facing and artificial waterfalls. For the most part these quarries now are idle.

In the early part of this century the American Carrara Marble Co. attempted unsuccessfully to quarry white marble for ornamental or monumental stone in the Carrara area (No. 8), Nye County, about 7 miles southeast of Beatty (Kral, 1951). The buildings erected during this venture may be seen just north of U.S. Highway 95 near its junction with the dirt road leading south to Chloride Cliff. The marbleized zone, in Cambrian limestone and dolomite, is about 50 feet wide and is intensely fractured. This close-spaced fracturing plus the presence of numerous dark veins in the white marble undoubtedly contributed to the failure of this operation.

Many small quarries have been started in varicolored volcanic rocks of western and central Nevada. A few of these quarries are briefly described by Kral (1951, p. 57), and by Vanderburg (1940, p. 23). A combination of factors including the small size of the deposits, distance to market, and lack of capital has limited these operations.

In the late 1800's and early 1900's, prior to the development of the western cement and brick industry, almost every town in Nevada had a local stone quarry. Many of the buildings still standing in the "ghost towns" of the State are constructed of such stone and descriptions of these old quarries, now of little economic significance, are given by Reid (1904) and by Burchard (1914).

## FLUORSPAR

(By R. C. Horton, Nevada Bureau of mines, Reno, Nev.)

Fluorspar, a nonmetallic aggregate containing a sufficient quantity of fluorite ( $\text{CaF}_2$ ) to be of commercial value, occurs in fissure veins in all types of rocks and in replacement bodies in reactive rocks, usually limestone or dolomite. Fluorite is also a common gangue mineral in metalliferous deposits. Fluorite is normally a hydrothermal mineral and most geologists believe that commercial deposits are formed from solutions accompanying the intrusion of igneous rocks. Although it is a nonmetallic mineral, fluorite is similar in its modes of occurrence to hydrothermal metalliferous deposits. Fluorspar is found also as a constituent of sedimentary rocks rich in phosphate, but never in concentrations great enough to warrant mining. Efforts are being made toward recovering the fluorine now wasted in phosphate processing plants and, if successful, large quantities of fluorine will be come available.

Fluorspar is marketed in three major grades: metallurgical, ceramic, and acid. Metallurgical-grade fluorspar, the lowest priced of the three, may be sold in lump form or as gravel, artificial pellets, or fine flotation concentrates, and usually is required to contain a minimum of 60 effective units of fluorite. Effective units are determined by subtracting 2.5 units of  $\text{CaF}_2$  from the total  $\text{CaF}_2$  content for each unit of  $\text{SiO}_2$  present. A unit is equal to 1 percent of a short ton, or 20 pounds. Metallurgical-grade fluorspar is used as a fluxing agent in blast furnaces. Silica,  $\text{SiO}_2$ , has the reverse action of fluorspar as regards fluxing properties and is therefore an undesirable contaminant.

Specifications for ceramic-grade fluorspar are not standardized, but depend largely upon the requirements of individual consumers. Most ceramic-grade fluorspar is fairly pure, commonly containing 95 percent  $\text{CaF}_2$ , 2.5 percent  $\text{SiO}_2$ , and 1.5 percent  $\text{CaCO}_3$ .

Acid-grade fluorspar should contain a minimum of 97 percent  $\text{CaF}_2$  and not more than 1.1 percent  $\text{SiO}_2$  for the manufacture of aqueous hydrofluoric acid, or 1.5 percent  $\text{SiO}_2$  for anhydrous hydrofluoric acid.

For many years the steel industry was the principal consumer of fluorspar, but since 1956 the quantity of acid-grade fluorspar consumed has exceeded the consumption of the metallurgical-grade product. This trend will continue as acid-grade fluorspar or hydrofluoric acid is required in ever-increasing amounts for the manufacture of aluminum, various plastics and chemicals, in spray can propellants, and in refrigerants.

The principal problem facing domestic producers in recent years has been the competition of foreign imports, particularly those from Mexico. As a result of these imports many domestic mines have been forced to close. Prices quoted for fluorspar have been stable for a number of years at: metallurgical grade, 72.5 percent effective  $\text{CaF}_2$  content, per short ton, f.o.b. Illinois-Kentucky mines, \$37 to \$41; acid grade, 97 percent  $\text{CaF}_2$ , per short ton, bulk, f.o.b. mine, \$45 to \$49; Mexican fluorspar, 70 percent  $\text{CaF}_2$ , per short ton, f.o.b. border, duty paid, \$27 to \$28. Mexican fluorspar is subject to a duty of \$7.50 per short ton.

Production of fluorspar in the United States in recent years has varied between 200,000 and 300,000 tons per year. Foreign imports often have exceeded 500,000 tons per year. Fluorspar reserves in

the United States were recently estimated to total 22.6 million tons containing 35 percent or more  $\text{CaF}_2$ , or the equivalent in combined fluorspar and metallic sulfides. An additional 12 million tons of lower grade material containing 15 to 35 percent  $\text{CaF}_2$  was estimated. The United States has an enormous reserve of phosphate rock—at least 13 billion long tons—and some authorities have estimated its fluorine content to be equivalent to about 900 million tons of fluorspar.

Production of fluorspar in Nevada during recent years has been between 15,000 to 20,000 tons annually with a value of \$300,000 to \$400,000. The location of fluorspar deposits is shown on figure 41 and listed in table 17. Fluorspar has been of commercial importance in Nevada since 1919, when the Continental Fluorspar Co. began mining fluorspar at the Daisy mine in the Fluorine district (No. 41, fig. 41) near Beatty, Nye County. In 1927, J. Irving Crowell, Jr., acquired the mine on a 99-year lease and has operated it continuously since that time.

The Kaiser mine in the Broken Hills district (No. 28), Mineral County, formerly the Baxter mine, was discovered by V. S. Baxter in 1938. Mr. Baxter operated it until 1951 when a lease and option-to-purchase agreement was made with H. W. Gould & Co. This agreement was transferred to the Fallon Fluorspar Mines, Inc., who, in 1952, sold the mine to the Kaiser Aluminum & Chemical Corp. The new owners operated the mine until early 1957 when mining ceased because available ore had been mined.

The Wells Cargo mine (No. 40), Lincoln County, was discovered in 1958 during an examination of the claims for barite. Substantial amounts of fluorspar have been shipped to the Kaiser Steel Corp. and to the U.S. General Services Administration stockpile.

Other small mines and prospects in Nevada have produced minor amounts of fluorspar, most of which was sold to the Kaiser Aluminum & Chemical Corp. mill near Fallon, Churchill County. The mill, constructed following the purchase of the Kaiser mine, has not operated since the mine was closed in 1957.

The fluorspar deposits of Nevada may be subdivided on the basis of their mode of occurrence, age of mineralization, and geographic distribution. For purposes of discussion the fluorspar deposits have been divided into "mesothermal" and "epithermal" types. This classification is tentative pending additional study of deposits considered to be mesothermal.

The mesothermal deposits are those genetically associated with granitic intrusives or having no apparent genetic association with Tertiary volcanic rocks. All of these deposits are presumed to have been formed at considerable depths below the surface of the earth and are generally older than the extensive Tertiary volcanism in Nevada. The epithermal deposits are associated with Tertiary volcanism and probably were formed near the surface.

Mesothermal deposits include those of the Union district and the Wells Cargo mine in Lincoln County. The epithermal deposits include those in the "western epithermal fluorspar belt" and in the Quinn Canyon Range district. Deposits in the Fluorine district (No. 41), previously classified by the author as mesothermal, may be intermediate in type between mesothermal and epithermal or may be wholly epithermal.

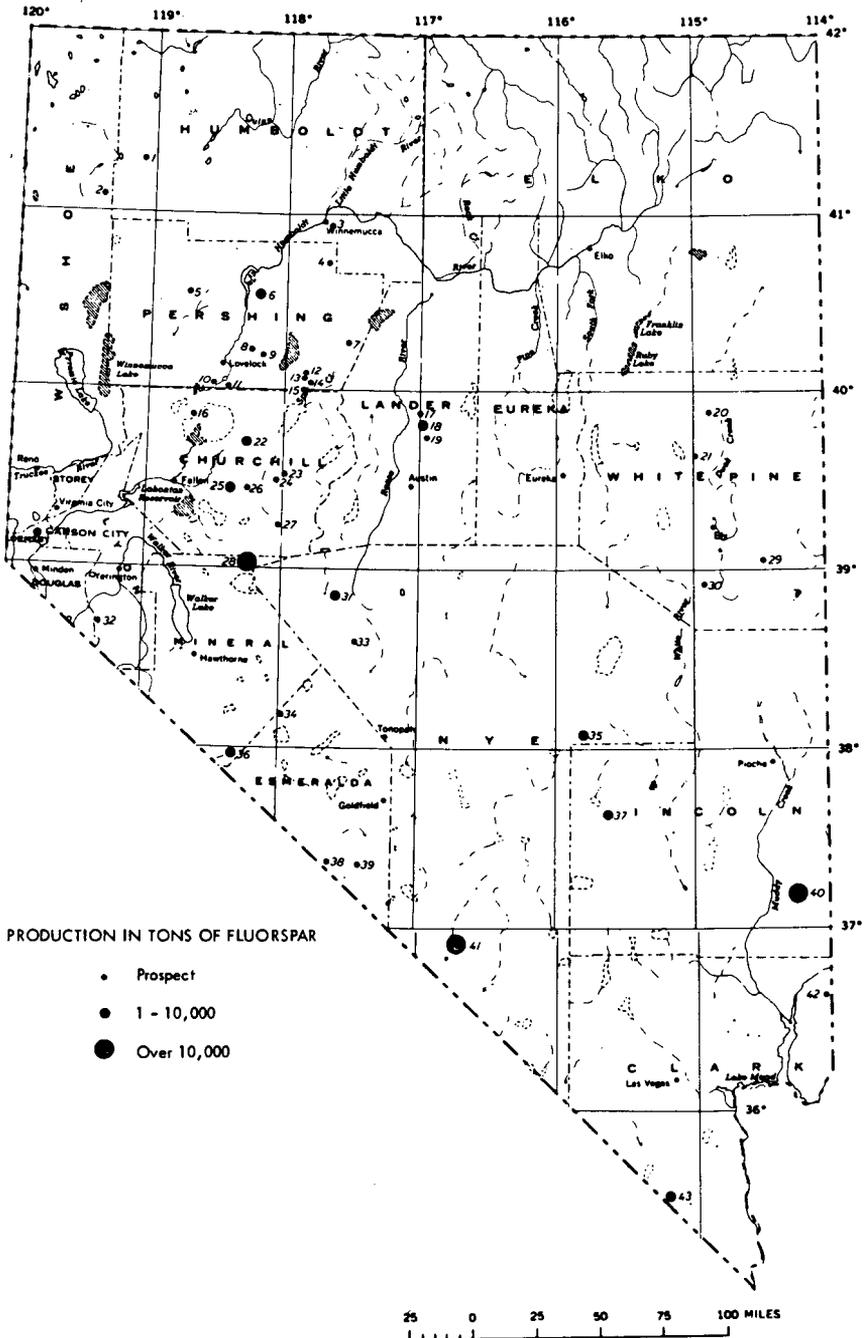


FIGURE 41.—Fluspar in Nevada (numbers refer to deposits or districts listed in table 17).

TABLE 17.—*Fluorspar occurrences in Nevada*

[Numbers identify symbols in fig. 41]

- |                             |                                 |
|-----------------------------|---------------------------------|
| 1. Sunset prospect          | 23. Purple Spar prospect        |
| 2. Leadville district       | 24. Little Jim prospect         |
| 3. Thunderbird prospect     | 25. Dixie mine                  |
| 4. Mammoth prospect         | 26. Black Hills prospect        |
| 5. Devaney prospect         | 27. Merkt prospect              |
| 6. Fluorine group           | 28. Broken Hills district       |
| 7. Needle Peak prospect     | 29. Rattlesnake Heaven prospect |
| 8. Emerald Spar group       | 30. Sawmill Canyon mine         |
| 9. Bohannan prospect        | 31. Union district              |
| 10. Baker prospect          | 32. Boulder Hill mine           |
| 11. Vexco prospect          | 33. Colton mine                 |
| 12. Susie prospect          | 34. Flora prospect              |
| 13. Hay and Inman prospect  | 35. Quinn Canyon Range district |
| 14. Harris prospect         | 36. Mountain Pass district      |
| 15. Edson-Wightman prospect | 37. Lincoln mine                |
| 16. Madraso prospect        | 38. Amry prospect               |
| 17. Eli Cee prospect        | 39. Bullfrog-George prospect    |
| 18. Iowa Canyon prospect    | 40. Wells Cargo mine            |
| 19. Hill Top prospect       | 41. Fluorine district           |
| 20. Hilltop prospect        | 42. Walker prospect             |
| 21. Rainbow prospect        | 43. Goodsprings district        |
| 22. Revenue group           |                                 |

The Union district (No. 31) is located on the west side of the Shoshone Mountains in northwestern Nye County. It includes the old mining camps of Ione, Berlin, and Grantsville. The geology has been described by Silberling (1959) and the mining activities by Kral (1951, p. 195-206). Substantial amounts of quicksilver have been mined in the district from Tertiary and Triassic rocks (Bailey and Phoenix, 1944, p. 149-154). High-grade gold deposits also have been mined in the Tertiary volcanic rocks. Gold, silver, copper, lead, and zinc have been mined from pyrometasomatic deposits in the Grantsville Formation (Triassic). The fluorspar deposits in the area, believed to be of the mesothermal type, are briefly described by Silberling (1959, p. 12) as follows:

Along the west front of the range, on either side of the mouth of West Union Canyon, fluorite mineralization is concentrated in the limestone member of the Grantsville. Fluorite occurs along the faults of both the northward-trending frontal range system and the northwestward-trending Union Canyon system where they transect the limestone. Fluorite also occurs as a replacement in the limestone, especially near the top of the unit where it is capped by the impervious siliceous conglomerates of the Luning Formation. Similar occurrences of fluorite are also present on the west slope of Richmond Hill.

Fluorspar deposits at the Wells Cargo mine (No. 40) were formed by replacement of a Mississippian(?) limestone with minor amounts of fissure filling. Mineralization has been controlled by a major fault that forms the footwall of the ore body. Minor amounts of barite occur with the fluorspar, and a small manganese prospect is located on the same fault, but outside the area of fluorspar mineralization.

Many small fluorspar deposits in Nevada have been found directly associated with granitic intrusives. The fluorspar is within the intrusive body or in the contact zone. These deposits have not been of commercial importance. Included in this category are many of the deposits in Esmeralda and White Pine Counties, including those associated with beryllium mineralization in the Snake Range, White Pine County.

The term "western epithermal fluor spar belt," as used in this report, includes most of the fluor spar deposits in western Nevada. Numerous fluor spar prospects, some with minor production, occur in a belt some 40 miles wide, extending 140 miles north and 80 miles south of the Broken Hills district (No. 28). All of the deposits in this belt, except those in the Union district and possibly the Fluorine district, are thought to be of the epithermal type and genetically related to Tertiary volcanism. This belt also includes 8 of the 12 most productive quicksilver districts in Nevada (Bailey and Phoenix, 1944, p. 10) and, if extended northward would include 10 of the 12. A similar concentration of antimony prospects is found within this belt. The inferences drawn from this alinement of epithermal mineral deposits must be considered carefully as there also are concentrations, within the belt, of tungsten, molybdenum, and iron occurrences.

The only major fluor spar producer within the epithermal belt is the Kaiser mine in the Broken Hills district. This mine produced 155,000 tons of fluor spar but is now reported to be mined out. Fluor spar was found in a lens-shaped shear zone 1,800 feet long in the upper workings, decreasing to 600 feet in length on the 700 level. No ore of importance was found outside the shear zone.

The fluor spar deposits in the Quinn Canyon Range district (No. 35) of Nye County are found in limestone, dolomite, and rhyolite or felsite. Many of the deposits are near or at the intrusive contact of rhyolite and limestone. The remoteness of the area has hindered development of the deposits and, had the area been convenient to transportation, there might have been a larger production. The deposits are similar in many respects to those found in the western belt in that they are generally narrow epithermal fissure veins or breccia fillings.

The fluor spar deposits of the Daisy mine in the Fluorine district (No. 41) are in the Nopah formation (Upper Cambrian), which has been sheared and brecciated by thrust faulting. Thurston (1943, p. 4) states:

The age relationships of the faults associated with the fluor spar deposits are not known, but the faults may have been formed in a single protracted period of deformation \* \* \*. Fluor spar deposition may have occurred within a period of major deformation, but it is also possible that the fluor spar was deposited along faults after one period of faulting and that the deposits were then dislocated by some later and unrelated movement which utilized, at least in part, preexisting fault planes.

The Daisy mine has produced 120,000 tons of ore, contains the largest known fluor spar reserves in Nevada, and, with continuing acceptable markets and prices, will operate for many years. There are several smaller fluor spar deposits in the Fluorine district. The deposits occur in dolomite and limestone near intrusive and extrusive rhyolitic rocks and were probably formed by deposition from hydrothermal solutions that emanated from underlying bodies of rhyolitic magma.

## GEMS AND GEM MATERIALS

(By J. B. Murphy, Nevada Bureau of Mines, Reno, Nev.)

Although virtually every variety of gem stone occurs in the United States, gem production is not of great economic importance as there are no known major deposits. Most gem material is collected or purchased by small lapidary shops or individual hobbyists. The thousands of lapidary hobbyists and mineral collectors who visit the State on collecting trips generate a considerable amount of trade.

Precious gems and organic gems are not known to exist in Nevada. Semiprecious gem material is quite plentiful in the State, and may be broadly defined as any naturally occurring mineral or rock suitable for ornamental use. The value of this material depends upon such factors as rarity, color, size, durability, and popularity. Only the two most notable materials of Nevada, turquoise (including variscite), and fire opal will be considered here. Location of the occurrences of these materials is shown on figure 42 and listed in table 18.

## TURQUOISE AND VARISCITE

Turquoise is a basic hydrous copper aluminum phosphate  $[\text{CuAl}_6(\text{OH})_8(\text{PO}_4)_4 \cdot 5\text{H}_2\text{O}]$  mineral of secondary origin, deposited by descending cold solutions. A cryptocrystalline material, it occurs as veinlets, seams, and nodules in various rock types, which commonly have undergone extensive alteration. It is not easily identified as it is a member of an isomorphous series, and is closely akin to other minerals. Common associates are quartz, chalcedony, limonite, kaolinite, and sericite. Turquoise varies in hardness from 5 to 6 (Moh's scale), and is relatively tough, although in its denser forms it tends to be brittle. It varies in color from near white through many shades of blue, green, blue green, to greenish gray. The more porous material ranges down to a chalky material with a dull earthy luster.

Color is the principal determinant in evaluating the material for market, the most highly prized being robin's egg blue. This color usually comprises only a very small percent of the material mined. Other colors are of less value but some enjoy a fair demand. Material having a waxy luster is the most desirable. Nevada is one of the foremost producers of turquoise in the United States. Much of the turquoise mined in the State has been of very fine quality, and much of the rest has been of good quality. Accurate production records are not available.

Variscite is a basic hydrous aluminum phosphate  $(\text{AlPO}_4 \cdot 2\text{H}_2\text{O})$  and an end member of a mineral series. It is of secondary origin and probably is deposited by descending cold solutions. It usually occurs as cryptocrystalline material in veinlets, seams, and nodules. Variscite commonly is associated with a variety of other phosphates formed by the alteration of the variscite. It has a hardness of 4 (Mohs' scale) with a color range from near white, to light or dark yellowish green, to pure deep green. Broken surfaces exhibit conchoidal to irregular fracture. Its luster is waxy in compact masses and dull to earthy in less compact masses. During the early 1900's variscite was in great demand, but little has been mined since 1910. The material is rather soft for a gem stone and its use is limited.

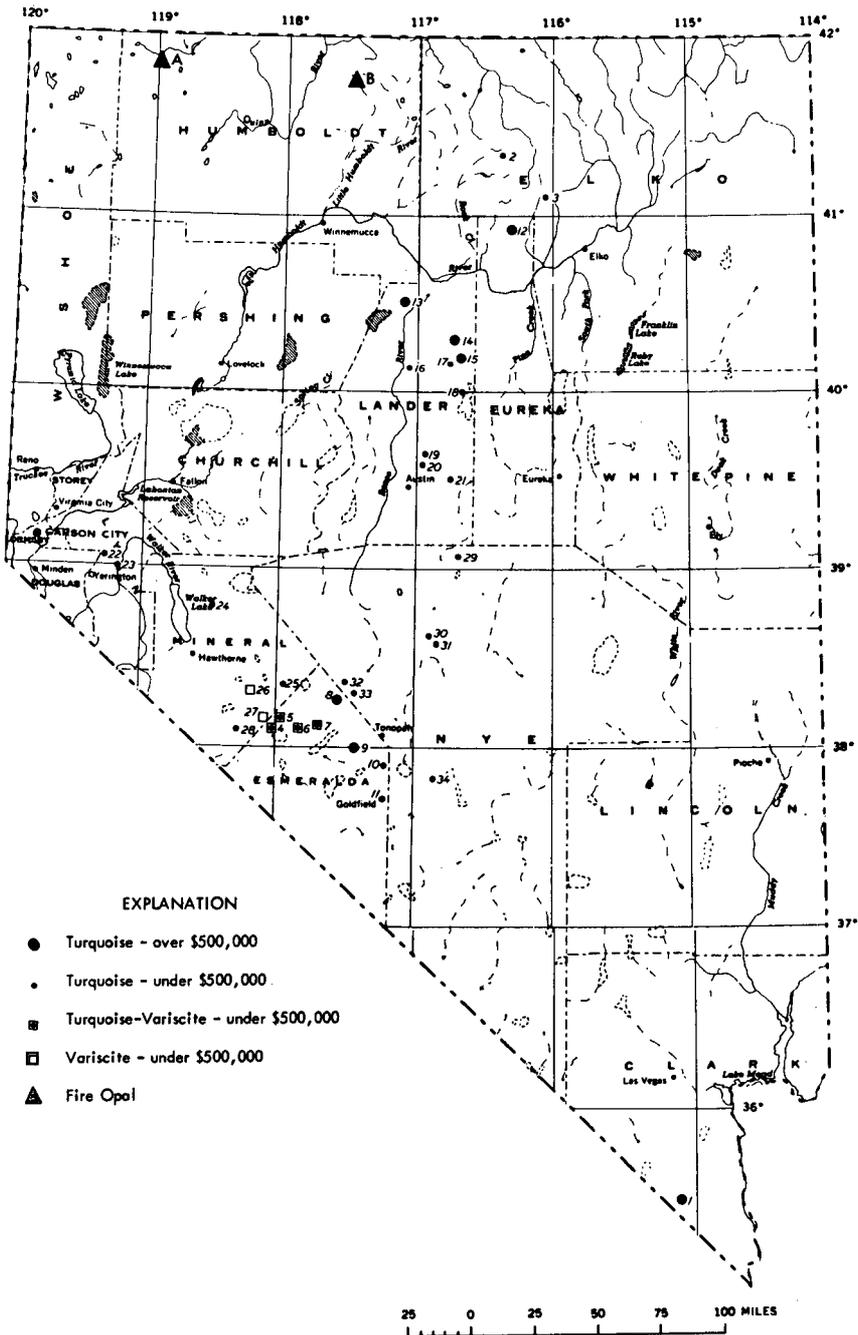


FIGURE 42.—Gems in Nevada (numbers refer to deposits or districts listed in table 18).

TABLE 18.—Occurrences of gems and gem materials in Nevada—turquoise and variscite occurrences

[Numbers identify symbols in figure 42]

## CLARK COUNTY

1. Crescent district  
Wood (Aztec, Toltec) mine  
Simmons (Crescent) mine  
Smithson-Phillips mine  
Morgan mine

## ELKO COUNTY

2. Rock Creek mining district  
Stampede mine
3. Merrimac mining district  
Carlin Black Matrix mine

## ESMERALDA COUNTY

4. Candelaria-Sigmund group
5. Los Angeles Gem Co. group
6. Coaldale mining district  
Holland claim  
Wilson-Capps claim  
Sigmund claim  
Wilson-Capps-Reik-Botts group
7. Carr-Lovejoy group
8. Crow Springs mining district  
Royal Blue mine  
Marguerite claim  
Hidden Treasure (Myers-Bonna) claim  
William Petry mine  
Oscar Wehrend claim
9. Lone Mountain mining district  
Lone Mountain mine  
Livesley mine
10. Klondyke mining district  
Smith Black Matrix mine
11. Goldfield mining district

## EUREKA COUNTY

12. Lynn mining district  
Number 8 mine

## LANDER COUNTY

13. Battle Mountain mining district  
Blue Gem Lease mine  
Myron Clark mine
14. Bullion mining district  
Gold Acres (Steinich) mine  
Mud Springs mine  
Tenabo group  
Stone Cabin (Steinich) mine

15. Cortez mining district  
Fox Cortez group
16. Pinto Watts mine
17. White Horse mine
18. Jimmey Allen mine
19. Greentree mine
20. McGinnis mine
21. Dry Creek mine

## LYON COUNTY

22. Otto Taubert #1
23. Yerington mining district  
Otto Taubert #2

## MINERAL COUNTY

24. Rand mining district
25. Pilot Mountains mining district  
Turquoise Bonanza  
Moqui-Aztec mine  
Troy Springs claim  
Copper King claim  
Montezuma mine
26. Silver Star mining district  
Dunwoody-Prichard group
27. Candelaria mining district  
Candelaria mine
28. Basalt mine

## NYE COUNTY

29. Indian Blue mine
30. Belmont mining district  
Weber mine
31. Zabrinsky mine
32. Blue Gem (Easter Blue) mine
33. Royston mining district  
Snow Storm claim  
Aztec claim  
C.O.D. claim  
Bunker Hill claim
34. Cactus Peak mine

## HUMBOLDT COUNTY

- A. Virgin Valley mining district  
Bonanza mine  
Rainbow Ridge mine
- B. Firestone Opal mine

Typically the mining of turquoise and variscite in Nevada is pursued as a small-scale operation, as the deposits do not lend themselves to large-scale mining. Intermittent pursuit is usually the rule due to cycles of popularity, and economic pressures. Available deposits apparently could support considerable production but future production probably will follow the pattern of the past due to the nature of the commodity.

Turquoise has been found associated with variscite at several localities in Nevada. Among these are: the Candelaria-Sigmund group (table 18 and No. 4, fig. 42), the Los Angeles Gem Co. group (No. 5), several localities in the Coaldale mining district (No. 6), and the Carr-Lovejoy group (No. 7), all in Esmeralda County.

The Wood Turquoise mine, also known as the Crescent mine (No. 1), is in the Crescent mining district (T. 28 S., R. 61 E.), Clark County, on the south side of Crescent Peak. The deposit had been worked for many years by Indians as evidenced by artifacts found at the site. Archeologists have dated the crude dwellings and lapidary shop at about the year 1292. It was rediscovered by a Mr. Simmons in 1889 or 1890. This mine and several other prospects in the immediate area were last worked possibly no later than 1910. A New York firm at one time established a lapidary shop at the site to cut gems for eastern trade. The turquoise occurs in decomposed monzonite porphyry (Sterrett, 1913, p. 697-698), mainly as nuggets but also as seams and veinlets. The nuggets, sometimes more than an inch across, are usually embedded in white claylike material. They are hard, dense, and of a pure light blue color. The largest, most-perfect stone found weighed slightly over 200 carats when cut.

The Royal Blue mine (No. 8) in the Crow Springs mining district (NW corner, T. 5 N., R. 40 E.), Esmeralda County, was discovered in 1902. It has been one of the most important turquoise mines of Nevada. William Petry, onetime owner, declared that the Royal Blue had produced more turquoise than any other mine in the United States and placed the value of cut stones produced at more than \$5 million. This was about 1915. The mine is known to have produced in the 1930's and 1940's but nothing is known of recent history. The mine was worked by five short adits, three shallow shafts, and open cuts. The turquoise occurs as veinlets, seams, and occasional nodules in fracture zones in altered trachyte and porphyry. The altered trachyte is soft in places but much has been hardened by silicification. The color ranges from dark sky blue to pale blue with the darker material tending to be dense and hard. The lighter colored material is softer. Dark to light yellow limonite commonly is present in matrix. The turquoise generally was of high quality, although some did exhibit a greenish cast.

The Lone Mountain mine (No. 9) is on the southern slope of Lone Mountain (sec. 11(?), T. 2 N., R. 40 E.) in the Lone Mountain (West Divide) mining district, Esmeralda County. Discovered by Lee Hand in 1920, the mine was active from 1927-35 under Mr. Hand's ownership. Development of the mine started with a 60-degree inclined shaft. At a depth of about 40 feet the first good quality "spiderweb" turquoise was found. In 1935 the workings consisted of a 200-foot inclined shaft with five levels totaling about 1,500 feet. Lone Mountain is a large granite stock which intrudes Cambrian limestones and shales. Both granite and sediments are cut by late diorite intrusives. The turquoise occurs as nuggets of solid, clear blue material in the harder shales and as spiderweb material in softer clays. The material, noted for its stability of color is unusually hard. This property is unusual for Nevada in having produced turquoise from such a depth.

The No. 8 mine (No. 12) in the Lynn mining district (T. 35 N., R. 50, 51 E.), Eureka County, was briefly mined for copper. In 1929 the property produced turquoise from an open pit. Production during the next 4 years amounted to about 5,000 pounds. Inter-mittent operation continued until about 1950. The country rock of the Lynn district is Tertiary rhyolite which has been cut by porphyritic intrusions. Turquoise is found as seams and nodules in the rhyolite. The seams, up to one-half inch thick, locally form unbroken sheets for as much as several feet. Nuggets are found within pockets enclosed in a brownish clay. The turquoise varies in color, quality, and pattern. Both solid-uniform and spiderweb types are found. Unusually large masses have been produced. One nodule, 10 ½ inches long with a girth of 16 inches, was recovered in 1950 and sold for \$1,600. In 1954 a turquoise nugget of gem quality, 33 inches by 18 ½ inches by 7 inches, weighing some 150 pounds, was found. Total production of turquoise from this location has been estimated as high as \$1,500,000.

The Battle Mountain mining district (No. 13) southwest of the town of Battle Mountain (T. 31 N., R. 43 E.) in Lander County, has produced copper, gold, lead, antimony, silver, and arsenic. An estimated nearly \$1 million worth of good quality turquoise has been mined from the early 1930's until 1941 as seam material in altered shale.

The Bullion mining district (No. 14) is on the east slope (T. 28 and 29 N., R. 46 and 47 E.) of the Shoshone Range in northeast Lander County. Fissure veins occur in Carboniferous quartzites, shales, and limestones; in granodiorite which intrudes the sediments; and in Tertiary andesite. Turquoise was discovered in the district in 1910, and between 1910 and 1950 many claims were worked with variable results. The turquoise, generally of good quality, is found in nodules, veinlets, and seams, as solid turquoise and as matrix turquoise. Some slabs of solid clear blue material an inch thick and a foot square were found as well as slabs of blue with black matrix and blue with golden spiderwebs. Little definite data are available concerning production although it is thought to have exceeded \$1 million.

#### FIRE OPAL

Opal is an amorphous substance of secondary origin, composed of silicon dioxide and water. It occurs as veinlets, seams, and nodules, in various rock types, and is quite commonly pseudomorphic after wood. It ranges in hardness from 5.5 to 6.5 (Mohs' scale). The luster is vitreous to resinous to pearly. The type sought as gem material exhibits a play of colors caused by differential refraction of light, probably from patches of included thin lamellae. Opal may lose some of its water after removal from the ground, causing it to craze or crack. The variation of water content (1 to 20 percent) at different localities is generally conceded to be the determining factor as to suitability for cut gems.

The Virgin Valley opal field (No. A), in the valley of Virgin Creek in (T. 45 N., R. 26 E.) Humboldt County, was discovered about 1908. The greatest activity took place before 1913. Important quantities of opal were mined from numerous shallow open pits. During this

period the two most important mines were discovered; the Bonanza (1908) and the Rainbow Ridge (1912). After 1920 there was no activity until 1949 at which time the Rainbow Ridge claim was purchased by a Mr. Hodson who later, in 1955, also purchased the Bonanza. Since purchasing these properties the Hodson's have continued to work them.

The Rainbow Ridge mine consists of an adit driven into the base of a hill and several short cross cuts with total workings of less than 1,000 feet. The Bonanza at the time of purchase was badly caved and is being reclaimed.

The opal deposits occur in Miocene ash and tuff beds, occupying a synclinal basin of older tuffs, ashes, and rhyolitic flows, which have been block faulted and tilted, and are capped along the valley rims by basalt. The opal is associated with petrified wood. The precious opal occurs chiefly as casts of portions of limbs and twigs, and as coatings and fillings in cracks in ordinary petrified wood and in the country rock (Lincoln, 1923, p. 104). In some specimens the play of colors is uniform over the whole stone or over large areas, changing, as the gem is turned, from green to red or from red to blue, and so on. Some of the gems show a rich ultramarine blue in one position with green or red in another. Many gems display various bright colors arranged in patches, and each patch changing color as the stone is turned (Sterrett, 1912, p. 1049).

The Virgin Valley opal is seldom used for cut gems because of its susceptibility to crazing or cracking, but the area is famous for the production of large specimen material. The Roebbling Opal in the U.S. National Museum is probably the most famous. This opal weighs 18.6 ounces, or 2,665 carats; it measures about 4 by 2½ by 1½ inches. Discovered in 1917, it has been variously valued from \$50,000 to \$250,000. In 1952 the Hodson's found an opal estimated to be 6½ pounds in weight measuring 9½ by 5½ by 4½ inches, valued at the time at \$50,000. About the same time a visitor is reported to have found a 6-pound fire opal.

The Firestone Opal mine (No. B) in T. 45 N., R. 40 E.(?) in the Santa Rosa Range is about 20 miles north of the town of Paradise Valley, in Humboldt County. Fire opal occurs as amygdules in vesicular basalt, and is reported to be amenable to cutting. The mine was opened about 1955.

Fire opal has been reported as occurring in several other places in the State but there are no other known important deposits.

#### OTHER GEMS

Nevada is richly endowed with other semiprecious gem materials sought by the hobbyists and weekend prospector. The silicates, representing the largest group of these materials, occur as jasper, agate, chalcedony, chrysocolla, etc., to name a few. There are also oxides such as hematite, common opal, cassiterite, and rutile, and the rare phosphate, faustite. Mineral species of groups such as the carbonates, sulfates, sulfides, and others are also common. Regrettably these semiprecious gem resources as yet have not been systematically evaluated.

### GYPSUM AND ANHYDRITE

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Gypsum, the hydrated calcium sulfate, and anhydrite, the anhydrous variety, are saline residues formed by the evaporation of sea or lake water of appropriate composition. They are also found as gangue minerals in metallic ore deposits of several types, but only the evaporite deposits are of commercial interest or are likely to be so for many centuries hence.

By far the greatest part of gypsum production goes into the construction industry, and the index of construction in the United States is generally an almost direct indication of the state of the gypsum industry. For these uses the gypsum is partially calcined to drive off roughly 75 percent of its moisture and the resulting material is used to make plaster, wallboard, lath, and innumerable other interior construction materials. Other uses for calcined gypsum are as fillers, in glass manufacture, in the brewing industry, for making pottery molds, in surgical and orthopedic casts, and many miscellaneous uses. Uncalcined gypsum is added to cement clinker to retard setting and is also used as a soil conditioner. Anhydrite is also used as a retarder for cement, but there are no other large uses for this mineral in the United States. In Europe both gypsum and anhydrite are used as raw materials in the manufacture of sulfuric acid, but there seems little likelihood of this being done in the United States.

The large gypsum deposits of the world are found as sedimentary rocks associated or interbedded with limestone, dolomite, shale, or clay. Most of these deposits are thought to be chemical precipitates formed from saturated marine waters. As a general rule in the sedimentary deposits gypsum predominates over anhydrite at or near the surface and this is thought to be due to the hydration of anhydrite, a presumably slow process. Many gypsum deposits grade into anhydrite at depth and many occurrences of practically solid gypsum have contained remnants of anhydrite. The only other type of deposit of commercial interest is gypsite, which is formed by precipitation of gypsum in sand and clay under surface conditions. Although this type of deposit can generally be mined more cheaply than rock gypsum, there are beneficiation problems which commonly render such operations economically unfeasible.

In 1962 approximately 10 million short tons of gypsum were produced in the United States and the products manufactured from this amount of ore had a value of almost \$400 million. The industry has increased slowly and steadily over the past decade, and the future outlook remains bright due to the necessity for its products in the construction industry. Gypsum reserves are plentiful; the U.S. Geological Survey estimates that known domestic gypsum resources would last 2,000 years at the present rate of production. In addition, many large and relatively pure gypsum deposits in the United States have not been worked due to excessive distances from a railroad and from major market areas.

Nevada in 1962 produced 817,000 short tons of gypsum from three mines which was valued by the producing companies at \$2,952,000. Similar to the United States as a whole, the gypsum industry of Nevada has increased slowly and steadily in recent years and is likely to continue to do so in the immediate future. Nevada has extensive gypsum resources, as shown on figure 43.

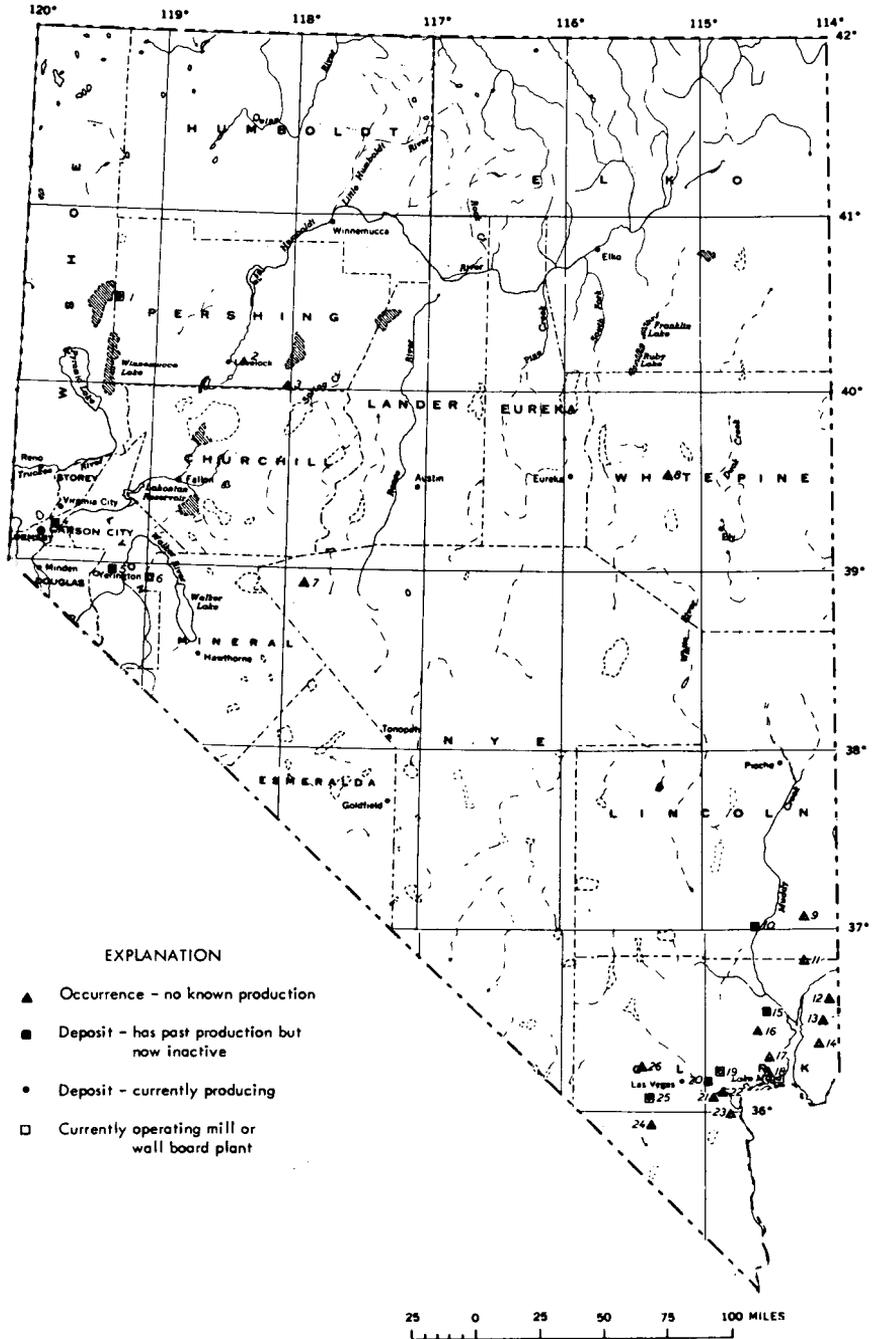


FIGURE 43.—Gypsum and anhydrite in Nevada (numbers refer to localities discussed in text).

Seven deposits are known in northwestern Nevada (Nos. 1-7, fig. 43) and, with the exception of the Empire and Lovelock deposits (Nos. 1 and 2), they are relatively small. Although absolute proof of geological age is lacking for many of the deposits, their overall appearance and geological settings are so similar that it seems certain that they are all either Triassic or Jurassic in age. Their areal extent is restricted by faulting and, in rare instances, folding. The Empire deposit (No. 1), Pershing County, is currently being mined by the U.S. Gypsum Co. which operates a wallboard plant at Empire, but this is the only currently active gypsum operation in northwestern Nevada. Three other deposits have been mined in the past (Nos. 4, 5, and 6) and the Lovelock deposit (No. 2), Pershing County, although never mined, shows great promise for the future if an economical method of eliminating lithologic impurities is developed.

No surface deposits of gypsum in northeastern Nevada are known to the writer, but there are several known evaporite occurrences in wells which have been drilled for petroleum (Lintz, 1957), and surface occurrences will undoubtedly be discovered as geological mapping increases. These beds of evaporite have been assigned to the Summit Springs Evaporite Member of the Pequop Formation of Steele (1960) (Permian). Where known at the surface this member generally forms a depression between ridges held up by carbonate strata. A large area in northeastern Nevada is underlain by these strata and probably contains gypsum occurrences (No. 8 therefore relates to an area of unknown size), but because of distance from rail and current markets, economic exploitation in the near future is not likely.

Southern Nevada contains abundant large deposits of gypsum and a good transportation network for the current and readily foreseeable future markets. The largest and most important deposits are shown on figure 43 (Nos. 9-26). The ages of the strata containing these deposits range from Permian through Pleistocene and deposits of commercial interest are found in every system of this interval excepting the Jurassic.

The Wells Cargo deposit (No. 9) in the Mormon Range, Lincoln County, is in Permian strata and has not been productive.

The Galt deposit (No. 10), Lincoln County, is in Triassic strata in the Meadow Valley Mountains and is said to have produced a small quantity of gypsum several decades ago, but is now inactive.

The Leavitt deposit (No. 11) is located in Clark and Lincoln Counties at the southeastern corner of the Mormon Range and contains gypsum in both Permian and Triassic strata. There is no known production from this property.

In Clark County the North Virgin Mountains (No. 12) and the South Virgin Mountains (No. 14) contain abundant gypsum beds. Most of them are in Permian strata, although there are minor Triassic and lower Tertiary occurrences. There has been no known production from these two large areas and because of their remoteness, exploitation of these deposits in the near future is unlikely.

The Wechech Basin deposit (No. 13) is in lower Tertiary strata in a low valley between the North and South Virgin Mountains. This deposit, unlike any of those previously described, shows evidence of secondary enrichment.

There are abundant gypsum deposits in Permian and Triassic strata of the Northern Muddy Mountains (No. 15). Several of these have produced in the past and most of them remain under the control of major companies. They are all fairly close to existing railroads and therefore have good economic potential, but because almost all are in overturned and steeply dipping strata the mining costs would be high compared to nearby active deposits which contain reserves adequate for a decade or more.

In the western end of the Valley of Fire (No. 16) gypsum occurs in Permian strata and, although the exposures are relatively small, the area might be of some interest because of the possibility of encountering strippable deposits at shallow depths beneath a wide pediment surface. No production is known from this area.

Near Bitter Spring in Echo Wash (No. 17) gypsum crops out in formations of early and late Tertiary age. These deposits of fairly pure gypsum although large have never been exploited due to their remoteness and inaccessibility. They constitute a distinct possibility for satisfying future needs of the gypsum industry of the Western United States.

In the general vicinity of Pinto Valley (No. 18) several large gypsum deposits occur in formations of Permian, Triassic, and late Tertiary age. They are widely scattered geographically and structurally deformed, but together form a huge potential resource. No production is known from any of these deposits.

The Gypsum Division of the Fibreboard Paper Products Corp. is currently mining an unusual gypsum deposit (No. 19) east of Gypsum Wash near the northeast corner of Frenchman-Sunrise Mountain. At this locality gently dipping Cretaceous red beds containing abundant gypsum have been pedimented and overlapped by the Muddy Creek Formation (Pliocene?). The Muddy Creek, which probably originally contained some gypsum, apparently has been secondarily enriched at the expense of the underlying Cretaceous beds. The Fibreboard Corp. is strip mining this rock, washing out the relatively minor clay fraction in a unique washing-upgrading plant, and shipping the resulting high grade to wallboard plants in South Gate and Newark, Calif. This plant has been in operation since 1959. The resources appear to be practically inexhaustible, for the deposit covers about 7 square miles and probably averages several tens of feet thick. Fibreboard intends to accurately delineate reserves with a drilling program in the immediate future.

Frenchman-Sunrise Mountain (No. 20) is a complexly faulted mountain block, which contains numerous large deposits of rock gypsum in formations of Permian, Triassic, Cretaceous, and Tertiary age. The strata dip steeply and mining costs would be relatively high, thereby reducing the advantages of proximity to a labor force and existing railroad transportation. The Pabco Products, Inc. (since incorporated into Fibreboard) mined several deposits in this area in the 1950's before moving their operations to their present site (No. 19).

Three relatively small Tertiary gypsum deposits lying south of Las Vegas Wash in the vicinity of the River Mountains show within a small area the wide differences in habit of these young occurrences. The White Rock deposit (No. 21) is assumed to be in the Horse Spring Formation (Eocene?) and the Dunton (No. 22) and the

Boulder (No. 23) deposits are in the Muddy Creek Formation (Pliocene?).

In the vicinity of Sloan (No. 24) there are numerous occurrences of rock gypsum in Permian formations; the dips are gentle but underground mining would have to be employed due to the presence of overlying thick formations. These outcrops extend from the Blue Diamond area to a couple of miles southeast of Goodsprings, from which point to the California border no further outcrops of gypsum-bearing formations are known. No production is recorded from this general area.

The Blue Diamond Co. (a division of the Flintkote Co.) is currently mining rock gypsum of high purity from the uppermost Permian strata near Blue Diamond Village (No. 25). This deposit has been continuously worked for over two decades. Thick ledges of rock gypsum occur in three stratigraphic members, but only the uppermost is being mined because of relative mining costs; the uppermost occurrence is being open pit mined, while the other two would have to be mined underground. A plaster and wallboard plant is served by an aerial tramway from the mine and a privately owned railroad spur connects the plant with the main line of the Union Pacific Railroad at Arden. Before the present deposit was mined by Blue Diamond, the U.S. Gypsum Co. operated underground mines along a low ridge about 4 miles to the east. Production here was from a geologically older formation than the one which Blue Diamond is currently mining.

The westernmost deposit of rock gypsum known in southern Nevada is the Longo deposit (No. 26) in Kyle Canyon about 25 miles west of Las Vegas. Based on reconnaissance study, the age of the gypsum is probably Permian. No production is known from the Longo deposit.

In summary—northwestern Nevada has several small scattered gypsum deposits and is relatively gypsum-poor, while southern Nevada has abundant large gypsum deposits and resources. Whether many of these southern Nevada deposits will ever be mined depends more upon relative mining costs and availability to cheap transportation and markets than upon the size and purity of the deposits.

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### KYANITE GROUP ALUMINOUS MINERALS

(By D. B. Tatlock, U.S. Geological Survey, Menlo Park, Calif.)

The high-alumina, nonclay minerals of the kyanite, or sillimanite, group provide a basic raw material for use in the production of mullite, a high-alumina refractory material that is exceptionally resistant to thermal shock and maintains its strength at high temperatures.

The kyanite group consists of andalusite, sillimanite, and kyanite. These have identical chemical compositions (63.2 percent alumina and 36.8 percent silica), but differ in their physical properties. Commonly included with the kyanite group are dumortierite (about 60 percent alumina and 30 percent silica, plus boron) and topaz (about 56 percent alumina and 32 percent silica, plus fluorine). All these minerals disassociate upon heating at temperatures ranging from about 1000° to 1650° C to form mullite and free silica.

Commonly occurring with minerals of the kyanite group, or at least in a similar metamorphic environment, are pyrophyllite (28.3 percent alumina, 66.7 percent silica, and 5 percent water), pinite (an

extremely fine-grained mixture of white mica and pyrophyllite), and corundum (pure alumina). The most common use for pyrophyllite, owing to its soft, flaky nature, is as a filler in paints, asphalt, rubber, and insecticides; pinitite might well be used for similar purposes. Corundum, because of its hardness, is used as an abrasive. All three of these minerals, however, are of use in the production of mullite and other high-temperature refractories.

Mullite (71.8 percent alumina and 28.2 percent silica) is stable to about 1,810° C., and hence can be used in a temperature range higher than that of less costly fire-clay refractories but somewhat lower than that of more costly pure alumina refractories. Actually, there is no sharp demarcation between classes of refractories; the alumina content of fire clays ranges from about 25 to 50 percent (and the pyrometric cone equivalent from 19 to 34) while in high-alumina refractories, including mullite, the alumina content ranges from 50 to almost 100 percent (and the pyrometric cone equivalent from 34 to at least 38). At the present time high-alumina refractories probably make up about 10 percent of the total refractories consumed in the United States; they are used wherever their higher service limits and greater resistance to slag erosion make them a more economic selection than fire clays. About 90 percent of high-alumina refractories are used as furnace linings in the metallurgical, glass, and cement industries.

Prior to 1924 mullite was produced only synthetically from finely ground mixtures of kaolin and alumina, either by calcining at high temperatures or by complete fusion of these materials in the electric furnace. About 1920 experimentation began in producing mullite directly from kyanite and its related minerals. Fine-grained concentrates yielded an inferior mullite, whereas lump material from massive deposits was shown to yield strong large aggregates of mullite crystals. This stimulated the development of massive deposits from which lump material could be mined. Among the first such domestic deposits were two small properties developed by the Champion Sillimanite Co.—andalusite in the White Mountains, Calif., and dumortierite in the Humboldt Range, Nev. Production began on these properties in 1924 and 1925 respectively and continued until 1945. During this time lump kyanite and sillimanite-corundum became increasingly available from India, Kenya, the Union of South Africa, Southwest Africa, and Korea. Imports reached a high of nearly 20,000 tons in 1951 but have since declined to about 5,000 tons per year. There is no production of lump kyanite or its related minerals in the United States at the present time. The only known reserve is about 5,000 tons of massive kyanite on Willis Mountain in central Virginia. Resources of disseminated kyanite group minerals, however, are very large, but all would require beneficiation.

In recent years there has been an increase in the production of mullite prepared by sintering or fusing high-alumina materials mixed in stoichiometric proportions. Among the most commonly used materials are Bayer-process alumina, domestic kyanite concentrates, low-iron siliceous bauxite, and high-alumina clays. The final product, termed "synthetic mullite," is at least equivalent to mullite produced directly from massive kyanite group minerals. Total mullite production in the United States probably exceeds 30,000 tons per year.

Of the nonclay high-alumina minerals, only pyrophyllite and fine-grained kyanite flotation concentrates from disseminated deposits

are being produced in the United States at the present time—kyanite and pyrophyllite from the Piedmont belt extending from Virginia to Alabama, and pyrophyllite from California.

In Nevada, nonclay deposits of sufficiently high-alumina content to be of potential economic value are known in Douglas, Mineral, and Pershing Counties as shown on figure 44. All would require selective mining techniques and/or beneficiation to yield concentrates for use in the production of synthetic mullite.

In Douglas County on the Blue Metal Group of claims (No. 7, fig. 44) about 20 miles northwest of Yerington in sec. 14, T. 13 N., R. 23 E., intimately associated andalusite and corundum occur as small fine-grained aggregates sporadically distributed throughout north-trending shear zones in siliceous altered volcanic rock. Exploration by the U.S. Bureau of Mines in 1945 and 1947 indicates the deposit is small. Beneficiation tests suggest that abrasive quality corundum is not recoverable but that the andalusite-corundum aggregates probably could be concentrated for use in high-alumina refractories.

In Mineral County, on the Green Talc and Bismark Groups of claims (No. 8) about 11 miles northeast of Hawthorne, exploration and development work carried on from 1945 to 1953 indicate significant resources of aluminum silicates consisting chiefly of andalusite, corundum, diasporite, halloysite, and pyrophyllite. The ore minerals are all fine grained, and occur in blebs and lenses distributed sporadically along recrystallized shear zones in altered volcanic rocks of probable Triassic age. The only recorded production from the Green Talc and Bismark claims was in 1949 when 3,000 tons of ore was shipped from an open cut. Several hundred thousand tons of material containing more than 20 percent  $Al_2O_3$  were outlined by drilling done during the 1950's. The material would require beneficiation for use in refractories.

In Pershing County, nonclay high-alumina minerals have been mined from two sources, both in the Humboldt Range. Both deposits resulted from the hydrothermal alteration of rhyolitic volcanic rocks of Permian age; both are rather unique occurrences. The dumortierite in Humboldt Queen Canyon (No. 9) on the west flank of the Humboldt Range, about 6 miles east of Oreana, is the only known commercial deposit of dumortierite in the world. More than 5,000 tons was produced between 1925 and 1945 by the Champion Sillimanite Co. All the ore was shipped to Detroit for use in the manufacture of spark plug insulators. Except for a small production in 1949, the mine has been idle since 1945. The dumortierite occurs as irregular lenses along two north-trending zones in a quartz-sericite-andalusite host rock. It is easily distinguished from other minerals owing to its pink-to-lavender color and its high specific gravity. Veinlets of dumortierite are common, but no attempt has been made to mine these owing to excessive contamination by quartz and mica.

Dumortierite, together with andalusite, occurs also at Lincoln Hill (No. 9) on the north side of Rochester Canyon, about two and a half miles south of the Humboldt Queen locality. Here the dumortierite is chiefly in veinlets up to 6 inches thick closely associated with brown tourmaline in a quartz-andalusite-sericite host rock. Gray andalusite is probably more abundant on Lincoln Hill than is dumortierite. A high alumina concentrate consisting of both andalusite and dumortierite could probably be obtained by beneficiation.

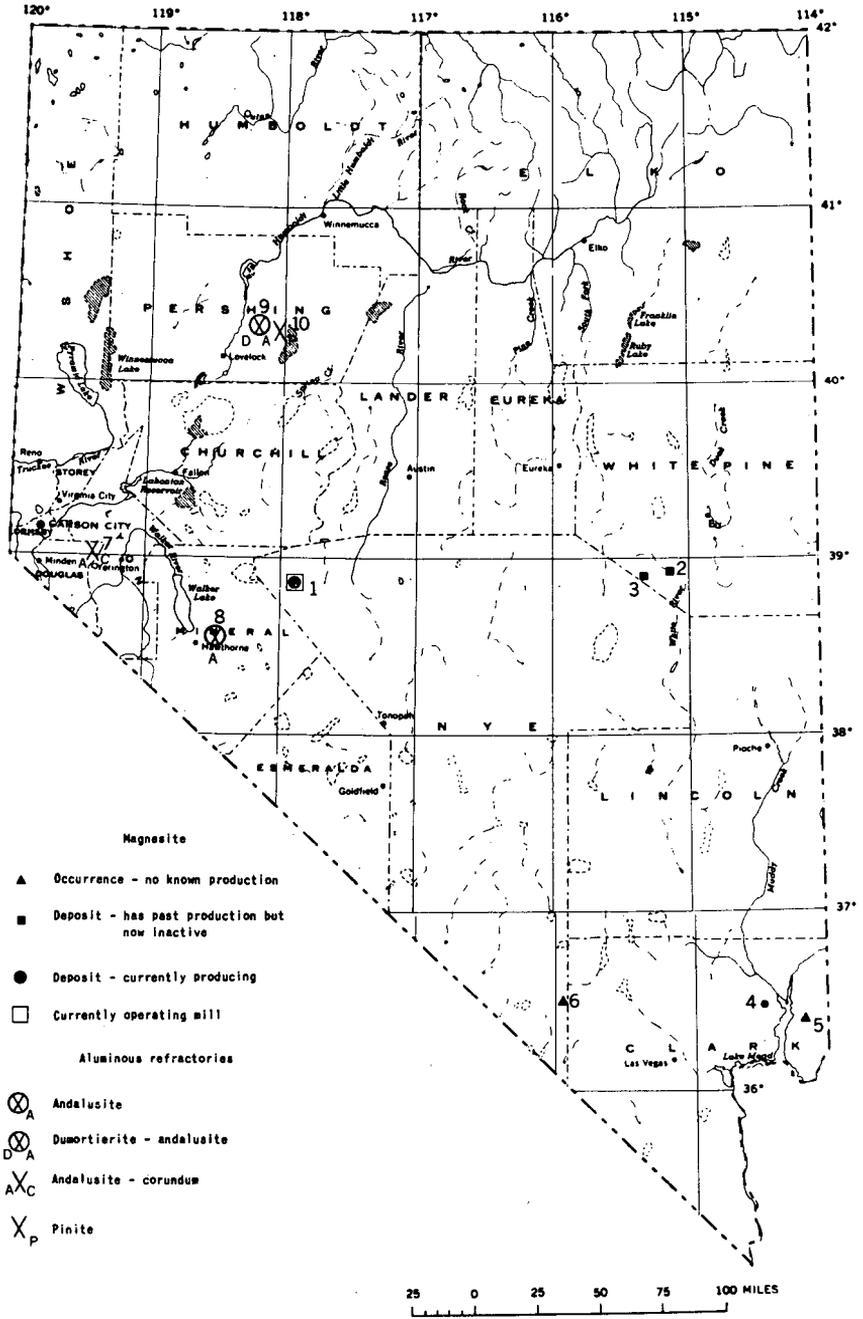


FIGURE 44.—Magnesite and aluminous refractory minerals in Nevada. (Numbers refer to deposits or districts discussed in text.)

On the east flank of the Humboldt Range (No. 10,), on the south side of South American Canyon, a "considerable" quantity of pinite was mined from 1939 to 1948 along a north-trending zone about 450 feet long and 40 feet wide in a quartz-sericite host rock. The pinite, an extremely fine-grained variable mixture of muscovite and pyrophyllite, averages about 36 percent  $\text{Al}_2\text{O}_3$ , 50 percent  $\text{SiO}_2$ , and 7.5 percent  $\text{K}_2\text{O}$ . It is massive, light gray in color, relatively soft, and essentially free of quartz and iron. It inverts readily to mullite (Kerr, 1940; and Page, Raine, and Sullivan, 1940). The fired product is snow white in color, extremely hard and resistant to abrasion and to molten enamel slags, and exhibits relatively low and uniform reversible thermal expansion.

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### LIMESTONE <sup>1</sup>

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Limestone and dolomite are the most widely used of all rocks. Fortunately they are abundant over the earth's surface.

Limestone uses are varied but the two main use categories are: (1) cement, and (2) lime and calcium. The main use in the cement category is as portland cement, which, after the addition of water, binds mineral aggregate into concrete. The use of reinforcing steel in concrete for added strength and the use of lightweight aggregate in concrete have greatly benefited the portland cement industry. The uses of lime can be grouped into three categories: chemical and industrial, construction, and agriculture. By far the greatest number of uses are in the chemical and industrial field where lime is used in steel manufacture, in ore concentration, in water treatment, and in the refining of base metals, petroleum, and sugar. It also is used in the manufacture of glass, paper, calcium carbide, petrochemicals, insecticides, and many other products. In the construction field lime is used in masonry mortars, plasters, cement, and as a soil stabilizer for many different types of construction projects. In agriculture lime is used for soil neutralizing and conditioning. The principal use of calcium is as a reducing agent, for which its major application is the reduction of various oxides of metal to the metallic state; but it also is used as an alloying agent.

Limestone and dolomite deposited in large marine basins are the most commonly used raw material. These rocks locally are extremely pure, as much as several tens of feet thick, and may cover many hundreds of square miles. Argillaceous limestone, or "cement rock," commonly is used in the manufacture of cement but is unsuitable for the production of lime and calcium because of noncarbonate impurities. Other sources of raw material include oyster shells and marl.

More than 450 million short tons of limestone and dolomite are produced annually in the United States. Approximately 332 million barrels of portland cement (376 pounds to the barrel) were produced and shipped in the United States in 1962 for a gross value of about \$1,090 million. The value of lime sold or used in the United States in 1962 was approximately \$242 million. In addition to this, lime-

<sup>1</sup> Including lime and cement.

stone and dolomite were produced in the United States in 1962 at the rate of about \$36 million in dimension stone and at the rate of almost \$650 million as crushed and broken stone; both of these categories use raw carbonate rock whereas that used in cement and for lime is calcined. The major portion of the value of the crushed and broken stone came from its use in concrete and as roadstone.

The United States has large reserves of limestone and dolomite and should remain self-sufficient for an indefinite period. This is not always true locally, where, due to shortages of suitable raw materials near large population centers, cement and lime must be transported considerable distances. Practically no substitutes exist for the major uses of cement and lime; so with the steady population increase that the United States is undergoing the future of these industries should remain bright and prosperous.

Until late 1963, Nevada's limestone and dolomite industry was restricted to the southernmost portion of the State. Production figures for these commodities are confidential. A safe estimate can be made, however, that in recent years the value of limestone and dolomite produced in Nevada is approximately equal to that of gypsum or of diatomite.

Much more limestone and dolomite of high purity exists in the eastern half of Nevada than in the western half, where abundant volcanic material is admixed. Limestone of sufficient purity for cement manufacture does occur in western Nevada, however, although such deposits will most likely not be as extensive or as close to population centers as those in eastern and southern Nevada.

The high purity limestone of Marble Bluff north of Nixon (No. 1, fig. 45), Washoe County, is probably the best known deposit in western Nevada. This limestone is thought to be Triassic. It is probable that almost all of the high purity limestone in western Nevada is either Triassic or Jurassic in age.

In late 1963 the Nevada Cement Co. began to erect a \$15 million cement plant on the west edge of Fernley (No. 2) with a planned capacity of 3,000 barrels per day. This is the first cement plant in Nevada; heretofore imports from northern California and to a minor extent from Utah satisfied the needs of northern and western Nevada. The cement needs of southern Nevada will continue to be served by various producers in southern California.

Southern Nevada has abundant high purity limestone and dolomite rock which is distributed in a wide belt parallel to the Union Pacific Railroad tracks for many tens of miles. Limestone operations are restricted to the uppermost Devonian lithologic unit, the Crystal Pass Limestone Member of the Sultan Limestone, an extremely pure rock. In regions where rocks have undergone alteration the Crystal Pass generally is much less altered compared to other carbonate rocks. The dolomite mined in southern Nevada has come from Mississippian formations.

The U.S. Lime Products Division of the Flintkote Co. is mining limestone from the Crystal Pass Limestone Member near Apex siding on the Union Pacific Railroad about 20 miles northeast of Las Vegas (No. 3), Clark County. Three large quarries have been opened a distance of about 1 mile in a north-south direction, about one-half mile west of U.S. Highways 91 and 93. Some of the limestone is converted to quicklime in a large rotary kiln and shipped by rail,

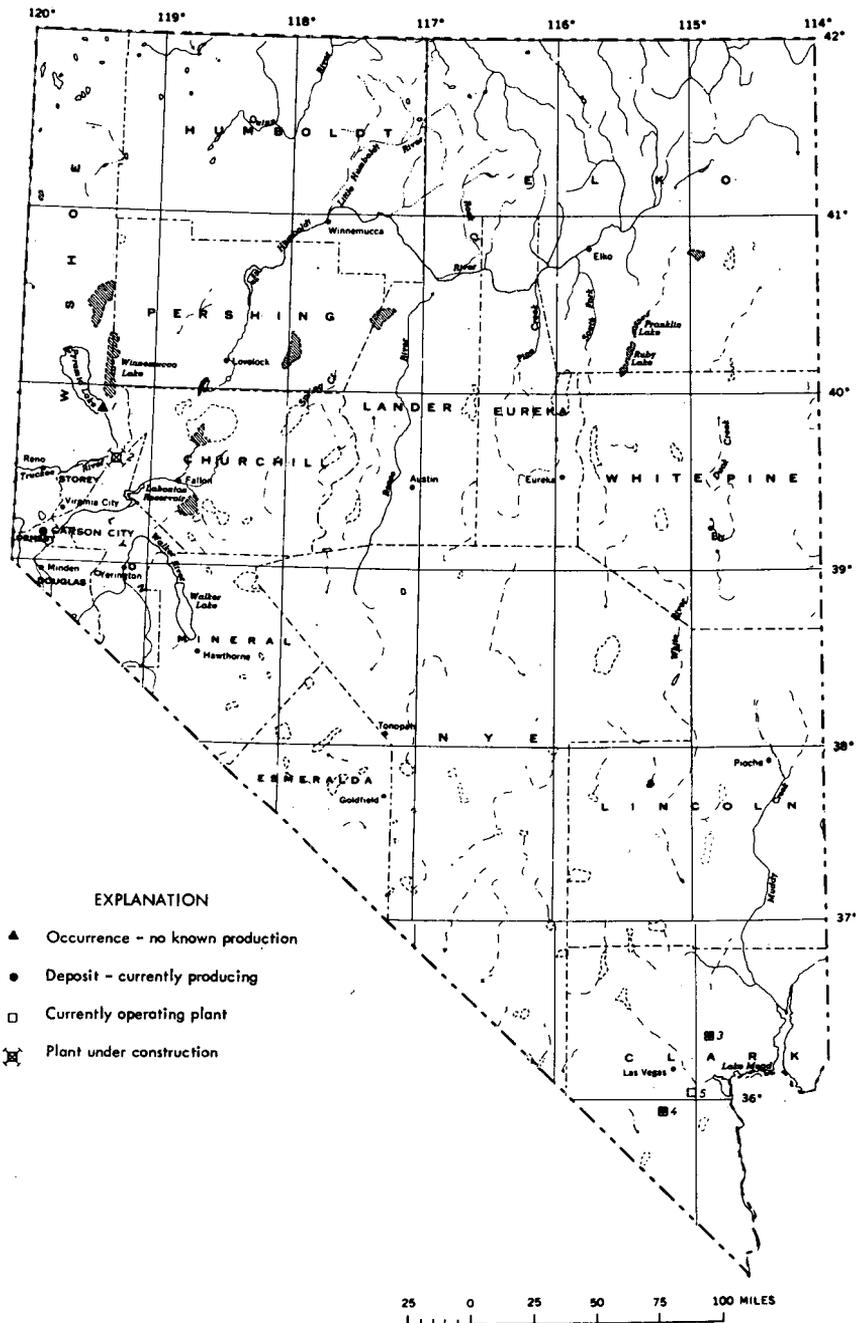


FIGURE 45.—Limestone and dolomite in Nevada (numbers refer to deposits discussed in text).

mostly to southern California, or to the Henderson plant (No. 5) for further processing. Most of the remainder is carefully sized and shipped as crude limestone for use in the sugar refining industry.

The same company operates quarries in dolomite and dolomitic limestone at Sloan siding on the Union Pacific Railroad about 20 miles south of Las Vegas (No. 4), Clark County. The geology of these deposits has been described in detail by Deiss (1952) who considers the dolomite to have been formed by the replacement of limestones and magnesian limestones by ascending solutions rich in magnesia. Investigations were made during World War II to determine if this rock could serve as plant feed for the large magnesium plant then operating in Henderson. The Sloan rock is crushed and sized at the site and shipped either direct to customers or to the Henderson plant (No. 5) for further processing. Until 1963 some of the calcining was performed at Sloan, but the kiln has been dismantled and transferred to another plant.

Calcining, pulverizing, and pressure-hydrating of the high calcium quicklime from Apex and the dolomitic limestone from Sloan is performed at a large modern plant which the U.S. Lime Products Division of the Flintkote Co. operates at Henderson (No. 5). The facilities include four rotary kilns, large bulk lime storage capacity, and a pressure hydrator. A branch line of the Union Pacific Railroad connects the plant with the main line.

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### MAGNESITE

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

The magnesium compounds produced from magnesite, brucite, olivine, dolomite ores, brines, and sea water are utilized mainly as basic refractories; materials which can withstand the high temperature and chemical attack encountered in steel refining. Of these, only magnesite and brucite have been mined in Nevada, and brucite is now relatively unimportant. The chemical composition of magnesite is  $MgCO_3$  and that of brucite is  $Mg(OH)_2$ . Almost all of the magnesite mined in Nevada is dead-burned in rotary kilns to form magnesia ( $MgO$ ) in various grades from which innumerable blends may be made.

Magnesite deposits of the world may be grouped into three main categories: (1) Replacement bodies in carbonate rock, generally dolomite; (2) fissure fillings resulting from alteration in ultrabasic rocks, particularly serpentine; and (3) sedimentary deposits. The first type is generally crystalline rock, and it is commonly difficult to distinguish this type of magnesite from the unaltered carbonate starting material. The other two types are commonly cryptocrystalline and although they may be difficult to recognize in the field with certainty, they have a characteristic textural denseness and are commonly extremely bright in reflectance properties. Burned magnesite is used as a standard in many laboratory reflectance tests.

In 1962 about 663,000 short tons of magnesia were sold or produced in the United States for a total value of approximately \$40 million. The United States is self-sufficient in magnesium compounds. Although bedrock occurrences of economic interest are restricted to Washington and Nevada, the sea offers an inexhaustible supply of raw material. At the present time approximately two-thirds of the

magnesium compounds produced in the United States are derived from sea water and brines. As long as present methods of steel refining are used the volume of magnesium compounds produced should continue to grow. The United States produces approximately 10 percent of the world's magnesite. Commodity specialists do not visualize a time, even in the distant future, when this country will have to depend upon imports of magnesite and other ores of the magnesium compounds.

Nevada produced only minor quantities of magnesium compounds prior to World War II, but in the early stages of the war the mining operations at Gabbs (No. 1, fig. 44), Nye County, were greatly expanded in order to produce large amounts of magnesia. This was then shipped to Henderson, where a processing plant to produce metallic magnesium from MgO was constructed, utilizing hydroelectric power from Hoover Dam. Nevada has been an important producer of magnesium compounds since then and should be for some time. Specific figures on magnesia produced in Nevada are not published; however, magnesite is definitely one of Nevada's most important industrial mineral industries in terms of values produced and people employed.

The largest magnesite deposit in Nevada is near Gabbs (No. 1) and occupies several square miles near the base of the western flank of the Paradise Range. The magnesite and brucite deposits are in the uppermost member, a dolomite of the Upper Triassic Luning Formation, and were formed by alteration of the regionally metamorphosed dolomite. Field relations show that the brucite was formed later than the magnesite, but the two are undoubtedly closely related. Vitaliano and Callaghan (1956) consider all of the magnesite-replaced carbonate rock in the Gabbs deposit to be in the overriding plate of a thrust fault and believe that almost all of the complex folding and faulting within the area of the deposit took place prior to the mineralization and the igneous invasion. The magnesite deposits of commercial grade are to the north and northwest of a granodiorite stock within an area of about a square mile. The brucite is distributed along the contact of the north side of the stock with adjacent magnesite and dolomite. Nearly all of the brucite recoverable by open pit methods has already been mined. The operations are hindered by the presence of impurities in the magnesite; these include iron, alumina, lime, silica, and the numerous types of igneous rocks which have intruded the magnesite, these rocks being the most troublesome impurity of all. There are even more impurities in the brucite than in the magnesite, due to its higher chemical reactivity. The crystalline magnesite and the recrystallized dolomite were formed, according to Vitaliano and Callaghan (1956), by replacement of regionally metamorphosed dolomite of the Luning Formation by upward-moving solutions. The process probably took place at moderate to great depth, and the solutions are believed to have been genetically related to an earlier intrusion of coarse-grained granite (i.e., earlier than the granodiorite stock of the mine area) which does not crop out in the mineralized area. The grade of the ore varies markedly over small distances both in the plan view and vertically. For this reason relatively low benches are carried in the open pitting and all drill cuttings are carefully collected and analyzed prior to blasting. The detailed grade information thus obtained guides the segregation of the ore into appropriate stockpiles.

Reserves, as computed by Vitaliano and Callaghan (1956) from almost 750 drill holes in an area of roughly a square mile, are tabulated below:

	Less than 5 percent CaO (as impurity)	Less than 5 to 26 per- cent CaO (as impurity)	More than 26 percent CaO (as impurity)
Measured ore.....	Tons 27,000,000	Tons 18,000,000	Tons 7,000,000
Indicated ore.....	2,000,000	100,000	-----

Other magnesite deposits of Nevada are very dissimilar to the Gabbs deposits in origin, mode of occurrence, and general geology. They are concentrated, with one minor exception, into two general areas: the Currant Creek district (Nos. 2, 3), White Pine County, southwest of Ely, and an area in the eastern part of Clark County (Nos. 4, 5). The deposits of these two areas are as different from each other as both of them are from the Gabbs deposit.

In the Currant Creek district the host rock is the bedded calcareous Currant Tuff, of Tertiary age, which lies between flow rocks (Vitaliano, 1951). The thickness of the tuff is variable but averages 300 feet and the unaltered variety may contain as much as 80 percent carbonate. The magnesite occurs in an unusual manner as nodules, as veins or lenses, and as disseminated grains in masses of altered tuff. Both the magnesite and its associated materials are low in alumina and iron content. The alteration of the calcareous tuff to magnesite is thought to have been accomplished by ascending hot spring waters, rich in magnesia, which formed hydrous magnesium silicate, dolomite, and nodular magnesite. Solutions at a later date deposited various forms of silica which cut or replaced these earlier minerals. The reserves of recoverable magnesite total about 8,500 tons; about 1,700 tons have already been produced in the form of experimental shipments, all from the Windous and Ala-Mar deposits (Vitaliano, 1951). The magnesite deposits of the Currant Creek district can be divided into an eastern and a western group; the eastern group (No. 2) contains the Windous, Rigsby, and Chester deposits and the western group (No. 3) contains the Ala-Mar, Rex-Pine Lode, Snowball, and White Knolls deposits. No deposits in the district are being mined currently. Magnesite in the Currant Creek district is especially valuable because of its high magnesium content and the low content of iron and alumina, but the grade of the magnesite is extremely variable and there are many mining problems.

A deposit of sedimentary magnesite is present in the basal portion of the Horse Spring Formation (Eocene?) near Overton (No. 4), Clark County. In two washes, slightly over a mile apart, careful sampling by Rubey and Callaghan (1934) has shown that there is a sequence of carbonate beds which contains 30 percent or more MgO that is 48 feet thick in the southern wash and 67 feet thick in the northern wash. There are practically no outcrops in between the washes, but careful analytical work indicates that the composition of any one bed remains almost constant over large lateral and down dip distances. The magnesite is cryptocrystalline, nearly pure white, and strikingly claylike in its physical properties. The magnesite beds are extremely thin bedded to laminated and are found only in one

sequence of carbonate beds which ranges from 155 to 325 feet thick. Field evidence, particularly the excellent preservation of bedding and other delicate structural and textural features, indicates that replacement and recrystallization have not been a major factor since the time of burial, and therefore this deposit is considered to be of the sedimentary type. Rubey and Callaghan (1936) give reserve data in a detailed account of the Overton magnesite deposit. Several carloads of this material have been mined annually in recent years by the Huntley Industrial Minerals Co. (now Standard Slag Co.) and shipped to their mill near Bishop, Calif., for custom grinding and blending in relatively small quantities with other industrial minerals to form high-value pigment and filler products.

The Bauer deposit (No. 5), Clark County, is also in the basal portion of the Horse Spring Formation and is so similar to the Overton deposit in geologic setting and general appearance that it gives the impression the two may be stratigraphic equivalents. The stratigraphic interval containing the magnesite strata ranges in thickness from 35 to 80 feet thick, dips gently easterly, and crops out for a distance of 3,500 feet along strike. Rubey and Callaghan (1936) investigated this deposit but did not sample in detail. They indicate that the material will also contain 30 percent or more MgO and if the total thickness of the magnesite averages 20 feet, they estimate reserves of 500,000 tons above the entry level of the two tunnels.

Davis (1957) notes a small deposit in southeasternmost Nye County, the Payne deposit (No. 6). No description is given, however, and there is no other known reference to this deposit in the literature.

Several other magnesite occurrences have been reported in Nevada, but to the writer's knowledge none of them has been verified by field inspection.

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### PEGMATITE MINERALS

(By F. G. Lesure, U.S. Geological Survey, Washington, D.C.)

Feldspar, beryl, and mica are the principal pegmatite minerals that may become economically important in Nevada.<sup>1</sup> Feldspar has important uses in the glass and ceramic industries, beryl is the principal source of beryllium, a space age metal, and mica is used extensively in the electrical industry. Only small amounts of these minerals have been produced in Nevada owing to the smallness of deposits, distance to markets, generally low unit value of the ore, and lack of detailed exploration.

Pegmatite is a coarse-grained igneous rock generally found as lenticular or tabular bodies in metamorphic rocks or associated with large igneous intrusions. Although pegmatites can range in composition from granite to gabbro, the term is more commonly applied to the so-called granitic pegmatites—those that range from granite to quartz-diorite. Grain sizes range in length from an inch or less to many feet, and a large variation in grain size within a single pegmatite body is common. Most pegmatite has a simple mineralogic composition consisting of feldspar, quartz, and mica. Minor accessory minerals, however, are present in a large number of pegmatites. The most com-

<sup>1</sup> The tungsten-bearing pegmatites of the Humboldt Range, Pershing County, are discussed in the chapter on Tungsten.

mon accessory minerals are garnet, tourmaline, apatite, and beryl; many other less common pegmatite minerals are rich in cesium, lithium, molybdenum, niobium, rubidium, scandium, tantalum, thorium, tin, tungsten, uranium, yttrium, zirconium, and the rare earths.

Recent studies have increased the general knowledge of the occurrence, origin, and economic importance of pegmatite deposits (Cameron and others, 1949; Jahns, 1955), and studies made during World War II have helped improve techniques of prospecting and exploration (Jahns and others, 1952; Page and others, 1953; Cameron and others, 1954; Norton and Page, 1956). This recent work has shown the importance of determining the shape, structure, and size of a pegmatite body. Many pegmatites are homogeneous or unzoned and the minerals are more or less evenly distributed throughout. Such deposits are mined by large-scale operations where a milling process has been developed. Many others are distinctly zoned, however, and the minerals are segregated into units. These units or zones can be selectively mined to recover certain minerals by hand sorting.

### FELDSPAR

Feldspar is the general name for a group of aluminum silicate minerals that contain varying amounts of potassium, sodium, or calcium. The feldspars are the most important group of rock-forming minerals and constitute nearly 60 percent of most igneous rocks. The principal potassium feldspars are orthoclase and microcline which have the same chemical composition ( $\text{KAlSi}_3\text{O}_8$ ) but different crystal form. The sodium-calcium feldspars, called plagioclase, form a complete series of minerals that range in all proportions from pure  $\text{NaAlSi}_3\text{O}_8$  (albite) to pure  $\text{CaAl}_2\text{Si}_2\text{O}_8$  (anorthite). Natural orthoclase and microcline generally contain 10–25 percent  $\text{NaAlSi}_3\text{O}_8$  and plagioclase generally contains 5–15 percent  $\text{KAlSi}_3\text{O}_8$ . Intergrowths of orthoclase or microcline with albite are called perthite, a common pegmatite mineral.

The potassium feldspars and the more soda-rich forms of plagioclase are the types generally mined. Until recently much of the feldspar produced was perthite which is commonly concentrated as very large crystals in certain zones in pegmatite bodies. Today finer grained pegmatite is mined in bulk and a mixture of potassium and sodium feldspar is recovered by milling and flotation. In 1961 about 62 percent of the feldspar used was from flotation concentrates, 23 percent was from hand sorting, and 15 percent was from feldspar-rich sand (de Polo and Tucker, 1962, p. 543). In 1957 these figures were 42, 46, and 12 percent, respectively.

The average price of crude feldspar was \$10.31 per long ton in 1961 and \$9.51 in 1960 (de Polo and Tucker, 1962, p. 544). The average price of ground feldspar was \$12.36 per short ton in 1961 and \$13.40 in 1960. In September 1963, quotations for feldspar according to the Engineering and Mining Journal Metal and Mineral Markets were as follows: North Carolina, bulk, f.o.b., 200 mesh, \$17 to \$21 a short ton; 40 mesh, glass, \$13.50 a short ton. From 1956 to 1960 about 55 percent of the feldspar sold in the United States was used in glass, 32 percent in pottery, 5 percent in enamel, and 8 percent in other ceramic

uses, scouring soaps, and abrasives. The United States is self-sufficient in feldspar production capacity. The major problems for a producer are the lack of a constant market, the high cost of production and low selling price. There is an increasing shortage of high-grade potassium feldspar but there is also an increase in use of lower grade and finer grained materials through milling and flotation. The largest production comes from North Carolina and California. Other important producing States include Colorado, South Dakota, New Hampshire, Maine, Virginia, Georgia, and Connecticut in order of recent production. Production of feldspar in Nevada has been reported for Clark and Washoe Counties.

### BERYL

Pegmatitic beryl is the principal source of beryllium in the world today but recently discovered low-grade deposits of nonpegmatitic beryllium minerals will probably become the most important beryllium resources in the future. Beryl is a beryllium aluminum silicate ( $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ ) commonly found as simple prismatic hexagonal crystals that range in diameter from less than an inch to a foot or more. The clear green crystals are better known as emerald and the blue as aquamarine. The beryllium content of beryl can be as great as 14 percent BeO but is generally 12 percent or less because some of the beryllium is replaced by other elements. Beryl from six areas in Nevada contains 11.9 to 13.5 percent BeO (Olson and Hinrichs, 1960, p. 142). Beryl occurs disseminated throughout an unzoned pegmatite or, more generally, concentrated in certain beryl-rich zones in zoned pegmatites. Beryl is recovered by hand cobbing the material mined from beryl-rich zones. Crystals less than 1 inch in diameter cannot generally be recovered economically by hand sorting. Recovery of fine-grained beryl by milling and flotation methods has been successful in the laboratory but not on a commercial basis (Eilertsen, 1960, p. 98).

Uses of beryllium metal are described in the chapter on beryllium, p. 70. Beryl is used in the ceramic industry as a minor constituent in high-voltage electrical porcelain and glass. The price of beryl ore, based on BeO content, is \$29 to \$32 per short ton unit for ore containing 10 to 12 percent BeO. Thus a ton of relatively pure beryl is worth \$290 to \$320.

The United States depends largely on foreign imports of beryl as a source of beryllium. Domestic production amounts to less than 6 percent of consumption. The principal domestic production in 1962 was 218 tons of hand-cobbed beryl from South Dakota, New Mexico, Colorado, New Hampshire, Arizona, Connecticut, Maine, and Wyoming. Low-grade beryllium ores from Colorado supplied nearly as much total BeO as the hand-cobbed beryl did. Pegmatitic beryl is reported from Clark, Elko, Esmeralda, Mineral, and Pershing Counties in Nevada. All the occurrences are too fine-grained for economic recovery by hand sorting and the known deposits are not large enough for milling. Although small amounts of beryl may have been recovered for mineral specimens or metallurgical tests, there is no recorded beryl production in Nevada.

## MICA

The principal mica minerals include muscovite (white mica), biotite (black mica), and phlogopite (amber mica). These are complex potassium aluminum silicates that contain hydroxyl or fluorine and varying amounts of magnesium, iron, sodium, or lithium, and rarely manganese, chromium, barium, and titanium. All the minerals of the group have a perfect basal cleavage and form crystals that can be split into thin sheets having various degrees of transparency, toughness, flexibility, and elasticity. The commercial micas are muscovite and phlogopite, but only muscovite is mined in the United States.

Commercial muscovite is divided into two distinct types, sheet mica and scrap mica. The sheet mica must be relatively flat, free from most defects and be large enough so that it can be cut into specified shapes. Sheet muscovite is an important insulating material in the electronic and electrical industries. Built-up mica made from very thin sheets and reconstituted mica made from scrap can be substituted for larger sheet mica in applications that do not require transparency, extreme thinness, flexibility, very high dielectric strength, low-power factor, or ability to withstand high temperatures (Skow, 1962, p. 11).

Sheet-quality muscovite is obtained from the large crystals scattered throughout unzoned pegmatites or concentrated in certain units of zoned pegmatites. The value of sheet mica depends on the size, structure, and purity of the natural crystals. The manner in which the crystals are obtained by mining and the care and skill of preparation are also important factors affecting the value. The erratic nature of most mica concentrations, the great range in quality of material, the expense of mining and the large amount of hand labor needed for preparation limit sheet mica mining to periods of very high prices or to countries with low-cost labor. Since the end of the Government purchasing program in June 1962, little sheet mica has been mined in the United States. Most of the recent production of sheet mica has been from North Carolina, New Hampshire, and South Dakota. There has been a minor amount of sheet mica produced in Nevada from Clark and Elko Counties.

Scrap mica is material that does not meet specifications for sheet mica because of size, color, or quality. Many pegmatite deposits contain only scrap mica and a large amount of scrap is produced during the mining, trimming, and fabricating of sheet mica. Scrap mica is also recovered from mica schists and as a byproduct from the flotation of feldspar and clay. The principal use of scrap mica is in the form of ground mica used in the roofing, wallpaper, rubber, paint, and other industries. Most of the mica mined in the United States is scrap mica. Some scrap mica has been produced from mica schist near Gold Butte, Clark County.

Prices of mica in September 1963 in North Carolina quoted by Engineering and Mining Journal Metals and Markets were as follows: Clear sheet, 1½ by 8 inches, \$0.07 to \$8 per pound; clear punch (material that will yield sheets less than 1½ by 2 inches) \$0.07 to \$0.12 per pound; wet ground, short ton, \$160 to \$180; dry ground, short ton, \$35 to \$75. Scrap mica is valued at \$20 to \$30 per short ton. Most of the buyers of mica are in the Eastern United States.

## PEGMATITE IN NEVADA

The wide occurrence of pegmatite has been mentioned in the geologic literature of Nevada but little has been published on the economic value of Nevada pegmatites (Olson, 1960, p. 137). Nine counties (fig. 46) in the State have areas in which pegmatite deposits are known but prospecting has been limited to five counties and recorded production to three counties. The earliest pegmatite mining in the State was done in Clark County for mica in 1893-94. Feldspar was produced in 1926 in Clark County and in 1931 in Washoe County. A minor amount of sheet mica was mined in Elko County during World War II.

*Clark County.*—Pegmatite dikes and sills cut Precambrian rocks in the North Virgin Mountains 9 miles southeast of Bunkerville, in the South Virgin Mountains east and south of Gold Butte, in the Eldorado Mountains, and in the southern McCullough Range. The larger areas of Precambrian rocks are shown on the recent geologic map of Clark County by Bowyer and others (1958).

In the North Virgin Mountains (No. 26) numerous concordant pegmatite bodies in mica schist range from small pods 25 feet long to lenses 400 feet long and one tabular mass 20 to 40 feet thick and 6,000 feet long. The pegmatite is generally fine- to medium-grained and consists of perthite, plagioclase, quartz, and muscovite. Beryl, chrysoberyl, tourmaline, garnet, and biotite are the principal accessory minerals. Most of the bodies are unzoned. The beryl content averages less than 0.1 percent. The mica is green and of scrap quality (W. E. Hall and W. P. Irwin, written communication, 1953). Some prospecting has been done but no production is recorded.

In the South Virgin Mountains (No. 27) Precambrian pegmatite dikes and lenses cut gneiss and granite near Gold Butte. Most of the pegmatite bodies consist of feldspar, quartz, and mica, but some also contain small amounts of garnet, tourmaline, columbite, beryl, samarskite, allanite, monazite, fluorite, and magnetite (Olson and Hinrichs, 1960, p. 188). Several ages of pegmatite may be present (Volborth, 1962, p. 819) and some prospecting has been done on at least 3 deposits. Production in 1893-94 from one mine was reported to be 1,800 pounds of sheet mica (Parker, 1894, pp. 753).

Two prospects on the west slope of the Eldorado Mountains (No. 28) about 9 miles by road northeast of Searchlight have exposed small zoned pegmatite bodies that consist of a massive quartz core, a coarse-grained perthite rich intermediate zone and a wall zone of medium-grained feldspar, quartz, and scrap muscovite. Beryl is reported and biotite and garnet are present as accessory minerals. There is no recorded production (Olson and Hinrichs, 1960, pp. 186-187).

Pegmatite bodies are present in the southern McCullough Range (No. 29) and one large body about a mile N. 5° W. of Crescent Peak (No. 30) has been mined for feldspar (Olson and Hinrichs, 1960, p. 186). The pegmatite is composed of perthite, plagioclase, quartz, muscovite, garnet, fluorite, and beryl. About 1,000 tons of feldspar have been produced since the mine was opened in 1926. Some beryl and scrap mica might be recovered if the deposit were mined for feldspar again.

*Elko County.*—Pegmatites are found in and associated with a granite stock in the Ruby Mountains (Olson and Hinrichs, 1960, pp. 147-173). The Dawley Canyon area (fig. 46, No. 4) on the east side

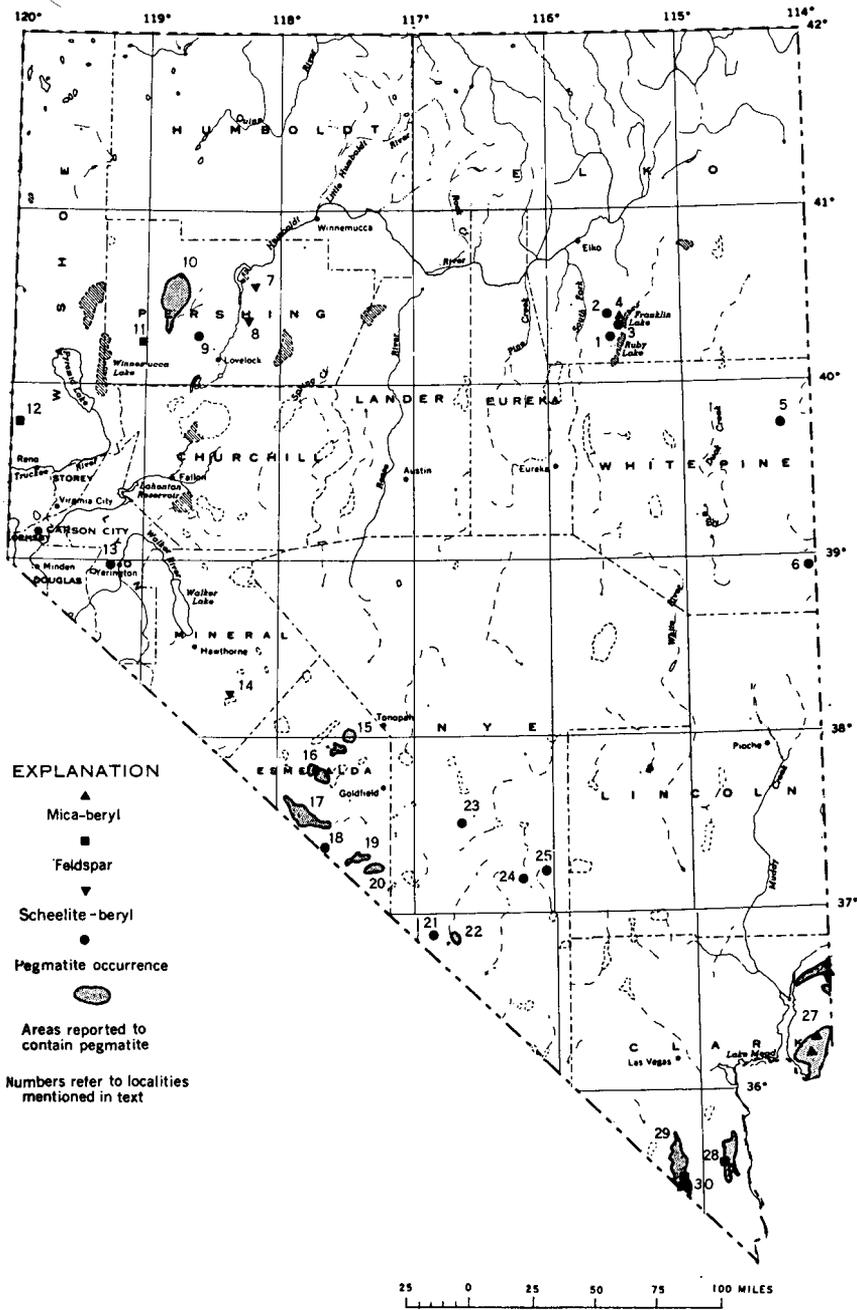


FIGURE 46.—Pegmatite minerals in Nevada (numbers refer to deposits or districts discussed in text).

of the range contains more than 250 pegmatite dikes intruding quartzite, schist, and granite. The dikes are tabular bodies ranging in thickness from less than 1 to 55 feet. The longest dike is 2,200 feet in length. Most of the bodies are fine- to medium-grained and zoned. The zones consist of a fine-grained plagioclase-quartz-muscovite border zone, fine- to coarse-grained plagioclase-quartz-muscovite-perthite wall and intermediate zones of various compositions, and quartz, quartz-perthite, or quartz-albite-perthite cores. Small amounts of garnet, beryl, and biotite are present and tourmaline, hematite, apatite, phlogopite, columbite-tantalite, autunite, andalusite, and sillimanite are rare accessory minerals. Only muscovite and beryl are of economic interest. The muscovite is generally of scrap quality; most of the crystals are broken, ruled, distorted, or small. Beryl is found in about one-third of the deposits but most of the crystals are smaller than 1 inch in diameter. The beryl content probably averages about 0.1 percent. Prospecting has been done in over 100 pits and excavations. The Errington-Thiel mine produced a little sheet mica during World War II but the total amount of mica and beryl recovered from the district is small.

Pegmatite is also exposed in Hankins Canyon (No. 3) about 2 miles south of Dawley Canyon. The pegmatite bodies are thinner than those in Dawley Canyon and range only 1 to 4 feet in thickness. More than half contain some beryl but there is no recorded beryl production.

Several pegmatite bodies are exposed in Gilbert and McCutcheon Canyons (No. 2) on the west side of the Ruby Mountains, 9 miles east of Jiggs (Olson and Hinrichs, 1960, pp. 171-172). A few pieces of beryl and columbite-tantalite have been found in several deposits.

Pegmatite cutting granite is also present near the head of Corral Creek (No. 1) about 8 miles south of Gilbert Canyon. Lepidolite and beryl have been reported but are not common (Olson and Hinrichs, 1960, p. 171).

*Esmeralda County.*—Pegmatites are exposed in several areas in Esmeralda County. The granite of Lone Mountain (No. 15) grades locally into pegmatite (Ball, 1907, p. 53). In the Mineral Ridge area (No. 16) there are numerous pegmatite bodies containing quartz, muscovite, feldspar, biotite, garnet, apatite, zircon, and magnetite. One deposit contains lepidolite (Olson and Hinrichs, 1960, p. 183). Pegmatite containing beryl is reported in the Sylvania district (No. 20) and pegmatite dikes and irregular masses are found in Gold Mountain Ridge (No. 19) and the Slate Ridge area (No. 18) (Ball, 1907, pp. 185, 192-193). Pegmatite is common in the granitic rocks of the southern part of the Silver Peak quadrangle (No. 17) (Spurr, 1906, pp. 22-26, 129-156).

*Lyon and Mineral Counties.*—Molybdenite is reported in a pegmatite in the Yerington district (No. 13) of Lyon County (Schrader, Stone, and Sanford, 1916, p. 196) and beryl occurs in wolframite-scheelite veins in the Marietta district (No. 14) in Mineral County (Olson and Hinrichs, 1960, pp. 181-182). No large pegmatite deposits, however, are reported in either county.

*Nye County.*—Pegmatites in Nye County have been described by Ball (1907, pp. 124-129, 134, 155-156, 179). Fine-grained sheared pegmatite and alaskite are exposed in the Bullfrog Hills near the

Original Bullfrog mine (No. 21). The deposit consists of quartz, feldspar, muscovite and accessory biotite, apatite, zircon, magnetite, and tourmaline (Olson and Hinrichs, 1960, p. 184). Small masses of fine-grained pegmatite are also found in Bare Mountain near Gold Center (No. 22) and in granite masses near Trappman's Camp (No. 23) and Whiterock Springs (No. 24). Larger pegmatite dikes are common in the Belted Range. Some of these are in a granite mass southeast of Oak Spring (No. 25) (Barnes and others, 1963; Houser and Poole, 1960).

*Pershing County.*—Pegmatites have been found in several areas in Pershing County. Scheelite-beryl-bearing quartz veins and pegmatite have been mined at Lakeview in Humboldt Canyon (No. 7) and at the Oreana deposit (No. 8), both in the Humboldt Range (Olson and Hinrichs, 1960, pp. 174–177). Small pegmatite dikes occur in granite in the Trinity Range west of Lovelock (No. 9). The pegmatite consists of fine- to medium-grained quartz, potassium-feldspar, plagioclase, muscovite, and biotite. In the Seven Troughs Range (No. 10) fine-grained pegmatites have been reported (King, 1877, pp. 775–778) but little prospecting has been done. The large pegmatite dike at the RFS feldspar-mica prospect near the east base of the Bluewing Mountains (No. 11) is 1,200 feet wide and at least 2 miles long (Olson and Hinrichs, 1960, p. 179). The mica content is low and mostly scrap, but the deposit is a possible source of feldspar.

*Washoe County.*—Pegmatites occur in several areas in Washoe County but the principal area is near Red Rock Road (No. 12) about 18 miles north of Reno (Olson and Hinrichs, 1960, pp. 180–181). In this area numerous pegmatite dikes 1 to 9 feet thick contain perthite, albite, and quartz. Minor amounts of biotite, muscovite, apatite, sphene, magnetite, hematite, epidote, and allanite are also present. Several carloads of feldspar were shipped from here to San Francisco in 1931, and some prospecting was done in 1945–47.

*White Pine County.*—Pegmatites have been reported in several areas in White Pine County. In the Kern Mountains (No. 5) large muscovite pegmatites cut granite and the sedimentary rocks near the granite contact (Hill, 1916, p. 30). Pegmatite dikes grading into quartz veins are present near Walter Canyon on the southwest side of the Kern Mountains (Hill, 1916, p. 207). Granite on the west front of the Kern Mountains about 30 miles east of Schellbourne station contains many small pegmatite masses mostly less than 2 feet thick (Olson and Hinrichs, 1960, p. 174). In the southern Snake Range (No. 6) quartz-rich pegmatitic veins contain small crystals of beryl.

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### PERLITE

(By Paul Gemmill, Nevada Mining Association, Reno, Nev.)

Perlite is a name derived from a petrologic description for specific structure in volcanic glass. The commercial usage of the name "perlite" is broadened to include volcanic glasses that will expand when heated to a suitable temperature. Perlite ores are high in silica and usually about the composition of the acidic volcanic rocks commonly called rhyolite, pumice, and tuff. Some perlites are porous and are, in fact, pumice-like in texture. To be a perlite ore, the rock

must be noncrystalline (a glass) and must contain sufficient water as an integral part of the solid rock to cause the rock to expand upon applying heat to the point of fusion. Entrapped water ranges between 3 and 5 percent for most perlites. When the temperature is raised to the point of fusion, release of water vapor causes expansion or "popping." The release of water vapor causes fusion temperature to rise and the expanded cellular particles are readily removed from the heat without further fusion.

Perlite types are designated first by their physical appearance. Color of the crude ore usually has little relation to quality, since dark ore will commonly expanded into white product. Texture and hardness of the ore will normally indicate crushing characteristics. Free, or uncombined moisture content, and ability of the crushed particle to remain a unit during the furnacing process are properties easily determined. Thus, the common types of perlite can usually be classified by visual appearance of the deposit in relation to important commercial qualities. Dense, or nonporous perlite ores, commonly termed "onion skin" or "massive" and also termed "hard" ores, do not retain free moisture, so there is no drying required in preparation for market unless rain or snow has wetted the crushed ore stockpiles. On the other hand, "pumiceous" perlite and "tuffaceous" perlite, which are classed as "soft" ores, retain moisture due to porosity, and require drying moist ore before screening. Dense ores also offer the advantage of producing less fines in the crushing and screening operation, so less mined ore is discarded in meeting the furnace operator's specifications. Dense ores are regarded by most furnace operators as better ores to control in making an expanded product with minimum of fines. One advantage of the pumiceous and tuffaceous soft ores comes in simpler mining. Some of these deposits can be mined without blasting.

Perlite ores are mined, crushed, and sized at or near the deposit because considerable waste of material is entailed in removing excessive minus 100 mesh fines caused by the crushing operation. The rejected fines usually range between 20 and 40 percent of the total, depending on the crushing characteristics of crude ores and the sizing demanded by the furnace operator in making specifications on expanded material. Furnacing of the crushed ore is accomplished as close as possible to the market or point of consumption of the expanded product. The bulky, expanded perlite is commonly distributed in 4 cubic-foot paper bags when it does not go into finished product at the point of furnacing. Important quantities now go into premix plaster and wallboard, as well as roof decking and other lightweight concrete at the point of furnacing. Weight per cubic foot of expanded perlite can be controlled at the furnace and varies with the end use: from less than 3 pounds per cubic foot for special loose fill insulation, to the more common 7.5 pounds per cubic foot plaster aggregate, and on up to 15 pounds per cubic foot for certain higher strength mortar ingredients and for perlite concrete. Perlite can be shipped to remote places because the crushed and screened ore with bulk density of about 75 pounds per cubic foot can be shipped as crude without packaging, then expanded to 10 times the volume before packaging near the place of use.

Almost all of the commercial furnaces are either (1) bottom-fired vertical tubes in which the crushed ore is fed in above the flame,

with the expanded perlite carried out in the updraft to be collected in chambers and cyclones, or, (2) the flat-lying rotary kiln-type furnace in which crushed perlite is fed opposite the firebox end and allowed to travel on a downward slope toward the flame, as the kiln rotates. The latter type is generally credited with the ability to make better concrete aggregate and the ability to expand the coarser grades, while the former type is credited with somewhat better economic performance as to fuel consumption and rate of throughput for making the less critical plaster aggregate and for insulation fill.

Production figures (U.S. Bur. Mines minerals yearbooks) show that perlite mined in the United States has held virtually static from 1959 at about 400,000 tons per year. After subtracting losses, the quantity sold totals about 320,000 tons per year with 200,000 tons being sold to expanders while 120,000 tons is used in the producer's own plants. In the United States as a whole, 15 companies are currently producing perlite from 16 mines. New Mexico is credited with 76 percent of the domestic total production for 1962. Other States, ranked in order of output, are: Nevada, California, Arizona, Colorado, Idaho, and Utah. In Nevada, three mines and crushing plants are active. The U.S. Gypsum Co. at Lovelock, Pershing County, and Paramount Perlite Co. at Caliente, Lincoln County, are two producers using their own ore, while the Combined Metals plant at Pioche, Lincoln County, sells exclusively to others with principal sales in the West, but with customers in the Midwest and the eastern seaboard.

Production of perlite in Nevada has been declining for several years and the maximum production for Nevada is believed to have occurred in 1958. Since the individual producers' figures were not made public, the Nevada total was not revealed until 1960. The following totals for Nevada production are given in Nevada Mining Association reports for 1960 and later.

Year:	Short tons sold
1960.....	35, 214
1961.....	29, 544
1962.....	25, 067
1963 (estimated).....	26, 000

Trends away from plaster in the building industry, with emphasis on hardwall construction, coupled with Nevada perlite ores not participating in the most rapidly growing filter-aid business, as discussed below, account for the rapid decline in Nevada production.

Average prices for U.S. production sold to expanders is quoted at \$8.14 per short ton for 1962, compared with \$8.49 for the year 1961. The average Nevada price for 1962, as revealed by the Nevada Mining Association publication, was about \$8.20. Average value of crude perlite expanded by prime producers is given at \$8.59, compared with \$8.75 in 1961. This figure is not available for Nevada.

Since perlite is expanded at or near the points of consumption, sales are roughly distributed in accordance with population, except for the fact that perlite has gained greater acceptance in proportion to population in the West than in the Eastern States, probably due to freight advantage and more rapid building rates in the West. For example, about 10 percent of domestic sales for expanded perlite are credited to California, while 5 percent of domestic sales are credited to the State of New York. Nevada can compete in the eastern area

only on quality and service to offset a freight differential in favor of New Mexico deposits and production capacity.

Within Nevada there are three perlite expanding furnaces in operation. The Blue Diamond Division of Flintkote operates an expanding furnace at their Blue Diamond gypsum wallboard manufacturing plant, Clark County, and the U.S. Gypsum Co. operates a furnace at their gypsum and wallboard plant near Gerlach, Washoe County. The third operator is Nevada Perlite Corp. in Las Vegas, Clark County. No figures have been published for production of expanded perlite within the State.

Although it is true, as stated above, that total perlite production has been stagnant since 1959, a study of trends in consumption shows that it would be a mistake to say that the perlite business cannot expect new periods of rapid growth. The young perlite industry did not become firmly established until the late 1940's, and the most ready market was found to be the use of expanded perlite in place of sand for building plaster. By 1951 total perlite use was 134,000 tons with building plaster use accounting for 75 percent, concrete aggregate 20 percent, and miscellaneous uses, 5 percent. All major uses showed growth over the 9-year period to 1960, when use of perlite was 248,000 tons. But a shift to more diversified uses was apparent with building plaster accounting for only 60 percent of the total (an increase in tonnage used per annum, however, of about 47,000 tons, to a total of 148,000 tons), concrete aggregate 13 percent (a net increase of 5,300 tons to a total of 32,300 tons); filter aids by this time had grown to deserve separate classification at 12 percent, or nearly 30,000 tons, and miscellaneous uses had grown to 15 percent, or over 37,000 tons. But the spectacular shift came in the 2-year period from 1960 through 1962. Total consumption dropped only 10,000 tons, although the plaster aggregate use dropped 33,000 tons. In total use of 238,000 tons, building plaster accounted for 47 percent (106,000 tons), concrete aggregate 16 percent (38,200 tons), filter aids 19 percent (45,000 tons), and miscellaneous uses accounted for 18 percent (43,000 tons). In round figures, 2 years accounted for a net decrease of 22 percent in the plaster aggregate use, while all other major uses showed rapid rates of increase; concrete aggregate use up over 18 percent, filter aid use up over 51 percent, and various other uses up over 16 percent, compared with the 1960 consumption.

In the miscellaneous classification, making up 18 percent of the 1962 consumption, uses reported are: oil-well cement 6 percent, insulation (loose fill) 3 percent, insulation (other) and soil conditioning 2 percent each, filler and wallboard 1 percent each, and various other uses 3 percent. Evidently, from these reported figures, most of the wallboard filler use has been included as part of the plaster aggregate consumption.

As to the significance of these figures, it is evident that if the indicated trends continue, the perlite business will soon show a healthy growth rate. But the fastest growing segment, that of filter-aid manufacture, is controlled by large operators, principally Great Lakes Carbon Corp., and Johns Manville, who own mines in the New Mexico area and thus have a freight advantage to the eastern part of the United States. In the Western States both of these corporations have high-quality diatomaceous earth deposits for the filter-aid and filter-medium markets.

The concrete aggregate potential may be found to offer an opportunity for large consumption of the hard-type Nevada perlite. One operator in the Los Angeles area has made and tested prestressed concrete beams with adequate strength for structural members, and much lower weight per cubic foot than similar members made from competitive lightweight aggregates. The use of perlite in structural concrete has been visualized from the inception of perlite production, but the reactive nature of perlite with commercial cements, together with difficulties of controlled expansion of the perlite to produce a harder aggregate, are problems that have not found easy solutions. Perlite concrete has been almost totally restricted to uses that require very low strengths, such as building blocks, roof-deck slabs and floor slabs, whereas other materials are depended upon for the support of heavy loads. When and if a real breakthrough is demonstrated, and gains acceptance for use of perlite as a lightweight aggregate in structural concrete, the nonporous, harder perlites of Nevada are believed to be the best quality raw material for the most exacting quality control in producing firm, expanded aggregate.

Occurrences of perlite in Nevada are shown in figure 47. These occurrences are mostly from a Union Pacific Railroad Co. report and a communication from W. C. McCulloch, chief geologist for the Southern Pacific Railroad Co. Deposits in Lincoln County are familiar to the writer and the original locations on some of them were made by the writer. These deposits would all be classed as "hard" ore. Samples tested at the Caselton plant of Combined Metals Reduction Co. from Pershing County would also be classed as "hard" ore, and descriptions given by Mr. Cochran of Clark County ores would indicate they are the hard variety.

No attempt is made to quote reserves because some deposits have not been estimated and also because reserves can be misleading unless coupled with a careful analysis as to uniformity and a definition of acceptable quality. Until perlite use grows far beyond the present rate, perlite reserves will not be a problem. Far more important are the quality, uniformity and factors affecting cost of production and transportation.

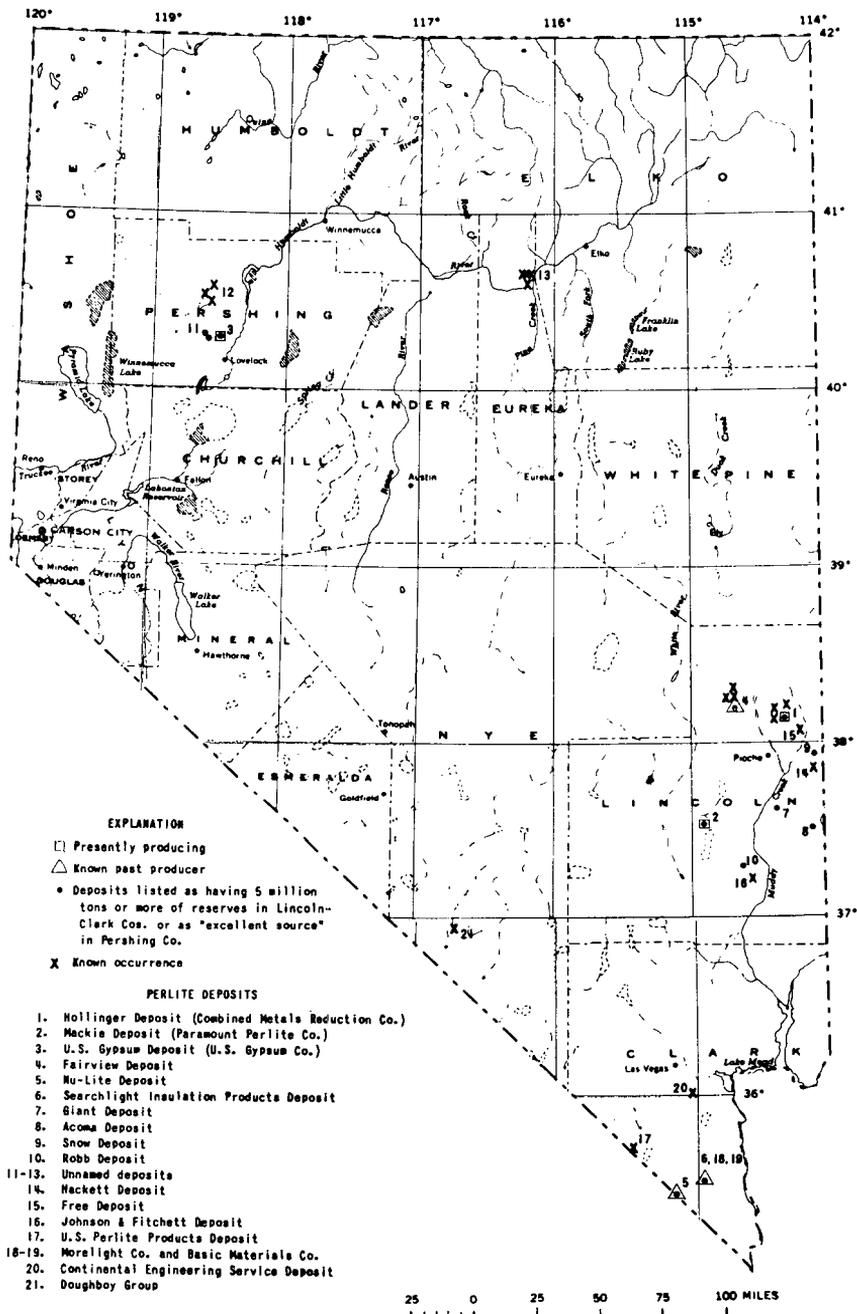


FIGURE 47.—Perlite in Nevada.

## PHOSPHATE ROCK

(By K. M. Tagg, U.S. Geological Survey, Menlo Park, Calif.)

Phosphate rock is used in the production of elemental phosphorus and phosphoric acid, which are used in the manufacture of baking powders, water softening agents, soaps and detergents, plasticizers, insecticides and pesticides, beverages, ceramics, photographic chemicals, oil-refining agents, dental and silicate cements, fertilizers, animal feed supplements, and, for military use, smokescreens and incendiary bombs. By far the greatest use in this country is in the manufacture of commercial fertilizers; in some parts of the country, even raw rock, finely ground, is applied directly to the soil (Ruhlman, 1960). Important mining operations are in Florida, Tennessee, Wyoming, Utah, Idaho, and Montana. In the Western States, the rock occurs as marine sedimentary deposits, mostly in Mississippian and Permian strata; the Permian Phosphoria Formation, which is best developed in southeastern Idaho, is the major source. In Nevada, Permian rocks that are believed to be lateral equivalents of the Phosphoria Formation occur in Elko County and are known to contain phosphate deposits that may eventually be of commercial value.

Chemical analyses of phosphate rock from the Western States usually are reported as percent  $P_2O_5$ . Analyses also may be reported as percent BPL (bone phosphate of lime), which is tricalcium phosphate,  $Ca_3(PO_4)_2$ . Percent BPL is converted to percent  $P_2O_5$  by multiplying by 0.458; conversely, percent  $P_2O_5$  is converted to percent BPL by multiplying by 2.18. Pure rock contains about 38 percent  $P_2O_5$ . In Idaho, rock containing 31 percent or more  $P_2O_5$  is considered to be high grade, and rock containing less than 18 percent  $P_2O_5$  generally is unacceptable for commercial operations. However, lower grade rock may be mined where reserves are large and beneficiation is possible.

The phosphate mineral is a variety of apatite ( $Ca_{10}(PO_4)_6F_2$ ) that is called carbonate fluorapatite. It occurs as structureless pellets (less than 2 mm diam.) and nodules (more than 2 mm diam.) and as concentrically banded oolites (less than 2 mm diam.) and pisolites (more than 2 mm diam.) usually in poorly exposed shaly beds. Individual beds may appear to be sandy or conglomeratic. Individual grains may be tan or dark bluish gray, depending on weathering, and, in moist environments, may have a light bluish-gray mottled coating.

In Elko County, Permian strata that contain phosphate deposits lie between the Kaibab Limestone and younger olive-green and greenish gray shales that are assigned to the Triassic (see fig. 3). Such deposits have been reported to be a few miles east of Currie, in the south end of the Pequop Range, in the north end of the East Humboldt Range, and in the mountains west and north of Montello (Cheney, McKelvey, and Gere, 1956). In the area 10 miles west of Montello, phosphate beds have been measured, sampled, and reported (Cheney, Gere, and Wallace, 1956) as follows: a 3-foot zone contains 28.7 percent  $P_2O_5$ , and a 10-foot zone contains 18 percent  $P_2O_5$ ; in the latter, 5.5 feet contain 20.5 percent  $P_2O_5$ . The rock occurs in a phosphatic shale that overlies cherty dolomite and is overlain by a thick sequence of chert and limestone.

Regional relations suggest that the richest Permian phosphate deposits in Nevada probably are north and east of Wells. However,

this does not preclude the occurrence of deposits in other parts of the State.

### PUMICE, PUMICITE, AND VOLCANIC CINDERS

(By R. C. Horton, Nevada Bureau of Mines, Reno, Nev.)

Pumice, pumicite, and volcanic cinders are products of volcanic activity, generally of an explosive character. Pumice and pumicite are formed by rhyolitic and andesitic volcanism, while volcanic cinders are formed by basaltic volcanism. The terms "pumice" and "pumicite" are often used for the same material, but "pumice" should be restricted to rocks that are light colored ejecta from rhyolitic or andesitic volcanism, that consist of cellular pumiceous glasses, and that have grains larger than 4 mm in diameter. "Pumicite" is the fine-grained equivalent of pumice and should be restricted to material with grains smaller than 4 mm. "Volcanic ash" and "pumicite" are often used interchangeably as the terms refer to the same grain size, but "volcanic ash" may be of rhyolitic, andesitic, or basaltic composition. "Tuff," or "volcanic tuff," is the name given to rocks formed of consolidated volcanic ash.

Pumice and pumicite are commonly used as abrasives, although this use has declined in recent years. At present large amounts of pumice are used in the Western United States as concrete aggregate. Pumicite is widely used in products where fillers are needed, particularly as a dilutant in paints and rubber goods, as an insecticide carrier, and as an additive in the manufacture of cement. Volcanic cinders are used as aggregate in concrete blocks, in monolithic concrete construction, and in roadbuilding; as roofing granules and ground cover; and as drain rock where a porous permeable medium is required.

Pumice and pumicite deposits occur as stratified layers deposited by air-fall or in bodies of water, and as unstratified deposits around volcanic vents. Pumice also occurs as a frothy or vesicular covering on extrusive rhyolite domes. In these deposits the pumice grades downward into obsidian or rhyolite. Volcanic cinders occur as deposits forming volcanic cinder cones and as semilayered deposits around these cones.

There are many deposits of pumicite in Nevada but they have not been systematically studied or described. The principal deposits of pumice in the State are those associated with intrusive rhyolite domes in Storey and Washoe Counties. There are many volcanic cinder cones in Nevada as shown on figure 48.

Attempts have been made to mine many of the cinder cones in Nevada but because of transportation costs only two of the operations have been successful. A volcanic cinder cone in sec. 28, T. 14 S., R. 49 E., Nye County, 1 mile north of the Las Vegas-Tonopah Highway and 23.4 miles southeast of Beatty, is mined by the Cind-R-Lite Corp. of Las Vegas. The company trucks the cinders to its building block plant in Las Vegas. The cinders also have been used from time to time by the State Highway Department in constructing highways in the area. According to Kral (1951, p. 66-67), mining first began in 1946 on a bench adjacent to the cone. A minimum of 500,000 cubic yards of cinders is estimated to be available on the bench in addition to the yardage in the cinder cone which is about one-half mile in diameter at the base and about 400 feet high.

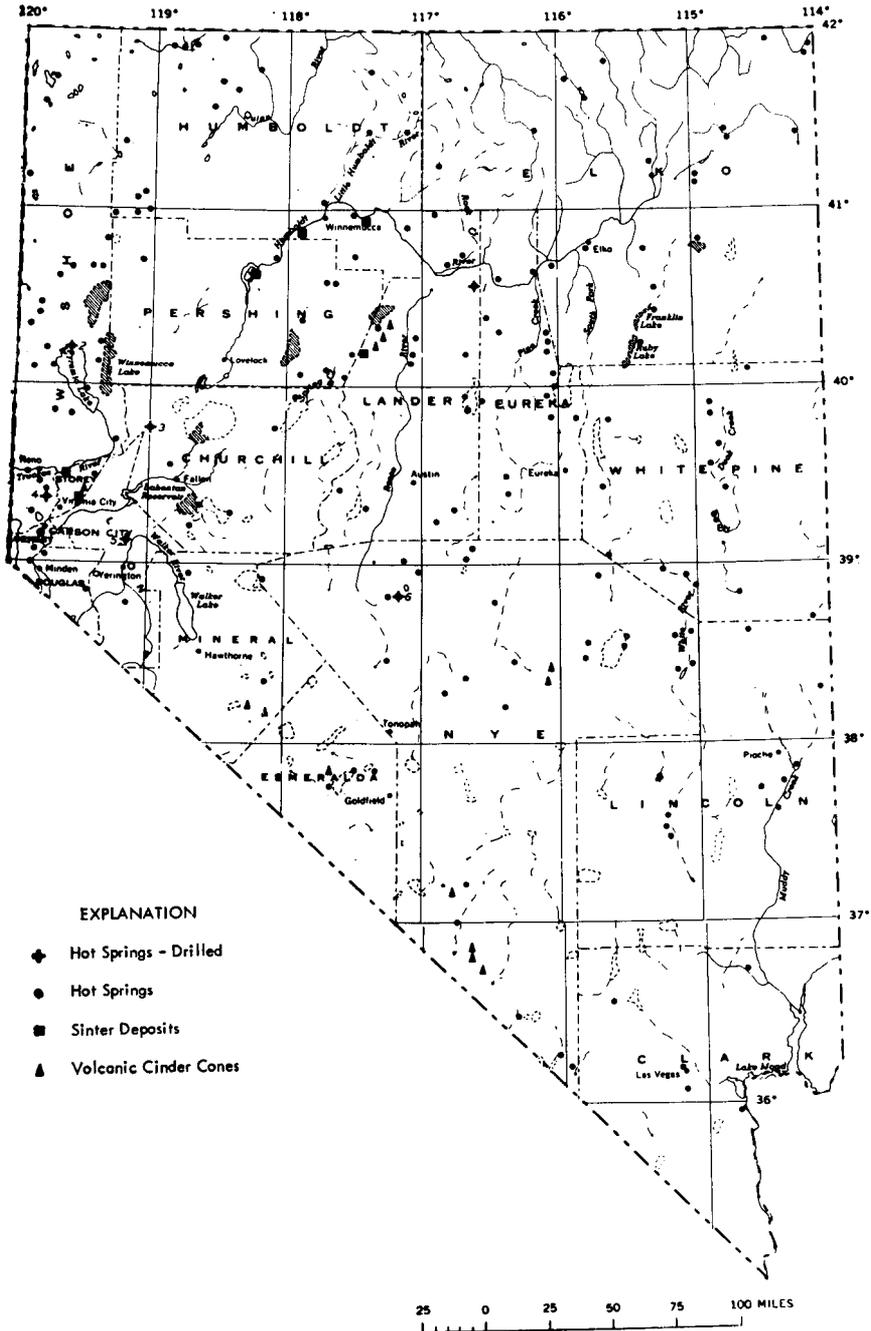


FIGURE 48.—Hot springs, sinter deposits, and cinder cones in Nevada.

The Cinderlite Products Co. is presently mining a cinder deposit in secs. 21, 22, 27, and 28, T. 16 N., R. 20 E., Storey County, about 2 miles north of the Carson City airport. This deposit, although of substantial size and with ample reserves for many years of operation, is not cone shaped, for it is located on the side of a steep range of hills, and sliding and erosion have destroyed any cone-like appearance it might once have had. The volcanic cinders are sold in the Reno-Lake Tahoe area for use in concrete block plants, in monolithic construction, as drain rock, and in various architectural applications. Substantial amounts also are shipped to consumers in the Sacramento, Calif., area.

A small operation, Pumco Aggregates, mines a deposit of volcanic cinders in sec. 27, T. 7 N., R. 35 E., Mineral County, near Mina. The material is used locally for concrete aggregate.

Most any of the volcanic cinder cone deposits in Nevada are suitable for use as concrete aggregates. Unfortunately, most of these deposits are located in remote areas, so it is unlikely that they will be exploited for many years. The advent of haydite and similar expanded shale products, now produced in large quantities in California, further limits the demand for volcanic cinders. The total volume of volcanic cinders available in Nevada, although not precisely measured, probably exceeds several cubic miles.

The only pumice deposit now mined in Nevada is located in secs. 8, 9, 16, and 17, T. 17 N., R. 22 E., near Sutro Springs, Storey County. The Naturalite Co. recently began mining operations, transporting the pumice by truck to a concrete block plant in Reno. This deposit is a pumiceous rhyolite formed on an extrusive rhyolite dome. This dome is one of a number described by Thompson (1956, p. 58) as follows:

The Steamboat Hills rhyolite is here named for the occurrence of pumiceous rhyolite in the Steamboat Hills,  $2\frac{1}{2}$  miles west of the Virginia City quadrangle. The rhyolite also occurs in two widely separated areas within the quadrangle; one along the west base of the Virginia Range, northwest of the Steamboat Hills, and the other at Sutro Springs, on the east side of the Flowery Range. All these occurrences are extrusive domes of fresh pumiceous rhyolite containing very sparse phenocrysts of sanidine, quartz, plagioclase, and biotite. Some of the rhyolite is perlite; and a very little obsidian. The extrusion of the dome in Steamboat Hills was preceded and followed by explosive eruptions, but there seems to have been little such activity at the other domes, which do not have craters.

The other pumiceous domes to which Thompson refers are in sec. 1, T. 17 N., R. 19 E., and in secs. 23 and 27, T. 18 N., R. 20 E., Washoe County.

A pumice deposit in sec. 7, T. 12 S., R. 47 E., just north of Beatty, Nye County, was mined at irregular intervals during the 1940's for use as an aggregate in the manufacture of concrete blocks in the Las Vegas area. The deposit has not been active for a number of years.

The Panaca Pozzolan Co. has been mining a pumice deposit near the southwest corner of sec. 19, T. 1 S., R. 68 E., Lincoln County, about 6 miles northwest of Panaca. Some of this material was used as a pozzolan in the construction of Glen Canyon Dam. The company is expanding its marketing operations and it is likely that additional

material will be mined. The deposit was described by Hewett and others (1936, p. 178) as follows:

The deposit occurs as a sandy, unconsolidated bed about 9 feet thick, which is exposed for about 1,500 feet in the banks of the wash west of Cathedral Gulch but extends at least 600 feet to the west and probably much further. The overburden of tuff and gravel is between 17 and 40 feet thick over most of the area, but in the valley of the wash it is probably not over 10 feet in an area 200 feet square. It seems reasonable to estimate that the deposit underlies an area 600 by 1,000 feet with a thickness of 9 feet, which should yield more than 5 million cubic feet of ash. Another bed of this material more than 8 feet thick lies about 1,000 feet to the northeast and is exposed for some 700 feet along a steep bank. It contains more carbonate cement than the main deposit.

The ash is light gray to white, fine grained (largely between 0.1 and 0.3 millimeter), angular, and friable but stands in vertical walls. It is composed of clear volcanic glass with mostly less than 10 percent of quartz and feldspar fragments. A fine carbonate dust occurs in even the most friable material and some, especially in the northern deposit, is partly cemented by carbonate \* \* \*.

A pumicite deposit in sec. 25, T. 32 N., R. 51 E., near Palisade, Eureka County, has been mined at irregular intervals since the early 1930's. The material was shipped to California consumers for use in scouring powders. According to Vanderburg (1938, p. 58) the pumicite occurs in stratified beds ranging in thickness from 8 to 30 feet. For the most part the beds are overlain either with alluvial detritus or volcanic ash, the latter, in places, tightly cemented.

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### SAND AND GRAVEL

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Sand and gravel are of such common occurrence and are so taken for granted, it is difficult to realize that greater tonnages of these are produced each year than any other nonfuel mineral commodity and that their value consistently ranks in the top five of all mineral commodities, fuels included. Sand and gravel are unconsolidated materials that range in particle-size from silt to boulders and have accumulated on the earth's surface as a result of the erosion of bedrock by water, ice, and wind, and subsequent transport by these agents to sites of deposition. They normally occur together but in a wide variety of volumes, types, and size classifications. The definitions and specifications for sand and gravel are so varied and complex as to be beyond generalization.

Almost 90 percent of the sand and gravel produced in the United States goes into the highway construction field as portland and bituminous concrete aggregate, base, or fill material, and to the building construction field as aggregates. Railroad ballast and various types of fill are among the many relatively minor uses of sand and gravel. Indeed, almost any type of construction calls for the use of some sand and gravel.

The main types of deposits are stream or fluvial, marine and lake, glacial, and residual in origin. Wind-blown deposits, although locally common on the earth's surface, are of minor economic importance. Because many different size ranges and widely different proportions of size ranges are needed for different uses, an understanding of the geologic processes which formed the various types of sand and gravel deposits is important for the correct selection of materials.

Until the beginning of this century, sand and gravel production in the United States was comparatively small, but 777 million short tons were produced in 1962 with a value of \$795 million. The rapid increase in construction of highways, dams, and buildings accounts for this phenomenal rise. Because new structures will probably be needed at even greater rates in the future, the sand and gravel production should continue to grow rapidly. They are such low-value commodities, generally less than a dollar per ton at the plant for washed and sorted products, that little fear need be held for substitution by other aggregate material. Deposits close to metropolitan consuming centers will become more difficult to exploit due to residential zoning, and deposits farther away from the markets, because of the low unit value of sand and gravel, will not permit much transportation of any kind.

Nevada in 1962 produced almost 8 million tons of sand and gravel for a gross value of approximately \$9,700,000. This makes it by far the most important in value of all industrial minerals produced in the State, and of all the natural commodities produced here in recent years, only copper exceeds sand and gravel in gross value.

Gravel is generally thought of as having an upper size limit of 3½ inches in diameter and sand and gravel must normally possess specific quantities of fine fractions. In these respects, and in the normal sense of defining sand and gravel deposits, Nevada has little true sand and gravel. The deposits worked thus far consist of a wide variety of relatively unsorted debris, such as alluvial fan material, extremely poorly sorted fluvial material, and alluvial valley fill, rather than the classical types of sand and gravel deposits enumerated above. As a consequence almost all of Nevada's sand and gravel production is "crusher-run material."

The sand and gravel industry of Nevada is understandably centered around the two major population centers, Reno and Las Vegas. During the course of highway construction several pits have been opened up around the State, but when such construction is completed, the pits are abandoned as they invariably are too far from existing market areas. No attempt will be made to describe these sporadic operations, and only the deposits that are operating are shown on figure 49.

In the Reno-Sparks area the numerous sand and gravel pits are so close together that they cannot all be differentiated on the index map. Many different rock types have contributed to the detritus that forms these deposits which have several geological origins. The two largest pits, both on the east side of the Reno-Sparks area (No. 1, fig. 49), Washoe County, are quite dissimilar. The Isbell Second Street gravel property consists largely of poorly sorted fluvial debris deposited in a broad valley by the Truckee River and its associated tributary streams. The other (Vista Rock Products), along the western base of the Virginia Mountains east of Sparks, is developed in coarse colluvium and alluvial fan material derived from the range. It is unlikely that much material was contributed to this deposit by the Truckee River and its ancestors.

Near the Southern Pacific Railroad siding of Mogul (No. 2), Washoe County, a sand and gravel pit recently has been developed in poorly sorted fluvial material in Truckee River terraces. The excavated material is trucked to a plant in Reno for crushing and other treatment.

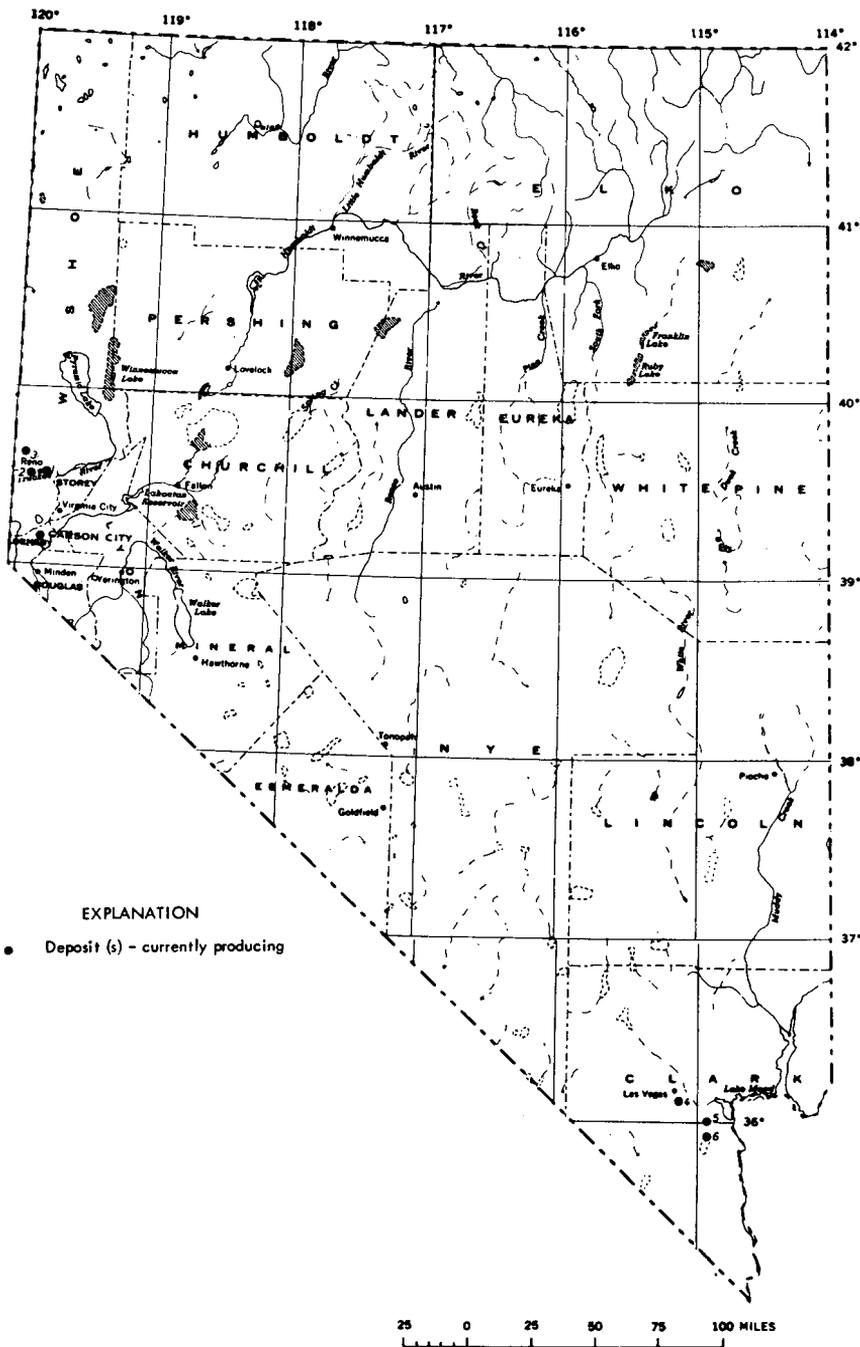


FIGURE 49.—Sand and gravel in Nevada (numbers refer to localities discussed in text).

Northwest and north of Reno numerous small pits have been opened on decomposed granitic rocks associated with the huge Sierra Nevada batholith. Production has been sporadic and the small size of most pits indicates they have had no important past history.

Extremely fine sand, probably deposited by the Truckee River, is mined on the western edge of Reno and used as foundation material for the laying of sewer pipe, etc.

An attempt recently was made to procure sand and gravel from an alluvial fan complex along the northeastern flank of Peavine Peak south of Stead Air Force Base (No. 3), Washoe County. Production from this property has been intermittent and although the outcome of the venture is unknown, it appears to be hampered by a relatively long haul to the Reno area.

All of the material excavated as sand and gravel in the Reno area, with the exception of the Acme Automatic Aggregates pit (No. 3), is crusher-run material and must be sent through several screening and washing steps.

There are some small aggregate operations currently producing sand and gravel in the Carson City-Minden area, but insufficient knowledge prohibits a discussion of them at this time.

Although no study is known to have been made of the aggregate situation in the Las Vegas area, some generalizations can be made. The valley fill complex in the Reno-Sparks area has had several different types of origin of which glacial, fluvial, and alluvial fan development are the most important. On the other hand, the geology of Las Vegas Valley is simpler in that most of the alluvial material is in classical alluvial fan complexes derived by the erosion of relatively rapidly uplifted fault-block mountain ranges in a desert environment. Several sand and gravel operations are currently producing in the Las Vegas area (No. 4), Clarke County, the majority of them to the south and southeast of downtown Las Vegas. To the writer's knowledge all are excavating alluvial fan material.

There are also several small pits in the Henderson area and between Henderson and Boulder City along U.S. Highway 93 (No. 5), Clark County, but their present operational status is unknown. These have also been developed in alluvial fan material.

Gornowich Sand and Gravel Co. has developed a large pit in the alluvial fan complex derived from the eastern flank of the McCullough Range along the western side of Eldorado Valley about 3 miles south of Railroad Pass (No. 6), Clark County. Although this deposit is not known to have been described or investigated geologically, the material produced is said to be excellent for meeting highway construction specifications.

In the future, sand and gravel operations in Nevada will continue to be developed as close to consuming areas as possible. Past experience in Nevada indicates that within a given area no single deposit will be far superior to any other in the economics of its operation or in the final product obtained.

## SILICA

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Silica ( $\text{SiO}_2$ ), as a naturally occurring commodity, is differentiated from sand and gravel. The latter are used mostly for constructional purposes of relatively minor value per unit volume, while silica has a wide variety of more expensive industrial applications. The most important source of silica is the mineral quartz, and those quartz deposits which have been purified and segregated by natural processes into nearly monomineralic deposits are the most desirable economically.

Silica sand, the most commonly mined variety of silica, has a wide variety of end uses, which can be roughly divided into abrasive, glass and chemical, metallurgical, refractory, and miscellaneous categories. The main abrasive uses are as blasting sand (used for cleaning surfaces), as glass-grinding sand, and as stone-sawing and rubbing sand used for the sawing and rough-grinding of dimension stone. Sands used in the manufacture of glass must be exceedingly pure (practically monomineralic) and of uniform grain size. Industrial silica for chemical uses must be about as pure as that used for glass manufacture and for this reason the same source may often satisfy both industries. The main chemical uses are the manufacture of sodium silicates and silicon carbides. Silica is used metallurgically chiefly as a component in the preparation of silicon alloys or as a flux in the preparation of elemental phosphorus. The refractory uses of industrial silica are extremely varied but essentially include sands used for foundry molding purposes, as a liner in steel furnaces utilizing acid processes, and in the manufacture of superduty acid refractory products. Miscellaneous uses include coal-washing sand, filter media, hydraulic-fracturing sand, standard testing sand, and traction sand.

Silica may be procured for the above or other uses from natural occurrences other than sands; such as byproduct sand from clay treatment, igneous quartz which may or may not be a byproduct, and byproducts of placer deposits worked primarily for other natural commodities. The volume of silica derived from such operations, however, is relatively inconsequential compared to that from the various types of silica sand and pebble deposits. The raw material utilized for the manufacture of silicon metal and its various alloys is igneous quartz of exceptionally high purity which occurs in place.

The main types of silica sand deposits are stream or fluvial, marine and lake, glacial, and residual. Windblown deposits, although extremely common and widespread throughout the world, are of relatively minor importance. In addition to having widely varying types of origin, silica sand deposits vary greatly in composition, thickness, areal extent, shape, and texture. Further discussion of the various types of silica sand deposits is beyond the scope of this article.

In 1962 approximately 20 million short tons of industrial sand were sold or used in the United States for a total worth of about \$67 million. The annual production figures for industrial sands have increased steadily since the end of World War II, and there seems little likelihood of anything other than steady increases in the future; for this commodity, like so many of the industrial minerals, is geared to a proportionate use by our ever-increasing population. Due to the fact that unit values are relatively low and that transportation costs

commonly may constitute the major part of the final costs, imports of industrial sands are decidedly minor.

Although the production of silica sand is and has been almost entirely restricted to Clark County, it is an important commodity among the industrial minerals produced in Nevada. The amount and value of its production, however, are included in the overall classification of "sand and gravel," so the foregoing statement cannot be verified statistically. Two plants and several deposits are currently being operated in the Overton area (No. 1, fig. 50), Clark County, and the industry has been holding its own against competition from other producers considerably nearer to the market areas.

Present production is restricted to an area about 9 miles long and several miles wide in the North Muddy Mountains west of Overton (No. 1), Clark County. The major producer is and has been for many years in the past the Scott Mining & Investment Co. (formerly Simplot Silica Products, Inc.) who operate open pit mines and a sand-washing plant about 2 miles south of Overton. When this operation started, the major portion of their production went to the glass industry with only a minor fraction sold as foundry sand, but today this position has been reversed. Sales have also been made to producers of sodium silicates in the Los Angeles area. The light-colored Baseline sandstone (Cretaceous), which is being quarried, is a second generation sandstone, having been formed by the reworking of the red Aztec sandstone (Jurassic?) which forms the spectacularly scenic cliffs of the valley of Fire State Park.

Unconsolidated windblown sand, which is generally not nearly as pure as that of the Baseline sandstone, is mined and sold without processing in the Overton area by independent operators for various uses which do not demand as rigid specifications as the glass and foundry industries. Murphy (1955) has described the silica sand operations in the Overton area in detail.

West of Ute siding on the Union Pacific Railroad tracks (No. 2), Clark County, the Eureka quartzite (Ordovician) has been quarried along the eastern flank of the Arrow Canyon Range. The rock was ground, treated by dry methods, and sold for metallurgical uses, but the operation has been abandoned for many years.

Glass-melting sand is reported to have been shipped in the 1930's from occurrences in the general vicinity of Arden (No. 3), a section town along the Union Pacific Railroad in southern Clark County. Although these operations were not well documented while they were in production and cannot definitely be located now, they were presumably in undifferentiated redbeds of Permian age along the eastern flank of the Bird Springs Range. This rock is not as well consolidated and lithified as the Eureka quartzite of the Arrow Canyon Range (No. 2) and could presumably be processed at considerably lower costs, as far as crushing is concerned.

Quantities of silica were produced from the Cuprite district (No. 4), Esmeralda County, from large deposits associated with alunite and sulfur (Fulton and Smith, 1932). All known production from these occurrences was in the period 1914-18.

In 1960 an attempt was made to mine and process silica from a hydrothermally leached acidic volcanic rock in the low hills along the western side of Stonewall Flat northeast of Lida Junction, Esmeralda

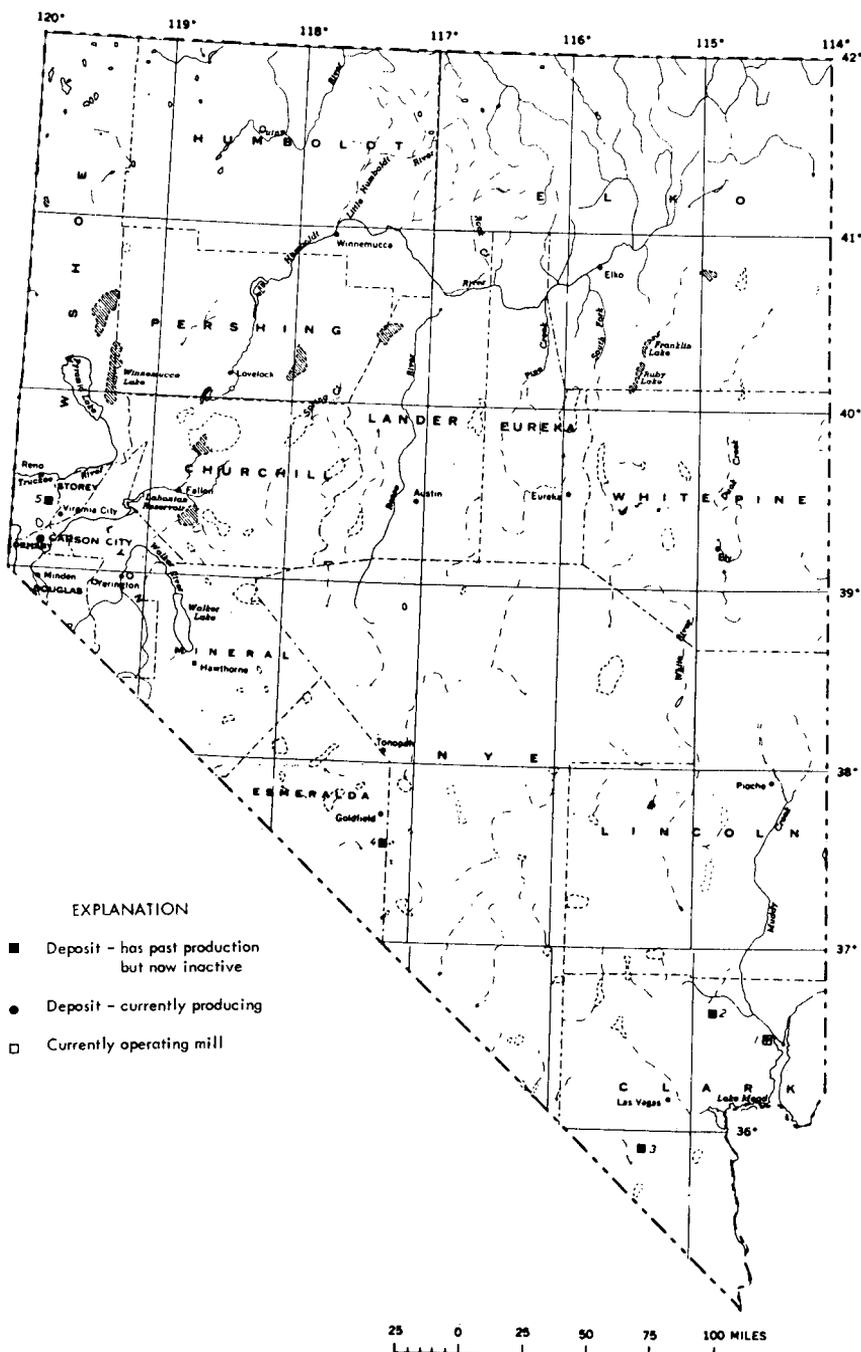


FIGURE 50.—Silica in Nevada (numbers refer to deposits discussed in text).

County, but the operation is now inactive. This occurrence is so close to the Cuprite district (No. 4) that it is not differentiated from it on the map (fig. 50).

Fulton and Smith (1932) report that a quantity of glass sand was mined and shipped to San Francisco in 1931 from Steamboat Springs, 10 miles south of Reno (No. 5), Washoe County.

Silica sand formations, particularly those of Paleozoic age, are widespread throughout Nevada, but the lack of railroad lines makes it probable that few of these occurrences will be exploited. There are likewise many deposits of massive igneous quartz in Nevada which presumably could supply the raw material for the manufacture of silicon metal and its alloys, but here again high transportation costs make it unlikely that these will be mined in the near future.

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### SODIUM COMPOUNDS

(By R. C. Horton, Nevada Bureau of Mines, Reno, Nev.)

Sodium compounds are of vital importance to man, both as a dietary essential and as the source of chemicals required in many industrial products and processes. The natural sodium compounds of major importance are sodium chloride, sodium carbonate, and sodium sulfate. These sodium compounds are found in brines, in underground deposits, and as efflorescent deposits on dry lakes.

Common salt, or sodium chloride, is a plentiful mineral commodity. Besides the oceans, which contain inexhaustible quantities of dissolved salt, large amounts are found in underground deposits throughout the world.

Despite an annual consumption exceeding 24 million tons, the United States has virtually unlimited resources of salt. About 60 percent is produced by dissolving the underground deposits in water and pumping the brine to the surface, 35 percent is mined by underground methods, and 5 percent is produced by solar evaporation of sea or lake brines. Although the quantity of salt consumed as a dietary essential is impressive, more than 30 times as much is used by industry, chiefly in manufacturing chlorine, caustic soda, and soda ash.

The production of sodium carbonate in the United States averages more than 5 million tons per year, of which 10 to 12 percent is produced from natural sources in California and Wyoming. Most of the soda ash consumed in or exported from the United States is manufactured at a few large Solvay plants in the East and Midwest. Sodium carbonate is used chiefly in the production of other chemicals, glass, nonferrous metals, pulp and paper, soap, cleansers, and in water treatment. Sodium sulfate is produced at the rate of about 1 million tons annually in the United States, mostly as a byproduct of chemical processes such as hydrochloric acid and rayon production.

Domestic reserves of both sodium carbonate and sodium sulfate are plentiful. Besides the natural bedded deposits and brines available in several Western States, there are large reserves of coal, sulfur, and sodium chloride from which sodium carbonate and sulfate are produced in large quantities.

In Nevada, prior to the arrival of the white man, the Basketmaker Indians, who lived at Lost City near Overton, mined salt at the St. Thomas salt deposit (No. 16) from A.D. 700 to A.D. 1150. It is likely that many other Indian tribes obtained salt from the various dry lake deposits scattered through Nevada.

Today, only small amounts of sodium chloride are produced in Nevada and there is no production of sulfates or carbonates, but this has not always been true. The early metallurgical practices of the Comstock Lode required large amounts of sodium chloride which had to be purchased in San Francisco for \$150 per ton delivered in Virginia City. The high cost of obtaining this common material threatened to slow development of the Comstock Lode. In 1862 a herd of camels was imported for use in hauling salt from Rhodes Marsh (No. 11, fig. 51) to Virginia City. In 1863 the Sand Springs salt deposit (No. 7) was discovered and supplied salt to Virginia City for \$60 per ton. Although the Comstock Lode has been essentially abandoned for many years, the Sand Springs salt deposit still produces a small amount of salt each year.

Many dry lake deposits in Nevada were worked for their salt content during the 1800's. The St. Thomas deposit is the only deposit of rock salt in Nevada and is now largely covered by the waters of Lake Mead. When the construction of Hoover Dam was being considered, there were many persons who feared that the salt deposit would be dissolved by the resulting lake and the water would become unfit for agricultural or domestic uses, but this did not occur.

#### CHURCHILL COUNTY

##### *Dixie Marsh salt deposit (No. 3, fig. 51)*

Dixie Marsh was formerly the site of a small lake. Its evaporation left a mixture of salts including sodium chloride, sodium sulfate, and sodium carbonate, with smaller amounts of sodium borate and potash salts, associated with silt and mud. Sodium chloride occurs as an efflorescence in the lowest part of the basin, covering an area of about 9 square miles. The surface salt layer is underlain by a series of salt and saline mud strata to a depth of perhaps several hundred feet. When the salt deposit was exploited during the 1800's, the salt was simply hoed into piles and shipped without refining. The borate minerals, chiefly represented by ulexite or "cotton balls," occurred as aggregates of acicular crystals. In 1916 the Railroad Valley Co. drilled three holes, ranging in depth from 70 to 98 feet in depth, in the deposit. Sample results of the brines showed 28.7 to 38.7 grams of solids per 100 cubic centimeters of brine. The approximate amounts of salts present in the brine were: NaCl, 27 percent; Na<sub>2</sub>SO<sub>4</sub>, 5 percent; Na<sub>2</sub>CO<sub>3</sub>, 4 percent; and K<sub>2</sub>O, 0.19 to 0.75 percent. Salt from the deposit analyzed by the U.S. Geological Survey contained the following: NaCl, 96.49 percent; sodium sulfate, 1.91 percent; sodium carbonate, 0.96 percent (Phalen, 1919, p. 140; Vanderburg, 1940, p. 49).

##### *Eagle Marsh salt deposit (Leete district) (No. 5)*

Salt was first produced here in 1870 by a Mr. Leete who discovered the deposit and organized the Eagle salt works. A small amount of borax was produced from the salines in 1871, but the venture was

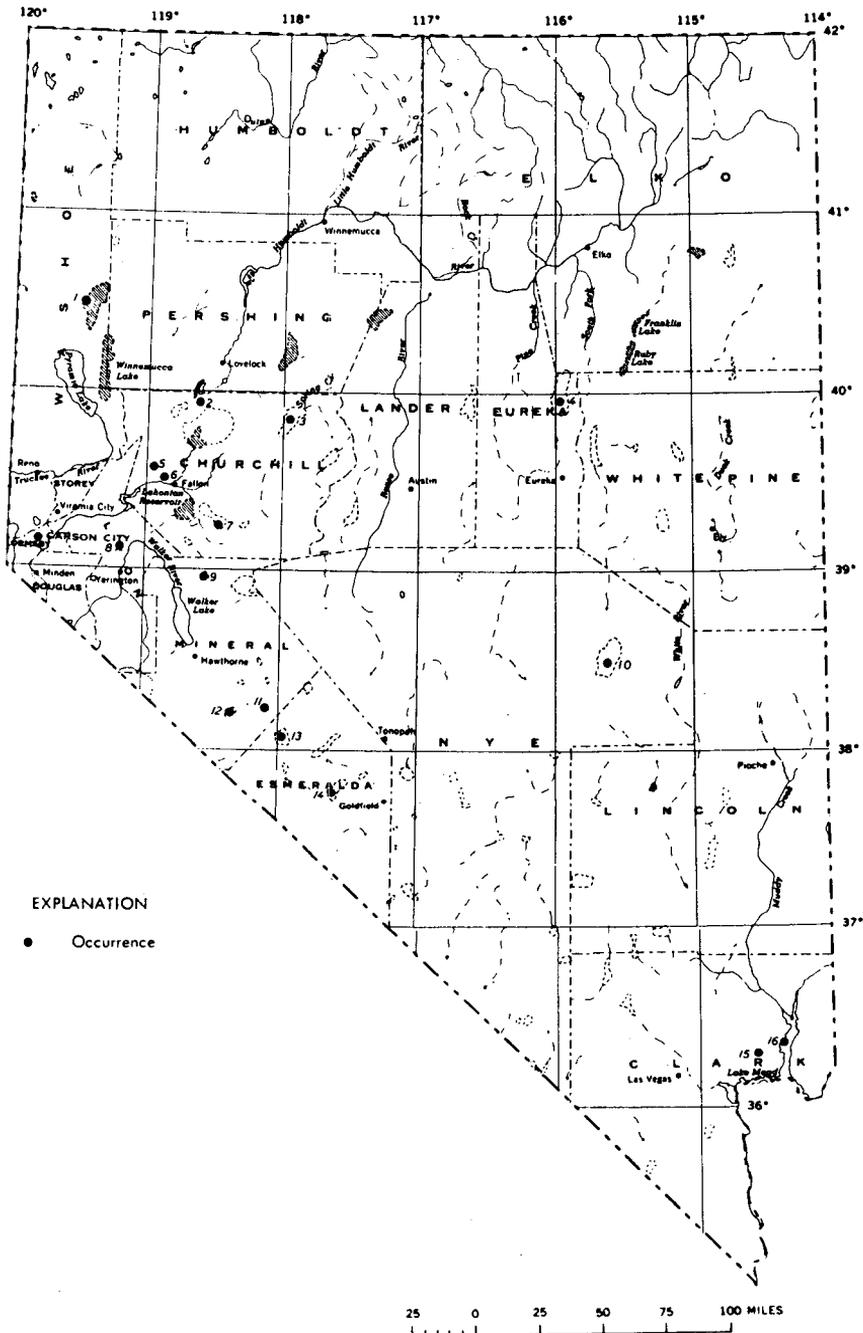


FIGURE 51.—Sodium compounds in Nevada (numbers refer to deposits discussed in text).

unsuccessful. From 1879 to 1884 the production of salt amounted to 334,000 tons, and total production probably exceeds 500,000 tons.

The playa lake in which the salt and borax occur is covered during the summer months with a white saline efflorescence. The saturated brine, occurring about 20 feet below the surface, was pumped into shallow pits and concentrated by solar evaporation. An analysis of the brine, having a specific gravity of 1.2, gave the following: calcium sulfate, 0.29 percent; calcium chloride, 0.36 percent; magnesium chloride, 0.4 percent; and sodium chloride, 25.38 percent (Phalen, 1919, p. 138; Vanderburg, 1940, p. 39).

#### *Sand Springs salt deposit (No. 7)*

Sand Springs salt marsh is a playa lake formed by the evaporation of a shallow body of water in an enclosed basin. During the winter months water collects on the surface of the playa, forming a brine lake 15 to 20 square miles in area. In summer months the water evaporates leaving a layer of salt several inches thick. The salines consist largely of sodium chloride with minor amounts of other salts. A test well drilled by the U.S. Geological Survey penetrated a 7-foot surface layer of hard crystalline salt underlain by soft black mud. The deposit is now owned by the Leslie Salt Co. Small quantities of salt, collected annually from the surface by scrapers, is sold locally for road deicing and stock purposes (Phalen, 1919, p. 137; Vanderburg, 1940, p. 41).

#### *Soda Lakes (No. 6)*

The Soda Lakes are on the edge of the Carson Sink, 7 miles northwest of Fallon. According to Russell (1885), the two lakes occupy deep depressions formed by extinct volcanic craters. Big Soda Lake is nearly circular, with an area of 268 acres; Little Soda Lake is smaller and varies considerably in size, depending upon weather conditions. There are no streams either tributary to or draining these lakes. At the time of Russell's investigation the larger lake was calculated to contain about 2 million tons of salt, of which 428,000 tons was sodium carbonate, 342,000 tons sodium sulfate, and 1,284,000 tons sodium chloride. The brines of Soda Lakes have been considerably diluted in recent years by infiltrating waters from the Truckee-Carson irrigation project.

From 1875 until 1893 the Soda Lakes produced 300 to 800 tons of soda annually. The old soda works are now submerged beneath the surface of the lake. Although the lakes have been diluted in recent years, it is possible that concentrated brines exist at depth. (Russell, 1885, pp. 73-80; Vanderburg, 1940, p. 44).

#### *White Plains salt deposit (No. 2)*

The White Plains salt deposit, discovered in 1870, was operated for many years by the Desert Salt Co. The last production of record was in 1915. Brine, obtained from springs in the vicinity, was pumped into vats and concentrated by solar evaporation. In addition to the springs, salt encrustations cover an extensive area of the adjacent Humboldt Sink (Phalen, 1919, p. 140; Vanderburg, 1940, p. 37).

## CLARK COUNTY

*St. Thomas (Virgin River, Pahranagat) salt deposit (No. 16)*

A large deposit of rock salt is exposed on the cliffs along the west side of the Virgin River for a distance of 10 miles, beginning 4 miles south of the former site of St. Thomas. This deposit now is submerged beneath Lake Mead.

The salt beds were mined by a tribe of Indians who lived in the Virgin River Valley from 700 A.D. to 1150 A.D. Evidence of this ancient mining could be seen on the walls and floors of a natural cave 4 miles south of St. Thomas. The Indians mined the salt by chipping circular channels with stone hammers and prying off the slabs. As early as 1866 white men mined the salt for use in chlorination mills in Arizona. For many years some 200 tons were mined annually to satisfy local demands for stock use.

The salt formation probably is quite extensive as wells drilled in sec. 6, T. 19 S., R. 68 E.; in sec. 22, T. 21 S., R. 62 E.; and in sec. 5, T. 32 S., R. 54 E., have penetrated thick sections of salt or have encountered substantial quantities of brine. From time to time plans have been made to utilize the salt or brine as a source of chlorine for use at the Henderson industrial complex.

A deposit of sodium sulfate also occurs on the west side of the Virgin River, about 5 miles south of St. Thomas, but is now submerged beneath Lake Mead. The sodium sulfate occurs as a crystalline mass of glauberite in horizontal sedimentary beds. Composite samples of the material contained the following: sodium sulfate, 46.8 percent; calcium sulfate, 45.85 percent; impurities, including sodium chloride, iron, alumina, and silica, 7.35 percent. The reserves in this deposit probably are large (Phalen, 1919, pp. 146-148; Vanderburg, 1937a, p. 67).

*White Basin sulfate deposit (No. 15)*

A deposit of sodium sulfate crops out along the side of a prominent cliff in the White Basin, about 3 miles south of the former American Borax mine. The sodium sulfate is intimately associated with siliceous impurities and no attempt has been made to mine the deposit. (Vanderburg, 1937a, p. 61.)

## ESMERALDA-MINERAL COUNTIES

*Columbus Marsh (No. 13)*

Columbus Marsh is situated near the Esmeralda-Mineral County line, but is largely in Esmeralda County. The marsh, covering an area of 35 to 40 square miles, is roughly elliptical in outline. It is a broad mud plain with a rough lumpy surface. Little salt shows on the mud surface except about the margins where several borax-producing plants were located in the earlier days of the borax industry. Test drilling by the U.S. Geological Survey failed to disclose any salt beds or concentrated brines beneath the surface (Gale, 1913; Hicks, 1915; Phalen, 1919, p. 142).

*Double Springs Marsh salt deposit (No. 9)*

Double Springs Marsh is in Mineral County, about 8 miles east of Schurze. The only mining activity on the marsh occurred about

1898 when the Occidental Alkali Co. produced a considerable amount of high-grade soda.

Double Springs Marsh is a typical dry lake deposit formed by the evaporation of mineral-bearing waters derived from drainage from the surrounding mountains and probably to some extent from hot springs and water of volcanic origin. About 500 acres of the marsh are covered with a deposit of salts ranging from 2 to 14 inches in thickness, averaging about 6 inches. The general chemical composition of the surface salts is: sodium carbonate, 20 percent; sodium bicarbonate, 25 percent; sodium sulfate, 15 percent; sodium chloride, 10 percent; water, 15 percent; and sand and insoluble matter, 15 percent.

Beneath the surface incrustation is a body of "soda clay" filled with soda crystals. Strong soda solutions constantly rise to the surface by capillary action and the salts are deposited by evaporation of the water. This process is slow when the top incrustation is undisturbed, but when it is removed, the accumulation of salts on the stripped portion is about 1 inch per year (Vanderburg, 1937b, pp. 27-28).

#### *Rhodes Marsh salt deposit (No. 11)*

Rhodes Marsh is in the lowest part of Soda Springs Valley, about 8 miles south of Mina. The marsh was first exploited in the early 1860's to supply salt necessary for the extraction of gold and silver from the ores of the Comstock, Aurora, Candelaria, Belmont, and other mining districts. In the 1870's, shortly after the discovery in Teels Marsh, borax was found in Rhodes Marsh. Considerable activity prevailed and borax mining was pursued for a number of years. It was known the mirabilite, a hydrated sodium sulfate, occurred in the marsh in large quantities and in the late 1920's and early 1930's efforts were made to recover it.

Rhodes Marsh is 3 miles long and has an average width of 1½ miles. It is dry and encrusted with salts for the greater part of the year. The accumulation of surface salts, mostly sodium chloride, varies in thickness with the season. The water level also fluctuates with the seasons and in summer stands 4 to 5 feet below the surface. Thenardite,  $\text{Na}_2\text{SO}_4$ , occurs in lenses 3 to 5 feet thick under an overburden of silt and salt varying from 2 to 6 feet in thickness. The Rhodes Alkali & Chemical Corp. sampled the marsh with several thousand hand drilled auger holes and, according to drill records, at least 3 million tons of sodium sulfate salts are available. The corporation produced a small amount of material from the thenardite. The finished product contained: sodium sulfate, 97.33 percent; sodium chloride, 1.07 percent; calcium sulfate, 0.28 percent; insolubles, 1.24 percent; and moisture, 0.08 percent (Phalen, 1919, p. 141; Vanderburg, 1937b, pp. 64-66).

#### *Silver Peak (Clayton Valley) Marsh salt deposit (No. 14)*

Silver Peak Marsh is 30 miles southeast of Columbus Marsh and occupies the lowest portion of Clayton Valley. It is about 10 miles long, 4 miles wide, and covers an area of approximately 32 square miles. Numerous wells were drilled in the area by the U.S. Geological Survey (Dole). It was estimated that not less than 15 square miles of the northeastern portion of the marsh contained a 10-foot-thick saline bed, of which at least 60 percent is salt, representing a

salt reserve of 15 million tons lying within 40 feet of the surface. A composite sample of salt that crystallized in surface pits contained the following: moisture, 1.22 percent; insoluble matter, 1.12 percent; calcium sulfate, 1.16 percent; calcium chloride, 0.46 percent; potassium chloride, 1.26 percent; sodium chloride, 94.71 percent; borax, 0.07 percent (Dole, 1912; Phalen, 1919, pp. 142-145).

*Teels Marsh salt deposit (No. 12)*

Teels Marsh is 2 miles south of the old mining camp of Marietta, in southern Mineral County. This marsh, actually a dry lake, was first worked for sodium chloride in the late 1860's. The first discovery of borax in Nevada was made here by F. M. Smith, better known as "Borax" Smith. Although Teels Marsh is not economically important at present, it produced a considerable quantity of borates and played an important part in the development of the borax industry in the United States.

Teels Marsh is 5 miles long, 1 to 2 miles wide, and covers an area of about 8 square miles. The boron-bearing mineral, principally borax, was intimately mixed with other salts forming a crust on the surface of the playa. The upper stratum was the purest worked, but when this crust was removed other strata were found at shallow depths associated with greater quantities of sodium carbonate and sodium chloride (Vanderburg, 1937b, pp. 77-78).

EUREKA COUNTY

*Williams Marsh salt deposit (No. 4)*

Williams Salt Marsh is 40 miles north of Eureka in the north end of Diamond Valley. In the 1800's the marsh was exploited for salt to supply the chlorination mills at Mineral Hill, Hamilton, Eureka, and other mining districts in eastern Nevada. With the decline of the chlorination process, salt production became unimportant, and little work has been done in the area since that time.

The marsh covers about 1,000 acres. Salt was first obtained by gathering the surface incrustations, without any refining. Such salt contained only about 60 percent sodium chloride. The ground water level is within 4 feet of the surface and contains about 12 percent sodium chloride. This water was pumped into pans and concentrated by solar evaporation. Salt produced in this manner contained about 95 percent sodium chloride (Vanderburg, 1938, pp. 65-66).

LYON COUNTY

*Wabuska sodium sulfate deposit (No. 8)*

Two miles east of Wabuska are a number of hot and cold springs that flow into a small flat valley. Large quantities of sodium sulfate apparently have been deposited from the hot spring waters. The American Sodium Co., using evaporating ponds, refined and shipped sodium sulfate from here during the 1930's, but there has been no activity since. Russell described the deposit as a 6- to 8-foot thickness of clear transparent crystals of sodium sulfate resting on saline clays. (Russell, 1885; p. 48, Stoddard and Carpenter, 1950, pp. 94-95.)

## NYE COUNTY

*Railroad Valley (Butterfield Marsh) saline deposits (No. 10)*

Railroad Valley is a typical desert basin, 100 miles long in a north-south direction and 10 to 20 miles wide. Butterfield Marsh, covering an area of 40 square miles, is in the lowest portion of the valley. A lake whose level was from 50 to 300 feet above the present playa surface once occupied the valley. Butterfield Marsh is commonly covered with a thin crust of salt. Toward its northern end are irregular salt pans where the incrustation is much thicker, and from which some salt was produced in the 1800's. Potash—as much as 12 percent  $K_2O$ —occurs in the efflorescent salts but no potash deposits have been found at depth by drilling.

The Railroad Valley Co. drilled seven holes, varying in depth from 745 to 1,204 feet, in Railroad Valley during 1912-14. Gaylussite ( $CaCO_3 \cdot Na_2CO_3 \cdot 5H_2O$ ) was encountered in three of the holes with one hole penetrating 194 feet and another 127 feet of mineral-bearing mud. The holes were drilled in the general vicinity of T. 7 N., R. 56 E. The Shell Oil Co. drilled a deep well in sec. 2, T. 7 N., R. 56 E., probably on the northern edge of the gaylussite beds and found considerable amounts of gaylussite in the interval 660 to 2,880 feet. The greatest thicknesses were encountered in the interval 861 to 894 feet (60 percent of the section being gaylussite), and in the interval 1,120 feet to 1,130 feet, 80 percent of the section being gaylussite (Kral, 1951, pp. 49-50; Phalen, 1919, pp. 144-145).

## WASHOE COUNTY

*Buffalo Springs (No. 1)*

Salt formerly was produced at the Buffalo Spring Salt Works, on the west side of the Smoke Creek Desert. Water flowing over the surface of the desert in the vicinity of the salt works soon becomes strongly impregnated with salt and on evaporating leaves a crust several inches thick. Sodium sulfate and other salines also are found at places in the adjacent lake beds. The sodium sulfate is reported to be several feet thick in places, but it has never been developed. Brine collected from wells near the salt works was found to contain the following: calcium sulfate, 0.15 percent; magnesium sulfate, 0.88 percent; potassium sulfate, 0.31 percent; sodium sulfate, 0.53 percent; sodium chloride, 14.84 percent; and water, 83.29 percent. (Overton, 1947, pp. 59-60; Phalen, 1919, pp. 145-146).

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SULFUR

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Sulfur is a nonmetallic element widespread in nature in both the native form and in combination with other elements, particularly in sulfides and sulfates. Elemental sulfur occurs in three types of deposits: salt domes (from which the bulk of the world's native sulfur is obtained), sedimentary deposits, and surface deposits resulting from vulcanism. The sulfides occur in metallic sulfide deposits, and as  $H_2S$  in "sour" natural gas, generally considered to mean gas with more than 0.04 percent  $H_2S$ . The sulfates, anhydrite and gypsum,

constitute large potential sources of sulfur, and although these are being used as raw materials for the manufacture of sulfur in Europe and Asia, it does not seem likely that this will be done in the United States in the near future. The chief commercial sources of sulfur are from native sulfur deposits, from sour natural gas, and from metallic sulfide ores such as iron pyrites.

The fertilizer industry is the largest single consumer of sulfur and, like the chemical, petroleum, rayon, and steel industries, uses it as sulfuric acid ( $H_2SO_4$ ). Approximately 80 percent of the sulfur consumed by this country goes into the manufacture of sulfuric acid. Major nonacid uses of sulfur are in the insecticide and rubber industries as well as in the paper industry which uses large amounts for sulfite pulp.

The United States is the world's largest sulfur consumer, in recent years using somewhat more than 5 million long tons annually. This country consumed 42 percent of the world's free sulfur production in 1950, the last year for which complete figures are available. In 1958 the United States produced about 71 percent of the world's native sulfur. Therefore, this country in recent years has been an exporter of sulfur and is self-sufficient. The world reserves of sulfur ores seem ample to supply any probable future demand. Until about 5 years ago, salt domes in Mexico and the Southeastern United States yielded the bulk of world production of native sulfur, but since then sulfur recovered from sour gas has become increasingly important.

The only sulfur deposits known in Nevada are of the native sulfur type; pyrite has never been recovered commercially and there are no sour gas wells. Nevada has produced little sulfur, but has been a relatively big consumer. Branner (1959) states that only 4,831 long tons of elemental or contained sulfur were shipped from Nevada during the period 1906-57, yet in 1957 alone slightly more than 50,000 tons of sulfur were consumed in Nevada. Although several deposits have produced in the past, the future does not look bright for Nevada sulfur production from presently known occurrences. Many of the deposits are relatively small, necessitating costly mining methods, and almost all of them would involve high transportation costs to get the product to markets.

The Rabbit Hole sulfur mines are at the western base of the Kamma Mountains (No. 1, fig. 52), Humboldt County, and were first worked in 1874. The sulfur occurs in water-laid deposits of probable Late Tertiary age. Native sulfur occurs as crystal masses on the walls of cavities and as disseminations in the highly altered siliceous rock. The most important masses appear to have been introduced as molten sulfur which welled up into open channels in the rocks (Adams, 1904). The deposit probably was formed by solfataric action; it lies in a thermal area and the rocks have an overall leached appearance with abundant siliceous cement. Alunite commonly occurs in the same cavities as the native sulfur, and small amounts of cinnabar and gypsum also are present. Operations have been sporadic. It is the only currently active sulfur mine in Nevada, and is now being exploited for agricultural sulfur. Vanderburg (1938) has estimated from the extent of the workings and tailings and from sketchy data on the early activity that at least 40,000 tons of sulfur have been produced, and this figure is substantially in excess of Branner's

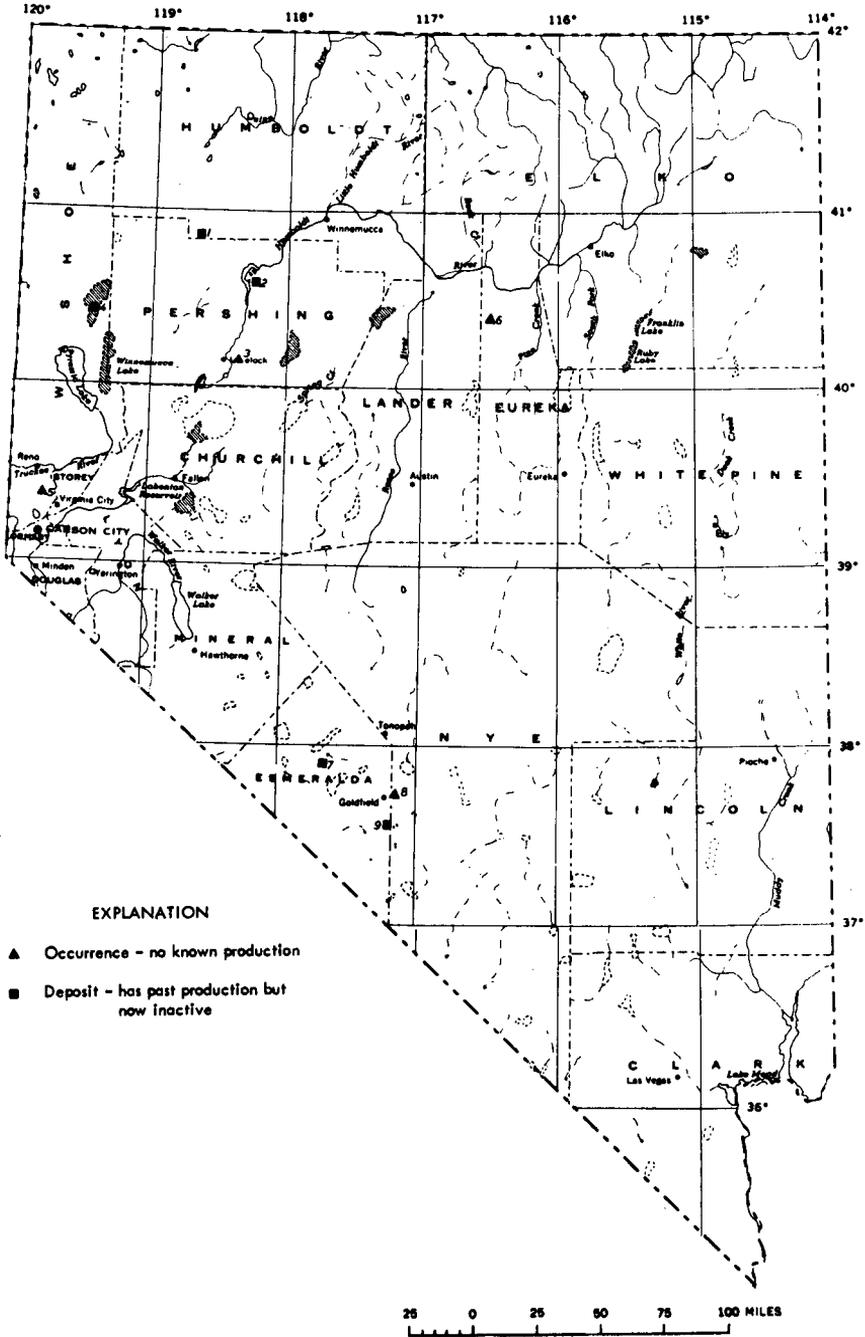


FIGURE 52.—Sulfur in Nevada (numbers refer to deposits discussed in text).

aforementioned production figures. Most of the sulfur has been mined from shallow depths. The content of the ore has varied from 15 to 85 percent sulfur. In 1908 silver ore was discovered at the south end of the sulfur deposits.

Some calcareous tufa mounds about one-half mile south of Humboldt, Pershing County, on the west side of the Southern Pacific railroad tracks (No. 2) have crystallized gypsum and native sulfur lining the mound openings near their tops (Lee, et al., 1915). These undoubtedly are hot springs deposits. Small pits and an old retort west of Humboldt marked the old workings.

Sulfur also has been reported from the large gypsum deposit a few miles east of Lovelock (No. 3), Pershing County, but the grade is considered too low to be potential ore.

Native sulfur occurs in deposits at several extinct thermal springs at the southern end of Mud Flat south of Gerlach (No. 4), Washoe County. The spring deposits are alined along a northerly trending fault which displaces Pleistocene lake beds. The sinter mounds can be traced over a strike length of approximately 7,000 feet. The sulfur occurs as crystalline masses and disseminations in siliceous sinter and clay. The deposits have been developed by several shallow open pits. A few tons of high-grade sulfur have been mined, but since the visible sulfur mineralization is low grade and of limited extent, the possibility of future production seems remote (H. F. Bonham, Jr., personal communication).

The Steamboat Springs area (No. 5) Washoe County, has several minor occurrences in a highly kaolinized granodiorite, some of which are reported to be of rather high grade. The deposits were discovered in 1875. No known attempt has been made to mine or process the sulfur directly. Cinnabar associated with the sulfur prompted the erection of a quicksilver furnace. Some sulfur was extracted as a by-product.

Native sulfur also occurs at Hot Springs Point (No. 6), Eureka County, about 13 miles south of Beowawe. Several unsuccessful attempts were made in 1957 and 1959 to mine the sulfur for use as a soil conditioner. The sulfur occurs in a northerly to northeasterly trending fault zone in Ordovician rocks, probably the Vinini Formation or its equivalent. Several hot springs occur along this fault for a distance of approximately 1 mile, and the sulfur appears to be associated with the hot spring activity. Small amounts of cinnabar and antimony occur sporadically throughout the sulfur (E. F. Lawrence, personal communication).

The Alum mine (No. 7), about 10 miles north of Silver Peak, Esmeralda County, has sulfur associated with alum and gypsum in pipes or chimneys in rhyolite (Spurr, 1906). The sulfur is thought to have been deposited by ascending sulfuriferous gases. Locally the decomposed rhyolite has sulfur as coatings of cracks and crevices, generally "not over a fraction of an inch" (Spurr, 1906). Although the deposit was discovered in 1868, no appreciable attempt was made to process the ore until 1921 when a plant for the production of both alum and sulfur was erected. This plant operated intermittently until 1923. It is believed that the sulfur content of the ore is about 10 percent. During recent years some of the raw material reportedly has been shipped as a soil conditioner.

Elemental sulfur occurs about 1 mile east of Tognoni Springs (No. 8), Nye County, as irregular bunches in a shattered and bleached andesite or andesite tuffbreccia (Ransome, 1909). Locally the sulfur forms the matrix for the fragments of greatly altered rock. The sulfur is massive and may occur in lumps large enough to be hand sorted from waste, but the mineral is unevenly distributed and the deposit is not commercial. The sulfur was deposited either in connection with fumarolic activity or by hot sulfurous waters.

Two deposits of sulfur near Cuprite (No. 9), Esmeralda County, are within a mile of each other. The more northerly one is the larger and a "car or two" of sulfur is said to have been shipped from several prospecting pits (Ransome, 1909). From 1915 to 1923 ore was shipped to Hawaii as a soil aid (Branner, 1959). The host rock probably was a rhyolitic glass or tuff which has been intensely altered by solfataric action. This same action, probably at a later stage, deposited the sulfur. The southerly deposit is smaller and is considered by Ransome (1909) to have been rhyolite pumice, which has been subsequently solfatarically altered.

The Anaconda Co., operating the large open pit copper mine near Yerington, uses large quantities of sulfur in manufacturing sulfuric acid for leaching copper oxide ore. For the past 10 years or so sulfur ore has been obtained at the Leviathan mine in Alpine County, Calif., about 3 miles from the Nevada border. In recent years this ore has been supplemented with relatively small imports of native sulfur recovered from sour gas in western Canada.

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### TALC

(By L. A. Wright, Pennsylvania State University, University Park, Pa.)

The mineral talc, a hydrous magnesium silicate, can be distinguished from most other minerals because it is both exceedingly soft and chemically inert. In a commercial sense the term "talc" also refers to a mixture of minerals, predominantly magnesium silicates, in which the mineral talc may or may not be a prominent constituent. Much talc of commerce, for example, consists largely of the hard mineral tremolite. Both the mineral and commercial material range widely in color and the ease with which they can be broken and ground.

Commercial talc is used mostly as an extender in paints, and as an ingredient in the manufacture of paper and various ceramic products including tile, whiteware, and electrical insulators. For these and various other uses a light color ordinarily is specified, white and shades of gray and green being the most common. It also is required to be of low iron content, and, when used in ceramics, to show desirable firing properties. Talcs of high iron content are considered to be of lower quality but are used as fillers and insecticide carriers and for other purposes where color and particular firing properties are not specified. The higher quality talcs are valued at the mine in the general range of \$10 to \$20 per ton and, when ground, ordinarily have a price range of \$25 to \$45 per ton. Certain high purity and

specially treated talcs sell for much higher prices. Several hundred thousand tons of talc are mined annually in the United States, mainly from New York, California, Texas, Vermont, Georgia, and Montana.

All talc, both the mineral and the commercial material, is an alteration of various common rocks. Most talc deposits of minable size have altered from highly magnesian rocks, especially serpentine and dolomite, but phyllite, quartzite, and granite also have been altered to talc on such a scale as to form exploitable deposits. Talc that has altered from serpentine is persistently iron-rich and of limited application. Most of the higher quality and, consequently, higher priced talc that is mined in the United States is an alteration of dolomite.

Since the mid-1920's talc has been mined nearly continuously in Nevada, generally at rates in the general range of 2,000 to 15,000 tons per year. It has been obtained entirely from the Palmetto-Oasis area in Esmeralda County near the western border of the State. Peak production was in the early 1940's when wartime uses placed heavy demands upon the deposits. Of the six mines from which virtually all of this total has been obtained, the Oasis mine has been by far the most productive. The talc bodies at this mine and those of the nearby Roseamelia, Reed, White Eagle, and White King mines have formed along or near a major thrust fault along which Mesozoic(?) granitic rock has been thrust over Paleozoic dolomite. The talc from these properties has consisted essentially of the pure mineral, much of it of such high quality as to be used in cosmetics and pharmaceuticals; this talc also meets the chemical specifications of steatite-grade talc, for use in the manufacture of electrical insulators, but the insulator manufacturers, in general, have preferred to use talc from other sources.

The high quality talc in the vicinity of the Oasis mine forms pods and irregular bodies, all alterations of the footwall dolomite. Talc of comparable quality also has been found at numerous other localities scattered through an area of about 30 square miles, but only at the Sun Down mine has it been mined in quantity away from the thrust fault. Most of the mined material has been obtained from lenses and irregular bodies that range in length from 50 to 500 feet and in width from 5 to 30 feet. Other occurrences generally are too small to be mined profitably.

In the granitic rock that forms the hanging wall of the thrust fault are bodies of green chloritic material which is termed "blue talc" by the miners. It has been extensively mined at one property, the Mac-Boyle mine, and also occurs, apparently in large tonnages, at the Oasis mine and vicinity. A limited market and a relatively low value have restricted the mining of this material.

As the bodies of high-quality talc are discontinuous and irregular in shape and have been worked by small-scale methods, the proved reserves of talc have been low at all times. This mode of occurrence also probably will prevent large-scale mining of talc in the future. Although most of the larger and well-exposed bodies appear to have been mined out, much talc probably remains to be recovered if the costs of exploration and mining permit.

## VERMICULITE

(By R. H. Olson, Nevada Bureau of Mines, Reno, Nev.)

Vermiculite is essentially an expandible mica, a hydrated magnesium-aluminum silicate which expands greatly when heated (a process known as exfoliation). The expansion accomplished by this process ranges from 6 to 30 times the volume of the crude material. Practically all the uses for vermiculite involve only the expanded material. Vermiculite is a platy brownish to greenish mineral which splits readily into individual laminae which are soft, pliable, and inelastic. Natural specimens resemble biotite in appearance. It is not a mineral of fixed composition and there is not yet complete agreement between workers on the exact chemical formula and composition. Vermiculite should be thought of as a variable mineral rather than as constituting a group of related species.

There is essentially only one type of vermiculite deposit, although more than one process of alteration was probably involved in the formation of most individual deposits. Vermiculite is intimately associated with such ultramafic rocks as pyroxenite, peridotite, dunite, and serpentine; pegmatite dikes or other acid intrusives are commonly found nearby. A few occurrences which are not closely associated with basic rocks are known, but they are small and have not yielded commercial expansible vermiculite. It is generally agreed that natural deposits are all secondary in origin and are formed by hydrothermal action upon the starting material (ultramafic rock), by weathering processes in the zone of meteoric water activity, or by a combination of the two processes.

Expanded vermiculite has many useful characteristics, but the most important probably are its excellent thermal insulation properties at temperatures ranging from below zero to 2,000° F., its low-bulk density, and its inertness (will not decompose nor decay during its use in process applications). It is estimated that over 70 percent of the expanded vermiculite produced goes into the building and construction field, with the major part of this going into plaster aggregate. Other major uses include horticulture, as various types of carriers, refractory firebrick, fillers, and binders. There are more than 40 proven uses for vermiculite.

The mineral vermiculite was discovered and named in 1824, but for almost a century its unusual chemical and physical properties were not exploited for commercial purposes. As late as 1940 only 22,000 short tons were produced in the United States, but in 1950 more than 200,000 short tons were produced and the output has remained at this level since. The United States and the Republic of South Africa produce almost all of the vermiculite used in the free world.

Nevada has never produced substantial quantities of vermiculite. There are only two known deposits, both in the southern portion of the State, and only one of them has been explored. Nevertheless, they are of interest because of their geographical position between certain western U.S. market areas and the extensive deposits at Libby, Mont., which currently are the principal source of supply.

The vermiculite deposits near Gold Butte (No. 1, fig. 53), Clark County, have been known for several decades. They occur in a Precambrian complex not too far south of a major transverse fault. Peridotites and related rocks are closely associated and believed by

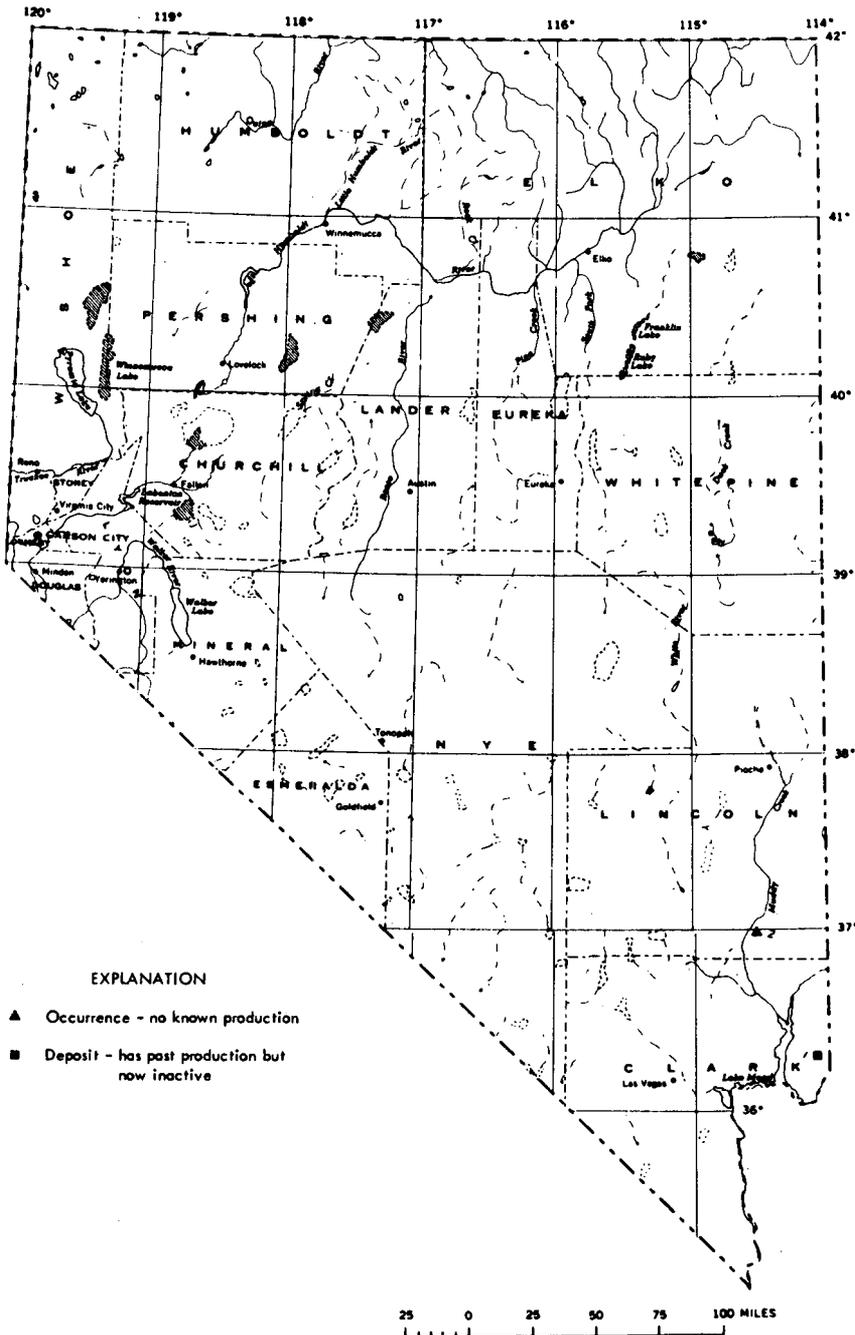


FIGURE 53.—Vermiculite in Nevada (numbers refer to deposits discussed in text).

Leighton (in press) to be genetically related; all of the vermiculite deposits were formed from these dark ultramafic rocks. Four carloads of material from these properties are known to have been shipped to Los Angeles, but there has been no steady production. A mill with reported capacity of 25 tons per day was set up in 1945, but it has since been badly damaged and partially dismantled. The extreme remoteness from rail transportation is a depressing factor affecting the worth of this deposit.

Another deposit along the base of the western flank of the Mormon Range (No. 2), Lincoln County, is much closer to rail transportation. The writer made a brief inspection of this property recently but samples obtained on this trip have not yet been evaluated. However, the claim owners state that commercial firms have tested samples and claim that it is vermiculite. This occurrence is also in a Precambrian sequence and like the Gold Butte deposit is also associated with pegmatitic dikes and other granitic rocks. The host rock is probably a pyroxenite or rock of similar composition, but metamorphic rocks, such as biotite schist, are more abundant here than at Gold Butte. There has been no production from this deposit nor have there been any beneficiation tests performed to the writer's knowledge.

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## POWER

### GEOTHERMAL POWER

(By R. C. Horton, Nevada Bureau of Mines, Reno, Nev.)

The utilization of the earth's heat for the production of power is a relatively new idea in the United States. The first, and so far the only, production of electrical power from natural steam was begun in 1960 at the Geysers near Cloverdale, Calif., where the Pacific Gas & Electric Co. currently operates a 12,500-kilowatt geothermal powerplant.

Elsewhere in the world geothermal power is not so new. A steam well was drilled at Lardello, Italy, about 40 miles from Florence, in 1904. By the late 1930's the Lardello steam wells were producing 100,000 kilowatts of electrical power and at present the production exceeds 300,000 kilowatts. In 1950 the New Zealand Government began drilling wells at Wairakei, North Island, and by 1958 were producing 65,000 kilowatts from 39 steam wells. The capacity of the Wairakei field, which is almost 50 miles long, has been estimated to be between 250,000 and 280,000 kilowatts. Russia, on the Kamchatka Peninsula, and Mexico, in the State of Hidalgo, are also producing electricity from natural steam power. Many other countries, including Chile, El Salvador, Fiji Islands, Guatemala, Iceland, Japan, and Nicaragua have initiated geothermal power developments.

The interior of the earth is hotter than the exterior, resulting in a flow of heat toward the surface. The amount of heat normally transmitted is so slight that it is not readily detectable at the surface. The normal geothermal gradient, that is, the increase of temperature with depth, varies from 1° to 2° F. per 100 feet of depth. There are many geologic factors that cause deviations from the normal, but these deviations are usually not extreme except in the cases of hot springs or volcanism.

In nonthermal areas the temperature of the rock a few feet below the surface is very close to that of the mean annual air temperature of the region (50° to 60° F. in most of Nevada). With a mean annual air temperature of 50° F. and a thermal gradient of 2° F. per 100 feet, the temperature at a depth of 1,000 feet would be 70° F. (50+20). It is fortunate that the temperature does not normally increase rapidly with depth as deep mining would be extremely difficult, if not impossible.

Thermal gradients at hot spring localities are much greater than normal. In addition, the initial surface temperature is higher than the mean annual air temperature. Many hot springs in Nevada are hot enough to boil (212° F. or less depending upon the elevation). Because of the hydrostatic pressure of the overlying column of water it is possible for hot water at depth to have a temperature well above the normal boiling point at the surface. At a depth of 1,000 feet; i.e., with a hydrostatic head of 1,000 feet, water will not boil until heated to 419° F. If a well is drilled into a zone of hot water at depth

and the hydrostatic pressure relieved through the drill hole, the water will flash into steam. This steam is then available for the production of power. Generally, the greater the depth at which the well taps the hot water zone the greater will be the pressure and temperature at the wellhead.

Very deep holes are not necessarily practical as the thermal gradient usually does not remain constant. As greater depths are attained, particularly in hot spring areas, the rate of temperature increase with depth becomes less. Various phenomena are responsible for this change in the thermal gradient but perhaps the most obvious one is where a hot body of solidified magma is buried at depth. The temperature will increase rapidly from the surface down to the solidified magma body, but the temperature increase will be much less once the heat source is reached. A decrease in temperature could occur if the well did not stay within the solidified magma body.

Most geologists believe that hot springs obtain their heat from near-surface igneous activity as mentioned above. Bodies of molten rock, formed at great depths, work their way toward the surface and greatly increase the quantity of heat flowing toward the surface. Even after the rock has solidified, considerable heat continues to be released from the cooling mass. When faults intersect or come close to such heat sources a channel is provided for rapid conduction of heated water to the surface. As the heated water rises cooler water moves downward establishing a convection system not unlike a boiler plant with gravity acting as a pump to supply fresh water to the boiler.

The transfer of heat from the igneous mass to the water can occur in a number of ways: heated magmatic water derived directly from the igneous rock mass may mix with the cooler ground water; hot gases may carry heat to the water; the ground water may come in direct contact with the igneous rock; heat may be conducted through an intervening rock mass; and other heat transfer systems or combinations of systems may be active.

Two types of water are involved in hot spring systems, magmatic water and meteoric water. Magmatic water is derived directly from the magma. Meteoric water is derived from rainfall. There is no agreement among geologists as to the relative abundance of these two waters in hot springs, but it is generally believed that the amount of magmatic water present in a particular hot spring system will depend upon the amount of ground water available to the system and the intimacy of the connection between the hot spring system and the igneous rock heat source. It would be easily possible for the igneous rock, molten or solidified, to supply heat to a hot spring system without supplying any magmatic water. The converse may also be true; some believe that all, or at least a large proportion, of the water found in one well drilled near the Salton Sea, Calif., may be of magmatic origin. The water in this particular well is a concentrated brine containing large quantities of various salts and lesser amounts of metals. It suggests the possibility of obtaining minerals, as well as power, from hot springs.

There are 185 known hot spring localities in Nevada, as shown in figure 48. An arbitrary lower limit of 70° F. was established in selecting hot springs for this map. It is probable that some of the hot springs which have temperatures in excess of 70° F. are warm by reason of artesian supply from deeply buried aquifers, while others cooler than 70° F. may be warmed by magmatic heat sources. However, for the map to be of value, it was necessary to select some arbitrary lower limit which would represent abnormal or unusual thermal situations.

Sinter deposits, other than those associated with active hot springs, are listed as they may represent recently sealed hot springs capable of producing steampower when drilled. The volcanic cinder cones are shown as they too represent thermal activity and, in some instances, appear to be associated with hot springs. The cinder cones in Lander County and those in Nye County are alined with active hot springs.

A number of hot springs have been drilled in Nevada, beginning with Steamboat Hot Springs (No. 4, fig. 48), Washoe County, in 1949. Since then wells have been drilled at Brady's Hot Springs (No. 3), Churchill County; Wabuska Hot Springs (No. 5), Lyon County; Beowawe Geysers (No. 1), Lander County; Darrough Hot Springs (No. 6), Nye County; near the Needles at the north end of Pyramid Lake (No. 2), Washoe County; and further drilling has been done recently at Steamboat Springs (No. 4), Washoe County. Plans are now being made for the construction of a steamplant at the Beowawe Geysers.

Additional drilling of steam wells in Nevada is almost a certainty. Legal problems concerning the ownership of natural steam, development of steam wells on public lands, and related problems presently plague the industry and must be solved before large-scale drilling can be undertaken. The development of natural steam power requires the intelligent use of geology and geophysics. Merely drilling close to an active hot spring does not guarantee success, as the heat source may not be directly below the spring; indeed it would be unusual to find it so.

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#### WATERPOWER

(By R. N. Doolittle, U.S. Geological Survey, Menlo Park, Calif.)

The waterpower resources of Nevada are, for the most part, fully developed. The capacity of existing hydroelectric power installations and the gross theoretical potential of the few remaining undeveloped sites are summarized in table 19. The locations of the powersites, developed and undeveloped, are shown on figure 54. The gross theoretical power figures are based on the total head available at the various sites, 100 percent efficiency and for flows available 95 and 50 percent of the time and mean flow, referred to as Q95, Q50, and Q mean. All developed sites are included, but undeveloped sites with a potential output of less than 1 megawatt (1,000 kilowatts) at Q50 were excluded.

TABLE 19.—*Developed and undeveloped waterpower in Nevada—Dec. 31, 1962*

Principal drainage area and subdivisions	Developed waterpower sites			Undeveloped waterpower sites			
	Number of sites	Installed capacity (MW)	Average annual generation (MWH)	Number of sites	Gross theoretical power with gross head, 100 percent efficiency and flows at—		
					Q95 (MW)	Q50 (MW)	Q mean (MW)
Colorado River Basin: Total (Hoover and Davis).....	2	1,569.8	6,678,000				
Nevada allocation.....	1	237.0	969,000				
Snake River Basin, Owyhee River.....				3	0.8	3.5	7.6
Great Basin:							
Truckee River.....	4	6.6	54,000				
Carson River.....	2	2.4	24,000	2	1.9	5.7	14.6
Lamoille Creek.....	1	.25	1,500				
West Walker River.....				1	.3	1.1	3.2
Duck Valley Creek.....	1	.8	1,900				
Total for State.....	9	247.05	1,050,800	6	3.0	10.3	25.4

MW = Megawatt = 1,000 kilowatts.

The Colorado River, which drains about 10 percent of the State, provided 96 percent of its hydroelectric power production. The 1569.8 megawatts of installed capacity at Hoover and Davis Dams represents about 4 percent of the United States total and provides complete development of the Colorado in the reach where it forms a common boundary between Nevada and Arizona.

Hoover Dam, a feature of the U.S. Bureau of Reclamation's Boulder Canyon project, was completed in 1931. The powerplant has an installed capacity of 1,344.8 megawatts. As turbines are installed at both ends of the dam, the Federal Power Commission for record purposes, prorates the power equally between Arizona and Nevada. However, by contract with the United States, Nevada is allocated 17.6259 percent of the energy produced at the plant until 1987. For the purpose of this report the Hoover powerplant will be considered as contributing its allocated percentage of installed capacity or 237 megawatts of power to the State total.

Davis powerplant, constructed in 1951, is located at the Arizona end of Davis Dam and has an installed capacity of 225 megawatts. This plant, a unit of the U.S. Bureau of Reclamation's Parker-Davis project, is interconnected with the Hoover plant and provides some power to the basic magnesium plant at Henderson, Nev. Because of the powerhouse location, the Federal Power Commission credits all of the Davis power to Arizona and the State of Nevada has no contractual allocation of any of this power.

The total installed capacity in Nevada hydroelectric plants is 247.05 megawatts, of which its allocation from Hoover Dam accounts for all but 10 megawatts. The 10 megawatts is divided between eight small privately owned plants with installed capacities varying from 0.3 to 2.4 megawatts. Most of these plants were constructed between 1901 and 1915. The new plant, constructed on "V-Canal," below Lahontan Reservoir, in 1955, is the most recently constructed hydroelectric powerplant in the State.

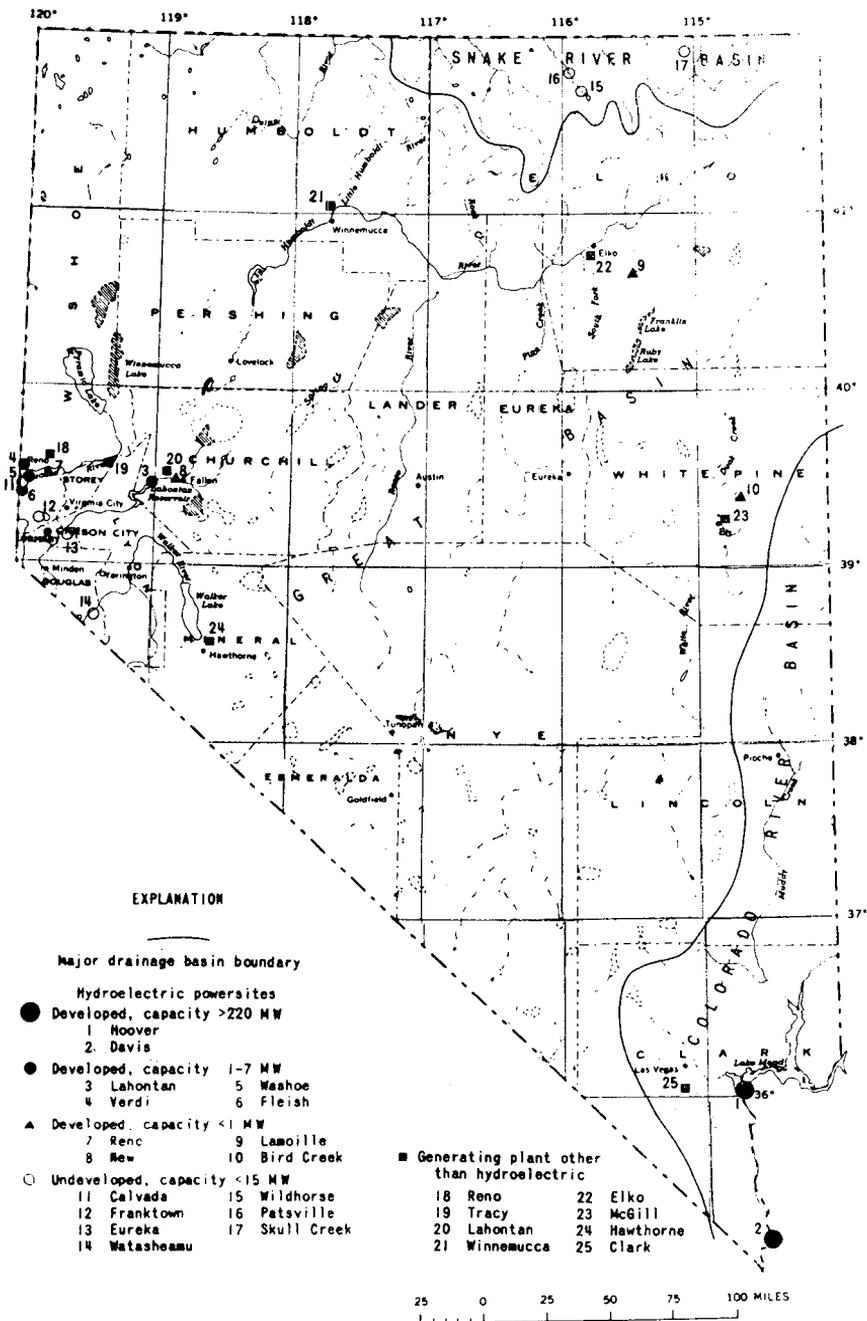


FIGURE 54.—Powersites in Nevada.

Of the six undeveloped hydroelectric powersites summarized in table 19, only one appears to be economically feasible. This is the Watasheamu site on the East Fork Carson River for which an installed capacity of 8 megawatts has been recommended. This site is included in the U.S. Bureau of Reclamation's Washoe project, construction of which is dependent on congressional appropriations. The Calvada powersite, which is located in Nevada but would have utilized storage in proposed Stámpede Reservoir on the Truckee River in California is no longer receiving serious consideration. A powerhouse location in California and considerably closer to Stámpede Reservoir has now been recommended. Table 19 lists three undeveloped sites on Owyhee River in the Snake River Basin. Although Wildhorse Reservoir provides 32,700 acre-feet of storage on the East Fork Owyhee River, it is unlikely that irrigation and recreation requirements will permit power generation at either this or the other two undeveloped Owyhee sites.

Few of Nevada's Great Basin streams lend themselves to hydroelectric power development because of the region's semiarid climate and the resulting heavy demands on its inadequate water supply. Only those streams originating in the higher elevations along the Sierras and in the mountains of northeastern Nevada get sufficient snowmelt to sustain average runoff more than 2 or 3 months of the year. It is therefore evident that the future will bring no significant increase in total hydroelectric power generation in Nevada although an 8-megawatt installation at Watasheamu would be a significant increase in Nevada's Great Basin production.

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## WATER RESOURCES

(By H. E. Thomas, U.S. Geological Survey, Menlo Park, Calif.)

The importance of water to the economy of Nevada is demonstrated by the distribution of the present population. About 50 percent of the people are in the Las Vegas Valley near the southern tip of the State, where there is a large reservoir of ground water; for a supplementary and sustained supply the Las Vegas area draws water from Lake Mead on the Colorado River, which is the largest stream touching Nevada. About 35 percent of the population lives in the valleys of the Truckee, Carson, and Walker Rivers, the three largest streams in the State and all rising in California; Reno is the commercial center for this region. Half of the remaining 15 percent of the State's population is in the basin of the Humboldt River, Nevada's largest intrastate stream. This leaves about 7 percent of the population to man tourist services, livestock ranges, mining operations, and county seats over about four-fifths of the State's area, which thus has a density considerably less than one person per square mile. Clearly, Nevadans are concentrated around the largest perennial sources of water.

This has not always been true. In the first half century of statehood—prior to World War I—the State's economy depended chiefly upon extraction of the mineral resources described in preceding chapters. Water was a secondary consideration, in some places so abundant as to drown out mining operations (p. 307), in others so sparse as to require long flumes or tunnels or pipelines or hauling to serve the miners and their communities. Some of these mining communities gained thousands of people in a few years and then dwindled as rapidly to caretaker and postmaster personnel. State census figures for these early years reflect the fluctuations of the mining economy: rising to 62,000 in 1880 with booming Austin and Eureka and especially the Comstock Lode, declining to 42,000 by 1900, rising to 82,000 in 1910 chiefly because of Tonopah, Goldfield, Rhyolite, and Bullfrog, and then declining to 77,000 by 1920. Even in these early days, perennial water supplies were an important factor in the selection of sites for ore-processing, shipping, and agricultural centers, and many of the resulting towns have prospered and grown in subsequent years.

Recognition that a perennial water supply is essential to a sustained economy and continued prosperity is reflected in Nevada's laws and policies concerning water development and use. By statutory declaration, all waters within the State belong to the public and may be appropriated for beneficial use, and such beneficial use is the basis, the measure, and the limit of the right to the use of water; but each new appropriation is subject to existing rights, so that the general principle is "first in time, first in right." According to the U.S. Supreme Court:<sup>1</sup>

<sup>1</sup> *Arizona v. California*, 283 U.S. 423 (1931).

To appropriate water means to take and divert a specific quantity of water therefrom and to put it to beneficial use in accordance with the laws of the State where such water is found, and by so doing to acquire a right under such laws, a vested right to take and divert from the same source and to use and consume the same quantity of water annually forever.

Renewability of the resource, and therefore a perennial supply, is inherent in this definition. The first question, then, concerning Nevada's water resources is, what is the perennial supply?

#### PERENNIAL SUPPLY

The perennial supply of fresh water in Nevada comes from precipitation, yet the population is so distributed as to obtain minimum direct benefit from it. The populated Las Vegas area receives an average of 4 or 5 inches a year, the minimum for the State. For communities within 50 miles of Reno the annual average precipitation is 5 to 7 inches, with the notable exception of Carson City's 11 inches. An average of 6 to 9 inches is characteristic of all other towns having population over 1,000. All these towns are in the valleys and basins of the State, generally at altitudes less than 6,000 feet, and all these "lowlands" are properly classed as arid.

In the few localities above altitude 6,000 feet where records have been collected, the average annual precipitation commonly ranges from 10 to 20 inches. At several storage gages in mountainous areas above 7,500 feet altitude the annual precipitation exceeds 20 inches, and some of the highest mountains may receive as much as 40 inches. Clearly, the basin and range topography has a pronounced effect upon the geographic distribution of precipitation within the State. These orographic effects are shown in figure 55, adapted from one by Hardman and Mason (1949, p. 10), which is based upon available precipitation data, extrapolated by means of topographic maps and maps of vegetation zones. In general, precipitation increases with altitude in each region; at the same altitudes, precipitation is about one-third lower in southern Nevada than in the northern half of the State; and the driest areas are in the western part of the State, where the barrier or "rain-shadow" effect of California's high Sierra Nevada is most marked. Calculated from this map, the average annual precipitation on the State is about 9 inches, which would produce a volume of 50 million acre-feet of water.

The perennial supply available for man's use and benefit is not the total precipitation, but merely that portion of the precipitation that is not returned to the atmosphere; in other words, precipitation represents the gross supply, from which must be subtracted the evapotranspiration in order to obtain the net supply that is perennially available for man's use.

#### NET WATER SUPPLY

Much of the water from Nevada's precipitation gets lost quickly, so that there is no visible evidence of it within a few days after a storm. The annual rate of evapotranspiration—return of water from the earth to the atmosphere—is generally far less than the evapotranspiration potential of which the climate is capable, simply because of the dearth of water that is accessible to evapotranspiration (except immediately after storms). We have evidence of the potential evapo-

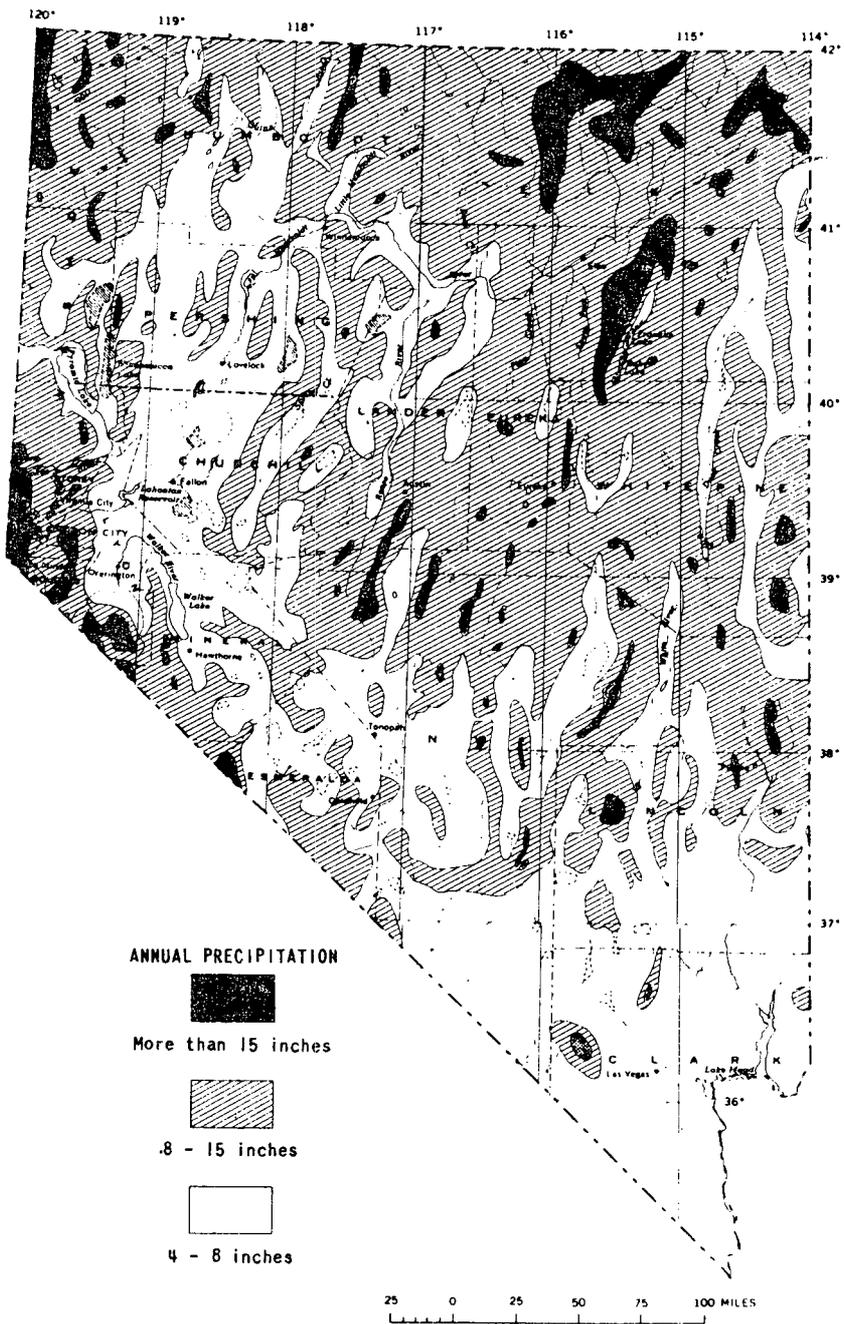


FIGURE 55.—Assumed average precipitation in Nevada (adapted from Hardman and Mason, 1949, p. 10).

transpiration rate only in places where water is continuously available: in the rate of evaporation from Lake Mead, for instance, averaging about 84 inches annually (Harbeck and others, 1958, p. 59), and in the requirements for consumptive use for irrigation projects throughout the State (Houston, 1950, p. 11).

Thorntwaite (1948, p. 64) shows the annual potential evapotranspiration to range from less than 24 inches in the northeast quadrant to more than 39 inches in the southern part of the State. On an annual basis potential evapotranspiration exceeds average precipitation in all parts of the State except on a few mountain crests. Therefore, on the basis of averages, practically all the State is an area of perennial water deficiency. In other words, if precipitation came regularly in accordance with daily, monthly, and annual averages, so much of it would be immediately claimed by evapotranspiration that the amount left for man would be negligible.

In part, Nevada has some perennial supplies because of the seasonal march of climate, wherein precipitation is greatest in winter when evapotranspiration is least, and potential evapotranspiration is greatest in summer when the least water is available from precipitation. In greater part, Nevada owes its perennial water supplies to the fact that the actual precipitation differs markedly from the calculated monthly and annual averages. Precipitation during storms, seasons, or decades that are markedly above the average provides water in excess of the concurrent draft of evapotranspiration, and this excess is stored in natural or artificial reservoirs. To the extent that this water can be used during subsequent drought periods (which are also an integral part of the climate embraced by our averages), it constitutes a perennial supply.

About 85 percent of Nevada is within the Great Basin, which extends also into California, Oregon, and Utah. From the Great Basin there is no surface outflow, and no known subsurface outflow of significant proportions. Within the Great Basin, or any self-contained subunit thereof, all precipitation is eventually returned to the atmosphere by evapotranspiration, and the total evapotranspiration equals total precipitation. From year to year, from season to season, or in shorter periods, there may be significant differences, reflecting changes in storage of soil moisture, ground water, and surface water within the basin. Man's quest for perennial supplies is thus a search for water that has been derived from precipitation and ultimately would be returned naturally to the atmosphere by evapotranspiration; in other words, a search for usable water in some form of storage during the interval between its arrival on earth by precipitation and its departure by evapotranspiration. But before we discuss water in storage, let us first consider the vagaries of precipitation and especially the outstanding events that contribute to storage.

#### DEVIATIONS FROM AVERAGE PRECIPITATION

Marked variations in annual precipitation are indicated in the statewide average, which has ranged from less than 5 inches (in 1928) to more than 14 inches (in 1891); this statewide average has been less than 7 inches in about 20 percent of the years of record and more than 11 inches in the same percentage of time.

At individual localities the year-to-year variations in precipitation are even greater than is indicated in the overall State averages. Reno, Winnemucca, Montello, McGill, and Las Vegas are used as examples (fig. 56). At each city the location of the gage has been

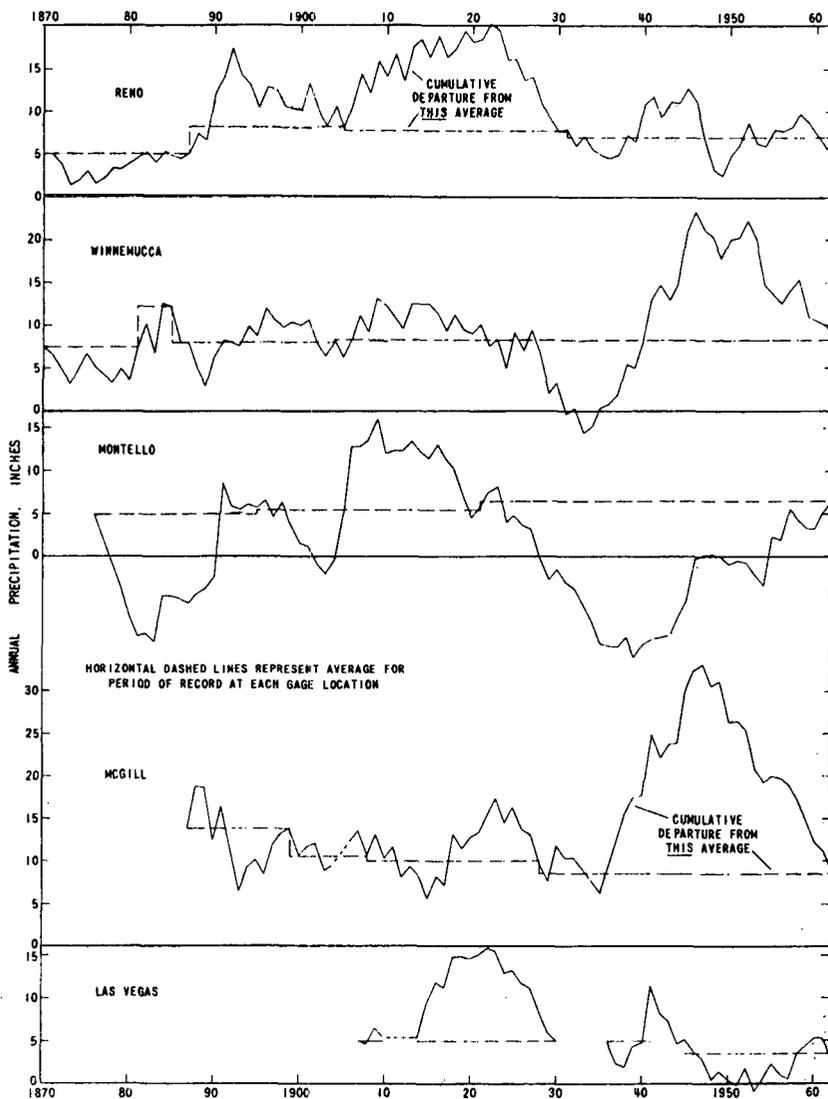


FIGURE 56.—Deviations from average annual precipitation at five cities in Nevada.

shifted several times in the course of the long period of record, with resulting change in average precipitation. Averages have therefore been computed for the record at each gage location, and these station averages are shown on figure 2 by horizontal lines for the applicable

years. The saw-toothed graph for each city depicts the cumulative deviation from the average at each gage location. A sharp rise in a single year indicates exceptionally great precipitation, as at Montello in 1891 and 1906, and in most communities in 1941 and 1945. A rising trend (as in 1936-46 at most of the cities) indicates a succession of years when precipitation was generally above average. All the graphs have a downward trend for the period 1924-34. This was a period when drought conditions prevailed throughout the State, as well as in California, which also receives its precipitation chiefly in the winter and chiefly from moist Pacific air masses moving eastward (Thomas, 1962, p. 23). Other extended drought periods are indicated at each locality, but generally not of statewide extent. The graphs show considerable variation in the climatic fluctuations that are recorded in various parts of the State.

Nevada's atmosphere provides a perennial supply of water in about the same way that its slot machines provide tourists a perennial supply of money. Habitually it is taking up the water by evapotranspiration, but there are occasional payoffs, and less frequent jackpots, in precipitation. If, unlike the tourist, the State can find pockets to store that payoff, preferably out of the reach of evapotranspiration, then there are prospects for continuity of supplies. The next question, then, is what are the facilities for storage?

#### STORAGE

The term "storage" is extended here to include all the water from the time it reaches the earth by precipitation until it returns to the atmosphere by evapotranspiration; in other words, all the liquid assets that are of present or potential use to man. Thus it can include snow, the water in lakes and surface reservoirs, the water in ground water reservoirs, and also soil moisture. As to water flowing in stream channels; most storm runoff in Nevada is on its way to storage either underground or in lakes or playas; and after the storm runoff has ceased, any streamflow is necessarily derived from ground water storage. Thus, in the total time that the water remains on earth, streamflow constitutes a short transitory stage in storage, under this broad definition.

#### SOIL MOISTURE AND SNOW

The soils and other rock material that form the land surface receive practically all of Nevada's precipitation, and return the great bulk of it to the atmosphere. Some of the water from precipitation is absorbed by the soil, and some of the absorbed water may continue downward beyond the depth of plant roots and out of reach of evapotranspiration processes; any water not absorbed must stand on the surface or run off overland. There are great variations from place to place and from storm to storm in the proportions of water that thus become soil water, ground water, and surface water. We can list the factors that are probably responsible for these variations, but we do not know the actual quantities involved in any part of the State. Rough estimates have been made of the total quantities of water used consumptively, chiefly in irrigation; of the evaporation from free-water surfaces; of surface-water outflow from the State;

and of the natural discharge of ground water by evapotranspiration. Adding these together, we can account for not more than 10 percent of the 50 million acre-feet which is the assumed average annual precipitation. Thus the soil zone disposes of about nine-tenths of the gross perennial supply.

In recent research (Waananen, 1964) neutron-scatter meters have provided quantitative data on the storage and movement of water in soil and other unsaturated materials. Such data are essential to an understanding of the processes involved in the natural recharge of ground water, and hopefully, in artificial recharge that would salvage a greater proportion of the gross supply for man's use.

Snow is a special form of storage on the land surface of the winter precipitation, which upon melting provides streamflow or ground water for use during the growing season. Snow surveys provide estimates of the quantities that will be available during the forthcoming season. Only a part of the snowfall contributes to the net water supplies, however, as the rest returns to the atmosphere by evaporation and sublimation.

#### CLOSED BASINS

The basin and range topography of Nevada includes many basins from which there is no surface outflow. In these closed basins, the rates of precipitation are greatest on the bordering ranges, and water flows from them toward the lowest part of the basin. These basins store not only the water but all the sediment and dissolved materials eroded and transported from the ranges. The thickness of accumulated sedimentary deposits in most basins is measured in hundreds and even thousands of feet.

The closed basins are a product of the Basin and Range geologic structure, but they are emphasized by the perennial water deficiency that has characterized Nevada's climate ever since the rise of the Sierra Nevada barrier in California. If the deficiency were less—that is, if the ratio of precipitation to potential evapotranspiration were increased—water would accumulate in the closed basins to form lakes, and some of these lakes might overflow into other lower basins. This has happened in geologic history (Feth, 1961 and 1963) notably during the Pleistocene Epoch (fig. 57). Also during geologic history, some streams have established channels through several alluvial basins and intervening ranges: the Humboldt River basin is a prime example of such an integrated pattern. Some of these integrated systems have subsequently disintegrated, because there has not been enough water to maintain them: as an example, the White River rising in the east central part of the State near Ely, is officially a tributary of the Colorado River, but in historic time there has been no flow-through from the headwaters down the channel to the Colorado.

In some of Nevada's closed basins, ground water also moves toward the lowest part of the basin and is discharged by evapotranspiration—all water from precipitation is stored within the basin until it returns to the atmosphere, and there is no outflow of water from the basin. However, evidence is accumulating that beneath several basins with topographic closure there is nevertheless outflow of ground water



## SURFACE WATER

In a typical small stream extending from range crest to valley floor in one of Nevada's closed basins, the streamflow pattern may be summarized as follows: the maximum runoff is likely to result from intense rainstorms, or from melting of accumulated snow, or from a combination of warm rain and melting snow cover. The volume of water in the channel generally increases as it traverses the mountainous runoff-producing area and then decreases by seepage as it flows out over the gentler slopes of the alluvial materials of the basin. Unless the water disappears entirely by seepage, some continues to the lowest part of the basin where it is stored in a lake or playa. Most of these small streams are ephemeral and erratic in flow; any perennial stream, or perennial reach of a stream, may be presumed to be fed by ground water discharged at springs and seeps.

This general pattern also fits, with some modifications, the larger streams of the State. For example, the principal water-producing area of the Humboldt River is the mountainous upper third of its drainage basin, and the river commonly attains its maximum volume in the vicinity of Palisade. Downstream the flow dwindles because of diversions and natural evapotranspiration in the valley, until it is not much more than half as great at Rye Patch Reservoir, although the drainage basin above Rye Patch is almost three times as great as that contributing to the river at Palisade. Rye Patch now stores water—for irrigation around Lovelock—that formerly flowed to natural and useless storage in Humboldt Sink.

Most of Nevada's surface water is in interstate streams. The average annual outflow to Idaho, in tributaries of the Snake River, is on the order to 400,000 acre-feet. About three times as much comes into Nevada from California in the Truckee, Carson, and Walker Rivers, and for these rivers, the natural storage is in the lowest parts of the respective basins: Pyramid Lake, Carson Sink, and Walker Lake. The flow of the Carson River, however, has long been regulated by Lahontan Reservoir, from which water is diverted for irrigation in the vicinity of Fallon. Similarly, reservoirs on the Walker and Truckee Rivers have provided regulated supplies for irrigation and other uses within the respective drainage basins. Because of these diversions from the sustaining streams, the levels of Pyramid Lake and Walker Lake have been lowering progressively for several decades.

Lake Mead is a major storage facility for water of the Colorado River, of which 300,000 acre-feet annually has been allocated for Nevada's use, and about 20,000 acre-feet is currently being used in Las Vegas Valley. The water loss due to evaporation from Lake Mead is equivalent to about 4 percent of the average volume in storage or 7 percent of the average annual inflow, and it is three times as great as the quantity allocated for Nevada's use (Harbeck and other, 1958).

An accompanying map (fig. 58) shows the streams whose average flow exceeds 10 cubic feet per second (or 7,200 acre-feet a year), and shows diagrammatically the magnitude of the flow in various reaches of the streams. The map also shows location of surface reservoirs with capacity greater than 5,000 acre-feet.

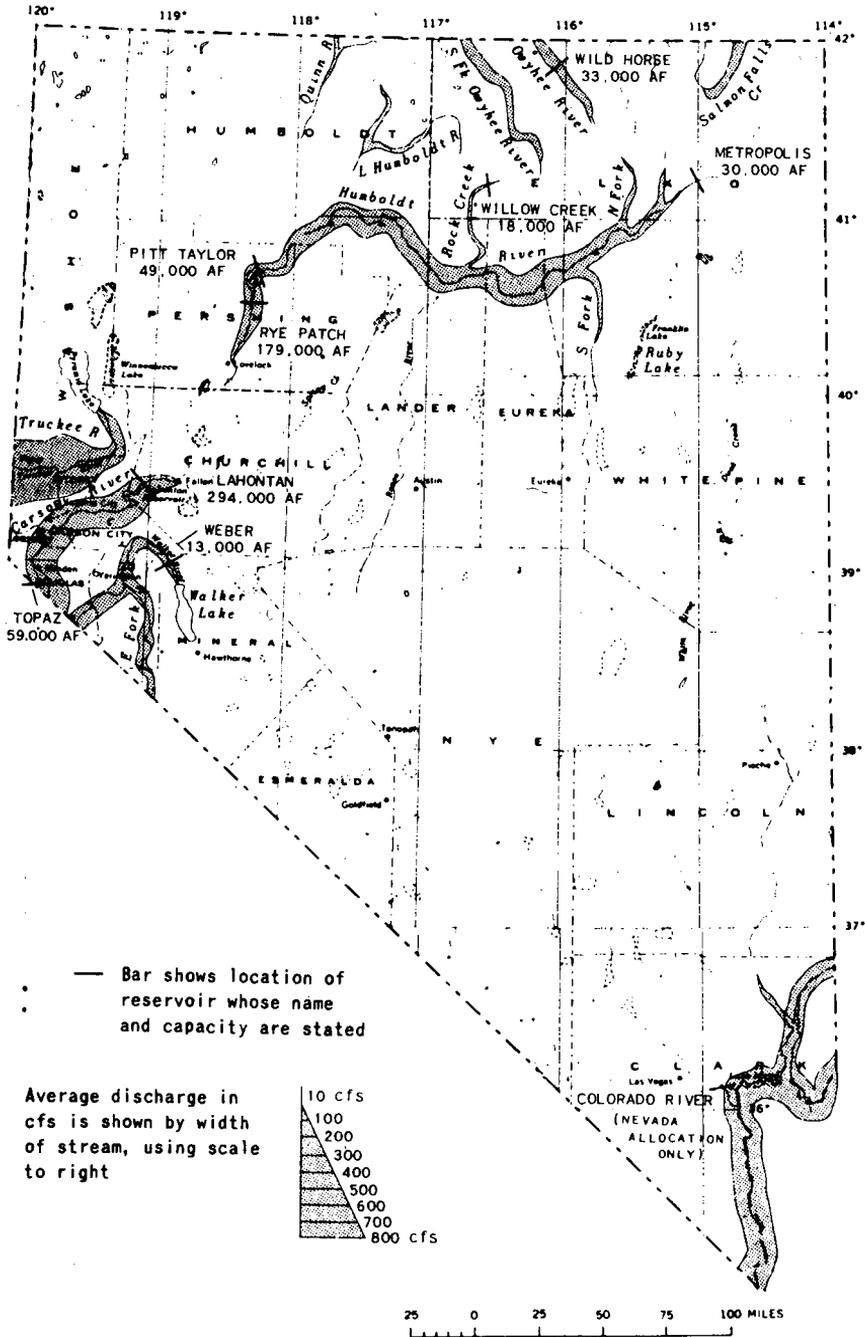


FIGURE 58.—Principal streams and surface reservoirs in Nevada.

## GROUND WATER

Most water stored in Nevada is ground water—a volume many times as great as the gross supply received annually by precipitation. This accumulation has been possible in spite of the arid climate because the soils and rock materials have pores capable of absorbing the water from precipitation and conducting it to depths beyond the reach of evapotranspiration. Of the total storage, the net perennial supply is only that small portion that is added each year by recharge, which is balanced under natural conditions by evapotranspiration losses or spring discharge from other parts of the reservoirs.

Practically all the wells in Nevada obtain water from gravel and sand strata in the alluvial basins. Data obtained chiefly from these wells indicate that large quantities of water are stored in the alluvium, which contains in addition to the sand and gravel, much silty and clayey material that is also saturated but does not yield water readily to wells. Ground water generally moves from the bordering mountains toward the lowest part of the valley, similar to surface water. Several closed basins contain "wet playas," from which ground water is continuously being discharged by evapotranspiration. As shown on figure 59, there are approximately a hundred alluvial basins in Nevada, which as a rule contain ground water reservoirs, although some of the ground water is too mineralized to be usable.

As we learn more of the hydrology of the State, we are finding that the alluvial basins do not provide the complete story of ground water in Nevada, and that the concept of basins as constituting independent hydrologic units isolated by barrier mountain ranges is oversimplified. Several items of evidence do not fit this concept: saturated and very permeable limestones and dolomites which are encountered in mines in several ranges; alluvial basins containing ground water but none of it being lost by evapotranspiration; large springs in arid valleys which discharge more water than could have been recharged by the precipitation within the apparently tributary basin; and recently, deep wells that have proved the existence of water in permeable bedrock beneath some alluvial basins.

From this evidence it appears that permeable carbonate rocks, which crop out especially in the southern and eastern parts of the State, may store water in the mountains and beneath the alluvium in the valleys. The alluvial deposits in some basins may be drained by these deep bedrock aquifers, and in others they may be separated from the carbonate rocks by relatively impermeable rocks and thus contain ground water perched above bedrock aquifers. Only a few producing wells tap such bedrock aquifers, but a considerable part of the potential perennial yield has been developed at springs that issue from those bedrocks. The flow system in these bedrocks is practically unknown, and hard to evaluate because of the complex pattern of geologic structure, which is also relatively unknown. The areas where carbonate rocks crop out are shown on figure 3, together with some of the large springs that may be related to them.

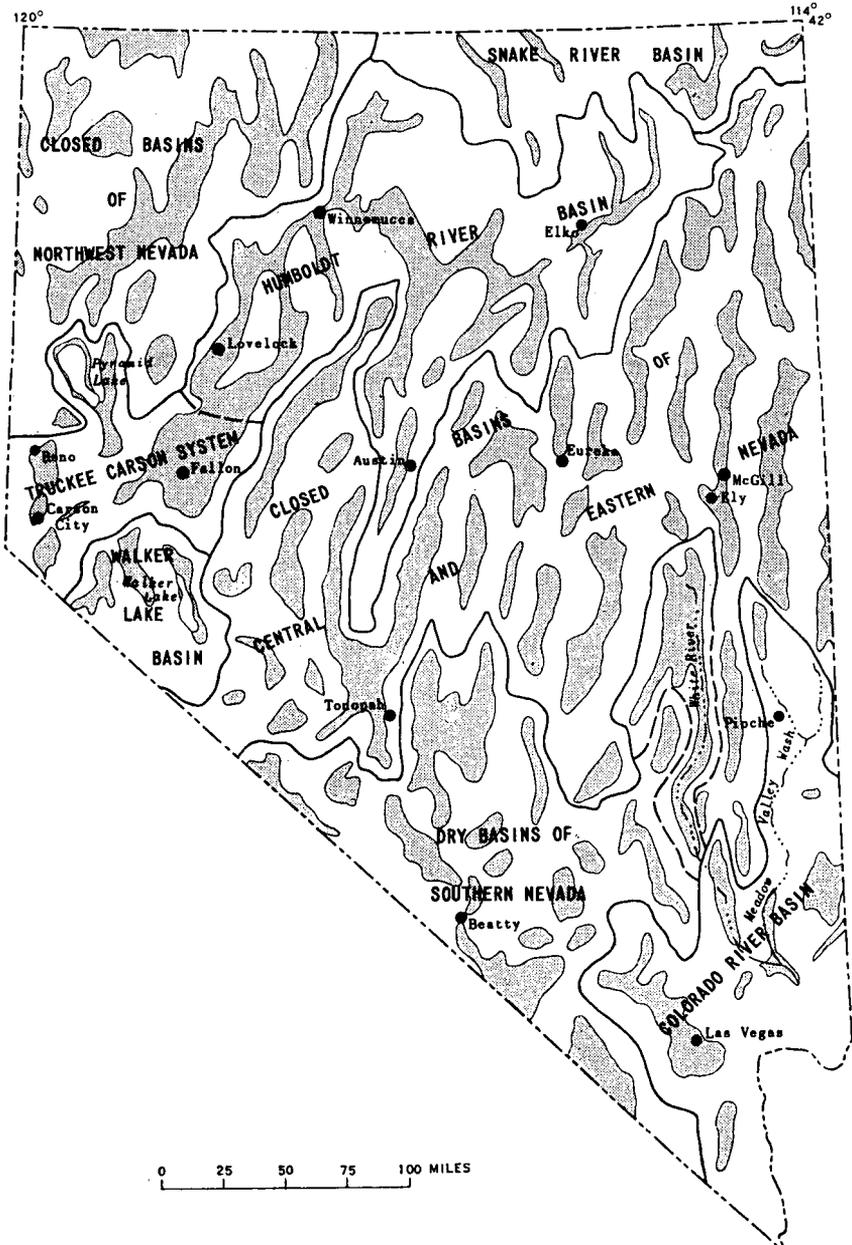


FIGURE 59.—Alluvial basins (stippled areas) in Nevada, and hydrologic units discussed in basin appraisals.

## WATERBORNE RESIDUES

Typically in Nevada's closed basins the sediment transported by the water also remains within the basin except for the small part removed by wind. This is true also of the minerals that are dissolved by the water and carried in solution. The dry lakes or playas where torrential waters occasionally accumulate and then evaporate are commonly called salt flats or alkali flats because of the saline residues that are prominent upon the dried surface. Similarly, the areas where ground water is shallow enough to be evaporated are characterized by saline soils and salt residues on the surface (fig. 60). Saline residues are so prevalent in the discharge areas of closed basins that their absence may be taken as *prima facie* evidence that a basin is not truly "closed," but must have some subsurface outflow or deflation by wind action (Langbein, 1961) to carry away the soluble salts that would otherwise accumulate.

Generally the waters of best quality are those most closely related to precipitation—snowmelt and storm runoff from the mountains. Soluble materials are dissolved principally by subsurface water, in the soil and underlying sedimentary deposits and bedrocks. The total load of dissolved materials in streams normally increases downstream because of inflow of ground water, and the concentration increases downstream because of evaporation of part of the water. In any area where saline residues have been left by evaporation, an influx of water by precipitation or irrigation or flooding may redissolve these residues, thus adding to the total dissolved load in the water. The long-range effect of momentary excesses of precipitation and runoff, then, is to transport the soluble materials downgradient, eventually to accumulate in the lowest part of the basin, or to move on out of the basin if there is outflow of water or deflation by wind.

At any point along a river, there are short-term variations in concentration and total load of dissolved constituents, reflecting the variations in streamflow and accretion of soluble salts. Nevertheless, there is a general trend toward increasing mineralization downstream, reaching a maximum in the area where the water is returning to the atmosphere. Artificial storage and use commonly change the locale of evapotranspiration of some of the water, with resulting changes in concentration of dissolved materials, both in the area of natural storage and in the area where water is artificially stored and used.

## WATER PROBLEMS

Since the earliest days of settlement the people of Nevada have had the continuing problem of finding sufficient potable water for their needs, in a region of prevailing water deficiency. Through the years, this problem has been solved satisfactorily, with minor reverses because of drought or other untoward natural phenomena, even in recent years when population has been increasing rapidly. Our understanding of the potentials and limitations of the natural resource has increased as water requirements have increased, and water supplies have been developed on the basis of this increased knowledge, so that the present population has better assurance of a sustained supply than did a much smaller population half a century ago. The basin-by-basin appraisal of water resources is still continuing, because



the potentials of several basins are entirely unknown, and many others are covered only by reconnaissance surveys that provide rough approximations of the perennial supply and development potential. Today, however, the principal water problems of Nevada are in areas where water has been found and put to use; they have arisen because of that use, and because the requirements of the people are increasing and changing.

#### STORAGE DEPLETION

The problem here is that large volumes of ground water must be removed from storage in order to salvage the relatively small perennial supply, but such depletion is not generally condoned by the people or their culture. The total storage is so great that Nevada could increase its present rate of depletion many times, and if the wells were scientifically spaced, still have more than enough water "for our time," but there is concern for future generations, and that creates a problem that is best resolved by holding storage depletion to a minimum.

If wells were restricted to areas of natural ground-water discharge, the water table would be lowered as storage is depleted by pumping. The natural discharge would also be reduced progressively until, as an ideal ultimate, all the water formerly wasted by natural discharge would be diverted toward and salvaged by the wells. Such opportunities exist in several areas, as for instance where greasewood (*Sarcobatus vermiculatus*, a deep-rooted phreatophyte) is established in soil suitable for crops, and taps ground water of a quality suitable for irrigation.

Unfortunately, the ground water in the area of natural discharge commonly has the poorest quality of any in the tributary basin, and even if it is usable, the soils are likely to be too saline for agricultural use. Also, the deposits in this lowest part of the basin commonly are fine textured and yield water very slowly to wells. Nevada's large-capacity wells are necessarily in areas underlain by permeable material, where the pumping lift is not excessive and where the water is of satisfactory quality. Since three-fourths of all water pumped from wells is for irrigation, the wells are also generally in areas where the soils are suitable for cultivation of crops. Such wells may be several miles from areas of natural discharge, and although they may be said to "intercept" the water en route to those areas, large volumes of water must be taken from storage before the wells can cause a significant diminution in the rate of natural discharge. The perennial supply developed by these wells is limited to the amount by which they have reduced the natural discharge.

Although depletion of storage by pumping may eventually result in salvaging some water for beneficial use that nature would have wasted, it may instead give rise to other problems. Removal of water from some earth materials, especially clays, may permit their compaction, with resulting subsidence of the land surface and possible damage to structures thereon—some such subsidence has occurred in Las Vegas Valley. Removal of water by pumping may also create hydraulic gradients favorable for inflow to the aquifer of water of inferior quality. Or pumping may induce flow to the well of water from lakes, canals, or streams—good water, but water to which someone else had established a right.

Artificial recharge appears as the logical antidote for ground water depletion caused by pumping. It is specially desirable if the recharged water reaches the aquifers in the areas of pumping, and reduces or offsets the depletion. Generally throughout Nevada, because of the perennial water deficiency, the greatest possible proportion of water should be induced to go underground out of reach of evapotranspiration.

The chief problem of recharge is that we know so little about the natural process or the physical principles governing it. Throughout the country there are numerous examples of successful artificial recharge, and also many areas where man has inadvertently increased the storage of water underground by such activities as construction of reservoirs, diversion through canals, and irrigation of land. But we do not understand, measure, or map the vertical movement of subsurface water, which is presumably dominant in recharge. Particularly we lack the means of measuring flow in unsaturated materials, which occur beneath the land surface in most natural recharge areas. Here is a major field for basic research, in order to understand how nature does it; also for applied research, to develop the techniques that we must have if we are to improve on the natural pattern of recharge.

#### MAINTENANCE OF USABLE QUALITY

In each closed basin, nature has established an area of ultimate disposal where the water, the soil, the mineral salts are so intermingled as to be of minimum economic value. Problems arise when man diverts the water from its natural route for his own use, because he then takes the vehicle by which the natural wastes would reach the area of ultimate disposal; and also when he uses the water, because he thereby contributes his own waste products to it. Unless he allows some means by which natural and artificial wastes can reach the natural area of ultimate disposal, they must accumulate in the areas of use, and cause deterioration in the quality of water. Waste disposal by dilution, a common practice in most of the United States, is generally unsuitable for Nevada because of lack of water surpluses. Usable quality must therefore be maintained by minimizing the pollution of the natural resources—that is, by complete treatment of sewage to remove degradable wastes, and by various means (canals, pipelines, wells) transporting other harmful wastes to places where they cannot mix with the usable resources.

For effective maintenance of usable quality, we need much more information concerning the occurrence and sources of impurities in the water resources than we now have for any part of Nevada. Thus adequate basic data is an urgent need, as a first step in attacking this problem.

#### TRANSPORT

Although the early settlers generally settled where there was water, the modern trend is to deliver water to the places where it is to be used. Even in desert regions nowadays, water is wanted for gracious living, with lawns, landscaping, swimming pools, golf courses, and other recreational features. Nevada is fortunate that its greatest concentrations of population are in its two regions of most abundant water resources; also that its inhabited valleys receive by gravity the

small surpluses from bordering mountain ranges. Nevertheless in each populated area, as water requirements approach the limit of the resources locally available, there will be proposals to bring in supplemental supplies by pipeline, canal, or other means from more remote areas where the resources are not being fully utilized. Furthermore, in areas of concentrated demand where much of the water is used nonconsumptively, as for example by industry, it may be necessary to collect and transport noxious wastes to suitable disposal areas in order to avoid pollution of usable supplies. The problems of long-distance transportation of water involve economics, with social and political overtones. Hydrologists can contribute to resolution of these problems by evaluation of the total effects—immediate and long range—of the diversion and transport upon the physical resources.

Deminerization constitutes a possible alternative to long-distance transport of water for supply or disposal, whenever and wherever the costs of deminerization become competitive with other means of supply and disposal. By deminerization it is possible to utilize brackish water from local sources for municipal or industrial purposes, or to make industrial wastes reusable, or to deminerize a part of the supply—as for example saline springs—to improve the overall quality of water in a stream or reservoir.

#### WATER RIGHTS

The basic doctrine of Nevada is that beneficial use is the basis, the measure, and the limit of the right to use water, and that priority in use gives priority in right. A similar doctrine is basic in many other arid regions—notably the Sahara and Arabian Deserts—where land is useless without water, and there is not enough water for all the arable land. This appropriation doctrine, however, has been accepted as implying a permanence that may be at variance both with the changing requirements and capabilities of man and with the changing physical conditions resulting from development and use of the resource. For example, an appropriative right (to a specified quantity of water so long as the beneficial use continues) can perpetuate uses that were once acceptable but, in the face of advancing technology and civilization, would now be classed as inefficient or of very minor benefit to anyone. To solve the problem of protecting all legitimate rights and also conserving water for the public good, the Nevada water code requires that the use of water, as well as the diversion and conveyance thereof, be reasonable and economical, as well as beneficial.

Ground water development also creates problems in the existing system of appropriative rights. The pioneers logically chose the water sources that were most accessible and least costly for development—springs, perennial streams and lakes, dug wells, flowing wells—which are generally products of full and overflowing ground water reservoirs. The subsequent construction and pumping of large-capacity wells inevitably causes some reduction of the storage in these reservoirs. So long as the pumped water comes from storage it is not truly a perennial supply. The Nevada water code has several distinctive sections to grapple with this problem of storage depletion: a “reasonable” lowering of static level in wells is expected and made an express condition of every ground water right; in areas where ground water is

being depleted by pumping, the State engineer may designate preferred uses of water, and he may issue temporary permits to appropriate water. A more complex problem is created where wells achieve a perennial supply, or "safe yield," because some of that perennial supply to wells may come from perennial streams or springs which have long been appropriated and to which primary rights attach. To solve such a problem under the appropriation doctrine will require correlation and adjudication of all water rights within an entire hydrologic unit, based upon adequate knowledge of the flow system, surface and subsurface.

#### LONG-RANGE PROGRAM

Many of the problems outlined above have arisen because of the effects of one person's use of water upon the water that is used or desired for use by others. The recognition of water as of critical importance in the State's economy, and the statutory declaration of public ownership of the water resource, lead to the corollary that the development and use of water should be controlled and planned to provide the greatest benefit and least detriment to the people. An essential element in the effective management of the resource is the adaptation of the fundamental physical principles of water storage and movement to these exceptional characteristics of Nevada.

#### HYDROLOGIC PRINCIPLES APPLIED TO NEVADA CONDITIONS

Nevada's water economy is necessarily a deficit economy, because of its climate. By evapotranspiration Nevada eventually loses nearly all the water it receives by rain and snow, and all the water flowing into it from California, and it will similarly consume most of the water brought into it from the Colorado River. Nevada is a creditor State only in the Snake River Basin, where it passes water to Idaho. In spite of the prevailing water deficiency shown by the averages, Nevada has momentary surpluses of water, thanks to the deviations of precipitation from the average, both in space and in time. The continuing water requirements of mankind must be supplied from these transitory surpluses of the past, present, and future. Such surpluses are stored in and on earth until they are lost by evapotranspiration; Nevada has large accumulations from past millennia, stored out of the reach of evapotranspiration, as ground water.

The surface water and ground water that can provide perennial supplies for man's use are derived from precipitation, and flow toward areas of discharge by evapotranspiration. Because of variations in precipitation there are continuing fluctuations in the storage and flow of surface and ground water at any point, but so long as the climate does not change there must be a long-range balance between inflow (precipitation) and outflow (evapotranspiration)—in other words, a natural equilibrium in the flow system. A perennial supply for the use of mankind is achieved by salvaging this water that would be lost under natural conditions—by intercepting it somewhere along its path of flow before it evaporates or becomes unusable. A program of conservation of the replenishable resource should seek to maximize the beneficial use and minimize the natural waste of the perennial supplies. Important elements in such a program would be techniques

and practices that encourage and maintain storage of water beyond the reach of natural evapotranspiration processes.

Ground water reservoirs are thus of major importance to the objective of achieving maximum sustained yield of Nevada's water for beneficial use, but their management is complicated by physical principles. In any environment, a well pumps water initially from storage accumulated in the aquifer, and it will continue to pump from storage until, as a result of the pumping, the recharge to the aquifer is increased or the natural discharge from the aquifer is decreased, or both. Thus, in ground water development some depletion of accumulated storage is inevitable and necessary, and wells may continue to draw some water from accumulated storage after years and even decades of operation. In many of Nevada's basins the replenishable resource—the annual recharge to and discharge from the ground water reservoir—is negligible in comparison with the accumulated storage, somewhat like a flow-through of a drop a day in a 10-gallon bucket. In such basins, wells can continue to pump water from storage as long as there is water in storage, but there is negligible hope for establishing an equilibrium that would insure a perennial supply from the well. In those places where an equilibrium is eventually achieved, it will mean that the water is being diverted through the aquifer to the well from somewhere else—perhaps from a stream or lake, perhaps from wetlands—ideally but not necessarily from places where it had been of no use to anyone.

Vast quantities of sedimentary deposits have accumulated in the closed topographic basins of Nevada, and soluble salts have also been accumulating in the basins that have no ground water outflow. The waste products of civilization which remain in nonconsumptively used water must similarly accumulate in the respective basins where they originate. Whether these wastes are natural or man made, they can be segregated, treated, or otherwise disposed, wherever it is economically feasible to do so.

Interrelations and interdependence of Nevada's waters are obvious in a brief recapitulation of the hydrologic cycle. Precipitation is the source of all fresh water, but about 90 percent of it returns to the atmosphere from the soil in the place where it fell. As to the remaining net supply, some passes through the soil to become ground water, and the rest becomes overland runoff and the stormflow of streams. The portion of the net supply that becomes ground water may be subsequently discharged at springs, or into streams (where it constitutes the base flow), or by evapotranspiration in areas of shallow water table. The portion of the net supply that has become surface water may seep down to become ground water, or it may remain on the surface in ponds, lakes, or reservoirs, where it is subject to evapotranspiration. Although Nevada has in the past been able to develop and administer its surface water and ground water separately in most areas, these natural interrelations have already been in evidence in the valleys of the principal streams, notably the Humboldt, Truckee, and Walker Rivers, where controversies have arisen between surface water and ground water users.

In general, the interrelations of ground water and surface water become increasingly evident with increasing development, and this is particularly true if the development is planned so as to utilize each to best advantage. For example, surface water storage is inferior to

ground water storage because of evapotranspiration losses, but ground water flow is far inferior to surface flow for transporting water over distances of even a few miles, and replenishment of ground water storage is limited by the prevailing slow rates of movement of water underground. These differences can be utilized to advantage in seeking the maximum sustained yield of usable water, by conjunctive use of surface and underground storage.

#### BASIC DATA

Pointing to Nevada's progressively increasing rate of economic development, Shamberger (1962, p. 1) states:

A vital factor in continued development involves the availability of water to meet the growing needs. We need to know more adequately the quantity, quality, and distribution of water that can be developed. We need to know how better to utilize our limited supplies. We need to determine improved practices of administration and regulation. These needs are required to permit optimum development of water in the best interests of the State and its people.

The present 10-year program proposed in this statement is focused upon the aspect of adequate determination of the quantity, quality, and distribution of our water resources, as this knowledge is requisite in the final development of the other aspects.

The interrelations and interdependence of water in the various phases of the hydrologic cycle dictate a need for quantitative data on all aspects of the water resource. With adequate data we can delineate the hydrologic boundaries of river basins or other natural units with which we must work, and make a comprehensive analysis of the flow system within each. Only thus can we have an adequate basis for assessing the degree of relationship of the various "sources" of the water used by man, or for predicting the short- and long-term effects of a proposed development.

The 10-year program for hydrologic data will build upon a firm but irregular foundation of scientific information already available (selected references, p. 311) and in many respects it is intended to continue along similar lines, but more purposefully and with better coordination. It is recognized that changing emphasis on development and management as well as improvements in technology will require flexibility in the overall plan.

In the plan the continuing inventory is recognized as the basic statewide program, intended to monitor the natural fluctuations and the artificial modifications in the quantity and quality of water.

Basin studies are discriminated as reconnaissance, areal, or comprehensive, to represent successive stages of work in individual hydrologic units. Most of Nevada's named basins are sparsely populated, and the inhabitants (if any) obtain water from springs, domestic wells, or small unregulated streams. Reconnaissance studies of geology, topography, ecology, and climatic records, prior to major water developments, have already been made of more than 20 of these basins, in order to give a preliminary idea as to the potentials for development. Areal studies are made of basins where development and use of water are sufficient to enable collection of quantitative hydrologic data. The studies cover the hydrologic framework and boundaries of the specific area; inflow and outflow; storage, flow, and quality of surface and ground water within the area; and effects of development and use of water. Comprehensive studies are evaluations that require all the information needed for areal studies plus

accurate subsurface information and delineation of flow-system boundaries. The 10-year program also anticipates specific problems in some areas and provides for special studies for their resolution.

The applied research envisioned as part of the 10-year program relates to deficiencies of knowledge and techniques peculiar to the water problems of Nevada, and may include application of the results of basic research elsewhere to these problems, the testing of new instruments and ideas—any means of improving standard operations or attacking complex problems. The first of these research projects is nearing completion after 3 years of study, embracing a reach of the Humboldt River Valley that includes Winnemucca (Shamberger, 1963).

Closely related to the basic hydrologic data, and in part dependent upon them, are surveys of water and related land resources. The Humboldt River Basin survey (1962-63) is by the U.S. Department of Agriculture in cooperation with the Nevada Department of Conservation and Natural Resources. The entire Humboldt River Basin is being studied by segments identified as subbasins, for the primary purpose of determining where improvements in the use of water and related land resources might be made with the assistance of projects and programs of the U.S. Department of Agriculture, as envisaged by the Watershed Protection and Flood Prevention Act (Public Law 566, 33d Cong., as amended).

Another source of basic data and hydrologic studies is the Desert Research Institute in Reno, whose members have made studies of various aspects of the hydrology and geology pertinent to the Humboldt River research project, as well as of other areas in the State.

The 10-year program necessarily stresses the knowledge of the water resources that we don't have but need, as a basis for attack on the broader water-related social and economic problems confronting the State in its development. A substantial amount of information is already available, however, as suggested by the selected references (p. 311) which constitute the basis for the following basin appraisals.

#### BASIN APPRAISALS

In the following summary the State is divided into major hydrologic units (fig. 59); the presentation begins at the northeast corner, proceeds westward along the north border, and then generally southward. A similar summary for the entire United States includes a basin-by-basin tabulation for Nevada (McGuinness, 1963).

#### SNAKE RIVER BASIN

About 5,900 square miles of northeast Nevada, chiefly in Elko County, is drained by northward-flowing tributaries of the Snake River, notably Goose Creek, Salmon Falls Creek, Bruneau River, and Owyhee River. Streamflow records indicate that the average annual flow from this region into Idaho is roughly 400,000 acre-feet—the only significant export of water from Nevada. The principal storage and regulation of this streamflow within Nevada is by Wild Horse Reservoir (capacity 33,000 acre-feet) on Owyhee River and by four small reservoirs (total capacity 16,000 acre-feet) on South Fork Owyhee River. In February 1962, prolonged rains upon melting snow caused record floods in several streams in northeast Nevada (Thomas and Lamke,

1962) but damages were slight in this mountainous, sparsely populated region.

There is very little information concerning the overall water resources of the region, and particularly the ground water, except for a reconnaissance study (Eakin, 1962c) of Independence Valley, which has an area of about 30,000 acres of valley floor along the South Fork Owyhee River. There it is estimated that about 250,000 acre-feet of ground water is stored in the upper 100 feet of valley fill. Natural recharge during the April-June freshet is augmented by irrigation of 18,000 acres of meadow and pasture. Fragmentary data indicate that the surface outflow from Independence Valley is less than the inflow during the annual freshet, but greater during the rest of the year; thus the ground water reservoir serves to stabilize the flow in the river. However, the irrigated bottomlands have a high water table and significant draft by evapotranspiration.

#### CLOSED BASINS IN NORTHWEST NEVADA

Included here are the closed basins that lie west of the Snake River Basin and north of the drainage areas tributary to the Humboldt River and to Pyramid Lake. The Nevada State boundaries cut across several basins that extend into Oregon, and others that extend into California.

*Quinn River Basin.*—The drainage basin of Quinn River comprises four approximately parallel troughs or valleys, separated by highlands of uneven crest. The lowlands have very low rainfall, but they receive runoff from the bordering highlands, especially from melting snow. This runoff is generally greater in the northern part of each trough, and greater in the eastern troughs than to the west. Sedimentary deposits have accumulated in each trough, to thicknesses of several hundreds or even thousands of feet, and have formed broad valley floors that interconnect across the lowest parts of the intervening uplands. The mountain ranges appear to be made up of relatively impermeable rocks, and hydrologic reconnaissances have, therefore, specialized in the valley areas. The drainage basin is of interest because each trough contains large quantities of ground water, of which some is of a quality suitable for irrigation. Many irrigation wells have been drilled in the past decade, especially in Quinn River Valley and Kings River Valley, and by 1960 the aggregate pumpage was about 50,000 acre-feet. Since this quantity is greater than the observed inflow from the principal streams—and that surface inflow also is used for irrigation which necessarily involves some consumptive use—the question of perennial supply is moot.

Quinn River Valley is the easternmost trough (Visher, 1957). Its surface inflow is chiefly near the north end from both sides of the Oregon State line, where several of the streams are perennial. The Quinn River flows southward about 40 miles, losing water by seepage to the valley fill, and then the channel continues westward through a gap in the mountains, but has water only during flood runoff. Quinn River Valley also receives ground water and seepage from ephemeral streams draining the bordering mountains. However, the part of the valley that extends south of the gap receives so little water that neither the sediments nor the ground water have been built up enough to establish a gradient toward the gap. Most of the water that enters

the valley is discharged by evapotranspiration from the valley floor, which has about 100,000 acres of phreatophytes. The use of surface water for irrigation has raised the ground water levels under the irrigated areas and thereby increased the evapotranspiration draft. In 1963 about 25,000 acre-feet was pumped from 83 wells (Huxel, personal communication). Pumping has reduced the ground water storage in the vicinity of the pumped wells, and will continue to do so until these wells salvage water now being used by the native vegetation.

The Quinn River Channel continues westerly across the next trough. Kings River Valley (Zones, 1963), in the portion of that trough north of Quinn River Channel, is similar in many respects to the north part of Quinn River Valley. The principal inflow is near the north end, from several streams that are perennial in the mountains. Kings River flows southward in the valley, losing heavily by seepage, so that only floodflows continue as far as its junction with Quinn River. Ground water and ephemeral streams enter the valley from the sides. Practically all the inflow to Kings River Valley is discharged within the valley by evapotranspiration from about 63,000 acres of phreatophytes. Large volumes of water are stored in the valley fill, and this storage is being depleted by pumping for irrigation, which in 1960 amounted to about 22,000 acre-feet.

The part of this second trough that is south of Quinn River is identified separately as Desert Valley, and it is analogous to the southern part of Quinn River Valley. In Desert Valley (Sinclair, 1962b) the ground water is generally at depths exceeding 25 feet, so that evapotranspiration is negligible. The ground water gradient toward Quinn River is so slight that there can be little outflow in that direction. However, the valley fill contains large quantities of water in storage, of which some (near the margins of the valley) has been found to be of quality suitable for irrigation.

The Quinn River channel continues westward through another broad gap in the mountains to enter a third trough, of which the north end is called Pine Forest Valley (Sinclair, 1962b), where there is inflow from several streams, of which one is perennial. Most of the water is discharged within the valley, by evapotranspiration from about 45,000 acres of phreatophytes. In 1960 several wells pumped about 3,000 acre-feet of water of good quality for irrigation. Some ground water enters the Quinn River channel and flows southward from Pine Forest Valley. There may also be appreciable underflow into Black Rock Desert.

Black Rock Desert, which occupies the southern part of this trough and extends into the fourth trough, is Y-shaped. It is the ultimate disposal area for any water and soluble salts that can reach it from the rest of the drainage basin (Sinclair, 1963b). There is also some inflow from the adjacent mountain ranges; several wells tap this water along the slopes above the valley floor where it is still moderately fresh. Generally under the valley floor the ground water is too saline to be usable. About 200,000 acres is occupied by a playa devoid of vegetation, where the water table is generally within 5 feet of the land surface.

The Quinn River basin has been described in more detail than will be possible for every closed basin, because it has many ingredients of the problems that may appear also in other basins: interest in ground-water development because of large quantities of usable water in

storage within economic pumping lift; evidence that nature is using up all the "perennial supply," and leaving the soluble salts; indication that a perennial supply for human use can be achieved only by cutting off this natural discharge; and problems as to how to manage the depletion of storage and the disposal of the salts that are dissolved in the water.

*Other closed basins.*—There are about 15 closed topographic basins in the northwest corner of Nevada (north of Pyramid Lake and west of Black Rock Desert) of which half a dozen cross the State line into California or Oregon. Reconnaissances have been made in several of these alluvial basins (Sinclair, 1963a)—Long Valley, Duck Lake Valley, Pueblo Valley, Continental Lake Valley—in order to estimate the storage, natural discharge, and quality of ground water, as a basis for a preliminary appraisal of the potentials for development.

One of these closed basins—Hualapai Flat (Sinclair, 1962c)—is west of and adjacent to the Black Rock Desert. Runoff from snowmelt and exceptional rainstorms accumulates in the playa in the lowest part of the basin, and subsequently evaporates. Most of the water discharged from the valley is by evapotranspiration from some 18,000 acres of phreatophytes on the valley floor. Ground water is also discharged on the valley floor by thermal springs and artesian springs and wells. Some ground water can move eastward under the topographic divide and into Black Rock Desert, and because of this outflow the accumulation of salt may be less and the quality of ground water better than it would be if the basin were hydrologically closed.

#### HUMBOLDT RIVER BASIN

The Humboldt River basin of 17,000 square miles is entirely in Nevada; it extends from within 40 miles of the Utah line to within 80 miles of the California line. In its 275-mile westerly course the Humboldt River transects Nevada's prevailing north-south basin and range structure. The principal water-producing area is the eastern third of the drainage basin above the gaging station at Palisade, where the river attains its maximum volume. From Palisade the river flows westerly and loses nearly half of its water in an alluvial valley en route to Rye Patch Reservoir. The alluvial valley is flanked by minor tributary basins that contribute little water to the river. From Rye Patch Reservoir the river flows southward in Lovelock Valley to end in Humboldt Sink, which has occasionally overflowed into the broader Carson Sink.

The principal physical difficulties faced by the water users in the Humboldt River basin are (1) the tremendous variations in flow of all streams, which are unregulated except by Rye Patch and two adjoining small Pitt-Taylor Reservoirs near the lower end of the basin; (2) the diminution in flow of Humboldt River below Palisade; and (3) the deterioration in quality of the river water below Palisade (generally the quality varies both geographically and in time: it is best in the headwaters and in periods of greatest runoff from melting snow, and becomes progressively poorer downstream and in periods of low runoff).

*Water-producing area.*—The riverflow at Palisade constitutes the essential supply for all downstream users. In the past 60 years the measured annual discharge has averaged about 256,000 acre-feet, but it has ranged from 25,000 in 1934 to 635,000 acre-feet in 1952.

In 12 of the years, the riverflow has been more than 50 percent above the average and caused flood damage to bottomland ranches and, in several of the years, to railroads and highways and to parts of several towns. In 14 of the years the riverflow has been less than 50 percent of average. Several of these "drought" years, like the flood years, have come in groups of two or three; in other words, there are alternations of extended wet and dry periods (Thomas and others, 1963a). The riverflow deviates so widely, so frequently, and so long from average, the the average is a poor indicator of the availability of supplies from these unregulated streams.

The measured flow at Palisade is less than the natural flow of the river because of upstream diversions for irrigation, chiefly of pasture and hay land. Water is diverted from the river and its tributaries in quantities that depend upon the flow in the stream and upon decreed rights; in some years as much as 150,000 acres may be irrigated above Palisade.

*Alluvial valley of Humboldt River.*—This alluvial valley, between Palisade and Rye Patch Reservoir, is generally 3 to 6 miles wide. Like the water-producing area above Palisade, this valley has no significant surface storage facilities, the streamflow is unregulated, and valley lands are subject to flooding. Some use is made of the water that disappears from the river in this alluvial valley, as indicated by the decreed rights for irrigation of about 37,000 acres of cultivated crops and hay land, 13,000 acres of meadow, and 31,000 acres of brush pasture. However, a significant proportion is consumed by phreatophytes such as greasewood, saltgrass, willow, and rabbitbrush, which occupy tens of thousands of acres of the alluvial valley.

*Lovelock Valley.*—Humboldt Sink, at the south end of Lovelock Valley, is the natural area of ultimate disposal for the river basin—where water evaporates and soluble salts accumulate—and has evidently been so for a long time; ground water at all depths penetrated by wells in its vicinity is too saline for use (Robinson and Fredericks, 1946). However, because of storage and use of the river water upstream, Humboldt Sink in the past 25 years has received water only from local storms and return flows from irrigation, except in the years of maximum runoff of the river. Thus, under present conditions, practically all the river is returned to the atmosphere somewhere along its course above Humboldt Sink. It might be expected that the dissolved salt load would remain in the areas where water is used for irrigation, but several factors operate against this tendency. In the areas above Rye Patch Reservoir, a system of irrigation by semi-controlled flooding is practiced, and water is applied in quantities exceeding the field capacity of the soils to hold moisture. The excess water returns to the stream channel and carries with it most of the salts contained in the water applied to the land, so that no significant buildup of salts in the irrigated soil is apparent after nearly 100 years of experience. In the Lovelock area, a reasonable salt balance is being achieved through a system of deep drains and the application of irrigation water in excess of crop requirements. The ground water at Lovelock, near the lower limit of irrigation from Rye Patch Reservoir, is too mineralized for most uses, and it is likely that the ground water in the upper part of Lovelock Valley—near Rye Patch Reservoir—is moderately mineralized (Eakin, 1962a).

Rye Patch Reservoir and the adjoining Pitt-Taylor Reservoirs near the upper end of Lovelock Valley have a combined capacity of 229,000

acre-feet and provide water for irrigation of as much as 35,000 acres of land in the vicinity of Lovelock. The inflow to these reservoirs is less than half of that passing Palisade, except in the years of greatest runoff, when they may receive as much as 75 percent of the volume measured at Palisade. Rye Patch Reservoir, which began storing water in February 1936, has provided holdover storage from each wet year, beginning in 1942. The most obvious beneficial effect of this storage was in 1954, when more water was released from the reservoir than the total runoff at Palisade. The capacity of the reservoir was insufficient to store all the inflow in 1942, 1943, 1945, 1946, and 1952, and in these years some floodwater wasted into Humboldt Sink.

*Minor tributary basins.*—These are the tributaries to the Humboldt River below Palisade (table 20), called "minor" because of their low average discharge to the river, and called "basins" because practically all their net perennial supplies are discharged by evapotranspiration, as in closed basins. Some of these tributaries have large catchment areas, as for instance Reese River, which is longer than is the Humboldt above the point where the Reese enters it. Reese River is generally dry in its lower reaches, but occasionally has high flood runoff, most recently in February 1962 when it inundated the town of Battle Mountain (Thomas and Lamke, 1962). Some tributaries drain mountains that generate significant runoff: the tributaries of Little Humboldt River discharge a median annual flow of 58,000 acre-feet of water into Paradise Valley where it is used for irrigation; but only in years of exceptionally heavy runoff does water flow out of Paradise Valley, traverse the sand dunes at its south end, and enter the alluvial valley of Humboldt River (Humboldt River Basin Survey, Rept. 1, 1962). Another type of tributary is Rock Creek, whose mountainous drainage basin produces the largest runoff of any tributary below Palisade; but as it enters the broad Boulder Valley it is used extensively for irrigation so that the quantity reaching Humboldt River is much less. Crescent Valley is a partly closed basin that contains a playa, so that discharge to the alluvial valley of Humboldt River is limited to flood runoff from a small portion of the basin and possibly to some underflow.

TABLE 20.—*Tributary basins to Humboldt River below Palisade, Nev.*

Valley	Drainage area (square miles) and direction from Humboldt River	Areas (in acres)			Discharge to Humboldt River		
		Irrigated from streams	Irrigated from wells	Natural discharge	Perennial stream	Under-flow	Flood runoff
Pine.....	1,000 S	5,600	400	30,000	Pine Creek...	(1)	(1)
Crescent.....	700 S	-----	800	47,000	-----	(3)	(1) (4)
Boulder.....	900 N	(1)	(1)	(1)	Rock Creek...	(1)	(1)
Reese.....	2,100 S	-----	3,000	+20,000	-----	-----	(1)
Kelly.....	----- N	-----	-----	-----	-----	(1)	(1)
Grass.....	----- S	-----	(1)	-----	-----	(1)	(1)
Paradise.....	1,700 N	35,000	2,500	47,000	-----	(1)	(1) (4)

<sup>1</sup> Affirmative, quantity unknown.

<sup>2</sup> Including playa of 6,000 acres.

<sup>3</sup> Unknown.

<sup>4</sup> From less than 20 percent of drainage basin.

<sup>5</sup> In 1862, 1890, 1907, 1910, 1914, and 1952.

Data from: Eakin (1961a); Zones (1961); Crosthwaite (1963); Loeltz, Phoenix, and Robinson (1949); Humboldt River Basin Survey Rept. 1 (1962).

The principal tributary basins are listed in order downstream from Palisade in table 20, which shows also the areas of consumptive use within each basin, and the means by which water is discharged to Humboldt River.

The evidence that most of the perennial supply of these tributaries is lost by natural discharge within the tributary basin would appear to justify treating each as a separate unit in which water is to be salvaged for beneficial use before it can be taken by natural evapotranspiration. Planning for such development would face the problems typical of closed basins—appraising the fresh water resource in ground water storage, and deciding to what extent that storage should be depleted in order to achieve optimum use and perennial supply.

But these basins are in fact not independent and separate from the alluvial valley of Humboldt River. They contribute floodflows, sometimes in damaging volume. They contribute some ground water to the alluvial valley, and if this underflow is reduced by development and use of water in the tributary basins, the flow of the Humboldt River may also be affected. They also contribute mineral salts in their ground water discharge to the alluvial valley: If future development and use of water in these tributary basins result in irrigation return flows or other nonconsumptively used water that increases the salinity of the discharge to the alluvial valley, the quality of water in that valley will be adversely affected.

At some time in the future the value of the water of some of these tributary basins may be great enough to justify their development as subsurface reservoirs for storage and regulation of flow in the Humboldt River system, as an alternative to surface storage that would be subject to evaporation loss. This could be achieved by depleting the existing storage by pumping, demineralizing the pumped water if it is brackish, and continuing the demineralization as long as soluble salts are leached from the soils and water-bearing materials in the reservoir area. The perennial supply of the tributary basin would ultimately be stored out of reach of evapotranspiration until withdrawn for use in the Humboldt River system.

*Humboldt River research project.*—In every part of the Humboldt River basin where water is seen, there is also evidence of nature's take by evapotranspiration. There are numerous opportunities for putting that water to better use so far as man is concerned. Recommendations have been made (Humboldt River Basin Survey, 1962-63) for specific projects that will increase recreational opportunities, provide for watershed protection, increase range forage production, provide supplemental irrigation water, and reduce erosion and sediment damage on irrigated lands. A proposed dam on South Fork Humboldt River (Chief of Engineers, U.S. Army, 1949) would create a reservoir of 120,000 acre-feet capacity for purposes of flood control, recreation, and irrigation. Dams have been proposed also at sites on Marys River and North Fork Humboldt River. Reconnaissances of several tributary basins show that they contain ground water in quantity and quality suitable for irrigation by pumping from wells (Loeltz, Phoenix, and Robinson, 1949; Loeltz and Phoenix, 1955; Eakin, 1961; Zones, 1961).

All these indications of opportunities for further development and use of water in the Humboldt River Basin are of belligerent interest to the holders of established water rights, who want assurance that their

supplies will not be reduced in quantity or deteriorated in quality by such development and use. Such assurance, very legitimately demanded by the established water users, cannot be offered lightly in a basin where the principal source of supply—the Humboldt River—has always decreased in quantity and deteriorated in quality below Pali-sade, even under natural conditions. There is a great need for quantitative information as to where, when, and how these changes occur, as a basis for understanding why they occur. Only when we comprehend the flow system sufficiently, can the effects of proposed modifications be predicted with reasonable accuracy. The Humboldt River research project is a step in this direction (Maxey and Shamberger, 1961).

An ultimate objective of the Humboldt River research project, a State-Federal cooperative program under the direction of the Nevada State Department of Conservation, is the appraisal of the entire flow system of Humboldt River, including the characteristics of the porous media and the inflow, outflow, and storage of water, both as to quantity and quality. Beginning in 1959, the work under this project was concentrated in the Winnemucca area and included such aspects as (1) studies of the consumptive use of water by phreatophytes (Robinson, 1962) and meadow grasses (Dylla, 1962) in tanks; (2) research in the storage and movement of water in the soil and other unsaturated materials (Waananen, 1964); (3) mapping and hydrologic interpretation of the geology of the alluvial valleys, including lithofacies maps based on drillers' logs, which indicate that extensive gravel aquifers are associated with major streams in Boulder Valley, Paradise Valley, Reese River Valley, and the alluvial valley of Humboldt River (Bredenhoft, 1963); (4) evaluation of the inflow, storage, and outflow of water in the reach of Humboldt River Valley between Comus and Rose Creek (Cohen, 1962); and (5) correlative geochemical studies which show, for instance, that in December 1961 practically all the water in Humboldt River came from ground water and reflected the quality of thermal and other water derived from nearby tributary areas. A summary report of this interagency project is being prepared by Cohen (1964). By showing in detail where and how the Humboldt River in this reach loses water and becomes more saline, and the effects of tributary inflow, as well as the underground facilities for storage of water, it provides the physical basis for effective water management and engenders problems as to the economic, legal, and political aspects of such management.

#### TRUCKEE-CARSON SYSTEM

The Truckee River and the Carson River both rise in the high Sierra Nevada in California. The Truckee begins in Lake Tahoe and ends in Pyramid Lake, and in its roundabout course receives water from Donner Lake and the lake-fed Little Truckee River in California, and from the lake- and spring-fed Steamboat Creek in Nevada. The Carson River has a roughly parallel course, generally within 25 miles southeast of the Truckee. Its water volume is two-thirds that of the Truckee, but it lacks those magnificent lakes. Lacking storage facilities, it has under natural conditions dumped all its surpluses into the drab Carson Sink, and then has dwindled to creek size in the heat of summer, and nearly to dryness in the throes of drought.

Although the Truckee and the Carson are naturally separate and independent, they have been associated in man's thinking for a long time—first in the Truckee-Carson project, and increasingly in the planning and development of recent years. Such a combination into a single system can provide greater flexibility in meeting the future requirements for water supply and disposal in a region that embraces resort facilities at Lake Tahoe; metropolitan development in the Reno-Sparks-Carson City area; agricultural use in the Fallon area, Carson Valley, and the Fernley area; and recreational opportunities at numerous lakes and mountain areas.

The Truckee-Carson project (renamed in 1919 in honor of Senator Newlands of Nevada) was the granddaddy of Federal reclamation projects: The Geological Survey started collecting basic data for it in 1889, and it was one of the first five projects considered by the newly organized Reclamation Service in 1902. The basic data showed that the average flow of the Carson was adequate for extensive irrigation, but that the summer minimum was far less than that of the Truckee. A canal for diversion from the Truckee to the Carson was completed in 1906, and Lahontan Dam was completed on the Carson in 1915 for storage of water. The Truckee-Carson Irrigation District has rights to sufficient water to irrigate 87,500 acres of land, and has contracts with landowners to provide water for approximately 70,000 acres from these facilities; but not more than 63,000 acres, exclusive of pastureland, has been irrigated in any year. This early development provides only partial regulation of the Carson, for the annual inflow to Lahontan Reservoir has been greater than the reservoir capacity in 16 of the 36 years of operation.

Another phase of the Truckee-Carson project was regulation of storage in Lake Tahoe by construction (in 1909-13) of a dam at the outlet. Because of its restricted outlet, Lake Tahoe under natural conditions provided regulatory storage especially in years of abundant runoff, which was partly responsible for the well-sustained flow of the Truckee River in rainless periods. In the 20 years before the dam was constructed at the outlet, the maximum annual lake level was generally 4 to 7 feet above the rim (Harding, 1935). The construction of the dam was followed by a court decree that the natural outlet shall not be disturbed, and later by an agreement that the lake level should not be permitted to rise more than 6.1 feet above this rim. Within this operating range, the controlled storage in Lake Tahoe amounts to 732,000 acre-feet, and the lake is thus by far the largest facility for controlled storage in the Truckee-Carson system.

The next facility for storage and regulation of water in the region was Boca Dam and Reservoir, completed in 1939 on the Little Truckee River, and furnishing a supplementary supply for irrigation of about 29,000 acres in the vicinity of Reno and farther east. This reservoir provides only partial regulation of the Little Truckee: its capacity (41,000 acre-feet) plus that of Independence Lake (17,500 acre-feet) is less than half of the average annual discharge of the river.

The incompleteness of the regulation of Truckee River below Lake Tahoe and of Carson River above Lahontan Reservoir has been demonstrated by several damaging floods in recent years, notably the floods resulting from warm rains in November 1950 and December 1955 when both streams inundated large areas, including downtown

Reno; and the flood resulting from snowmelt in the spring of 1952, when the combined runoff of the two rivers exceeded a million acre-feet.

The Bureau of Reclamation's Washoe project, authorized in 1956, proposed several new facilities and their coordinated operation with existing facilities, to develop Truckee and Carson River flows now being wasted, and to effect exchanges of the flow of the two rivers that would bring about the most efficient utilization of available water supplies. Thus the Stampede Reservoir on the Little Truckee would have a capacity about equal to the average annual runoff of the river; the Watasheamu Reservoir on East Fork Carson River would have a capacity of about half the average annual flow of that stream, and would provide firm supplies for irrigation especially in Carson Valley.

In parts of each area irrigated by surface water the ground water is so shallow that it is detrimental to agriculture. Thus the water table is within 5 feet of the surface under extensive areas in Carson Valley (Minden-Gardnerville to Genoa), Truckee Meadows (Sparks and Reno Airport), the Dayton and Fort Churchill areas, and the Fallon area. The Truckee-Carson Irrigation District combats its drainage problem near Fallon with about 350 miles of drains. The Washoe project proposes to solve similarly the problems of Carson Valley and Truckee Meadows by drains that will reduce waterlogging and evapotranspiration, improve the soils for crop production, and yield water that can be used down gradient with other irrigation return flows. Wells are also proposed as a means of reducing artesian pressures and thereby ameliorating the drainage problem.

There has been little development and use of ground water in the Truckee-Carson system, partly because of the availability of surface supplies, partly because of opposition by owners of flowing wells, and partly because the ground water hydrology is not sufficiently well known. Although there are several large capacity wells, notably those used for supplemental municipal supply in Reno, ground water has generally been viewed from its detrimental aspects that create drainage problems. However, these drainage problems also indicate that the ground water reservoirs can be recharged by the streams and by irrigation of land. A further step in the comprehensive development of water resources will be the use of ground water resources for cyclic storage—pumping from wells when surface water is in short supply, and then recharging the subsurface reservoirs in years of abundant runoff. Studies to date indicate that Truckee Meadows has a reservoir from which water of satisfactory quality could be pumped from wells in some areas, but that the water in other localities is warm and highly mineralized (Cohen and Loeltz, 1964). Much of the ground water in the Fernley-Wadsworth area is either of unsuitable quality or is not readily obtainable in large quantity (Sinclair and Loeltz, 1963). Appraisals have not been made of the ground water hydrology of Carson Valley or other areas in the Carson River drainage basin, as a basis for effective management of subsurface storage.

The problem of waste disposal at Lake Tahoe is somewhat akin to that of drainage of agricultural lands, in that it is a manmade problem, but it is of direct concern to many more people and of indirect interest to many others. The problem results from the population explosion, Lake Tahoe division: in 1962 the year-round population was about 11,000, increasing to 132,000 in August; and

this is predicted to increase in 50 years to a permanent population of 107,000 and a summer horde of 596,000. The total water usage for community purposes was approximately 5,300 acre-feet in 1962; it is expected to increase to 22,000 by 1980 and to 40,000 acre-feet a year by 2010. The question of water rights in such quantities in the two States is complicated enough. But about 70 percent of the water used will be converted into sewage, and that sewage includes nutrients which are not eliminated by standard ("complete") treatment or by ground disposal, nutrients that can generate a population explosion of algae and other plankton in the water of Lake Tahoe, which might ruin the unique color of the lake and clarity of the water. Significant aspects of the problem are presented in a comprehensive report to the Lake Tahoe Area Council (1963), which concludes that a new concept of disposal is needed, involving either the transport of the sewage effluent from the watershed, or the removal of chemical nutrients from these effluents before they are disposed of within the watershed. The nutrients that can be detrimental to the unique qualities of Lake Tahoe are tolerable and perhaps even beneficial for some other uses, consisting as they do chiefly of phosphates and nitrates. Thus they might not be detrimental if discharged into tributaries of either the Carson or the Truckee.

The Pyramid Lake Indian Reservation, at the low end of the Truckee River, has a primary (1859) right to about 30,000 acre-feet of water annually from the river for irrigation. The river is generally a gaining stream in its lowest reach (below the Truckee-Carson canal), and has habitually carried enough water to satisfy these rights, although far less than enough to balance the evaporation from Pyramid Lake, so that the lake level has dropped 70 feet since 1920. The maintenance of quality of water in the Truckee River under full development, always a problem at the lower end of a river basin, may have a more satisfactory solution in the management of the Truckee-Carson system than would be possible in most basins, because of the opportunity for disposal of highly mineralized waters and noxious wastes in Carson Sink. Segregation of such wastes, and disposal by separate pipelines, will probably be necessary, in order to maintain suitable quality of water in the Newlands project and other areas of use.

#### WALKER LAKE BASIN

Walker Lake basin receives most of its water supply from the Sierra Nevada (Thomas and others, 1963a). The economy of the sparsely populated region is founded principally upon irrigated agriculture, livestock, mining, and tourism, and this economy in turn has set the pattern of water use in the Walker Lake basin. Use for recreation is important but almost entirely nonconsumptive; domestic use is likewise important, but at present requires only a very small proportion of the total water supply to meet the needs of a permanent population less than 5,000, which may increase by several thousand in some months. The predominant use of water, and practically the only consumptive use, is for irrigation of as much as 17,000 acres in California and 80,000 acres in Nevada.

Water supplies come chiefly from the tributaries whose drainage basins reach the crest of the Sierra Nevada. West Walker River near Coleville, Calif., has a drainage basin of 245 square miles, and on the

basis of a 33-year record has an average annual yield of nearly 200,000 acre-feet; East Walker River near Bridgeport, Calif., with drainage basin of 362 square miles, has an average yield about half as large. Assuming that the irrigated lands throughout the Walker Lake basin require an average of 3 acre-feet per acre or less, the average yield of these two streams is sufficient to meet all developed water requirements. However, despite the apparent adequacy of the average runoff from the Sierras, some water users in the basin are confronted with shortages not only in drought years, but in almost every year. And despite the sparse population Walker Lake basin has had a full share of water problems and controversies during the past half century, involving State rights and Federal rights, Indian rights, riparian rights and appropriative rights, natural-flow rights and storage rights, and interstate problems that are now the subject of compact negotiations.

Several features of the hydrology of Walker Lake basin help to explain these apparent anomalies of adequacy and deficiency, and the controversies that have resulted. The record of precipitation at Bridgeport indicates a general pattern of wet years and dry years in randomlike succession. The trends in annual runoff of West Walker River near Coleville are generally in accord with those in precipitation. The maximum runoff, in 1907, was about 7 times the minimum, in 1924, but this range is less than is likely to occur in a single year, for the runoff in May is characteristically 10 to 25 times as great as the runoff in the following September. Because of this marked seasonal fluctuation in runoff and lack of adequate storage facilities there are water shortages in the latter part of most irrigation seasons.

The Walker River Irrigation District, which distributes the water of the Walker River system in Nevada, has two principal storage facilities. Topaz Lake is an offstream reservoir for West Walker River; since 1937 it has had a capacity of 59,400 acre-feet. Bridgeport Reservoir on East Walker River was developed in 1924 with capacity of about 42,000 acre-feet. The third largest reservoir in the basin is the Weber Reservoir with capacity of 13,000 acre-feet constructed in 1934 along the Walker River for Walker River Indian Reservation. The combined capacity of these three reservoirs is only about 40 percent of the mean annual yield of the river system. The annual inflows to both Topaz and Bridgeport Reservoirs have been greater than their capacity in every year since 1931, and the reservoirs have reached capacity in two-thirds of those years. In most years the reservoirs are drawn down to less than one-third their capacity by the end of the irrigation season, and thus they do not stabilize the supply to the extent of holding over the surpluses of wet years for use in dry years. They do, however, stabilize the flow and thus extend the irrigation season in a given year.

About 8 miles northeast of Topaz Reservoir the West Walker River enters Smith Valley, crosses it, and then flows through a short canyon into Mason Valley, where it joins the East Walker River. In Smith Valley (Loeltz and Eakin, 1953), the river water is diverted into canals, both to the north and south, for irrigation of about 12,000 acres of cultivated land and 7,000 acres of pasture. There is also evapotranspiration from about 11,000 acres of playa and phreatophytes in the valley. By 1949 the irrigation by surface water had increased the ground water storage in Smith Valley, as shown by increasing artesian pressure and high water table. More than a hundred flowing wells

were used chiefly for domestic supplies. In subsequent years pumping from irrigation wells has served the dual purpose of lowering the water table and rate of natural discharge, and of supplementing the surface supplies in periods of deficiency. In the dry year 1961 about 18,000 acre-feet of water was pumped from wells, but in subsequent wet years pumpage was less than 5,000 acre-feet.

In Mason Valley the Walker River and its branches are similarly the chief source of water for irrigation, and in periods of deficiency this is supplemented by pumping from wells. About 5,000 acre-feet is pumped annually from wells by Anaconda Copper Co. for industrial use south of Yerington.

Walker Lake, in the deserts lowest part of the basin, receives inflow almost solely from Walker River, and its level reflects the changing balance between inflow from the river and evaporation from the lake surface. Since 1927 the lake level has lowered each year except in 1938 and 1952, the 2 years of greatest runoff in Walker River. The decline in lake level results in large part from consumptive use of water diverted from the river for irrigation. Part of the lake bed uncovered by this lowering is additional land suitable for irrigation within the Walker River Indian Reservation. In recent years the lands irrigated within the reservation have ranged from 3,100 to 5,000 acres, and are about twice the area irrigated in 1924.

#### CLOSED BASINS IN CENTRAL AND EASTERN NEVADA

Many of these basins can be seen by traveling east on U.S. 50 from Fallon to the Utah State line, and then returning via U.S. 6 through Tonopah. Several are in individual troughs between Carson Sink and Walker Lake on the west and Reese River to the east; the floor of each valley contains an extensive playa or alkali flat, and a bordering area of phreatophytes, from which shallow ground water is discharged by evapotranspiration. East of Reese River the Toiyabe Range and several other high ranges enclose valleys that are isolated and must be entered over passes.

In table 21 these valleys are listed in succession from west to east, grouping those that appear to be in the same structural trough. The table lists only those valleys having "wet" playas, where ground water is discharged. The other valleys in the region (including Fairview, Ione, Little Fish Lake, Monitor, Antelope, Little Smoky, Hot Creek, Butte and others) have external drainage, either surface or subsurface, and thus are tributary to the basins listed in table 21.

Diamond Valley is cited as an example of what may happen in several other of these valleys, which are known to have ground water in storage. There the area of ground water discharge is the northern half of the valley floor (Eakin, 1962b), with a barren playa of 49,000 acres, and a slightly smaller bordering area of phreatophytes. Beginning in 1943, flowing wells were developed near the edge of this area, and the artesian pressure and yield diminished in subsequent years. Beginning in 1958, wells were drilled for irrigation, and by the end of 1961 about 85 had been equipped for pumping at rates of 500 to 2,500 gallons per minute. During 1961 the aggregate pumpage did not exceed 7,000 acre-feet, but doubtless expanded greatly thereafter. Although some of these irrigation wells are within 5 miles of the edge of the natural-discharge area, most of them are more than 10 miles

TABLE 21.—*Undrained basins in central and eastern Nevada*

WEST OF REESE RIVER						
Valley	Area of drainage basin (square miles)	Minimum altitude (feet)	Area of ground water discharge (acres)		Estimated recoverable water (acre-feet) <sup>1</sup>	Reference
			Playa	Phreato-phyte		
Buena Vista.....	800	3,950	9,000	61,000	10,000	Loeltz, 1955. Cohen, 1963. Eakin, 1962d.
Dixie.....	2,360	3,360	29,000	125,000	15,000	
Gabbs.....	1,150	4,100	18,000	27,000	4,000	
Edwards Creek.....	-----	-----	-----	-----	-----	
Smith Creek.....	-----	-----	-----	-----	5,000	
EAST OF REESE RIVER						
Big Smoky.....	3,330	{ * 5,500 * 4,700	30,000 10,000	70,000 20,000	30,000	Meinzer, 1917.
Grass.....	-----	-----	-----	-----	10,000	
Kobeh.....	-----	-----	-----	-----	5,000	Eakin, 1962b. Eakin, 1960.
Diamond.....	3,160	5,770	49,000	47,000	20,000	
Newark.....	1,390	5,830	25,000	47,000	18,000	Eakin et al., 1951.
Railroad.....	3,560	4,630	48,000	48,000	-----	
Ruby.....	1,900	5,990	32,000	60,000	20,000	Do.
Penover.....	700	-----	-----	-----	5,000	Do.
Stale-Stephoe.....	3,290	5,850	-----	-----	50,000	Snyder, 1963.
Clover-Independence.....	975	5,600	5,000	130,000	12,000	Eakin et al., 1951. Snyder, 1963.
Spring.....	1,640	5,530	-----	-----	25,000	
Snake.....	-----	-----	-----	-----	30,000	-----
Thousand Springs.....	-----	-----	-----	-----	-----	-----

<sup>1</sup> From MacGuinness, 1963.<sup>2</sup> North.<sup>3</sup> South.

away. Thus the wells may pump for years before they cause any measurable reduction in the natural discharge, and in the meantime they will be pumping from storage and from each other's cones of depression. The aggregate quantity in storage is large, and the chief problem foreseen is the economic one of increased cost of pumping as water levels decline.

The two easternmost basins listed in the table are parts of the Great Salt Lake drainage basin, which lies chiefly in Utah. Also, the Thousand Springs Creek Basin, near the northeast corner of Nevada, is adjacent to the Snake River drainage basin, and is similar to it in many respects, notably in topography, precipitation, surface runoff, and available hydrologic information. (See p. 293.)

#### DRY BASINS OF SOUTHERN NEVADA

The part of Nevada south of the latitude of Tonopah contains numerous topographically closed basins, but only a few of these have wet playas or areas of ground water discharge: Fish Lake Valley (Eakin, 1950), Clayton Valley (Meinzer, 1917), Sarcobatus Flat (Malmberg and Eakin, 1962), and the Amargosa Desert (Walker and Eakin, 1963)—all near the California State line.

Pahrump Valley (Maxey and Jameson, 1948) is an interstate closed basin southeast of these basins, and is similar to Las Vegas Valley (p. 309) in several respects. The Spring Mountains, with Charleston Peak the highest summit, stand between the Pahrump and Las Vegas Valleys and are the principal source of water for both. Prior to 1937 two large spring areas provided water used in Pahrump

Valley, averaging about 9,600 acre-feet a year. Several large wells were drilled in the following decade, and by 1946 the total supplies had increased to 17,500 acre-feet, of which nearly 11,000 acre-feet came from wells. By 1960 the water use was about 26,000 acre-feet, from 65 wells and several springs that continued to flow. Since pumping began, water levels have declined, more than 100 feet in some wells, a depletion of storage that is taken as evidence that the present rate of use exceeds the perennial supply. Balance can be achieved either by reducing the rate of use or by importing water into Pahrump Valley to supplement the supply from local sources.

The other closed basins in southern Nevada are dry in the sense that they have playas which contain water only as a result of infrequent flood runoff. Under these dry playas the water table is tens to hundreds of feet below the surface and quite beyond the reach of vegetation. Thus within the basin there is negligible return to the atmosphere of either ground water or surface water. The dry playa deposits lack the soluble salts that are commonplace in wet playas, and the ground water encountered at depth is of fair to good quality. Because of the lack of accumulation of either water or soluble salts in such basins, Thompson (1929, p. 125) concluded that they must be subject to underground leakage, and Snyder (1962) marks dry playas as characteristic features of "closed and drained" valleys.

It has been difficult to pinpoint the drainage or outflow from these dry basins, in which there are very few wells. Most wells have obtained water from the alluvial valley deposits, but they have not provided enough data to show the direction of movement of the ground water, and particularly the pattern of drainage from one closed basin to another. In fact, in some alluvial basins the water levels in wells indicate movement toward a low point within the basin, as if the basin were a separate and independent hydrologic unit, and not yet filled to a "spill" level—an unlikely condition in a region where the Pleistocene climate was humid enough to have formed several lakes (fig. 57).

Widely dispersed in southern Nevada and beyond its borders are several springs whose discharges are too large to be readily accounted for, unless they represent the aggregate of underground outflow from the numerous dry basins in the region. Such interbasin circulation is indicated by geochemical studies of springs in Death Valley, Calif., by Hunt and Robinson (1960) who suggest that some of the water may have moved through carbonate rocks and along faults from the Amargosa Desert Basin in Nevada. Elsewhere in the State the carbonate rocks are known to be extremely permeable in some mountain ranges, as for example at Eureka, where the Eureka Mining Co.'s Fad shaft was abandoned because it could not be drained by pumping (Stuart, 1955). However, there have been no hydrologic studies of the mountain ranges, and the water-bearing properties of the carbonate rocks, or of the bedrocks generally, are practically unknown.

Interbasin movement of ground water at the Nevada Test Site is indicated by data from deep test drilling in Yucca Flat in 1960-61. There the alluvium and tuff that had been tapped by shallower wells is underlain by less permeable clastic rocks, and by far more permeable carbonate rocks (Winograd, 1962). Ground water in the alluvium and tuff is semiperched, and moves slowly downward into the permeable carbonate rock, and then laterally out of the Yucca Flat Basin.

From these and other NTS data plus limited data from a broad surrounding region, Eakin, Schoff, and Cohen (1963) suggest that ground water moves generally southward or southwestward, especially in Paleozoic carbonate rocks that underlie the alluvial basins and form the highlands that separate those alluvial basins. Ash Meadow Springs, in Amargosa Desert, constitute a major discharge outlet for these carbonate rocks, and these may discharge water that has traveled as much as 100 miles underground.

It may be tentatively concluded that Fish Lake Valley, Clayton Valley, Sarcobatus Flat, and Amargosa Desert contain the discharge areas of ground water that has moved generally southward from (and under) an impressive list of dry, closed basins: Ralston Valley, Alkali Spring Valley, Stone Cabin Valley, Mud Lake Valley, Stonewall Flat, Cactus Flat, Gold Flat, Reveille Valley, Kawich Valley, Oasis Valley, Emigrant Valley, Yucca Flat, and Frenchman Flat.

Farther east there are many more closed dry basins, several with dry playas, and some with small areas where ground water is at shallow depth; but generally the ground water is at too great a depth to be discharged by evapotranspiration. Ground-water reconnaissances indicate that there is underflow of ground water from Cave Valley toward White River Valley (Eakin, 1962f), and that Pahranaagat Valley may receive underflow from Dry and Delamar Valleys (Eakin, 1963a) Garden Valley and Coal Valley (Eakin, 1963b). Also, ground water moves southward from Lake Valley toward Meadow Valley Wash (Rush and Eakin, 1963). Thus, although these basins are closed, and separate from Colorado River insofar as surface water is concerned, it is likely that underflow from them enters ground-water reservoirs within Colorado River Basin (pp. 309, 310), and may contribute to the discharge of the springs in Pahranaagat Valley or, farther south, along Muddy River or Virgin River.

At present we know just enough about the deep ground water in southern Nevada to suggest big opportunities and to raise big questions. The State geologic map (fig. 3) shows extensive areas of outcrop of carbonate rocks in the ranges of southern and eastern Nevada, and similar rocks can be expected also in intervening highland areas where they are covered by younger volcanic rocks. In the basins of the region, carbonate rocks may be beneath the valley fill and thus receive water by downward movement directly from the alluvium, or they may be separated from the alluvium by less permeable rocks, so that water in the alluvium is perched above the water of the carbonate rocks. In extensive areas the thickness of the Paleozoic rocks is of the order of 2 or 3 miles, of which more than half may be carbonate rocks of variable but unknown permeability. At any rate, there is a likelihood of vast quantities of ground water in storage in southern Nevada; and, therefore, opportunity for water development by means of deep wells.

The big question is two-pronged: where are the most suitable sites for such development, and what will be the effect of that development upon existing supplies and established water rights, particularly in the springs of that region? To date we have only bits and pieces of the answer to this question, as for example, the indications of remarkable hydrologic continuity in a broad region around the Nevada Test Site, and the indications of remarkable hydrologic discontinuities that give rise to springs at various elevations in the White River Basin.

An understanding of the flow system in the carbonate rocks, sufficient to answer the big question, will require deep exploratory drilling and geophysical testing, supplemented by detailed mapping of the stratigraphy and structure, with particular attention to the hydrologic properties. With this knowledge of the flow system, it may be possible to salvage and use the water now being wasted by natural discharge or the water now issuing forth in saline springs. And it may be possible to deplete the accumulated storage in some areas, with negligible effects upon existing rights.

#### COLORADO RIVER BASIN

Although about 13,500 square miles of its drainage basin is in southeastern Nevada, the Colorado River receives a negligible volume of water from the State. The largest contributor is Virgin River which enters the Nevada portion of Lake Mead, but its water comes almost entirely from Utah and is reduced in volume as it flows in Nevada, because of diversions for irrigation of about 2,800 acres near Bunkerville and Mesquite (however, a substantial proportion of its minimum flow in this reach comes from springs in Arizona). Las Vegas Wash, with a drainage basin of about 2,200 square miles, formerly contributed only storm runoff to the Colorado, but is now a perennial stream because of industrial waste, irrigation return, and sewage effluent. Meadow Valley Wash, with a drainage area of 4,250 square miles, contributes negligible quantities of water to Lake Mead. Except for the irrigation return flows and occasional surpluses from Muddy River springs (p. 310), White River has not in historic time had enough water to flow through to the Colorado from its 3,850-square-mile drainage basin.

*Las Vegas Valley.*—As summarized by Malmberg (1963), Las Vegas used only ground water prior to World War II, entirely from springs until 1907, chiefly from flowing wells until 1941, and chiefly from pumped wells in subsequent years. It is estimated that the natural discharge from the valley's ground-water reservoir in 1905 was about 26,000 acre-feet, of which 7,500 was discharged by springs and the remainder by upward leakage from the artesian reservoir. By 1915 the draft by wells was about 12,000 acre-feet of a total discharge from the reservoir of about 38,500 acre-feet. After 1925 this total discharge probably declined somewhat with declining artesian head, to about 35,000 acre-feet in 1942. Since that year the total discharge has been increasing because of pumpage for Las Vegas expanding population. By 1955 it was nearly 50,000 acre-feet, of which 40,000 was discharged by wells, 3,000 by springs, and the rest by upward leakage and evapotranspiration. Currently the discharge from the reservoir is of the order of 60,000 acre-feet a year.

Water levels in wells in the valley have generally declined during the 40-year period of record, and particularly since World War II as the rate of pumping increased to supply the increasing population. This declining trend is evidence that the total discharge from the reservoir has exceeded the total recharge. Although pumping from wells is chiefly responsible for this decline, a part of the decline resulted from less than average recharge from precipitation during the drought of 1942-56 (Thomas and others, 1963b).

Nevada's decreed share of Colorado River water is 300,000 acre-feet a year, most of which will likely be used in the Las Vegas area. Since 1942 water has been brought into the valley by pipeline from Lake Mead, first to supply industries in the Henderson area and then to supplement the ground-water supply in other parts of the valley. The current use of Lake Mead water is only about 20,000 acre-feet a year, and the area thus has assurance of more water than will be needed for several decades. Nevertheless, many problems remain, of which perhaps the most important is the optimum pattern by which conjunctive use of ground water and Lake Mead water can be developed most effectively and economically. Among the elements to consider in seeking this optimum pattern are: (1) The water now pumped from wells is of better quality than that from Lake Mead (which contains as much as 800 parts per million of dissolved solids), but some other parts of the ground-water reservoir contain water of inferior quality; (2) the pumping lift at wells is markedly less than that required from Lake Mead, but increases as water levels decline; (3) the removal of ground water has caused some subsidence of the land in Las Vegas and vicinity, and this will continue with additional depletion, to the possible detriment of structures on the land surface; (4) cessation of pumping, particularly in the vicinity of natural spring areas, will be followed by rising water table, to the possible detriment of human occupancy of the land.

*Rivers without water.*—White River is perennial as it enters White River Valley from the east slope of the high White Pine Range (about 25 miles southwest of Ely), and for short segments southward about 40 miles, where it is replenished by several large springs. Then the channel turns southeastward through the Seaman Range and into Pahroc Valley, where the water table may be as much as 1,000 feet below the channel, which rarely has any water. Still farther south, in Pahrnatagat Valley, the Hiko Springs issue at a level approximately 150 feet lower than that at which water is encountered in deep wells in Pahroc Valley. Water from these and other large springs in Pahrnatagat Valley (Eakin, 1963c), used for irrigation, also maintains some flow in the river channel as far south as Pahrnatagat Lake. Downstream, in Coyote Spring Valley (Eakin, 1964), the channel is always dry and ground water is far below the surface. Below Arrowhead Canyon, large springs near Moapa again fill the channel (here called Muddy River); this is the water that is used for irrigation on Moapa River Indian Reservation and near Logandale and Overton, with return flows continuing to Lake Mead. Several dry basins mentioned on page 308 and possibly Jakes Valley and Long Valley farther north, have evidently contributed to the supplies that issue from large springs along this ancient river valley.

Meadow Valley Wash, flowing southerly within 40 miles of the State line, is the water level route followed by the Union Pacific Railroad from Caliente south to Glendale (Phoenix, 1948). It is perennial in some reaches because of inflow from springs, and ephemeral in others, until it joins Muddy River near Glendale. Its average discharge into Muddy River is negligible. However, in contrast to the White River, Meadow Valley Wash frequently carries flood-flows down its entire length, and some of these floods have caused severe damage to the railroad. The two river basins are nevertheless similar in that their continuous channels appear to be relics

of formerly more significant tributaries of the Colorado River. The deep ground water reservoirs that occur in some parts of the Colorado River drainage basin are similar to those recently tapped in other parts of southern Nevada, as summarized on pages 307-308.

#### ACKNOWLEDGMENTS

In writing this chapter I have attempted to synthesize the findings of the many scientists who have made significant contributions to the hydrology of Nevada. Their names appear below. Especially, for their ideas and for their review of my expression of them, I wish to thank the men who are chiefly responsible for the going program of basic hydrologic data: Philip Cohen, Thomas Eakin, George Hardman Edward Harris, Glenn Malmberg, Hugh Shamberger, and George Worts.

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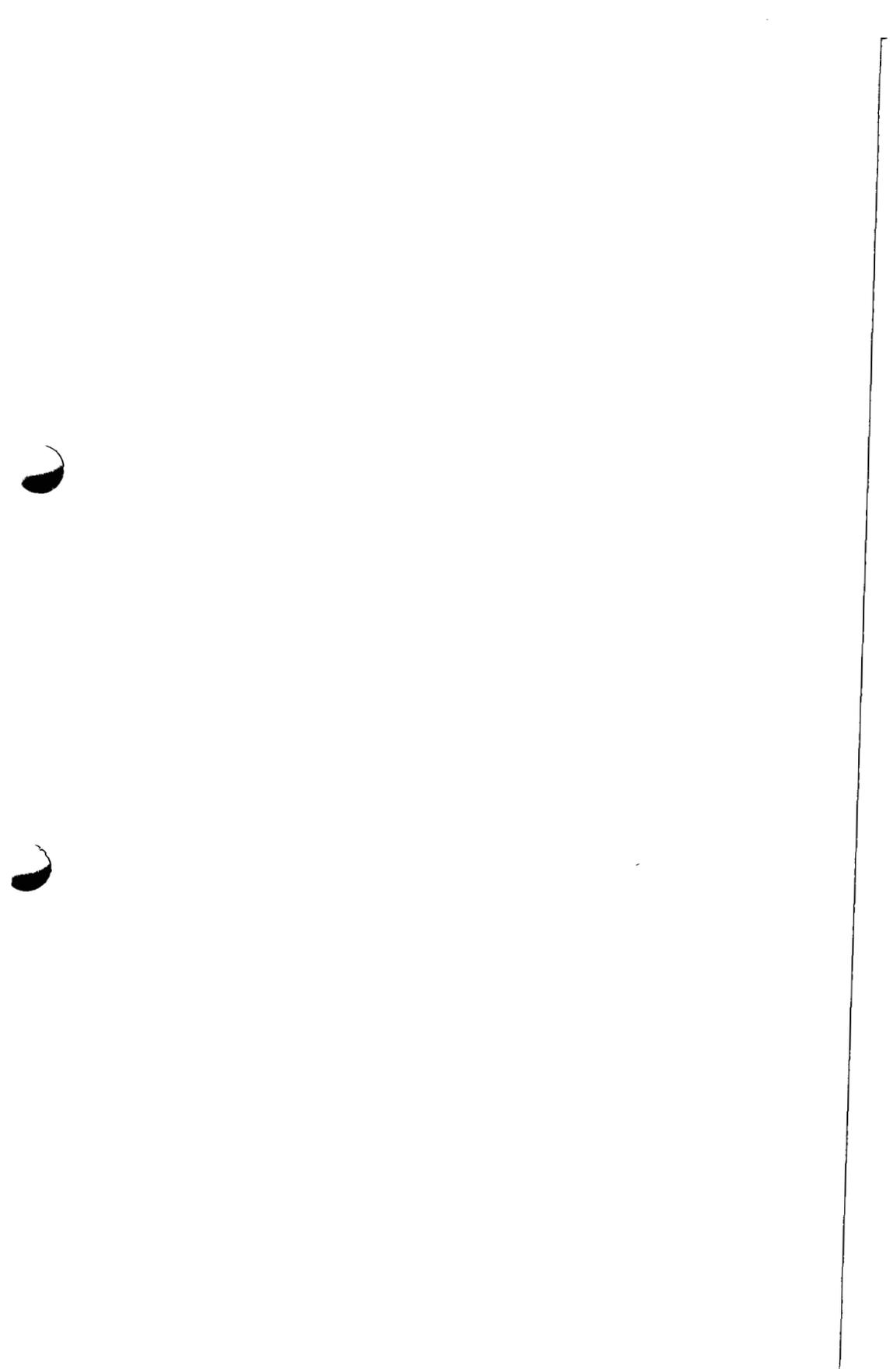
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