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GEOLOGY AND MINING SERIES No. 40

The Geology of Nevada Ore Deposits

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AND

The Mining Districts of Nevada

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JAY A. CARPENTER, *Director*

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FOREWORD

The Bureau for many years has received requests for a geological map of the State, with general information on the State's formations and ore deposits.

There has been such a small area of the State's wide expanse mapped geologically, that a State map is still far in the future. There is, however, now in preparation by the Bureau a bibliography of the geological literature on Nevada. Much of this is already covered in the present Bureau publications, "Mining Districts and Mineral Resources of Nevada, 1923," and "Metal and Nonmetal Occurrences in Nevada, 1932."

The material for a bulletin on the formation and ore deposits of the State came about through the work of Henry G. Ferguson of the U. S. Geological Survey and of Bernard York, an alumnus of the Mackay School of Mines.

In 1929 Mr. Ferguson published in *Economic Geology* a most excellent paper on "The Mining Districts of Nevada"; but it had a very limited distribution in Nevada and was soon unobtainable.

Bernard York, because of his acquaintance with the State as an exploration engineer, was employed in 1939 as a special field engineer of the Nevada State Bureau of Mines to make a field study of all the county-owned patented claims in the State, which study extended over many months and from one end of the State to the other. The methods and results of this study were mimeographed by the Bureau and much publicized by the State press. In 1941, he submitted to the University of Nevada a thesis on "An Outlook for the Future of Mining in Nevada," which gained him the degree of Engineer of Mines.

As much of this thesis was worthy of publication as a bulletin, Mr. York was employed by the Bureau during the summer vacations of 1941 and 1942 on field work and the preparation of a general paper on economic geology for the use of Nevada citizens.

Due to Mr. York's recent year-round employment as Assistant Professor of Mining at the University of California, his two papers have been consolidated and amplified over several months time by the Director of the Bureau and by Dr. V. P. Gianella, head of the geology department of the University of Nevada, and the geologist of the Bureau.

It is hoped that it will now fill the long-felt need for a geological treatise on Nevada geology and that with its many specific references to districts and camps in the State, it will hold the interest of the reader and encourage prospecting for the still undiscovered mineral resources of the State.

To supplement it, Mr. Ferguson's more technical paper on "The Mining Districts of Nevada" is included in the bulletin to make this important paper available to Nevada citizens, and to interested examining engineers and geologists from without our State.

JAY A. CARPENTER,
Director.

THE GEOLOGY OF NEVADA ORE DEPOSITS

By BERNARD YORK[1]

THE ELEMENTS

The elements that are combined to form the earth's "crust" are not uniformly distributed and are rarely present singly. They occur in chemical combinations that are stable under the conditions existing at the time of their union. Their rearrangement into new compounds may be brought about by a change in their environment with both chemical and physical processes influencing their arrangement. Combinations which are stable under the new conditions have remained unchanged. Those unstable are affected and changed to a stable composition either by the addition, removal, or interchange of one or more elements. These natural occurring compounds, when of definite chemical composition, are called minerals.

The earth's crust is that solid portion to a depth of approximately ten miles and made accessible to man either through boring and mining operations or exposed by faulting, folding, or erosion. It is composed principally of minerals and a few which predominate are normally called the rock-forming minerals. The crust consists mainly of igneous rocks, or their derivatives, the bulk of which are composed of a relatively few mineral species, mostly silicates and oxides. The predominate minerals are quartz, feldspar, pyroxene, amphibole, mica, olivine, garnet, magnetite, and ilmenite. Eight elements, oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium, make up approximately 98 percent of the rocks. Only three of these, iron, aluminum, and magnesium, are metals of economic importance. The other metals are present in amounts of less than 0.1 percent. Many of the most useful metals occur in quantities of less than 0.01 percent. The amount of useful metals present in a rock does not represent that which is available to industry. Only a small fraction of these metals occur in sufficient concentration to be recoverable by man. It is indeed fortunate that natural processes have accumulated a portion of the useful metals and localized them into concentrations containing many times the general rock average.

In general, igneous rocks contain more of the useful metals

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than do sedimentary rocks. This fact, and the conditions under which some of the local concentrations occur, has led to the belief that igneous rocks are the original source of the metals. However, sedimentation under proper conditions may bring about local concentration of metals.

THE MINERALS

Most of the known elements are present in greater or lesser amounts in the crust of the earth. They have combined through natural processes to form relatively definite and stable compounds, most of which are called minerals. A mineral may be defined as a natural-occurring inorganic substance of definite chemical composition found in the earth's crust. A mineral deposit is a localized concentration of a certain mineral, or minerals, and may, or may not, be of such composition, size or concentration as to have commercial value.

Solid minerals, and most minerals occur as solids, have formed by the union of elements. Their occurrence as a solid indicates a transition from a liquid or gaseous form to that of a solid. Precipitation from solution is then an important process in the formation of minerals. In general, the minerals composing igneous rocks formed while the magma was in a molten or liquid state, and the relative solubilities of the silicate compounds was a factor in controlling their formation.

Mineral deposits are formed through both mechanical and chemical processes of concentration. Those formed by mechanical processes of concentration include the detrital deposits such as placers. Deposits formed by chemical processes of concentration have been the source of the bulk of the metals that are so valuable to man in his industrial advancement.

The minerals of Nevada have been listed, classified, and described by Dr. Vincent P. Gianella in "Nevada's Common Minerals (Including a Preliminary List of Minerals Found in the State)," a recent publication of the Nevada State Bureau of Mines and the Mackay School of Mines as Univ. of Nevada Bull. Vol. 35, No. 6, Geology and Mining Series No. 36 (1941). Persons who are interested in minerals, particularly those found in Nevada, should obtain a copy of this publication. Copies may be obtained by applying to the Nevada State Bureau of Mines, Reno, Nevada.

THE ROCKS

Rocks are composed of an aggregate of minerals grouped together to form a relatively solid mass. Rocks belong to three main groups: igneous, formed through the solidification of molten material; sedimentary, rocks derived from erosion and deposition; and metamorphic, rocks derived by modification of either igneous or sedimentary rocks. All rocks were originally of igneous origin. At present igneous rocks compose approximately 95 percent of the crust. Sedimentary rocks, though widespread, form only a relatively thin veneer on the earth's surface, and metamorphic rocks are present in even less quantity.

Classification of rocks into groups has been based upon mode of formation, texture, and the mineralogic composition rather than on the chemical composition. The combined average chemical composition of all sedimentary rocks agrees closely with that of the igneous rocks from which they were derived. Metamorphic rocks have been formed through prolonged heat and pressure which have changed the original rock, either sedimentary or igneous, to such an extent that it retains but few of its original physical characteristics. The rocks of each main group have been classified according to composition and texture and given a distinct name.

It is of interest to note that in the early days of the State many types of rock were used as building stones, and the earliest mining bulletin published by the University of Nevada was a "Preliminary Report on the Building Stones of Nevada," by John A. Reid in 1904.

The State capitol building and the State prison buildings at Carson City are excellent examples of early sandstone buildings erected in the State. Bower's Mansion in Washoe Valley is a beautiful example of granitic rock masonry work.

The Museum of the Mackay School of Mines contains a piece of tuff inscribed "1847" that came from an old fireplace near Wamonie in Nye County, its origin being a mystery. Some of the early buildings of Eureka, and, at a later date of Tonopah, are constructed of tuff, and a quarry in tuff alongside the highway east of Sparks has furnished the rock for recent residences and service stations in that city and Reno.

IGNEOUS ROCKS

Igneous rocks are of two types, intrusive and extrusive. Each has solidified from a molten mass, or magma, that rose from some deep source. The rate of cooling controlled the segregation of constituents and the rate of formation and growth of minerals to such a marked degree that each type is texturally distinct.

The magmas that formed the intrusive rocks invaded the overlying formations but did not reach the surface, hence they retained most of their constituents until nearly solidified. Slow cooling permitted the growth of large crystals. The resultant rock is composed wholly of an intergrowth of relatively coarse crystals and has a granular texture. The molten masses, or magmas, that formed the extrusive rocks flowed out upon the surface. Such flows have often been covered by succeeding flows or by sedimentary beds.

The release of pressure at or near the surface permitted the escape of part of the gaseous or vaporous constituents, and thus changed the composition of the mass. Rapid cooling and solidification restricted the segregation of components and growth of crystals. These conditions result in a rock of small to medium sized crystals enclosed in a finely granular or glassy groundmass, or a rock made up entirely of glass. The lava of some flows solidified so rapidly that a portion of the gasses did not escape and were retained as bubbles. This is particularly evident in vesicular basalts.

The composition of the magma and the rate of cooling controlled the amount and kind of minerals formed during solidification, resulting in the formation of rocks of relatively definite mineral assemblage and proportions.

Petrographers have classified igenous rocks on the basis of their mineral composition and texture. This classification is based on the presence or absence of certain minerals, and on the proportions of minerals in the aggregate. A high proportion of ferromagnesian minerals and a low proportion of silica places the rock in the basic group. Further distinction involves a quantitative estimate of the kind of feldspar or ferromagnesian mineral present, and whether or not quartz is one of the components. A classification of such refinement, though very useful to the experienced petrographer, is neither necessary nor practical for the prospector in the field, who must identify the rocks by eye, or aided by a low-power magnifying glass. Usually the prospector's needs will be satisfied if he can distinguish an intrusive rock from an extrusive rock and classify it as basic or acidic in composition. However, if the prospector wishes to be advised of the petrographic name and mineral composition of certain rocks, he may send representative pieces to the State Analytical Mining Laboratory, University Post Office, Reno, Nevada, for determination. This free service is maintained by the State of Nevada as an aid to the Nevada prospector, and includes analyses and assays on a limited number of samples.

Rock specimens sent for determination should be chosen carefully. The specimen should be as fresh and unaltered as can be

obtained. This means that pieces should be chosen that show a minimum of weathering, and they should be best taken from a point far enough from the zones of mineralization to be relatively free from alteration.

The textural terms are here defined before describing the common rocks:

Phenocryst is a term applied to any one of the relatively coarse and obvious crystals of any mineral that occurs in a fine-grained or glassy groundmass of an igneous rock.

Porphyritic texture is one having distinct and numerous phenocrysts in a fine-grained or glassy groundmass. "Porphyry" is a commonly used term applied to a rock having such a texture and therefore simply denotes texture, and not mineral composition. Many igneous rocks are porphyritic, particularly the lavas.

Felsitic, almost or wholly crystalline, but made up of crystals too small to be readily distinguished by the unaided eye.

Aphanitic, of such fine texture that separate crystals are invisible to the unaided eye.

Conglomerate, an aggregate of rounded and water-worn pebbles and boulders cemented together into a coherent rock.

Breccia, a rock composed of angular fragments cemented together. It may be either volcanic, sedimentary, or the product of crushing as "fault breccia."

INTRUSIVE IGNEOUS ROCKS

Only the most common types of the intrusive igneous rocks will be defined.

Alaskite is a granular rock of white or light-gray color. It is composed almost entirely of quartz and orthoclase feldspar. It closely resembles granite, but lacks mica and hornblende. Alaskite is common at Silver Peak, and is found at Goldfield, near Reno, and in many other Nevada localities.

Granite is a granular rock of pink or gray color, composed of orthoclase, quartz, and either muscovite, biotite, or hornblende.

Granite porphyry is a rock of the composition of granite with abundant phenocrysts of quartz and orthoclase imbedded in a granular groundmass.

Monzonite is a granular rock resembling both granite and diorite in appearance and composition. It contains orthoclase and plagioclase in approximately equal proportions. If quartz is present, the rock is called a quartz monzonite. It is usually of a gray color with a few prominent pink crystals. The monzonites are common in Nevada and are particularly abundant at Ruth and Kimberly.

Monzonite "porphyry" is a rock of the composition of monzonite with abundant phenocrysts of orthoclase and plagioclase.

Granodiorite is a granular igneous rock with the minerals contained in a quartz diorite but also containing considerable orthoclase. It has less orthoclase than quartz monzonite. Granodiorite is a common rock throughout Nevada as at Austin, Steamboat Springs, and in the Sierra Nevada in western Nevada.

Diorite is a gray crystalline igneous rock, composed essentially of plagioclase, feldspar, and hornblende. Biotite or augite may also be present. When much quartz is present the rock is termed a quartz diorite.

Diorite "porphyry" is a rock of the composition of diorite with abundant and prominent crystals of plagioclase, hornblende, and biotite in a granular ground mass. Diorite makes up the upper portion of Mount Davidson at Virginia City.

Gabbro is a granular rock usually of dark color. It is composed of plagioclase and pyroxene, diopside or augite. The ferromagnesian mineral commonly has a laminated parting. Olivine, biotite, or hornblende may be present in small amounts. Gabbros are found in the Pine Forest, Jackson, and other ranges of the northern and northwestern part of the State.

Peridotite is a granular rock usually of dark color. It is generally composed essentially of olivine, with some form of pyroxene, and with or without hornblende or biotite. Plagioclase feldspar may be present in small amounts. This rock occurs as dikes in eastern Clark County.

EXTRUSIVE IGNEOUS ROCKS

Andesite is a volcanic rock of porphyritic or felsitic texture. The most conspicuous features are the dark-colored phenocrysts of hornblende, biotite, or augite and the light-colored phenocrysts of plagioclase. Andesite is similar to diorite in chemical composition, but differs texturally. Andesites make up the great bulk of Tertiary lavas in western Nevada. It is the chief rock at Divide, Tonopah, Virginia City, and Tuscarora.

Basalt is a black or dark-gray lava rock which is often vesicular; that is, it contains small irregular spherical cavities formed by gas or steam bubbles. Crystals of olivine, plagioclase, and pyroxene may, or may not, be visible in the dense or finely crystalline ground mass. This rock is of widespread occurrence in the State and it commonly caps mountains in northern Nevada and also south of Goldfield. It forms the cap which gives Table Mountain, in Churchill County, its name. Also in the vicinity of Hot

Springs in Churchill County, and forms Black Knob west of the Packard mine in Pershing County.

Dacite may be roughly defined as a quartz-bearing andesite. It often closely resembles rhyolite, but may be distinguished from rhyolite by the presence of plagioclase in place of orthoclase. Dacite is one of the principal rocks among the lavas at Goldfield.

Diabase is a basaltic rock commonly of aphanitic texture and of dark color. Its composition is similar to that of basalt. It may usually be distinguished from basalt by its granular texture. Diabase commonly occurs as dikes. Many of these are to be seen in the Humboldt Range.

Latite is a rock of porphyritic, felsitic, or glassy texture. Orthoclase and plagioclase are present in approximately equal amounts. Either hornblende, augite, biotite, or olivine is usually present. Latite is chemically similar to monzonite. Latite is found at Silver City and Yerington.

Rhyolite is a rock of porphyritic or felsitic texture with the phenocrysts embedded in a glassy groundmass. Orthoclase and quartz are usually the most prominent phenocrysts, although those of biotite, augite, and hornblende may also be present. Rhyolite has the same chemical composition as granite and is quite common in Nevada as flows. Rhyolite is an important rock at Rhyolite, Rawhide, Tuscarora, Tonopah, Virginia City, Yerington, Ruth, Austin, Eureka, and many other regions.

Tuff is a porous granular or cellular rock. The volcanic tuffs are formed by the accumulation and hardening of volcanic dust and cinders. It is found in many places in Nevada either with other volcanic rocks or associated with lacustrine sediments. Tuffs make up much of the volcanics at Tonopah, Virginia City, Carroll Summit, Eureka, and other regions, and also make up much of the Siebert lake beds at Tonopah and Goldfield, and the Truckee lacustrine deposits of northern Nevada.

SEDIMENTARY ROCKS

Surface water, wind, and glaciers act as erosion and transporting agents in the wearing away of a land mass, and explosive volcanism scatters unconsolidated material over large areas. This redistribution of the material at the earth's surface has been continually in progress since the beginning of geologic time. Material that was once deposited on the bottom of the sea and then elevated into a land mass is again subjected to erosive action. The bulk of the sedimentary material has been deposited in basins occupied by bodies of relatively quiet water, therefore the discussion here will be limited to a few brief statements of the processes of deposition in seas and lakes. Distinct terms are used to designate the sediments deposited in each type of water: "lacustrine" for fresh water sediments, and "marine" for sediments deposited in the sea.

The disintegration and decomposition of rocks sets free material that is transported by surface waters, either in solution or in suspension. Material in suspension settles out as the stream loses carrying capacity through loss of velocity. There is a sudden loss of velocity as the stream enters a body of water and the coarse material settles near shore. The extremely fine material remains in suspension longer and therefore is transported far from the point of entry. In this way, there is a segregation of the material according to size, and to a lesser extent a segregation according to chemical composition. Quartz crystals, and grains, are highly resistant to disintegration or solution, therefore much of the quartz is transported as pebbles or grains and deposited in layers or beds near shore. Minerals of the feldspar and ferromagnesian groups are readily decomposed by processes of weathering and break down into both soluble and insoluble products. The dissolved material remains in solution until finally precipitated by chemical reactions or removed either by evaporation or by organisms. The insoluble products are transported as extremely fine grains, some of which are of colloidal dimensions, and are carried in suspension far from shore. Soluble material removed from solution by plant and animal life of the sea or lake is incorporated into their supporting structures. Upon the death of the plants and animals the skeletons and body structures settle to the bottom. Layers or beds of diatomite and occasionally of limestone have accumulated in this way.

Varying conditions in a large body of water as a change in direction or velocity of the currents, change in depth of water, or a change in the volume of material being delivered, cause material of different size or composition to be deposited over the same area at different times. This forms distinct layers or beds. There may be great diversity in the character and composition of separate beds, but the material within any individual bed is relatively uniform. The sediments as we see them today, after they have been elevated, tilted, and partially eroded, are a series of layers of reconsolidated material. Some layers are only a few inches in thickness while others are several hundred feet. Some sedimentary rocks are thin bedded, others are massive. Shales, limestones, and sandstones are the most common reoccurring sedimentary beds.

The material as laid down was loose, as coarse material intermixed with moderately fine grains as a layer of gravel, as fine-grained material as a layer of sand, as clayey material as a mud or ooze, or as plant and animal remains in a porous mass. Prolonged pressure from the weight of great thickness of overlying material has in time consolidated the loose fragments into rock.

Deposition took place on a nearly horizontal surface so the normal attitude of the beds was approximately horizontal. Faulting and folding have warped, tilted, and elevated large blocks to such an extent that, in many places, the beds are now inclined at steep angles. In some cases folding has been so extreme that the beds have been overturned, placing the older above the younger, and beds that were once buried to a depth of tens of thousands of feet have been so elevated and tilted that they are now exposed at the surface.

This discussion on the origin and formation of sedimentary rock is extremely brief and generalized. The reader should consult the published literature on the subject for detail. Books on sedimentation and sedimentary rocks are available at any good library.

Here again, as in the case of the igneous rocks, only the common types are defined. These terms are loosely used and in many cases indicate structure rather than chemical or mineralogical composition.

Chert is a term for a compact, microcrystalline silica, usually of light color. It occurs in rounded, nodular, concretionary masses, replacing limestones as in the Pogonip limestone at Cortez, Eureka, and Ely.

Conglomerate is formed of rounded pebbles cemented together. It differs from ordinary sandstone only in size of particles.

Limestone is a rock composed almost entirely of calcium carbonate. Magnesium sometimes replaces part of the calcium. It can be distinguished from dolomite by its effervescence when treated with dilute hydrochloric acid. Limestones are formed both through the accumulation of fragmental remains of marine animals and from chemical precipitation. Calcium carbonate readily undergoes crystallization, even at low temperature and pressure, so that many limestones show a crystalline structure with little evidence of their origin remaining. When crystalline, limestone is known as marble. Limestones are present in the sediments in many parts of the State, and ores occur in these rocks at Eureka, Goodsprings, Pioche, Cortez, Yerington, and elsewhere.

Dolomite is a magnesian limestone. It can be distinguished from limestone by its increased hardness and specific gravity or by chemical test for the presence of magnesia and by its reaction with acid. Limestone effervesces readily when treated with dilute hydrochloric acid, dolomite does not. Dolomite is common in the sediments in eastern and southern Nevada. Large quantities of dolomite are present at Gabbs, in the Paradise Range, associated with magnesite and brucite. Large deposits of very pure dolomite occur at Sloan in Clark County. Lead ores at Eureka occur in the Eldorado dolomite.

Sandstone is a rock composed of an aggregate of small to medium sized quartz grains bound together by material of a calcareous, ferruginous, siliceous, or argillaceous nature. Sandstone can be distinguished from quartzite by the weakness of the binding material.

Quartzite is a sandstone thoroughly cemented by silica. It can be distinguished from the crystalline igneous rocks by the predominance of rounded grains, most of which are of quartz. It differs from sandstone in the strength of the cementing material, as quartzite breaks through the grains rather than around them as is the case with sandstone. The most widespread quartzite is the Prospect Mountain quartzite which lies at the base of the Paleozoic sedimentary rocks in many regions, particularly at Eureka and Pioche. The Eureka quartzite is present in many mining districts. The gold ores of Delamar occur in quartzite, while those at Cortez are in places terminated against the Eureka quartzite.

Shale is a more or less laminated rock formed by the induration (hardening) of muds, silts, or clays. It can be distinguished from the other rocks by its laminated structure, comparative softness, and lack of visible grains. Shale is the wall rock of the gold ore at the Getchell mine in Humboldt County and also the copper ores at the Rio Tinto mine in Elko County. Shales are also found at Ruth, Eureka, and Pioche.

Slate is a metamorphosed shale which splits readily along cleavage planes. A slate of roofing quality occurs both in Humboldt County and in Clark County.

Tufa is usually a calcium-carbonate rock deposited from solution in spring or lake water. It occurs at Pyramid Lake and along the shoreline of old Lake Lahontan.

Tuff is a fine-grained fragmental rock resulting from explosive volcanic activity. When the volcanic material is deposited on a water surface, it forms a sedimentary bed.

Much of the lacustrine sediments of Nevada contain a large proportion of volcanic dust or ash.

METAMORPHIC ROCKS

By metamorphism, the geologist means any change in the constitution of any rock, usually sediments, induced through physical and chemical agencies. Sedimentary rocks may become deeply buried and subjected to intense and prolonged heat and pressure causing induration of the fragmental material, accompanied by crystallization. The resulting metamorphic rock may have little resemblance to the original rock. Cleavage that was once parallel to the beds may no longer exist or may now be inclined to the original bedding. Massive igneous rocks have been converted into schistose aggregates having the appearance of well-stratified sediments. These changes are rarely brought about by physical agencies alone, as chemical action has also been active, causing some rearrangement of the elements into new combinations, but the chemical composition of the rock usually remains essentially unchanged.

The commonest evidence of the metamorphic effect of prolonged pressure is manifested by flattened and elongated grains or crystals. Elongation takes place in a direction normal to the direction of greatest pressure. This elongation without fracturing has been accomplished by molecular flow. Another common form of metamorphism is indicated in the change of siliceous sandstone to quartzite. This is brought about by the deposition of silica in the pore space or the partial solution and intergrowth of the original sand grains.

Localized metamorphism of the invaded rocks accompanies the intrusion of a molten igneous mass or magma. Heat, together with the chemical action of vapors and solutions, is responsible for the changes. New minerals are formed through the introduction and interchange of elements, resulting in a rock differing from the original material in both texture and chemical composition. Since these changes are most pronounced along the contact between the two rock bodies, the phenomena has been descriptively termed contact metamorphism.

All gradations of metamorphism occur from minor changes to those so extreme that none of the characteristics of the original rock remain. Few of the older rocks have escaped metamorphic action, and many geologists prefer to classify quartzite and slate as sedimentary rock, even though metamorphism has been responsible for their physical characteristics. The mode of origin of the material from which the schists and gneisses were formed is not so readily ascertained, so they are normally classified as distinctly metamorphic rocks.

Those aggregates, of varying mineral composition, formed by the processes of contact metamorphism have not been given specific rock names because the variation in texture and mineral composition makes their classification impracticable. Several general terms are used that signify contact-metamorphic material, but they are used primarily for the sake of convenience.

Herewith are defined under the heading of metamorphic rocks. only those considered to be strictly of metamorphic origin:

Gneisses are rocks of banded structure, and of variable chemical composition. Gneisses have been formed through the metamorphism of sedimentary or igneous rocks. Their composition corresponds closely to that of the rock from which they were derived. Accessory minerals, formed during metamorphism, are present in abundance.

Hornfels is a compact, fine-grained, silicated rock having an appearance similar to that of flint, formed principally through the contact metamorphism and metasomatism of clay-rich rocks, and is composed chiefly of biotite, andalusite, staurolite, garnet, and feldspar. It is highly resistant to erosion and forms prominent outcrops. Hornfels is abundant in many areas, and it is the wall rock of the tungsten ores at Mill City.

Marble is crystalline limestone or dolomite altered in texture but not changed chemically. It is granular in texture and often of pleasing color. Marble is present in many places, and was once mined at Carrara in Nye County.

Schists are a group of rocks characterized by a pronounced foliated structure, due to the parallel arrangement of the various constituents. They are crystalline in contrast to slate, a rock which they resemble structurally. The gold ores of Manhattan are mainly in schist.

Slate (see Sedimentary Rocks).

Tactite is a rock of more or less complex mineralogy formed of lime silicates through the contact metamorphism of limestone, dolomite, or limy shales, into which foreign matter has been introduced by hot solutions from the intruding magma. It is present in large quantities in most contact-metamorphic regions such as Nightingale, Adelaide, Yerington, and Contact.

AGES OF ROCKS

A discussion of the events that have occurred during the formation of the manifold variety of rocks that now constitute the earth's crust is beyond the scope of this bulletin. However, a brief statement of the history of the earth's crust, as interpreted by geologists through the study of accessible rocks, may assist in an understanding of rock relations.

Geologic time has been divided into eras, periods, and epochs, during which continents, ocean basins, and mountains were formed through the deformation of the earth's crust. Areas that were once continents, and subject to erosion, became ocean basins and subject to sedimentation. Evidence from rocks now accessible shows that none of the areas that are now continents remained continually as a land mass throughout geologic time. Parts of these areas have been alternately an ocean basin and then a land mass, and were periodically folded and crumpled by diastrophic processes. Sediments accumulated on erosion surfaces only to be in turn eroded away. Intrusive magmas invaded, and lavas buried the older rocks. The result is a complex structure, the history of which was pieced together by observation of the rock sequence on all continents.

Various means have been used to correlate and establish the relative ages of the rocks in a region or the rocks of widely separated regions. Some of the means of correlation are by fossils, similar kinds of rocks or lithologic units, extent of folding and metamorphism, similar relation to large intrusive masses, and similar relation to great unconformities.

A list of geological eras and periods is given here in chronological order from youngest to oldest. Minor subdivisions are not here shown.

PRINCIPAL DIVISIONS OF GEOLOGIC TIME
FROM YOUNGEST TO OLDEST

Era	*Period*	
Cenozoic	Quaternary	Recent or Human
		Pleistocene or Glacial
	Tertiary	Pliocene
		Miocene
		Oligocene
		Eocene

(Most of the volcanic rocks in Nevada are of Tertiary age as also are the lacustrine deposits of the Esmeralda, Siebert, and Truckee formations, and the borax-bearing sediments of Clark County.)

Era	*Period*
Mesozoic	Cretaceous
	Jurassic
	Triassic

(Cretaceous sedimentary rocks are practically unknown in Nevada. Jurassic and Triassic rocks crop out over much of northeastern Nevada and also parts of western Clark County. Rocks of this age are present at Yerington, Rochester, Mill City, and in the Valley of Fire.)

Era	*Period*
Paleozoic........	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian

(The older sediments of eastern and southern Nevada, as at Pioche, Eureka, Ruth, Contact, Manhattan, and Goodsprings are Paleozoic.)

Proterozoic Archeozoic	........................Pre-Cambrian

Formations of the Proterozoic and Archeozoic eras (for lack of sufficient evidence) are often grouped under the general heading of pre-Cambrian. The only occurrence of pre-Cambrian in Nevada is found in Clark County.

Numerous exposures of rocks of the Cambrian system occur throughout eastern and southern Nevada and in many places are the principal country rocks of important mining districts. The chief ore deposits at Eureka, Pioche, and several other mineralized areas are in Cambrian strata. Because of its economic importance much study has been devoted to the Cambrian of the State and the Bureau has published the following bulletins:

Univ. of Nevada Bull., Vol. 33. No. 3, Geol. and Min. Ser. No. 31, Cambrian Formations of the Eureka and Pioche Districts, by Harry E. Wheeler and Dwight M. Lemmon, 1939.

Univ. of Nevada Bull., Vol. 34, No. 8, Geol. and Min. Ser. No. 34, Revisions in the Cambrian Stratigraphy of the Pioche District, Nevada, by Harry E. Wheeler, 1940.

Univ. of Nevada Bull., Vol. 38, No. 3, Geol. and Min. Ser. No. 39, Lower and Middle Cambrian Stratigraphy in the Great Basin Area, by Harry E. Wheeler, 1944.

FORMS AND ORIGIN OF MINERAL DEPOSITS

Mineral deposits occur in diverse forms. Some of them are thin and tabular, some pipe-like, others massive and irregular. They usually occur inclined at various angles from the horizontal and seldom maintain the same strike or dip for more than a few

hundred feet. Few deposits are uniformly mineralized throughout their length and depth; the richer or economically valuable portions are called ore shoots. The terms commonly used to designate the forms of mineral deposits are briefly defined as follows:

A vein is a single tabular deposit of minerals occupying a fissure, one or both walls of which generally are well defined. Veins following the bedding planes in sedimentary rock are called bed veins. A number of parallel veins are called a vein system. Vein deposits with sharply defined walls are well exemplified in the Austin and Belmont districts.

The term lode is used by miners as nearly synonymous with the term vein, and is little used in late geological literature.

Contact-metamorphic deposits are deposits occurring at or near the contact of intrusive rocks with sedimentary rocks and carrying minerals characteristic of contact metamorphism. Some of these deposits are roughly tabular, others are quite irregular. The copper mines of the Yerington district are mainly of this type, as are also most of the tungsten deposits of the State.

Replacement deposits are masses of mineral formed by the alteration and replacement of rocks, particularly limestones and dolomites. They are often extremely irregular in form and in many places grade into country rock. The lead ores of the Eureka district and the zinc ores of the Mt. Hope mine in Eureka County are examples of this type of deposit, as is also the lead-zinc ore of the Combined Metals bed in the Pioche district.

Disseminated deposits contain ore minerals disseminated throughout a localized body of rock. The so-called "porphyry copper" deposits are of this form as at Ruth, Nevada.

A stockwork deposit is a complex system of small fissure veins, not of tabular or sheet form, so interpenetrated that the whole must be mined together. The deposit of gold ore at the Dexter mine at Tuscarora has been termed a stockwork.

A placer deposit consists of heavy resistant minerals formed as a result of mechanical concentration of detrital material through the action of surface waters. The gold placers of Manhattan and Round Mountain in Nye County are striking examples.

A bedded deposit is a sedimentary deposit mined for its mineral. The best illustration in Nevada is to be seen in the mining of gypsum beds in the Arden district of Clark County.

The mode of origin of these forms of mineral deposits varies from those formed by pure mechanical processes, to those formed from minerals in solution, to those of magmatic affiliation.

DEPOSITS FORMED BY MECHANICAL PROCESSES

Through disintegration and decomposition of rocks and mineral deposits, material is set free. The agents of erosion transport this loose material, first into the stream channels, then into basins occupied by lakes or seas. Running water, or wave action, separates the grains according to size and specific gravity. Those that are coarse or have a high specific gravity settle out first. The particles of highest specific gravity are usually concentrated in the lower part of the detritus. Fine, easily moved, material is transported far out to accumulate as sedimentary layers. Resistance to disintegration and decomposition determines the relative size of particles into which a mineral will be broken. The highly resistant minerals, such as gold, platinum, magnetite, cassiterite, garnet, and quartz are broken down into grains. The less resistant minerals undergo chemical alteration, as well as disintegration, into very fine particles.

PLACER DEPOSITS

Placer deposits are formed by the accumulation and concentration of heavy and resistant minerals in stream channels or along beaches. The products are concentrated by the churning and jigging action of water in motion. The jigging action causes the heavier particles to settle through and accumulate at or near the bottom of the detritus. This accounts for the occurrence of economical quantities of valuable minerals on bed rock in some stream gravels. Where the force of the currents was insufficient to cause jigging action or movement in the whole mass of detritus, concentration of any consequence was accomplished near the top of the detritus, leaving a concentration of minerals in layers high above bedrock; a type common in the channels of intermittent streams.

Some of the least abundant minerals have been concentrated into placer deposits of great commercial value. The valuable minerals can be readily and inexpensively recovered from such deposits through the use of concentrating processes which are very similar to those that have accomplished the concentration in the stream channels. The free state of the mineral grains, their purity and high specific gravity, and the high unit value of the minerals may make possible their economic recovery from low grade deposits.

Gold is the most important metal occurring in placer deposits and has been recovered in quantity from both ancient and present stream channels and from ocean beaches. The source of placer gold is not always apparent on account of the distance that the gold has been transported. The gold was derived through the

disintegration of gold-bearing veins, lodes, or shear zones. These deposits were not necessarily rich and, in many cases, they have been entirely removed by erosion.

Few of the gold placers in Nevada occur in the well-defined channels of permanent streams. Most of them are found in the illuvium on hillsides or in the channels of intermittent streams. Disintegration of the gold-bearing deposits has set much of the gold free, but there has been insufficient water to transport and sort the material except during "cloudbursts," torrential rains of short duration. The water from these heavy rains runs off the steep mountain slopes in such volume, and with such velocity, that it has extremely high transporting power and tends to scatter rather than to sort and concentrate the material in the stream bed. The particles of gold and detrital material in the placer deposits formed on hillsides, and in intermittent stream channels, have not been subjected to the prolonged pounding and grinding action of a permanent stream, consequently they are sharp and angular. Several Nevada streams have cut their channels down through ancient and buried stream channels. Where this has taken place, the well-worn material from the ancient channel has been carried into the present stream and deposited along with the angular fragments from recent erosion.

The subject of gold placers is covered in the Univ. of Nevada Bull., Vol. 30, No. 4, Placer Mining in Nevada, by William O. Vanderburg, 1936.

Deposits of minerals are formed in the same way and under much the same conditions as the gold placers. The source of the mineral is also much the same. In every case, it has been derived through the disintegration of primary deposits. As examples, platinum occurs in minute quantities in the sands of the Colorado River near the Boulder Dam, and interesting placer deposits of cassiterite (the oxide of tin) occur at Rabbit Hole in Pershing County, at Tuscarora in Elko County, and near the Izenhood Ranch in Lander County, but none have been proven to be of commercial importance. Minerals of high specific gravity such as scheelite, cinnabar, and several of the lead minerals are sometimes found in detrital material. While they have not been found in commercial quantity in Nevada, they can be readily concentrated and recognized in the miner's pan, and the source of the minerals has often been located in Nevada by panning the alluvium up the stream bed or hillside.

Residual concentrations formed on hillsides through the disintegration of rock, without the sorting effect of running water, are commonly called "eluvial" deposits to distinguish them from stream placers. In a strict terminology, many of Nevada's productive gold placers have been eluvial deposits. The original placer worked at Round Mountain by dry washers was of this type.

DETRITAL DEPOSITS OF NEARLY PURE MINERAL

In contrast to the gold placer deposits, where small amounts of a highly valuable mineral occur in a great bulk of worthless sand and gravel, some deposits are valuable because they are composed almost wholly of one mineral. Deposits of quartz sand, and those of some of the industrially valuable clays, belong in this class.

Quartz is highly resistant to weathering and is set free as grains during the disintegration and decomposition of rocks. The sorting and classifying action of running water may deposit the grains in layers of nearly pure silica. Those deposits of extreme purity, or having desirable physical properties, are the most valuable. However, concrete construction or road building makes valuable a nearby deposit of much less purity.

The fine material resulting from the decay of rocks is transported in suspension in water and deposited on the beds of lakes and seas as sedimentary clays. Their usefulness is dependent upon certain desirable physical properties, rather than on chemical composition. The clays of the Ash Meadows district in Nye County and in other districts have found use in the oil industry. A clay for common brick within the city limits accounts for the predominance of brick houses in Reno. Small deposits of fire clay occur in the State; and bentonite, desirable because of its absorbent qualities, has been mined in several localities.

DEPOSITS FORMED IN BODIES OF SURFACE WATER

During decomposition of the rocks, part of the material goes into solution as soluble salts and is transported by water to the sea or into lakes. Much of this material remains in solution as is evident from the high mineral content of the ocean and also of many lakes, such as Pyramid and Walker Lakes. Deposition of the dissolved salts is brought about (a) by precipitation as a relatively insoluble compound through chemical reaction between dissolved substances or between such substances and carbon dioxide or oxygen absorbed by the water, (b) by precipitation as a result of evaporation of the water, and (c) indirectly by the accumulation of the boney structure of plant and animal remains. Deposits of limestone, magnesite, diatomite, colemanite, and manganese oxides in Nevada are of these types.

Limestones are sedimentary rocks, composed principally of calcium carbonate. They may contain minor amounts of magnesium and iron, and other impurities such as clayey or sandy material. Limestone has been deposited either by the accumulation of the shells of animals and the supporting structures of plants, or by precipitation from solution by chemical reaction. Many fossiliferous limestones have been so thoroughly crystallized by metamorphism that their type of deposition remains in doubt as the fossils have been practically obliterated.

Limestone, to be of commercial grade, must be comparatively free of clayey, sandy, or cherty material. The deposit at Sloan, Nevada, has been noted for its purity and has been mined steadily for many years.

Dolomite is composed of both calcium and magnesium carbonate, and it also occurs as thick sedimentary beds. Pure dolomite contains 54.35 percent calcium carbonate and 45.65 percent magnesium carbonate.

Dolomitic limestones contain varying proportions of the two compounds. Most dolomites, and dolomitic limestones, have been formed by the replacement of part of the calcium carbonate of limestone by magnesium carbonate. It is of common occurrence in the eastern and southern part of the State.

Dolomite is used as a substitute for magnesite and brucite in the manufacture of refractory brick. It is burned as a source of quicklime and may ultimately be used as a source of magnesium metal in Nevada. A deposit of excellent purity has been mined at Sloan, Nevada.

Magnesite sometimes occurs as stratified deposits, but these deposits, on account of impurities contained, are seldom commercially valuable. Such a deposit occurs southeast of Overton, Nevada, on the edge of Lake Mead.

The commercial deposits of magnesite at Gabbs, Nevada, mined both for refractory uses and for reduction to metal magnesium, are closely associated with dolomite and are generally considered to be an alteration product of dolomite. It occurs as a massive rock similar in appearance to the surrounding dolomite, while the magnesite of California occurring in serpentine is commonly white in color, with a vitreous luster and a distinctive conchoidal fracture. The relatively rare mineral, brucite (magnesium hydrate) is found in large tonnage adjacent to the magnesite at Gabbs.

Diatomite (diatomaceous earth) is a chalky appearing, often pulverulent, sedimentary deposit, composed almost wholly of diatoms. The diatoms, a class of small aquatic plants, construct protective coatings or tests of opaline silica extracted from solution. These tests accumulate as stratified deposits in fresh-water lakes as well as in the sea.

Diatomite is of widespread occurrence in Nevada and has been mined in many places at frequent intervals, mainly for insulation use.

Colemanite, a calcium borate, occurs quite extensively in Clark County as a bedded deposit associated with beds of limestone and clay. It was actively mined until the discovery of thicker beds of borate minerals near Mojave, California.

There are "Bedded Deposits of Manganese Oxides near Las Vegas, Nevada," according to the Univ. of Nevada Bull., Vol. 25, No. 6, of that title. The origin is given as precipitation from solution and the occurrence as "lenticular beds interstratified with tuffaceous material." The tonnage available resulted in the construction of a large metallurgical plant for its treatment by the Defense Plant Corporation in 1943.

The evaporation of bodies of surface waters form deposits of easily soluble mineral salts that accumulate as saline residues. The easily soluble salts, leached from the weathered rocks, are transported to basins occupied by lakes or seas where evaporation leaves an accumulation of salts. Saline deposits may also form on playas of intermittent lakes, marshes, and on slopes below mineral springs.

Precipitation takes place in a saturated solution, therefore complete evaporation is not necessary for deposition. Fine silt and sand often settle out of suspension and accumulate with the salts, resulting in impure deposits. A dry climate accelerates evaporation. A closed basin prevents dilution and dissipation, thereby confining the deposition to a limited area. Such conditions existed throughout the Great Basin area of western United States, including Nevada.

A great variety of mineral salts are present in the saline deposits although many of them are found only in minor amounts. The more abundant ones in Nevada are common salt, gypsum, anhydrite, sodium carbonate, sodium sulphate, and the borates, while the scarce, but yet important ones, in other localities are bromine salts, potassium salts, calcium chloride, and sodium nitrate.

Gypsum and anhydrite, as saline residues, occur abundantly in Nevada in sedimentary beds. Gypsum contains water of crystallization as one of its constituents, and when calcined it combines with water to make an excellent cementing material. It

finds extensive use in industry as wall plaster and plaster board. Also, large tonnages of raw gypsum are used in the manufacture of Portland cement.

In the past forty years large deposits of very pure gypsum have been worked in the vicinity of Yerington and Mound House in Lyon County, near Gerlach, but in Pershing County, and along the Union Pacific Railroad in Clark County.

Anhydrite, the nonhydrous calcium sulphate, finds its only use as a low-cost fertilizer. Anhydrite, through absorption of water, slowly alters to gypsum. Therefore, the top portion of many deposits in Nevada is gypsum, grading with depth into anhydrite. Both of these minerals are also common as gangue minerals in some ore deposits. Some minor occurrences are the products of reactions of acid solutions on lime-bearing minerals.

Sodium chloride (common salt) occurs in many of the playas or marshes in Nevada. In the days of the early silver mills at Virginia City, Candalaria, Tybo, and other camps, much salt was produced at the closest marshes such as the Eagle Salt, Dixie, Diamond, Columbus, Rhodes, Teels, Butterfield, and Sand Springs marshes. The latter has produced salt in recent years, as has also the rock salt deposit southeast of Overton in Clark County.

Sodium carbonate and sodium sulphate are present in the muds of playas in many Nevada valleys, and in some localities they are combined in various proportions with calcium carbonate, and calcium and magnesium sulphates. The presence of these salts is evident from the white coating on the ground. Few of these numerous deposits are of commercial value.

Deposits of sodium carbonate are relatively rare in Nevada. In the days of the early mills, deposits were worked at Soda Lakes in Churchill County and at Double Springs in Mineral County. Soda from chemical plants now supplies the market.

Sodium sulphate is used mainly in the glass and paper manufacturing industry, and attempts have been made to utilize Nevada deposits. Deposits have been worked at Sodaville, in Mineral County, and at Wabuska, in Lyon County, and many other deposits are known.

The borates occur in notable quantities in the playas of intermittent lakes as natural water soluble borax and as ulexite ("cotton ball") mixed with other salts, silt, and sand. All of the early borax was recovered from this type of deposit, and in Nevada the marshes of Churchill, Mineral, and Esmeralda Counties were important sources until the bedded deposits of colemanite were discovered in Death Valley. In recent years a small quantity of borax was produced from a marsh in Fish Lake Valley.

At frequent intervals over the years extravagant claims are made as to the fabulous content of gold and mercury in the muds of the playas and dry lakes and its easy recovery. The fallacy of these claims is set forth in the Univ. of Nevada Bull., Vol. 35, No. 4, Geol. and Min. Ser. No. 35, "An Investigation as to the Presence of Commercial Quantities of Mercury and Gold in the Dry Lakes of Nevada," by Jay A. Carpenter, 1941.

DEPOSITS FORMED BY RESIDUAL CONCENTRATION

During the disintegration and decomposition of the near surface rocks, the easily destructible or soluble minerals are the first to be removed. If erosion does not keep pace with weathering, deep zones of weathering result, and soluble material is leached from the rocks near the surface and either transported away or carried downward along joints and fractures and deposited by chemical reaction at greater depth. This separation and removal of the soluble material leaves behind the insoluble components in a concentrated form and often a large mass consisting almost entirely of a single mineral will be the result.

The carbonate and most of the silicate minerals are unstable in the zone of weathering and are broken down into soluble and insoluble components. Iron or manganese are commonly left behind as oxides during the decomposition of the original minerals. The relatively insoluble minerals, such as quartz and kaolinite also constitute part of the residual mass.

The processes of weathering are aided and accelerated by active solvents created through the decomposition of certain minerals. The weathering of pyrite produces sulphuric acid and ferrous sulphate, both of which react chemically to decompose minerals, resulting in the formation of hydrated iron oxide and clay.

Rich and extensive mineral deposits have been formed through residual concentration during the weathering of large masses of rock that contained relatively small amounts of the elements that now constitute the bulk of the residue. Important deposits of iron and manganese ores have been formed from rocks or mineral deposits originally containing only minor amounts of these elements. Important deposits of aluminum ore as the mineral bauxite have likewise been formed in this way. In each case the residual minerals are oxides or hydrous oxides.

Economically important residual deposits of iron or aluminum ores have not been found in Nevada. Some manganese deposits in Nevada have been formed through residual concentrations of primary manganiferous deposits, but most of these deposits are of low-grade or contain excessive amounts of undesirable impurities such as a high silica content.

DEPOSITS FORMED BY CIRCULATING METEORIC WATER

Atmospheric water percolates down along available channel ways in the rocks of the earth's crust and is then termed meteoric water. Readily soluble minerals are taken into solution and transported until deposited from solution by evaporation or precipitation. That circulating water has dissolved and removed large volumes of material from below the earth's surface is apparent from the large caverns that now exist in some of the calcareous rocks. Some of this water penetrates to considerable depth where a rise in temperature increases its dissolving power, and much of this water then returns to the surface as springs, bearing a heavy load of soluble salts. Part of its load is deposited along the channel ways by precipitation, part around the spring vent by evaporation, as spring deposits, and the remainder is carried away in surface streams to accumulate in a lake or sea.

Calcium, sodium, potassium, and magnesium salts are easily soluble, and have been taken into solution in large amounts and either removed entirely or deposited where conditions were favorable. Silica and many of the metallic minerals are but slightly soluble in meteoric water, but some important deposits of copper, zinc, and vanadium have been formed as a result of concentration by circulating water.

Indeed, it would be a unique mineral deposit that did not show the effects of circulating water in its near-surface portion, but no economically important mineral deposits, formed strictly by circulating meteoric waters, so far have been found in Nevada.

DEPOSITS FORMED AT OR NEAR THE SURFACE BY HOT SPRINGS

Ascending hot waters bring a variety of mineral matter to the surface. What portion of this water is meteoric water returning to the surface after percolating deep into the earth and what portion is of magmatic origin is difficult to determine, however, the bulk of it is certainly heated meteoric water. Any water of magmatic origin would probably be highly diluted by surface water before reaching the surface.

A variety of minerals are deposited at the vents of hot springs by precipitation from the cooling solution, or by evaporation. Limonite, calcium carbonate, and silica form the bulk of the material deposited. These materials have accumulated as a cellular or porous mass spread over the surface around the vent. The calcium carbonate occurs as tufa, or calcareous sinter, the silica as opaline or chalcedonic sinter. Some deposits contain many metallic and nonmetallic elements in detectable quantities. Sulphur, which is often present in notable amounts, occurs both in the free state and in combination with the metals. The odor of hydrogen sulphide is distinctly noticeable in the vicinity of certain springs. Antimony, arsenic, mercury, lead, and copper, are present in some deposits, usually in the form of sulphides. The presence of gold and silver has also been reported from several spring deposits.

At Steamboat Springs, 11 miles south of Reno, Nevada, sulphur, stibnite, and cinnabar are being deposited in the siliceous sinter at the present time. Unsuccessful attempts have been made to recover the mercury from certain portions of the deposit and to utilize the silica in glass manufacture. These springs are widely known among students of ore deposits because of the great variety of minerals being deposited, and are spectacular due to the large quantity of steam issuing from fissures.

Nevada has many hot spring deposits. In some, the springs are still active; in others, all activity has ceased. Many of them contain unimportant amounts of metals, but a few have been worked for their mercury content. A deposit at Golconda that appears to be of hot spring origin is now being exploited for its tungsten content. This deposit contains a high proportion of iron and manganese and a few tons of manganese ore were mined from the deposit during the war of 1914–1918.

DEPOSITS OF MAGMATIC AFFILIATION

The commonly accepted theory is that igneous rocks, both intrusive and extrusive, have formed by the cooling and solidification of a hot silicate melt. These silicate melts are called magmas. Magmas at high temperature are in a liquid or mobile state with both the volatile and nonvolatile components in a mutual and relatively uniform solution. Dissociation and differentiation accompany cooling and solidification resulting in the formation of compounds according to their solubility. The least soluble and least fusible compounds are the first to segregate and solidify. Segregation and solidification continue progressively during cooling so that the unsolidified portion becomes richer and richer in certain constituents, the more volatile constituents becoming more concentrated toward the end of the igneous cycle. Water is the most plentiful volatile constituent and much of it escapes, carrying with it dissolved substances.

Differentiation in the cooling magma causes the formation of

rocks of distinctly different mineral composition. The first minerals to solidify are those of the ferromagnesian or basic group, which predominate in the ultra-basic rocks. The orthoclase feldspars and quartz, which are the predominant minerals in the acidic rocks, are among the last to solidify.

Concentration of the products formed during solidification is brought about in several ways. Minerals of high specific gravity settle through the still liquid portion, causing a concentration of heavy minerals near the bottom of the magma. Pressure developed by contraction, folding, and thrusting, or an increase in volume forces the still liquid portion out of the parent magma, forming rocks of distinctly different mineral composition. Differentiation in the magma also brings about a segregation of the metals that are present. Those that crystallized early remain with the basic portion of the magma, while those that crystallize late escape with the liquid and volatile portions. Mineral deposits formed in the magmas as products of differentiation, and those formed by deposition from solutions from the magma, are the chief source of the industrially valuable minerals such as iron, tungsten, tin, gold, silver, copper, and zinc.

Lindgren[1] classifies the deposits of magmatic affiliation into types and discusses the mode of formation, characteristics, and economic importance of each, a brief discussion of which follows.

The types of deposits are: (1) liquid-magmatic, (2) pegmatites, (3) pyrometasomatic (contact metamorphic), (4) hypothermal, (5) mesothermal, and (6) epithermal.

LIQUID-MAGMATIC DEPOSITS

Mineral deposits of the liquid-magmatic type have formed in deep-seated intrusives as products of magmatic differentiation. These deposits are enclosed in the parent rock. The gangue minerals are those which make up the rock mass itself. A few metals occur in this type of deposit, mainly as simple oxides or sulphides. Among the most prominent metals are iron, nickel, chromium, titanium, platinum, copper, and tin. A rather characteristic mineral assemblage is associated with each type of rock. Diamonds, chromite, and platinum occur with peridotites; chalcopyrite, pyrite, pentlandite, and pyrrhotite usually with gabbros, and cassiterite with granite. No deposits of this liquid-magmatic type are known in Nevada.

PEGMATITE DEPOSITS

Mineral deposits of the pegmatite type have formed in material

[1] Lindgren, Waldemar, Mineral deposits. 3d ed., pp. 516–907, McGraw-Hill Book Co., 1928.

that solidified at a late stage during the cooling of the magma. They occur as dikes, sills, pipes, or irregular masses, formed as a result of injection of the still liquid portion of the magma into fractures in the invaded rock or into previously solidified portions of the parent intrusive mass.

The pegmatites are composed principally of quartz, feldspars, and micas as a coarsely crystalline aggregate. A variety of minerals are often present, including magnetite, tourmaline, topaz, cassiterite, apatite, ilmenite, rutile, and beryl. Some of the sulphide minerals, like pyrite, arsenopyrite, pyrrhotite, chalcopyrite, molybdenite, bornite, and sphalerite may be present. Gem varieties of ruby, beryl, and tourmaline are of rare occurrence. Reaction with the wall rocks has produced some minerals otherwise foreign to this type of deposit.

Although the pegmatites in Nevada contain a variety of minerals, they have, with few exceptions, been of minor economic importance. Pegmatites in the Humboldt range contain beryl and have also yielded considerable tungsten in the form of scheelite.

PYROMETASOMATIC DEPOSITS

Pyrometasomatic deposits are a distinct type because of the predominance of characteristic minerals and because of their position along, or near, the contact between the intrusive rock and the invaded rock (thus the common term "contact-metamorphic deposits"), and where the invaded rocks are usually of calcareous composition, like limestone, dolomite, or calcareous shale.

The deposits have formed by replacement of the adjoining rock by reaction with solutions emanating from the magma. Permeable rocks are most extensively altered. Where limestones are present silicate minerals may occur hundreds of feet from the contact. Similar silicate minerals also form along fractures and in fragmented portions of the intrusive near the contact, indicating that at least a portion of the magmatic solutions permeated the intrusive after the upper portion had solidified. Quartz, calcite, and metallic minerals often accompany the silicates, and the bulk of these minerals usually occur on the cooler, or invaded rock, side of the contact.

The characteristic gangue minerals are garnet and epidote with other silicates of calcium, magnesium, iron, and aluminum. Quartz and calcite are subordinate.

The sulphide minerals are usually of simple composition such as pyrite, chalcopyrite, pyrrhotite, sphalerite, molybdenite, arsenopyrite, and galena. The oxides of iron, magnetite and specularite,

are sometimes common and abundant. Scheelite occurs in important amounts in some deposits.

The forms of the deposits are variable. Tabular, as well as irregularly spaced lenticular bodies, on or near the contact, are common. Deposits may form through the irregular replacement of certain beds and have the same attitude as the sedimentary series, like the scheelite ores at Mill City.

Contact-metamorphic deposits are numerous in Nevada, particularly in the western part of the State, and yield important tonnages of scheelite ore. Some of the Nevada iron deposits are also of this type.

HYPOTHERMAL DEPOSITS

Hypothermal deposits have probably been formed by cooler solutions than those that formed the pyrometasomatic deposits. They occur both as veins and as replacements deposits, both in the intrusive and in the adjacent rocks, indicating that deposition took place after the upper part of the magma had solidified.

The mineral composition of the hypothermal deposits is rather characteristic. Quartz predominates as a gangue mineral, and the characteristic silicate minerals are tourmaline, mica, and topaz. Magnetite and specularite are common, and the other ore minerals most often present are pyrite, arsenopyrite, chalcopyrite, cassiterite, wolframite, and gold.

The distinguishing characteristics of the deposits of this type are the predominance of coarse-grained quartz, the lack of banded structure, except where layers of wall rock are included, and the presence of relatively high temperature minerals such as tourmaline.

Many vein deposits of this type occur in Nevada, but only a few of them have been economically important. Spurr[2] described the gold-bearing deposits of the Silver Peak district and presented evidence to support his belief that some of the deposits were formed as a direct transition from alaskite dikes to quartz veins and lenses, indicating deposition at high temperature. The ores of Rochester and Majuba Hill are of this type.

MESOTHERMAL DEPOSITS

Mesothermal deposits have formed by deposition from solutions emanating from solidifying magma. The escaping solutions penetrated along fissures and deposited their load. Deposition was largely confined to fissures in siliceous or aluminous rocks, while silicification and replacement occur in calcareous rocks. Alteration of the wall rock is usually pronounced, with feldspar

[2] Spurr, J. E., Ore deposits of the Silver Peak quadrangle: U. S. Geol. Survey, Prof. Paper 55, 1906.

and ferromagnesian minerals being altered to sericite, while pyrite is introduced into the country rock.

The identifying characteristics of the mesothermal deposits are their close association to deep-seated intrusives, comparatively massive appearance of the vein filling, lack of distinct colloform structure, absence of high temperature minerals, and the presence of a variety of complex metallic minerals.

The ore minerals are of less simple composition than those in the deposits formed at higher temperatures. Sulphide, arsenide, sulphantimonide, and sulpharsenide minerals are prevalent. The common ones are pyrite, chalcopyrite, arsenopyrite, galena, sphalerite, tetrahedrite, sulphantimonides and sulpharsenides of silver, and native gold. Oxides such as magnetite and specularite may be present in small amounts. Quartz is the predominant gangue mineral. Calcite, siderite, and barite are subordinate. High temperature minerals, such as tourmaline, garnet, biotite, and topaz are absent.

Many of the major metal producing deposits of the world are mesothermal and occur both as veins and as replacement bodies. Many of the veins have been notably continuous in both length and depth and occur in both the intrusive and in the adjacent rocks. The replacement deposits are often extensive, particularly where the mineralizing solution permeated easily replaceable calcareous rocks.

The mesothermal type of deposits occur throughout Nevada and have been the source of much silver, copper, lead, zinc, and gold, as at Eureka, Pioche, and Belmont.

EPITHERMAL DEPOSITS

Epithermal deposits have formed from hot solutions which had their origin in the deep-seated reservoirs where the magma supplied the various types of flow rocks. That they were not formed by solutions emanating directly from the flows is evident from the fact that they occur in fissures that cut a whole series of flows. Their common occurrence near the center of volcanic activity has led to the belief that the ore-forming solution rose from the same deep-seated source as did the lavas.

Epithermal deposits have formed near the surface where open fissures and cavities could exist. Deposition was not entirely confined to simple fissures, but also took place in the shattered wall rocks, and formed irregular masses. Deposition in open spaces is evidenced by thinly-banded textures indicating deposition in successive layers. The quartz is usually fine grained and often has the appearance of unglazed porcelain. Small quartz crystals lining cavities are common.

Here again, as in the mesothermal and hypothermal deposits, quartz is usually the most abundant gangue mineral. The texture of the quartz is distinct and it seldom appears as a glassy or milky aggregate. Calcite, dolomite, barite, and fluorite are common gangue minerals and predominate in some deposits. Rhodochrosite and rhodonite are plentiful in many occurrences. Adularia, a vein-forming feldspar, is a particularly characteristic gangue mineral and often occurs intergrown with quartz and calcite. High temperature minerals are conspicuously absent. The enclosing rocks may be of igneous or sedimentary origin, but most of the epithermal deposits of Nevada are found where Tertiary volcanics are the predominate rocks.

Successive stages of mineralization are prominent features of these deposits. Earlier gangue minerals, such as calcite and barite, may be wholly dissolved and replaced by later quartz and adularia, however, the original texture is often preserved. Where the calcite was dissolved, but only partially replaced, a cellular structure results.

Intense alteration accompanied mineralization, developing chlorite and pyrite far out into the wall rocks. Silicification is most intense adjacent to the fissures. In some cases this silicified rock contains sufficient gold and silver to constitute an ore of these metals.

A variety of metallic minerals are usually present, but only a few of them occur in sufficient abundance to be of economic importance. Massive ore bodies are rare. Among the metals, gold and silver are of major importance, while minor amounts of copper, lead, and zinc may be present. Small quantities of arsenic, antimony, tellurium, and bismuth are found in some ore bodies. Pyrite is not particularly abundant. The commercially valuable quicksilver ores in Nevada are usually confined to more shallow deposits of this type.

Gold is commonly present as native metal, usually combined with silver. The gold often occurs in fine particles so completely enclosed in quartz and other minerals that extremely fine grinding is required to liberate it. Gold or gold-silver tellurides are not uncommon.

The most abundant silver mineral is argentite, however, the complex silver sulphantimonides and sulpharsenides are abundant in many districts. Native silver and silver chloride (horn silver), which are often present in the near surface portion of the deposit, are due to the alteration of primary silver minerals.

Epithermal deposits are numerous and widespread in Nevada and have furnished a major portion of Nevada's gold and silver.

Some of the more notable districts of this type are the Comstock Lode, National, Tuscarora, Goldfield, and Tonopah.

INFLUENCE OF THE PARENT MAGMA AND LOCAL ENVIRONMENT

Many of the metalliferous ore deposits of economic importance have been formed through deposition from aqueous solution given off by magmas during cooling and solidification. The composition, shape, and location of these deposits are not merely the result of chance, but have been influenced, or controlled, by the combined effects of physical and chemical factors. Recognition of the effects of these factors is necessary to the systematic search for ore deposits, not only in and about operating mines, but also in unexplored areas.

Solutions that originate from the cooling magmas or magma basins find their way upward along channelways such as fissures, faults, sheared or crushed zones, folds, contacts, or any other places of weakness. The solutions are guided by the accessible channels, and the largest volume of solution will flow through those openings offering the least resistance, so the shape, position, and open condition of the channels are reflected in the resulting deposits. From these solutions the various ore and gangue minerals are deposited as a result of cooling, relief of pressure, influence of wall rocks, mingling of chemically different solutions, or chemical reaction with previously deposited minerals. Of the conditions that cause mineral deposition, lowering of the temperature and a decrease of the pressure on the solutions are probably the most effective. However, a change in acidity or alkalinity of the solution by reaction with the wall rocks is effective where the solutions contact or permeate rocks which react chemically with the solutions. Another factor which has a profound effect on the composition of the resulting deposit is the composition of the mineralizing solutions. Only those elements contained in the solution can possibly be deposited by that solution. Since the composition of the solution is a function of its source, the parent magmas and differentiation within them effect a primary control on the composition of the mineral deposits. The ores of certain elements show a definite tendency to occur in association with particular types of rock. Chromium, platinum, nickel, and cobalt seldom occur in commercial quantities in other than basic plutonic rocks. Tin is most often associated with granitic rocks. Most of the deposits of gold, silver, copper, lead, and zinc occur associated with intrusions, but are not limited to rocks having some particular composition. However, the majority of Nevada deposits valuable for their gold and silver content alone occur associated

with dikes and flows of Tertiary igneous rocks. Within a given area the association of certain elements with particular rocks may be so apparent that this criterion serves as a guide in the search for ore. That certain elements occur associated with particular types of rock can be definitely shown, but this does not mean that commercial deposits have formed in association with every exposure of that rock. On the contrary, many areas apparently exhibiting all of the conditions favorable to ore deposition contain no ore deposits.

INFLUENCE OF ZONAL DEPOSITION

Metals are deposited in a rather definite sequence. This is reflected in the changing composition of deposits in depth. Minerals deposited at higher temperature and pressure are found at greater depths than are those deposited at a lower temperature and pressure. Overlapping of deposition is common, and the occurrence of metals in reverse of the normal order is not unknown. Changing environment during deposition would probably account for this variation.

Spurr[3] shows that the order of deposition of the metals upward from the magmatic source are similar in many of the major metal-producing districts of the world and that the usual sequence in the deposits associated with intrusive rocks in the order of deposition away from the source of the solutions are molybdenum, tungsten, gold, copper (silver), zinc, lead (silver). Emmons[4] shows that the metals are usually arranged in a rather definite sequence outward as well as upward from the source, and has listed the metals according to a zonal arrangement. His zonal sequence successively from the surface toward the parent batholith is here reproduced.

A RECONSTRUCTED VEIN SYSTEM FROM SURFACE TO NEAR BATHOLITH ROOF. (After W. H. Emmons.)

BARREN.......... 1....Barren zone, chalcedony, quartz, barite, fluorite, etc. Some veins carry a little mercury, antimony, or arsenic.

MERCURY........ 2....Quicksilver veins, commonly with chalcedony, marcasite, etc. Barite-fluorite veins.

ANTIMONY..... 3....Antimony ores, stibnite often passing downward into lead, with antimonates. Many carry gold.

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[3]Spurr, J. E., A theory of ore deposition. Econ. Geol., 2, 1907, pp. 781–785. The ore magmas, 2, 1923, p. 611.

[4]Emmons, W. H. Primary downward changes in ore deposition. Trans. A. I. M. E., vol. 70, 1924, pp. 964–992; Relations of metalliferous lode systems to igneous intrusives. Trans., A. I. M. E., vol. 74, 1926, pp. 29–70.

GOLD, SILVER	4	Bonanza ores of precious metals. Argentite, antimony, and arsenic minerals common. Silver minerals, some copper, lead and zinc sulphides, quartz, calcite, rhodochrosite, adularia, alunite, etc.
BARREN	5	Most nearly consistent barren zone, represents the bottoms of many Tertiary precious metals veins. Quartz, carbonates, etc., with pyrite and small amounts of other sulphides.
SILVER	6	Argentite veins, complex antimony silver sulphides, stibnite, etc. Galena veins with silver. Commonly silver decreases with depth. Quartz gangue, siderite common, often increasing with depth.
LEAD	7	Galena veins, commonly with some silver. Sphalerite, generally present, increasing with depth. Chalcopyrite common. Gangue is quartz and often carbonates (Fe, Mn, Ca).
ZINC	8	Sphalerite veins with some lead and chalcopyrite, quartz gangue.
COPPER	9	Tetrahedrite veins, commonly argentiferous, chalcopyrite present. Some pass downward into chalcopyrite. Enargite veins generally with tetrahedrite and tennantite.
COPPER	10	Chalcopyrite veins, generally with pyrite, often with pyrrhotite. The gangue is quartz and in some places carbonates. Some pass downward into pyrite and pyrrhotite, with a little chalcopyrite. Generally carry silver and gold.
GOLD	11	Gold veins with quartz, pyrite, and commonly arsenopyrite and chalcopyrite. At places, 10 and 11 are reversed.
BISMUTH	12	Bismuthinite and native bismuth with quartz and pyrite, etc.
ARSENIC	13	Arsenopyrite with chalcopyrite and often tungsten ores.
TUNGSTEN	14	Tungsten veins with quartz, pyrite, chalcopyrite, pyrrhotite, etc. Arsenopyrite is commonly present.
TIN	15	Cassiterite veins with quartz, tourmaline, topaz, etc.
BARREN	16	Quartz with small amounts of other minerals.

There is a general agreement in the order of deposition of the metals as listed by these authors. Spurr and many other students of ore deposits have expressed the same general conclusions. It must be emphasized, however, that in no single deposit are all of these changes observable. Erosion may have removed all but the lower zones or, as is the case with many deposits formed at shallow depths, mining operations have been carried to insufficient depth to prove or disprove the zonal deposition theory. That the metals have been deposited in an orderly sequence outward from the magmatic source is evident from the relative position of deposits in some areas. It is not uncommon to find deposits of tungsten and copper near the intrusive, and those of zinc, lead, and silver several hundreds or thousands of feet from the intrusive.

INFLUENCE OF STRUCTURAL CONDITIONS

The effects of structural control limit the position, size, shape, and attitude of mineral deposits. Faults, sheared or crushed zones, or contacts guided the mineral-bearing solutions. Deposition occurred only where the solutions could penetrate so the resulting deposit conforms roughly with the preexisting fractures. Since all of the minerals were not deposited at the same time, local concentrations of certain minerals formed in those parts of the channels open during the time that other conditions favorable to their deposition existed. These local concentrations, when within a mineral deposit, are commonly called ore shoots.

The permeability and replaceability of the rocks adjacent to the channels are also factors that control the physical characteristics of mineral deposits. Where the wall rocks were permeable or replaceable, massive and irregular bodies occur, such as those formed by the replacement of limestone or dolomite.

Many mineral deposits are composed entirely of economically valueless minerals, some contain local concentrations which constitute the only valuable portions, and only a few are of uniform composition and valuable throughout their whole volume. This lack of uniformity in composition is partly due to a variation in the composition of the mineral-bearing solutions and conditions causing deposition, and partly due to the effects of structural control. The structural conditions favorable to abundant and concentrated deposition are: (1) the intersection of veins or veins with fissures, particularly where the intersection is at an acute angle, (2) recurrent fault movement causing fracturing and reopening of a fissure or vein during mineral deposition, (3) impervious layers or beds that confine solutions, (4) the crests, troughs, or flanks of tight folds, (5) the intersection of fissures with permeable or replaceable rocks, (6) masses or zones of brecciated, fragmented, or closely jointed rock, (7) open parts of a fissure formed by displacement along an undulating surface, (8) fissures formed by branch faults, and (9) volcanic rocks, chimneys, or pipes.

Faulting and folding accompanying igneous activity form zones of weakness that later serve as channels for circulating solutions. In many areas faulting continued during and after mineral deposition, displacing the mineral deposits as well as the rock masses. Faults formed prior to mineral deposition are termed premineral faults, and those formed later than mineral deposition, postmineral faults. Only premineral faults can serve as channels for the circulation of ore-bearing solutions. Postmineral faults shatter or displace portions of the deposit, complicating the work of the geologist and miner in finding and extracting the ore.

SUPERGENE ENRICHMENT

Many minerals are formed by ascending thermal waters and are termed hypogene. Deposits resulting from rearrangement of the hypogene deposits through oxidation and the action of descending surface waters are termed supergene. The near-surface portion of most deposits show evidence of some supergene action, and in many deposits only the supergene enriched portions have been economically valuable.

Supergene enrichment, commonly termed secondary enrichment, is brought about by oxidation, solution, and redeposition. Oxidation converts many of the minerals, particularly the sulphides, into more readily soluble compounds. Surface water dissolves and removes the soluble compounds, leaving the insoluble minerals behind. Redeposition occurs where the solutions encounter conditions that cause precipitation. Much of the dissolved material is dissipated, but the greater part of it descends in solution and is redeposited within the confines of the deposit, thus increasing the metal content. Supergene processes cause both separation and concentration. Insoluble minerals, and those converted to the insoluble state by oxidation, remain in the oxide zone as a residual mass.

Enrichment is influenced by many factors, such as relative rates of erosion and oxidation, duration of exposure to weathering and erosion, permeability, mineral composition, depth of the water level, and climatic conditions.

If erosion proceeds more rapidly than oxidation and leaching, the metals are carried away and enrichment thereby prevented. On the other hand, when erosion is feeble the rate of oxidation is much slower at considerable depth than it is near the surface, and enrichment is retarded. Conditions for maximum enrichment exist when erosion just keeps pace with the rate of oxidation and leaching, as exemplified in many Nevada deposits.

Oxidation is such a relatively slow process that it must be active over a period of long duration to have appreciable effect. Young deposits, and those only recently exposed by erosion, show but minor effects. Old deposits that were soon buried by younger rocks likewise have been little effected. Enrichment is most pronounced in old deposits that have been exposed during much of their geological history.

Permeability is essential for supergene enrichment. Oxidation and solution progress very slowly in relatively impermeable deposits. Intensely shattered and brecciated deposits are those most thoroughly affected. Oxidation and solution increase permeability, but openings must extend into the zone below water level for the formation of important quantities of supergene sulphide ores. Maximum concentration occurs where circulation of the solutions is confined to the mineral deposit, and the minimum where the solutions penetrate the wall rocks.

Mineral composition has a profound influence on the progress of enrichment. Solution of many of the minerals is dependent upon the presence of acid sulphate solutions which can form in the deposit only by the oxidation of sulphides, so the presence of appreciable quantities of sulphides, particularly iron sulphides, are necessary for intense leaching. Furthermore, any minerals that will quickly neutralize the acid will inhibit enrichment processes.

A shallow water level restricts oxidation to a small upper portion of the deposit, preventing the formation of important quantities of supergene ores. A deep water level permits extensive oxidation, but a large part of the metals may be precipitated on their long downward journey, and an important concentration will not form. Supergene concentration is greatest when the water level is at moderate depth.

In a warm climate oxidation and solution progress more rapidly than in a cold climate. Heat hastens chemical reaction and solution. Where the ground is frozen throughout most of the year supergene action is slow. Since water is essential for solution, rain or snow are necessary. However, the annual rainfall need not be heavy. Many deposits in arid regions have been extensively enriched, as has been the case in Nevada.

As indicated previously, the metals taken into solution by supergene processes may be redeposited above ground-water level in the zone of oxidation, or below ground-water level where free oxygen is excluded. Redeposition may occur from any of several causes. Descending solutions that dissolve metals are acid, and any conditions that neutralize the solutions will precipitate the metals. Solutions coming in contact with carbonate compounds are quickly neutralized with precipitation of the metals as carbonates, consequently there is only a limited amount of migration of metals in sulphide mineral deposits containing plentiful quantities of calcite, dolomite, siderite, or limestone. The feldspars also act as neutralizers, but their action is much slower than that of the carbonate compounds, and some metals are precipitated when their solutions pass through finely divided silicate minerals, kaolin in particular. Deposition results from a chemical exchange. Powdered clay gouge often contains finely divided particles of metals and their compounds, indicating that finely powdered silicates do cause precipitation.

Metals in the descending solutions are deposited as sulphides below ground-water level. Here, also, as in the zone of oxidation, there are several causes of precipitation. Precipitation is brought about by a diminution of the solvent power of the solutions due to a decrease in acidity. Acidity diminishes below water level because air is excluded and the rate of oxidation of the sulphide minerals is no longer rapid enough to replenish the acid as fast as it is neutralized. Hydrogen sulphide, an active precipitant of some metals from sulphate solutions, is generated when acid sulphate solutions attack sphalerite or pyrrhotite. Hydrogen sulphide is quickly used up in the zone of oxidation by reaction with oxygen or ferric sulphate, so it can not precipitate important quantities of metals there. Even if it did, the newly formed compounds would be subject to attack and destruction by the agents of oxidation. However, in the reducing environment of the zone of saturation, hydrogen sulphide is free to precipitate the metals and probably plays a part in the formation of the supergene sulphide ores of some deposits. Deposition of metals below ground-water level is also brought about by chemical exchange between solutions and solids. In many cases this is probably the most important precipitating process. One metal

replaces another according to the relative solubility of their sulphides. Each replacing those of higher solubility. Thus, silver or copper would be precipitated by sulphides of lead, zinc, or iron; lead from solution by zinc and iron. Supergene metallic sulphides, such as sulpharsenides and sulphantimonides form by the same process.

Supergene sulphide ores are often exceptionally rich because they contain the metals not only leached from the existing oxide zone, but also in part from the portion of the deposit that has been removed by erosion.

The history of a mineral deposit is not displayed conspicuously in its outcrop. The agents of erosion and decomposition have destroyed much of the evidence of its original mineral composition. However, the prospector, geologist, or mining engineer must base his predictions of continuity or change of ore in depth upon this scant evidence if he is to appraise a newly discovered deposit. Evidence indicative of its type, size, shape, and attitude can often be obtained from a study of the relation of the deposit to the general geology of the area. Such evidence will serve as a basis for estimating possible tonnage. The metal content of the outcrop can be ascertained by sampling and assaying. However, the results of surface samples are generally unreliable as a basis for predicting the persistence or change of values in depth.

The composition and environment of mineral deposits are so variable that rules for the identification of criteria in the outcrop indicative of supergene enrichment are not universally applicable. However, there are certain features that are most often evident, and that serve as the best guides. The favorable features are summarized as follows:

1. Indications of a strong primary mineralization, together with a porous or cellular texture, and evidence of post-mineral fracturing.
2. Thorough oxidation and solution, that is, absence of sulphide minerals other than galena, and presence of limonite, quartz, and kaolin.
3. Indications that the primary material contained only minor amounts of the rapid neutralizers, calcite, siderite, limestone, or dolomite.
4. Moderate-to-strong relief and a moderate-to-deep ground-water level.
5. A moderate-to-rapid erosion rate.

6. Long exposure to weathering agents.

The unfavorable features are as follows:

1. Presence of sulphide minerals other than galena.
2. The presence of, or evidence indicating the prior existence of, abundant rapid neutralizers.
3. Base-leveled terrain, where erosion is slow and the water level shallow.
4. Evidence indicating that the deposit has been exposed to oxidation and leaching for only a short time.
5. Compact, impervious deposits through which solutions cannot permeate freely.
6. Evidence of regional glaciation, particularly if the glacial erosion has been deep. Small mountain glaciers have only local effect.

As previously stated, evidence in the outcrop of the extent of supergene enrichment is seldom conspicuous. Weathering has frequently so modified the exposed portion that diagnostic criteria are obscure. Even the limonite, manganese oxide, kaolin, and small particles of gold are often removed by running water leaving a bleached and uninviting siliceous or earthy mass on the surface. Shallow pits or trenches, however, are usually sufficient to expose material in which evidence of leaching is fairly well preserved.

A porous or cellular mass of earthy, quartzose, or jaspery material stained by iron oxide is the best evidence of a strong primary mineralization, since it indicates that the primary material contained sulphide minerals, part of which, at least, were iron-bearing. The most common sulphide carrying iron is pyrite, and it often occurs as the only sulphide, thus giving no chance of secondary enrichment of other metals.

It is asserted that the amount, the color, the form, and the position of the limonite in the leached outcrop all serve as indicators of the original sulphides which existed there.

Blanchard and Boswell[5] make the very positive statement that "today not only is a limonite that has been derived from pyrite clearly distinguishable from one derived from the other sulphides named (chalcopyrite, chalcocite, sphalerite, or galena), but where the copper, lead, and zinc minerals are involved, the grade of the material prior to leaching can be judged in many instances as accurately as if the original sulphides were still visible in the outcrop," and to one skilled in the interpretation of the type of limonite "the various limonite products left by chalcocite,

[5] Blanchard, Roland, and Boswell, P. F., Status of leached outcrops investigation: Eng. Min. Journal, vol. 125, pp. 280 and 282, 1928.

sphalerite, or galena, for examiple, are not much more difficult to distinguish from one another than would be the respective copper, zinc, or lead carbonate or sulphate minerals."

Much excellent material has since been written on this subject; but many authorities are much less positive in their statements as to the accuracy of the deductions and the value of this type of study.

The surface residue varies according to the mineral composition of the original deposit. Quartz, hematite, limonite, pyrolusite, and kaolin constitute its bulk. Cassiterite, wolframite, gold, cerargyrite, and often anglesite and cerussite remain. The soluble minerals and those converted to soluble salts are transported and precipitated as newly formed compounds, both in the zone of oxidation and at or immediately below ground-water level. Oxides, carbonates, sulphates, silicates, chlorides, and native metals predominate among the compounds precipitated in the zone of oxidation, and sulphides at or below water level.

The processes of supergene enrichment have been described by many investigators and summarized by Emmons[6] in particular. Investigations carried out in both the field and in the laboratory indicate that solution is aided and hastened by the products formed by the oxidation of pyrite. In the presence of water, oxygen attacks pyrite, forming sulphuric acid and ferric sulphate. These products, in association with free oxygen, react with many of the primary minerals, converting them to sulphates. The solubility of these sulphates has a marked influence on their migration. The sulphate of iron is readily soluble. However, in the presence of water and ample free oxygen, iron sulphate is changed to the insoluble hydrous iron oxide, and sulphuric acid is liberated, thus much of the iron remains in the leached material.

Copper and zinc sulphides are particularly soluble in oxygen-laden acid waters. Their removal from the zone of active oxidation may be nearly complete, which accounts for many barren outcrops above bodies of copper and zinc ores.

Silver sulphides are soluble and much of the silver taken into solution as the sulphate is quickly precipitated out by any alkaline salt as the relatively insoluble chloride, cerargyrite, commonly termed horn silver. Since sodium chloride (common salt) is prevalent in meteoric waters, much of the silver is prevented from migrating far, and remains close to the surface.

Galena is to some extent soluble, but the resulting lead sulphate

[6] Emmons, W. H., The enrichment of sulphide ores. U. S. Geol. Survey Bull. 625, 1917.

is so highly insoluble that it remains in its original position and often forms a coating around a central core of galena, protecting it from further attack by acid solutions. The result is generally a near-surface enrichment.

Cinnabar is practically insoluble and remains unaltered, with no consequent mercury enrichment from reprecipitation.

Gold is not soluble in sulphuric acid or ferric sulphate. However, it is soluble in acid solutions containing uncombined chlorine. Chlorine is liberated in the reaction between sodium chloride and sulphuric acid in the presence of the strong oxidizing agent, manganese oxide. Thus, an active solvent of gold is present in some deposits. The gold would be immediately precipitated by ferrous sulphate were it not for the fact that manganese oxide converts ferrous sulphate to ferric sulphate which does not precipitate gold. Thus manganese oxide plays a dual part in the supergene enrichment of gold ores, and its presence in outcrops may indicate a possible leaching and redeposition of gold with corresponding enrichment.

Thorough oxidation and leaching are essential for enrichment. Solution is dependent upon the conversion of the metals to soluble compounds by oxidation. Leaching is essential for their downward migration. Any metals fixed in the upper oxide zone will be removed and dissipated as erosion proceeds. The presence of sulphides, other than galena, denotes incomplete oxidation. The presence of abundant metals, the oxidation products of which are usually easily soluble, indicates that leaching has not been thorough. The metals most diagnostic of the extent of leaching are copper and zinc. If carbonates and silicates of these metals are abundant in the upper oxidized zone, leaching has not been intense, and insufficient quantities of the metals have migrated downward to appreciably increase the grade of ore in depth.

Evidence of abundant rapid neutralizers is usually apparent, though not invariably so. Since rapid neutralizers impede migration of the metals, it is essential that the results of their influence be recognized and given proper weight. Where the rocks of one or both walls are limestone or dolomite, acid solutions will be rapidly neutralized upon coming in contact with them. Carbonate wall rocks have impeded migration of the metals except in a few rare cases where a protective coating or seal of gypsum has formed along the boundaries of the deposit.

Evidence of carbonate wall rocks should be obvious, but evidence of rapid neutralizers within the deposit may not be particularly obvious, since these minerals are converted to soluble

compounds by the very reactions that neutralize the acid solutions and are removed. The best evidence lies in the minerals that the rapid neutralizers have prevented from migrating. Iron remains practically in place as highly pulverulent or earthy limonite; copper and zinc are precipitated as carbonates. The significance of rapid neutralizers is this: downward migration of the metals is impeded, preventing their accumulation as enriched masses in depth.

The depth of ground-water level, though conforming roughly to the ground surface, is influenced by the general relief of the terrain. Ground-water level usually lies much deeper high up on steep slopes than it does near the edge of valleys or in a region of gentle slopes. Structures, such as impervious strata or fault zones, may impound the water and form local areas of shallow ground water where the water level would otherwise be deep. A deep water level permits deep and extensive oxidation and downward migration of the metals, while a shallow-water level prevents this. The best criteria of a deep ground-water level are strong relief, steep slopes, low annual rainfall, and the absence of springs near the deposit.

The present water level may be higher than in a previous period of leaching, with consequent oxide ore now extending below water level, or it may be lower with secondary sulphide ores above it.

The rate of erosion influences the progress of oxidation. Slow erosion retards its progress, whereas rapid erosion may remove material before oxidation and leaching are complete. For maximum effectiveness, erosion should just keep pace with thorough oxidation and leaching. The erosion rate varies with the gradient, amount of precipitation, climate, and resistance of the deposit and enclosing rocks. The rate of erosion is most conducive to sulphide enrichment in regions of moderate-to-strong relief. Slow erosion is favorable to residual enrichment, hence deposits enriched by residual processes are most numerous in regions of low relief.

Since oxidation and leaching are slow processes, long exposure to their action is essential if extensive enrichment is to result. As young deposits, in general, have been subject to enrichment processes for a much shorter time than have the older ones, the degree of enrichment is correspondingly less.

Criteria by which to judge the age of mineralization are the age of enclosing rocks, the relation to rocks or old erosion surfaces of known approximate age, the depth of erosion since mineralization, and the mineralogy of the deposit.

GENERAL TOPOGRAPHIC AND GEOLOGIC FEATURES OF NEVADA

The State of Nevada is situated largely in the Great Basin area, in which the outstanding structural and topographic features are the prevailing north-south basin ranges with intervening narrow valleys. The steep mountain slopes, which are covered with but a thin mantle of overburden and a sparse growth of vegetation, constitute a large area having numerous outcrops. This well-exposed condition of the rock formations facilitates the discovery of mineral deposits.

In Nevada there are exposures of rocks representing most of the geologic periods from the oldest (pre-Cambrian), to the youngest (Recent). The pre-Cambrian rocks are found in the Cresent, Eldorado, and Searchlight mining districts of Clark County in the southern part of the State.

The Paleozoic sedimentary rocks are well represented, particularly in eastern Nevada. This era is characterized by thousands of feet of interbedded quartzites, limestones, dolomites, and shales. Wheeler[7] has found evidence indicating that at least part of the sedimentary rocks, and particularly the Koipato formations of the Humboldt Range in Pershing County, are of Permian instead of Triassic age as formerly designated.

The best exposures of early Mesozoic (Triassic) sedimentary rocks occur in the central and western part of the State and are typically thick limestones interbedded with shales. They are particularly well exposed in the Humboldt Range in Pershing and Humboldt Counties, and in some of the ranges in Churchill, Mineral, and Esmeralda Counties. Effusive andesites and rhyolites are found interbedded with these sediments and are, therefore, Triassic in age. The Sierra Nevada granitic batholith is generally regarded to have been intruded during late Jurassic time. These Sierran granitic intrusives predominate throughout the western part of the State, and are considered as extensions of the Sierra Nevada batholith and were therefore intruded at about the same time. This massive batholith, and its satellites, intruded both the Paleozoic and the Triassic rocks in Nevada.

The granitic rocks of eastern Nevada are generally considered to be genetically related to the granitic intrusives of the plateau region to the east. These are of early Tertiary age. Late Tertiary rocks are represented by widely distributed areas of andesitic and rhyolitic flows and lacustrine sediments. The two epochs of late Tertiary volcanism (Miocene and Pliocene) are separated by a period of erosion, and in several areas by nonmarine sediments (Truckee and Esmeralda formations) which are of early Pliocene age.

[7] Wheeler, H. E., Helicoprion in the anthracolithic (late Paleozoic) of Nevada and California, and its stratigraphic significance: Jour. Paleo., vol. 13, No. 1, pp. 105–106, January 1939.

Pleistocene and recent basalts are the youngest igneous rocks in Nevada and cover large areas of the older formations, especially in the western part of the State.

EPOCHS OF ORE DEPOSITION

Ore deposition accompanied both general periods of granitic intrusion, late Jurassic in western Nevada and early Tertiary (Eocene) in eastern Nevada, and two distinct periods of ore deposition are associated with late Tertiary volcanism, Miocene (pre-Esmeralda and Truckee), and Pliocene (post-Esmeralda and Truckee). The deposits occurring in the Mesozoic sediments and interbedded lavas of western Nevada are genetically connected

Eras	Epochs	Igneous Association of Deposits	Types of Deposits
Quaternary	Pleistocene or glacial	Basalt	Quicksilver ?
Tertiary	Pliocene	Deposits associated with Pliocene lavas.	Epithermal gold-silver veins. Quicksilver deposits.
	Esmeralda Formation		
	Miocene	Deposits associated with Miocene lavas.	Epithermal silver-gold veins.
	Oligocene		
	Eocene	Deposits associated with granitic intrusives of eastern Nev.	Replacement, contact-metamorphic, and disseminated copper deposits.
Mesozoic	Cretaceous Jurassic Triassic	Deposits associated with granitic intrusives of western Nev.	Argentiferous quartz veins. Contact-metamorphic deposits.

FIGURE 1. Epochs of ore deposition in Nevada as related to geologic chronology.[3]

[3] Butler, B. S., "Ore deposits as related to stratigraphic structural and igneous geology in the western United States"; in *"Ore Deposits of the Western States,"* Lindgren, First Edition, A. I. M. E., New York, 1933. (Table condensed and adapted to best demonstrate conditions in Nevada.)

with the granitic intrusives. Still other deposits may be genetically related to the Pleistocene basalts.

EXAMPLES OF ORE DEPOSITS IN NEVADA

In previous pages, the origin and characteristics of different types of ore deposits have been discussed. In the following pages descriptions of specific Nevada occurrences are given.

The author adheres closely to Ferguson's[8] original and excellent study of the epochs of ore deposition in Nevada and of the relations of the Nevada deposits to the granitic intrusives and the Tertiary lavas.

The deposits are discussed in the order of their association, first, with granitic intrusives, second, with basic intrusives, and, third, with Tertiary and Recent extrusive rocks, and then followed by examples of zonal deposition and of supergene enrichment.

QUARTZ VEINS ASSOCIATED WITH GRANITIC INTRUSIVES

The predominant productive type of ore deposit associated with the granitic intrusives of western Nevada is a silver-gold-bearing quartz vein that cuts either the intrusive or the intruded rock, or both, with little or no alteration of the walls. The metallic content usually composes only a small part of the vein material and the primary sulphides in order of abundance are pyrite, chalcopyrite, arsenopyrite, galena, tetrahedrite, sphalerite, and stibnite. These deposits are much more argentiferous than auriferous. Antimonial silver minerals are characteristic of these veins, and supergene (secondary) enrichment has played a very important role in increasing the silver content of the oxidized ore to a profitable grade. The primary ore is usually too low grade to be workable. Some of the best examples of this type of deposit are those in the Reese River, Belmont, Star, and Rochester mining districts. The supergene-enriched ores were very profitable; the primary ores unprofitable. Deposits of this type almost invariably contain small amounts of the base metals (copper, lead, and zinc), but have not produced such metals in important amounts.

Where the quartz vein and fissure cuts limestone beds, conditions were favorable to the formation of replacement ores. An example showing the deposition of vein ore in the volcanic rock, and replacement ore in limestone, is found in the Queen of Sheba mine in the Star mining district. (See Figure 2.) The deposit is

[8]Ferguson, H. G., The mining districts of Nevada: Economic Geology, vol. 24, No. 2, March-April, 1929.

a steeply dipping, narrow quartz vein in the interbedded andesite, and a large lenticular replacement body in the overlying limestone. In contrast, the quartz veins in the Belmont district cut both the granitic rock and the limestone, with neither being appreciably altered or mineralized.

Eastern Nevada contains few significant quartz vein deposits

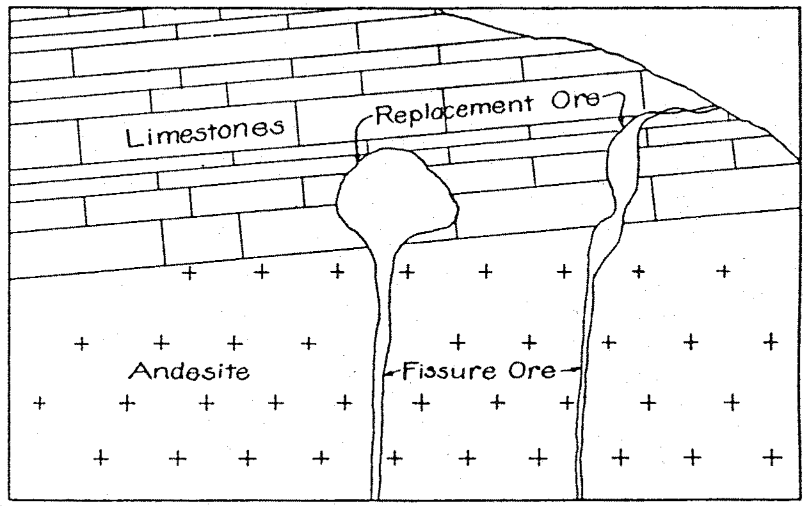

FIGURE 2. East-west vertical cross section through ore bodies of the Queen of Sheba mine, showing relation of replacement ore in limestone to fissure ore in andesite. (This mine was sampled and examined by the writer in December 1934.)

associated with granitic intrusives. Cherry Creek (Egan Canyon) district,[9] in White Pine County, is probably the most productive occurrence of this type in the counties bordering the eastern boundary of Nevada. Here, as in the western deposits, the valuable metals were contained in distinct quartz veins and the bulk of production was derived from the zone of secondary enrichment of silver ore. These deposits differ only from similar deposits situated in several western counties by having a higher base metal content in the primary ore.

CONTACT-METAMORPHIC DEPOSITS

Contact-metamorphic deposits are particularly widespread in northwestern Nevada, especially in a north-south belt in the west central part of the State. This belt lies roughly between the 117th meridian on the east, which is probably about the eastern limit of the granitic rocks dominantly satellitic to the Sierra batholith,

[9]Schrader, F. C., Cherry Creek (Egan Canyon) district, White Pine County: U. of Nev. Bull., vol. 25, No. 7, 1931.

and the western border of the State. In this area Triassic limestones and shales were intruded by Jurassic granitic rocks. Numerous contact-metamorphic deposits formed between the sediments and the intrusives. The complex silicates of calcium, magnesium, iron, and aluminum (garnet, epidote, pyroxene, wollastonite, amphibole, and idocrase) are the typical minerals developed on the contact and always are present in varying amounts. Often they are the predominant minerals where the intruded rock is limestone. The other commonly associated primary minerals are calcite, quartz, pyrite, chalcopyrite, galena, molybdenite, sphalerite, magnetite, specularite, wolframite, scheelite, and fluorite. Metamorphism extends from a few feet to several thousand feet into the intruded sediments, and the width may show considerable variation along the length of the same contact. Argillaceous shales and slates are usually changed into "hornfels," a dense fine-grained holocrystalline rock, usually made up of the complex magnesium, iron, and aluminum silicates that contain little or no calcium, such as biotite, andalusite, staurolite, garnet, and feldspar.

Generally, the ore minerals occur near the contact, but may extend outward, along favorable limestone beds, for several thousand feet. This is especially true where fissuring or brecciation has guided and furnished conduits for the ore-forming solutions. Conditions most favorable for deposition occur where masses of limestone are included within the intrusive, or where a mass of the limestone extends into the intrusive, because these conditions present more surface to the heating and mineralizing action of solutions from the intrusive, favoring a maximum of ore deposition. Due to various factors certain limestone beds, or horizons, are particularly favorable to metamorphism, and the bulk of the ore occurs within these favorable beds.

The contact-metamorphic deposits of western Nevada have been economically important as sources of copper and tungsten, but have produced only minor amounts of other metals. The only important copper production in this area has been from deposits of this type in the Yerington and Santa Fé districts. Most of the production from the Yerington district[10] was derived from primary sulphide ores. The profitable ores of the Santa Fé district in Mineral County were limited to small supergene-enriched

[10] Carpenter, Jay A., The Yerington copper district, Nevada: Min. S. P., vol. 101, p. 8, 1910.
Knopf, A., Geology and ore deposits of the Yerington district, Nevada: U. S. Geol. Survey Prof. Paper 114, pp. 13–15, 1918.

bodies in the upper parts of the deposits. Much of the tungsten production in the United States is derived from scheelite-bearing contact-metamorphic zones as replacement deposits.

The Nevada Massachusetts Company's mine near Mill City in Pershing County is one of the most important tungsten-producing mines of the world. The deposit at this mine, unlike the usual contact-metamorphic mineralization extending along the contact, is a garnet-epidote replacement of limestone beds at a steep angle to the contact. These beds are interstratified with shales that are now largely converted to hornfels by the same metamorphic action.

Numerous other scheelite-bearing deposits in contact zones are distributed throughout western Nevada, with a majority of them concentrated in a belt about fifty miles wide, extending from the Getchell district in Humboldt County on the north to the Silver Dyke district in Mineral County on the south.

Contact-metamorphic deposits are not so widespread in eastern Nevada as they are in the western part of the State. This is probably due to the lesser number of intrusive cupolas. It certainly is not because of the lack of limestone. Limestone is the dominant rock of the region. Some of the eastern deposits have produced small quantities of base metals and others show promise of becoming tungsten producers, but, as a whole, the contact-metamorphic deposits of the eastern counties have contributed a very minor part to Nevada's metal output. The following districts have produced copper, lead, or silver ores from contact-metamorphic deposits: Contact, Railroad, and Spruce Mountain in Elko County, and White Pine in White Pine County. However, part of the ore from each of these districts came from replacement deposits in limestone.

Scheelite has recently been discovered in several contact-metamorphic zones in eastern Nevada. Scheelite occurs in the garnetized limestone of a broad contact-metamorphic zone near the west base of Mount Hamilton. Former mining activity here was confined to the production of small quantities of copper and gold ores, and scheelite was not identified by the early operators. Another similar discovery of scheelite has been made in the northern part of the Tem Piute district in Lincoln County.

REPLACEMENT BASE-METAL DEPOSITS

Replacement base-metal ore deposits are almost unknown and are of little economic importance in western Nevada. Conditions favoring their formation, such as replaceable limestone in the vicinity of intrusive batholiths, are prevalent. Hence the lack of such deposits in this area must be attributed to a deficiency of base metals liberated by the intrusives.

Replacement deposits are distinctly the most prevalent type of ore deposit occurring in eastern Nevada and have been responsible for the major production of silver, lead, and zinc from this area. Some of the outstanding districts with large productions from replacement deposits are Eureka, White Pine, Cortez, Pioche, and Goodsprings. Most of these districts were first started as silver and gold producers during the mining of the shallow, enriched, oxidized silver ores. At Eureka the oxidation penetrated to a depth of about one thousand feet,[11] with oxidized lead-silver ore to that depth.

The Yellow Pine[12] (Goodsprings) district in Clark County is the only district in the State yielding, in addition to lead-zinc ores, important quantities of ore valuable only for its zinc content. The zinc, lead, silver, and copper ores of the district occur as replacement deposits in limestone and dolomite near dikes of granitic rocks. In contrast, the gold ores occur in or near the intrusive rocks.

The bedded ores of the Pioche district are excellent examples of the replaceability of certain limestones by ore-bearing solutions. Here insignificant fissures, with but minor accompanying brecciation, cut quartzites, shales, and limestones of lower Cambrian age. Ore-bearing solutions ascending along these fissures have deposited only small irregular bodies of ore in the quartzite and shale, but they have replaced a certain limestone bed, the replacement extending along the fissures for several hundred feet and penetrating as much as one hundred feet on either side into the bed.[13] The replacement sulphide ores in the Combined Metals mine are an almost microscopic intergrowth of pyrite, sphalerite, and galena, with the galena carrying about an ounce of silver to each percent of lead in the ore. Only very finely ground ore is amenable to concentration by selective flotation. At present this mine is the most important producer of lead-zinc ore in Nevada.

In the adjoining Prince mine similar bedded ores occur along a different fissure from that of the Combined Metals mine. The Prince ore bodies are large in three dimensions and were deposited at several horizons in thick limestone beds. Mining in past

[11] Lincoln, F. C., Mining districts and mineral resources of Nevada; Nevada Bureau of Mines, Reno, Nevada, p. 91, 1923.
[12] Lincoln, F. C., *op. cit.*, p. 29.
[13] Westgate, L. F., and Knopf, A., "Geology and ore deposits of the Pioche district": U. S. Geol. Surv. Prof. Paper 171, p. 55, 1932.

years was confined to the oxidized ore, principally valuable as smelter flux due to its high content of lime, iron, and manganese, together with low silica. With the recent installation of a flotation plant in the district the sulphide ore on the lower levels is now being mined.

DISSEMINATED COPPER DEPOSITS

The only disseminated copper deposits so far discovered in Nevada are those in the Ely district, and the bulk of Nevada's copper output has been from this district. The principal production has been from a large mass of pyritized monzonite carrying a low copper content. The copper minerals are mainly chalcopyrite with lesser amounts of chalcocite. Early copper mining in the district was restricted to supergene-enriched ores. According to Pennebaker[14] the bulk of production in recent years has come from the primary pyrite-chalcopyrite ores. The large size, uniform character, and shallow depth of the ore bodies make ideal conditions for the open-pit and block-caving methods of mining. The low mining cost per ton by these methods and the high recovery by concentration of the ore by flotation, has made possible profitable large-scale operations. Without these conditions favorable to low operating costs, only selected portions of the ore could have been mined, and the production from such operations would have been far short of its present magnitude.

Ferguson's[15] study of Nevada's ore deposits associated with granitic intrusives brings out several important facts. The distinct silver-bearing quartz veins, low in base metals, which are so prevalent in the western counties are almost lacking in the counties along the eastern border. Western Nevada contains few replacement deposits. Such occurrences are numerous and of great economic importance in the eastern part of the State. The bulk of the contact-metamorphic deposits occur west of the 119th meridian. Several of these have been important producers of tungsten. The principal production from deposits associated with granitic intrusives in western Nevada has been derived from the secondary enriched ores of the silver-bearing quartz veins. In contrast, the similar production from eastern Nevada has been derived principally from the base metals.

DEPOSITS ASSOCIATED WITH BASIC INTRUSIVE ROCKS

The basic intrusives of gabbro, peridotite, and norite are rarely

[14] Pennebaker, E. N., Geology of the Robinson mining district, Nevada: Mining and Metallurgy, p. 167, 1932.
[15] Ferguson, H. G., *op. cit.*

encountered in Nevada, and ore deposits associated with them have played an insignificant part in Nevada's metal production. A Nevada deposit of this type is situated in the Copper King (Bunkerville) district of Clark County.[16] [17] [18] In this locality small amounts of nickel, cobalt, and platinum occur with pyrrotite, pyrite, and chalcopyrite in peridotite dikes. These dikes cut pre-Cambrian schists and gneisses and probably are products of magmatic differentiation from a deep-seated intrusive mass. Small ore shipments containing copper, nickel, cobalt, and platinum have been made, but the deposits show little promise of becoming an important source of these metals.

Chromite is a mineral definitely associated with the basic intrusive rocks, especially with peridotite and its alteration product, serpentine. This mineral has not been found in commercial quantity in Nevada.

References have been made to the occurrence of nickel, cobalt, and platinum in several Nevada mining districts where the deposits are associated with diorite and quartz-monzonite.

In the Table Mountain (Boyer) mining district of Churchill County nickel, cobalt, and copper occur in stringers in the altered sediments near the contact with intrusive diorite. A few tons of selected nickel and cobalt ores were shipped from this district prior to 1900, but the mines have long been inactive.[19]

In the Yellow Pine (Goodsprings) district of Clark County cobalt and platinum minerals occur closely associated with lead-zinc and copper replacement deposits in sediments. The deposits occur near quartz-monzonite intrusives, which were doubtless responsible for their origin. They show little promise of becoming important sources of either cobalt or platinum.[20]

DEPOSITS ASSOCIATED WITH TERTIARY EXTRUSIVE ROCKS

During late Tertiary time Nevada has had at least two distinct periods of lava flows. The older (Miocene) lavas are separated from the younger (Pliocene) lavas by a period of erosion. In many localities there is an approximate intervening series of lacustrine deposits variously known as the Siebert, Esmeralda, or Truckee formations. These formations supply convenient markers in the central and southwestern portions of the State, but they are not so widespread as the lavas, however. Large areas of the Miocene lavas were being subjected to erosion throughout the period in which the lacustrine sediments were being deposited. These erosion surfaces formed during the interval serve as important markers in areas where the lacustrine sediments are absent, as they occupy the same relative position of lying between the Miocene and Pliocene lavas.

[16] Lincoln, F. C., *op. cit.*, p. 18.

[17] Lindgren, Waldemar, and

[18] Bancroft, H., "Platinum in southeastern Nevada," U. S. Geol. Survey Bull. 430, pp. 192–199, 1910.

[19] Ferguson, H. G., Nickel deposits in Cottonwood Canyon, Churchill County, Nevada: U. of Nev. Bull., vol. 33, No. 5, December 1939.

[20] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, 1931.

Ore deposition accompanied, or followed shortly after, both the Pliocene and the Miocene periods of extrusion. This conclusion is substantiated by the relation of several deposits to the lavas of the two periods of volcanism.

The deposits in the Comstock,[21] Aurora,[22] and Tonopah[23] districts are examples of those formed in Miocene time. In all of these districts the veins were formed by the filling of fissures in the older volcanics. They were truncated by erosion and then buried under a series of later lava flows. Late Pliocene and Quaternary erosion has subsequently cut through the overlying lavas exposing the veins. This indicates that ore deposition was later than the older lavas, but preceded the capping rocks by at least the duration of the period of erosion which separates the two extrusions.

To the above-mentioned occurrences may be added the deposits of the Como district in Lyon County. Here, persistent epithermal quartz veins containing a high ratio of silver to gold occur in Miocene andesites, and these andesites, until comparatively recent time, had been buried under younger flows of andesite. Erosion removed the much younger lavas thereby uncovering the quartz veins and part of the older andesite. These lavas are similar to the Miocene and Pliocene rocks of the Comstock district.

A similar example was noted by the writer about three miles south of Ellsworth in Nye County where several quartz veins carrying low gold and silver values occur in andesite. In this area the mineral deposition is in Miocene andesite that was subjected to erosion, buried under (Pliocene[?]) lavas, and then re-exposed by later erosion. Only a part of each vein has been re-exposed, the remainder still being covered by a glassy andesite.

[21] Gianella, V. P., Geology of the Silver City District and the Southern Portion of the Comstock Lode, Nevada: U. of Nevada Bull., vol. 30, No. 9, 1936.

[22] Ferguson, H. G., The Round Mountain district, Nevada: U. S. Geol. Survey Bull. 725, pp. 383–406.

[23] Nolan, T. B., Underground geology of the Tonopah mining district, Nevada: U. of Nev. Bull., vol. 24, No. 5, 1935.

The magnitude of erosion that may have taken place since Pliocene volcanism is noted at Sherman Peak, about two miles northeast of the deposit. It is made up entirely of the younger lavas, and stands about two thousand feet above the general level of the truncated Miocene lavas, indicating at least that depth of erosion since Pliocene volcanism.

Deposits occurring in the Pliocene lavas are not so numerous as those in Miocene lavas. However, several of Nevada's productive gold and silver deposits have been in the younger formation. Goldfield,[24] Manhattan,[25] and Round Mountain,[26] are examples.

The prevailing difference between the deposits of the two periods is the much higher ratio of silver to gold in the Miocene veins, together with the indistinct and erratic character of the vein-filling in the Pliocene deposits. The ratio of silver to gold in the older veins varies from three or four to one to as much as one hundred to one. In the younger veins gold may exceed silver by as much as two to one.[27] Locally the ratio in a given deposit may vary greatly, so the average for the deposit is used for comparison. Mineralization that attended the vein-filling in the Miocene deposits caused some silicification of the wall rock, but the ore minerals are confined almost entirely to the vein-filling. In the younger (Pliocene) deposits the vein-filling was indistinct and erratic, forming bunches and shoots along the length of the fissure. There was much silicification of the walls and the shattered rock along the trend of the fissure. The ore minerals accompanied the silicification of the walls as well as the vein-filling, and much of the dense silicified wall rock constitutes ore.

The Miocene deposits have been much more productive than those of Pliocene age.[28] The Miocene ore shoots have proven to be more continuous, and to have been workable to a greater depth than those of the younger period of mineralization. Secondary enrichment of silver has played a much more important part in the older than in the younger veins. This feature is probably due to the higher silver content, the more porous condition of the deposits, and to the longer period of erosion and accompanying weathering. The lack of production of base metals from deposits of either period is notable.

[24] Ransome, F. T., The geology and ore deposits of Goldfield, Nevada: U. S. Geol. Survey. Prof. Paper 66, 1909.

[25] Ferguson, H. G., Geology and ore deposits of Manhattan, Nevada: U. S. Geol. Survey Bull. 723, 1924.

[26] Ferguson, H. G., *op. cit.*

[27] Ferguson, H. G., The mining districts of Nevada: Econ. Geol., vol. 24, p. 136, 1929.

[28] Ferguson, H. G., *op. cit.*, pp. 136–137.

The following examples of ore deposits associated with Tertiary extrusive rocks are given in turn according to the metal content.

PRECIOUS METAL DEPOSITS

Most of the precious metal deposits associated with Tertiary extrusives are typically epithermal, according to Lindgren's classification of ore deposits. In discussing epithermal deposits Lindgren[29] states: "In regions of comparatively recent volcanic activity where the measure of erosion since the eruptions ceased is in hundreds rather than in thousands of feet, we find a group of important ore deposits, usually in the form of fissure veins. They generally occur in igneous flow rocks and most commonly in andesite, latite, trachyte, and rhyolite. They are rarely found in basalts. But they also cut the underlying or adjacent formations. They constitute the source of a large part of the world's production of gold, silver, and quicksilver, and they contain the spectacular bonanzas of the Cordilleran region, of which examples are found at Tuscarora, Virginia City, Goldfield, Cripple Creek, Pachuca, Guanajuato, and many other districts."

Many very productive deposits of this type occur in Nevada districts besides those mentioned by Lindgren, such as Aurora, Tonopah, Rhyolite, Fairview, Wonder, Rawhide, Seven Troughs, Olinghouse, National, Jarbidge, Gold Circle, Manhattan, Round Mountain, Searchlight, and Delamar. Though most of the ore deposits of this type are enclosed within the Tertiary lavas, several extend into the adjacent or underlying formation. Those in the Delamar district[30] are associated with rhyolite dikes and occur along brecciated zones in the surrounding quartzite. At Manhattan many of the veins are enclosed in early Paleozoic sediments.

By weight, silver usually predominates over gold. Deposits containing one without the other are exceedingly rare. Native silver is often found, but is usually of secondary origin and occurs with silver chloride, which, as cerargyrite (horn silver), is the dominant supergene-silver mineral. Silver bromide and silver iodide have been found in many deposits, but only in minor amounts. Silver sulphide as argentite, and silver sulphantimonides and sulpharsenides such as pyrargyrite, stephanite, proustite, and polybasite, are the abundant and characteristic silver minerals. Some of these sulphide minerals may be either or both primary or

[29] Lindgren, W., Mineral deposits, 4th ed., p. 444. McGraw-Hill, N. Y., pp. 516–517, 1928.

[30] Callaghan, Eugene, Geology of the Delamar district, Lincoln County, Nevada: U. of Nevada Bull., vol. 36, No. 5, 1937.

secondary, and their origin has been the subject of much controversy among students of ore deposits. Recognition of their origin is essential for a reliable prediction of the persistence of ore in depth.

Quartz is the most abundant gangue mineral, and usually occurs as an intimate intergrowth of fine crystals, giving it the appearance of translucent porcelain. The quartz is seldom glassy like that from deposits formed at greater depths and at higher temperatures. Drusy vugs and growths of fine quartz crystals around included pieces of wall rock are common, and banding due to alternate layers of varying grain is a very prononunced and characteristic feature.

The epithermal ore deposits in Nevada Tertiary extrusive rocks have been mined to considerable depth and, in many, the bonanza ore persisted below the zone of supergene enrichment. Generally, as exploitation has continued in depth, the gold and silver content has decreased, with the quartz veins usually persisting, indicating a deep origin for the veins with the mineralization limited to a shallow range.

That these deposits owe their origin to a source similar to that which formed the volcanic flows, and not to a particular flow, is brought out by the fact that some of the deposits cut more than one flow, and that many of them are capped by post-mineral flows. Mineralization must have followed the extrusion and solidification of the lavas in which the veins occur, and obviously preceded the lavas which capped them. Some of these vein deposits not only cut lava flows, but also very much older sediments. In such cases the source of the mineralization could not have originated in the lavas themselves, and consequently must have had a deeper source. This is further substantiated by the fact that the deposits usually occur near the center of volcanism. The deposits of the Comstock Lode are good examples and exhibit both conditions. The veins cut both the old sediments and overlying andesite and rhyolite. The veins were truncated by erosion and later capped by a series of lava flows.[31]

MERCURY DEPOSITS

Nevada's mercury (quicksilver) deposits have had an origin similar to that of the epithermal gold-silver veins. Their association with Tertiary lavas is well established. These deposits may occur in almost any kind of rock, but they are usually in close

[31] Gianella, V. P., Geology of the Silver City district and the southern portion of the Comstock Lode, Nevada: U. of Nevada Bull., vol. 30, No. 9, p. 103, 1936.

association with either effusive rocks or hot springs.[32] The association of many of these deposits with hot springs is a conspicuous characteristic. At Steamboat Springs, eleven miles south of Reno, cinnabar has been deposited by hot springs that are still active. Deposition under similar conditions has taken place at Lee's Hot Springs, about fifteen miles south of Fallon in Churchill County. Here the cinnabar occurs in the siliceous sinter within a few feet of the still active spring.

The mineralization of mercury deposits is extremely simple. Cinnabar is the only important mineral of mercury, with native metal and calomel often occurring in minor amounts. Metacinnabarite may occur near the surface, often appearing as a black coating on cinnabar. In addition, minor amounts of pyrite, stibnite, and marcasite occur frequently. Other minerals of the metals are conspicuously absent. The predominate gangue minerals are chalcedony, quartz, and opal.

Deposits also occur as irregular veins along fractures, in brecciated zones, or as fillings and replacements in porous rocks. It is generally stated that conditions favoring concentrated deposition exist where the fissure, along which the mineralizing solutions ascend, cuts a porous formation such as sandstone, which is overlain by an impervious layer. Under such conditions, the impervious layer retards the upward progress of the solutions and forces them to flow outward into the porous wall rock.

The Bottle Creek district in Humboldt County has been one of the outstanding mercury districts of the State, and in 1937 the author found the Scossa mine to be a very interesting geological study.

In a gulch the erosion of an overlying rhyolite had fortunately exposed cinnabar ore extending along a narrow diabase dike in a shaly sandstone. Drifts and crosscuts from an exploratory shaft proved the diabase dike of about 16 feet width to be intruded along a fault zone of small displacement, with cinnabar in chalcedonic quartz occurring along the walls and in numerous shrinkage cracks and fault fractures within the diabase. The mineralizing solutions probably came from the same deep-seated source as did the diabase, and they penetrated along the dike with kaolinization of the wall rock and diabase over a narrow width. The overlying and later rhyolite is probably of Tertiary age and the deposit of Miocene age.

[32] Ross, C. P., Quicksilver deposits. Ore deposits of western States. Lindgren, 1st ed. A. I. M. E., N. Y., pp. 652–653, 1933.

In a short period in 1942 this mine produced 2,500 tons of ore yielding over 100 pounds of mercury per ton, and shortly thereafter it was again a marginal producer, indicating the irregular deposition of cinnabar that is characteristic of most mercury deposits.

In his recent report on the Bottle Creek district Roberts[33] states: "The Tertiary(?) rocks of the district may be divided into five units. The three oldest units, which may be conveniently called the lower group, include a lower unit of tuffs, conglomerate, and sandstone and an upper unit of tuffs and clays separated by a basalt unit. These three units are cut by diabase dikes, which contain the ore bodies. The lower group and the diabase dikes are unconformably overlain by rhyolite flows. No fossils were found in any of these rocks, but they resemble known Tertiary rocks in adjoining areas."

The origin of many mercury deposits is similar to that of the epithermal gold-silver veins in the Tertiary volcanics. A deposit that occurs about one mile south of the Warrior mine in the Omco mining district in Nye County contains both cinnabar and gold occurring together in a quartz vein. Deposition of the two metals probably did not occur contemporaneously, but a common origin is suggested. The quartz is chalcedonic in character and resembles that mined as gold ore in the Warrior mine. The vein strikes east-west and dips about forty-five degrees south, within walls of Pliocene lavas. The combined value of the gold and mercury are probably not sufficient to constitute ore, but selected samples assayed several dollars in combined values. This deposit may have little economic significance, but the fact that gold and cinnabar occur together indicates that the origin of the mercury deposits is much the same as that of the Pliocene gold-silver deposits.

Nevada has produced considerable quantities of mercury from numerous deposits throughout the west-central part of the State. Why the bulk of these deposits are concentrated in this area is probably explained by the prevalence of Tertiary lavas in this area and their scarcity elsewhere in the State.

TIN DEPOSITS

Nevada's tin deposits occur in association with extrusive rhyolitic rocks and were formed during one of the Tertiary periods of mineralization. This is in contrast to the productive tin mines of the world which usually occur in granite and presumably originated at great depth.

[33] Roberts, R. J., "Quicksilver deposits of the Bottle Creek district, Humboldt County, Nevada: U. S. Geol. Survey Bull. 922A, p. 6, 1940.

The interesting tin occurrence near the Izenhood ranch, twenty-two miles north of Battle Mountain, is described by Fries,[34] in general, as tin-bearing veinlets occurring in thick rhyolitic flows of Miocene(?) age, with most of the minerals contained being likewise present in cavities in the rhyolite and with spectographic analysis indicating that the average rhyolite contains about 0.001 percent of tin. The tiny veins were presumably formed by the contraction of the rhyolite, and the cassiterite had its origin in the cooling mass.

The most promising occurrence of tin in the State also occurs in rhyolite at Majuba Hill in Pershing County. It is described by Messrs. Smith and Gianella[35] as associated with copper in deposits in a brecciated plug of Tertiary rhyolite which is altered to quartz with sericite, with much tourmaline present.

The cassiterite in minute quantity is widely and unevenly distributed through the brecciated rock and in a small amount in the copper ore, and abundant in one small shoot. Exploration work in 1943 in the vicinity of this shoot disclosed a considerable body of 0.25% to 0.50% tin ore. Concentrates produced from 3.0% ore and shipped to the Metals Reserve Company had a content of over four tons of tin.

Cassiterite was recognized in placer concentrate from the Rabbit Hole district in Pershing County by Director Walter S. Palmer of the State Analytical Laboratory. The source was apparently from the erosion of an extrusive rhyolite nearby.

Good specimens of cassiterite have been found in the gold-bearing veins of the Jumbo Ex mine at Goldfield in Esmeralda County. The Goldfield ores occur in Tertiary dacite, rhyolite, and latite, and are considered to be of Pliocene age. A spectographic study of the Goldfield ore by Wilson[36] established the fact that "three elements, bismuth, silver and tin, are genetically associated with gold values in the deeper veins."

TUNGSTEN DEPOSITS

Most all of the Nevada tungsten deposits are of the contact metamorphic type, but there is at least one known thermal spring deposit that contains commercial quantities of tungsten. This deposit is situated about three miles northeast of Golconda in Humboldt County. It was first prospected for precious metals

[34] Fries, Carl, Jr., Tin deposits of northern Lander County: U. S. Geol. Surv. Bull. 931-L, 1942.

[35] Smith, W. C., and Gianella, V. P., Tin deposit at Majuba Hill, Pershing County, Nevada: U. S. Geol. Surv. Bull. 931-C, 1942.

[36] Wilson, H. D. B., Geochemical studies of the epithermal deposits at Goldfield, Nevada: Econ. Geol., Jan.-Feb., 1944, page 37.

and manganese. This unusual deposit was described and the presence of tungsten was reported first by Penrose,[37] [38] later by Harder,[39] and still later by Pardee.[40] Each of these authors ascribes a thermal spring source to the deposit. Their conclusions differ only in the mode of precipitation of the metals and the sequence of events.

The ore, which is composed principally of manganese and iron oxides, with some calcite, occurs as flat-lying bodies embedded in a soft calcareous tufa. Pardee[41] concludes that the deposit is later than the Quaternary Lake Lahonton tufa, and that solutions rising through a reopened quartz vein in shale spread out horizontally as soon as the contact between the shale and overlying tufa was reached, and, by replacing the tufa, deposited the flatlying bodies of manganese and iron oxide.

The tungsten is so intimately combined with the manganese and iron oxides that its mineral has not been isolated. It cannot be concentrated by the usual gravity concentration methods.

Kerr[42] states "the ore minerals are colloidal in origin, tungstic acid having been absorbed in psilomelane and limonite while both were gels."

A few tons of the ore were mined from this deposit as manganese ore in 1918. It is now being mined for its tungsten content, the metal being extracted by a chemical process.

Similar manganese ore that contains tungsten so intimately combined with the other minerals that it cannot be concentrated by the usual gravity methods, has been reported from several other districts in Nevada by Palmer.[43]

Lindgren[44] describes a thermal spring deposit in Bolivia, and shows the similarity between it and the one at Golconda.

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[37] Penrose, R. A. F., Jr., Manganese: Its uses, ores, and deposits. Geol. Survey of Arkansas for 1890, vol. 1, 1891.

[38] Penrose, R. A. F., Jr., A Pleistocene manganese deposit near Golconda, Nevada: Jour. Geology, vol. 1, pp. 275–282, 1893.

[39] Harder, E. C., Manganese deposits of the United States: U. S. Geol. Survey Bull. 427, pp. 153–157, 1910.

[40] Pardee, J. T., Deposits of manganese ore in Nevada: U. S. Geol. Survey Bull. 710, pp. 235–238, 1919.

[41] Pardee, J. T., *op. cit.*, p. 238.

[42] Kerr, Paul F., Tungsten-bearing manganese deposit at Golconda, Nevada: Bulletin of the Geological Society of America, vol. 51, pp. 1359–1390, September 1, 1940.

[43] Palmer, W. S., The occurrence of tungsten in manganese ore: Eng. and Min. Jour., vol. 105, p. 780, 1918.

[44] Lindgren, Waldemar, A recent deposit of a thermal spring in Bolivia: Econ. Geol., vol. 17, pp. 201–206, 1922.

NONMETALLIC DEPOSITS

This subject was covered in the Univ. of Nevada Bull., Vol. 26, No. 7, "Nonmetallic Minerals in Nevada," by J. A. Fulton and A. M. Smith, 1932. (Now out of print.)

As used here, the term nonmetallic means those minerals and natural-occurring compounds useful principally in their natural form and not as a source of the metallic elements.

Nevada has a variety of such deposits, many of which are or have been important producers. The total value taken from these deposits, however, has been small in comparison with that from the metallic ores of the State. Among the deposits that were once important for their production are the borate deposits of Clark County, several borate and sodium chloride deposits occurring in the dry lake beds in other counties, and the sulphur deposit in the Sulphur mining district in Humboldt County. In recent years exploitation of these deposits ceased because richer and more profitable deposits were discovered and worked elsewhere.

Transportation costs and market prices are important factors in controlling the profitable exploitation of nonmetallic deposits. The former is a handicap to production from Nevada and limits the marketing of most of the State's nonmetallic products.

Nevada's nonmetallic production at present is limited mainly to limestone, gypsum, barite, fluorspar, dumortierite, brucite, diatomite, clay, magnesite, and silica sand. Limestone of commercial purity has been mined and calcined at many places in the State, but the only notable production of lime now comes from Sloan in Clark County. Nevada has been one of the leading States in gypsum production since 1910, the tonnage coming mainly from Clark, Lyon, and Pershing Counties. The gypsum occurs in sedimentary beds, with a marked tendency, as mining proceeds away from the surface, to give place to anhydrite.

According to Gianella,[45] "barite deposits are of widespread occurrence in Nevada. The barite occurs both in veins and also as replacement deposits in limestone."

When only a barite white in color could be marketed, production was very limited and it came mainly from the Eagleville district in southeastern Churchill County from a vein deposit. In recent years there has been an active demand for barite with no color specification, resulting in large annual shipments of cream

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[45] Gianella, V. P., Barite deposits in northern Nevada: Amer. Inst. of Min. Eng., vol. 144, p. 294, 1941.

to very dark-gray color from deposits of the replacement type, mainly from Lander and Eureka Counties.

Fluorspar is reported as occurring in several mining districts in the State. It has been mined for over 20 years in small tonnages from two properties, one in the Broken Hills district in Mineral County and the other in the Beatty district in Nye County. Both are strong vein deposits, and now worked to 300 feet in depth.

Dumortierite, a rare silicate of aluminum of less common occurrence than the better known similar mineral andalusite, is found in commercial quantity in the Rochester district in Pershing County. It occurs as segregated lenticular masses in a schistose rock which resulted from metamorphic action on a trachyte by an intruding granitic magma.[46] For nearly twenty years small annual carload shipments have been made of this rare mineral to Michigan for use in the manufacture of spark plugs.

Brucite, the relatively rare mineral of magnesium hydrate, occurs in a very large deposit in the Mammoth mining district in Nye County, near the newly-established town of Gabbs, Nevada. The brucite, according to Callaghan,[47] lies between granodiorite and dolomite, the product of action of hypogene magnesium solutions upon pre-existing dolomites. Discovered in 1927, brucite has gradually grown in importance until it is now mined at the rate of approximately 200 tons a day for refractory use in the eastern steel plants.

Magnesite is of rather infrequent occurrence in Nevada. A large impure sedimentary deposit near Overton, in Clark County, has been known for nearly 30 years. Small shipments have been made from fairly pure deposits of irregular size out from Ely, Nevada. Huge deposits of very pure magnesite running into the millions of tons lying close by the brucite deposit in the Paradise Range are described by Callaghan,[48] and given the same general source of origin as the brucite.

This magnesite was first mined in 1940 for refractory purposes, but since 1943 it has been mined in large tonnage as the source of metallic magnesium for the largest electrolytic magnesium plant in the United States, located at Henderson, in Clark County, near the Boulder Dam.

Beds of diatomite occur frequently in northern Nevada, and

[46] Mackay School of Mines Staff. Dumortierite: Univ. of Nevada Bulletin, vol. XXII, No. 2, 1928.

[47] Callaghan, Eugene. Brucite deposit Paradise Range, Nevada: U. of Nevada Bull., vol. 27, No. 1, 1933.

[48] Callaghan, Eugene: *op. cit.*

from time to time small tonnages have been mined and shipped. The largest clay beds to have been worked in the State were those in the Ash Meadows district in Nye County, the clay having been used in the oil industry. Large tonnages of silica sand for glass manufacture have been shipped from the Moapa and Overton districts in Clark County.

Since 1940, discoveries of high-purity talc were made in the Palmetto district in Esmeralda County about 50 miles southwest of Goldfield, close to the highway and near the California State line. The deposits are spoken of as 4- to 20-foot-vein deposits on limestone-granite contacts. About four properties are being operated on a small scale.

Several exploratory holes have been drilled in Nevada in search of oil, but without success. The oil shales near Elko are the only known occurrence of petroleum. The only deposit of coal to be opened up in the State is in the Coaldale district in Esmeralda County, and its high moisture and ash content places it at a great disadvantage with the superior coal of Utah.

EXAMPLES OF ZONAL DEPOSITION

Zonal deposition is indicated by the deposits of several districts, and an excellent example is described by Larsh[49] in the White Pine district near Hamilton.

Here, the silver belt on Treasure Hill was a large producer of phenomenally rich secondary horn silver ore. The lead-zinc belt several miles to the west of Treasure Hill contains bodies of lead-zinc-silver ore which are responsible for most of the district's more recent production. The contact-metamorphic copper belt several miles still farther west, and nearer the quartz-monzonite and granodiorite intrusives, produced some copper and gold ore. Recently scheelite has been discovered in the garnetized zone of the copper belt adjacent to the intrusives. (See Figure 3.)

Hewett[50] states that in the Goodsprings district in Clark County there is a distinct tendency toward zonal arrangement of the ore deposits in several parts of the district, with the most productive gold deposits wholly in or adjacent to bodies of intrusive porphyry. The copper deposits tend to lie stratigraphically and topographically below nearby zinc and lead deposits and closer to the intrusive. This zonal arrangement is most apparent in that part of the district where deposits are most numerous.

[49] Larsh, W. S., Mining at Hamilton, Nevada: Mines and Minerals, vol. 29, p. 521, 1909.

[50] Hewett, D. F., Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, p. 100, 1931.

EXAMPLES OF SUPERGENE ENRICHMENT

Supergene enrichment, enrichment through the chemical action of descending surface waters and oxygen, has been an important process in concentrating the metallic content of many Nevada ore deposits. Its influence has been most profound and of greatest economic importance in those ores mined for silver or copper. Its effect on deposits of other metals has been negligible by comparison.

With the dissolving of the soluble constituents in the well-oxidized part of the deposit, the residuum, consisting of the insoluble portion, forms an oxidized zone having a higher content of

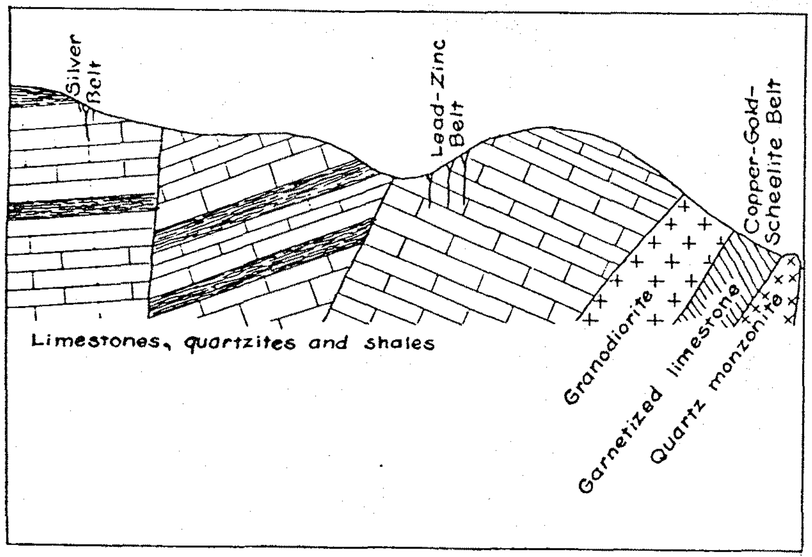

FIGURE 3. East-west section through the White Pine district showing relation of mineral belts to exposed intrusives.*

insolubles than the original mass, and may be more or less valuable than the original mass. Generally, in the case of gold, silver, and lead ores, this surface ore is richer, while in the case of copper and zinc ores it is poorer.

Free gold and pyritic gold deposits are enriched at the surface because of the accumulation of gold in a siliceous iron-stained mass.

This has been true in almost all cases since the discovery of gold at Gold Hill on the Comstock in 1859 down to the relatively late discovery at the Getchell mine in Humboldt County.

*From observations made by the writer in September 1935, and August 1939.

The presence of horn silver at or near the outcrop of silver-bearing veins in Nevada is very common, and in many cases this enriched oxidized ore is the only ore of sufficient grade to be commercial.

The most striking example is the Treasure Hill mine at Hamilton in White Pine County. Lincoln states "that from a space 70 feet wide and nowhere over 28 feet deep on the Eberhardt mine, 3,200 tons were mined which milled $1,000 a ton, and one boulder of silver chloride found in this mine weighed six tons."[51] Unfortunately the corollary of this is that the unaltered ore below did not contain enough silver to be commercial ore.

After the main ore bodies had been mined at the Divide mine in Esmeralda County, stringers of pure horn silver were discovered outcropping close to the shaft. There is on exhibit at the Museum of the Mackay School of Mines a large piece of this ore assaying over 17,000 ounces in silver per ton, and illustrating the difficulty of drilling through this waxy mineral.

At several districts in Nevada, notably Pioche in Lincoln County and Tybo in Nye County, the main value at the surface of the lead-zinc-silver veins was almost entirely in horn silver, and was the cause of the early rush to and development of the camps.

At Eureka where the primary ore below water level is argentiferous galena, pyrite, arsenopyrite, and sphalerite, the oxidized ore for several hundred feet in depth has been mined mainly because of its lead content as cerussite and anglesite, the carbonate and sulphate, respectively, of lead. The silver remained in the oxidized ore as horn silver, and the iron as iron oxides. The arsenic gave much speiss at the smelters, but the zinc was apparently well leached out of the ore.

Generally the copper and zinc content of ore bodies containing those metals has been leached out of the oxidized zone which accounts for many barren outcrops above bodies of copper and zinc ore; but if the ore contains calcite or is in limestone, the copper and zinc content is precipitated out in great part as the carbonates in the oxidized ore at or near the surface.

The most striking example in Nevada of this enrichment in the case of copper is at the Ludwig mine in Lyon County. Thousands of tons of rich, almost jewelry, ore of malachite and azurite, containing chrysocolla also, were shipped directly to the smelter. Below this ore was rich cuprite and native copper ore, and below

[51] Lincoln, F. C., *op. cit.*, p. 258.

this at water level secondary chalcocite, then a primary chalcopyrite ore too low grade to be profitably mined.

The most striking example in the case of zinc is at the Yellow Pine mine in Clark County where all the ore has been in the form of zinc carbonates occurring in dolomite. At the Anchor mine in the same district the zinc occurs as a carbonate, while the lead, also present, occurs as unaltered galena.

In the case of both silver and copper ores much or all of the metal may be dissolved out of the oxidized zone and reprecipitated as a sulphide near the water level.

In the case of silver ore, the silver is precipitated as secondary argentite, termed "sooty" argentite, as it does not assume a crystalline form, being black and powdery.

According to Knopf,[52] the silver sulphide ore mined in the Divide district in Esmeralda County contained both the primary crystalline and the sooty secondary argentite.

Where the primary silver minerals are sulpharsenides and sulphantimonides, as in the case of the ruby silver minerals, the secondary sulphide may take the same form, and it is often difficult to distinguish the secondary from the primary silver sulphides. This is particularly true in the case of the rich silver ore of Austin, Nevada.

Native silver is in almost all cases considered secondary. It is relatively rare in Nevada, though it has been found in Tonopah and other camps.

Supergene enrichment of Nevada's silver and silver-gold quartz veins, Ferguson[53] states, has been more important in those mesothermal deposits associated with granitic intrusives than in the epithermal deposits associated with Tertiary extrusives. This is probably due to the longer period of erosion, higher pyrite content, and more porous conditions of the vein associated with granitic intrusives.

In several of the mesothermal deposits, particularly those at Austin and Belmont, the supergene-enriched silver ores were highly profitable even under the high cost of early-day mining, but the primary ores are too low grade to be worked, even under modern low-cost methods. Although the primary ores in many of the Miocene epithermal veins have been of profitable grade, the ores of the supergene-enriched zone have been responsible for much of the profit from production.

[52] Knopf, Adolph, The Divide silver district, Nevada: U. S. G. S. Bull. 715, 1920.

[53] Ferguson, H. G., *op. cit.*, p. 146.

In the case of copper ore, the copper is precipitated as the sulphide chalcocite. This secondary sulphide along with the primary copper sulphides often gives a total copper content approaching bonanza ore.

At the Rio Tinto mine in the Mountain City district in Elko County the leaching out of the copper in the oxidized outcrop was practically complete, with a remarkable secondary sulphide enrichment near water level that has been responsible, as direct shipping ore of over 20% copper content, for a large share of the mine's copper production.

In 1926 S. Frank Hunt,[54] an experienced prospector and student of geology, referred to barren limonite outcrops in the Mountain City district in Nevada as follows: "Situated three and four miles south of town, the Nevada Rio Tinto and Monzonite groups cover two wide copper veins of unusual promise."

Fortified by his almost solitary faith in his judgment, he struggled for six years amid hardships to push a shaft down through the leached outcrop before finally encountering, in February 1932, the secondary enrichment at 228 feet in the shaft, being within a few feet of his estimated depth to water level.

On February 28, 1932, he wrote: "At noon on the 26th at 228 feet deep in the shaft we uncovered the sulphide zone. Tonight at 234 feet the whole bottom of the shaft is in solid, good, ore—nearly all pure copper glance and high grade. From present appearances and from what we know about the magnitude of the Rio Tinto vein, it is most likely the biggest deposit of high grade copper-gold ore ever discovered in Elko County."[55]

On April 5, 1932, this self-made geologist wrote as follows:

> Dean, Mackay School of Mines,
> Reno, Nevada
> Honorable, Sir:
>
> The Rio Tinto Copper Company, of this place, is presenting to your institution and mailing today by Parcel Post, a 70-pound box of specimens and samples of its sulphide ore. All these specimens of secondary sulphide enrichment come from the 250-foot level, the deepest workings attained at this time. They have been selected as tagged in wrappings, across the 65 feet of the deposit so far exposed. But the actual width of the ore between walls has not yet been ascertained, since the discovery

[54] Hunt, S. Frank, Mining geology outlined: Hunt Foundation, Mackay School of Mines, p. 104, 1936.

[55] The Mining and Contracting Review, Salt Lake City, Utah, March 15, 1940.

beneath 225 feet of remarkably barren gossan, was made only five weeks ago. Judging from surface indications, however, the deposit may prove to be 100 feet or more wide north and south with an undetermined length east and west beyond 600 feet.

This ore deposit is not a fissure, but what prospectors would call a "contact vein." The footwall country is a mile-wide formation of dark colored paleozoic quartzite; the hanging, a dark gray slate intercalated with thin beds of white quartzite, fading upward into black calcareous shale and blue limestone at top. The footwall is probably Lower Cambrian and the hanging slate of Middle and Upper Cambrian age; and the observable structural features show that the deposit fills or occupies a regional unconformity. Its age is Cretaceous, or possibly older, since the terrain appears to have undergone a long process and period of denudation and weathering during most, if not all, of Tertiary Time. As an example and study of weathering and secondary enrichment, Rio Tinto is unsurpassed in the Great Basin Region.

Handicapped by 90 miles of nearly impassable roads between Mountain City and Elko at this season, our information as to the average copper content of the ore is quite meager at present. All together less than a dozen reliable tests have come to us. But five control assays, made in Salt Lake and wired here, give us approximately the following: Copper, 43.5 percent; insoluble, 18 percent; Sulphur, 20 percent; Iron, 12 percent, with nominal gold and silver; the remaining 6.5 percent undetermined and unknown.

My belief is, the ore should be analyzed for nickel, tin and tantalum; besides, the more common elements of arsenic, antimony, manganese, and bismuth may be present. So if your school is at liberty to enlighten us further, we would feel grateful for the kindness.

At any future time—say June—when roads and weather conditions are favorable to auto travel, your Engineers and Geologists have a standing invitation to visit Mountain City District and Rio Tinto.

I am, respectfully, yours truly,

S. F. Hunt, Superintendent.

The development of the mine since these letters were written

may have proved his early conception of the geology somewhat faulty, but its production to 1944 of over $20,000,000, in great part from the zone of secondary enrichment, has justified his prophesies and given a great stimulus to the study and development of leached outcrops.

It is interesting to note that the vigorous exploration work on leached outcrops in the Mountain City districts since Mr. Hunt chose the Rio Tinto for development have failed to find the expected secondary enrichment of copper.

The low-grade-ore body of immense tonnage at the open pit at Ruth, Nevada, owes its commercial grade to surface leaching and enrichment of the ore below with secondary sulphide.

The usual leaching of zinc from oxidized outcrops should theoretically result in a secondary sulphide zone above the primary zinc ore, but this is practically unknown.

Cinnabar resists oxidation and solution and is found in its primary state in surface outcrops, and there is no known evidence in Nevada of its solution and reprecipitation to give richer ore below. As the minerals associated with cinnabar are likewise resistant, there is no enrichment as a surface residuum. All the above applies likewise to the deposits of scheelite, the common mineral of tungsten in Nevada.

One marked difference is that cinnabar turns black under the sun's rays and scheelite is a bright white under fluorescent rays.

In the case of manganese, few deposits in which supergene processes have not been intense (except possibly some of those formed by thermal springs), contain a sufficient proportion of the metal or are free enough from objectionable impurities to meet industries' rigid specifications for manganese ores. The hypogene manganese minerals, rhodochrosite, rhodonite, and alabandite are usually intergrown with an abundance of nonmanganiferous minerals, some of which, quartz in particular, are objectionable impurities. Manganosiderite and manganiferous calcite contain only subordinate amounts of manganese. The products resulting from thorough oxidation and leaching of the primary material are the usual ores.

Oxidation converts the original manganese carbonates and silicates to oxides and hydrous oxides, and leaching removes many of the dilutents, thereby increasing the grade and quality of the material. Oxidation and leaching are usually complete to a shallow or moderate depth only, so the better ores lie at or near the surface. Poorer ore is to be anticipated as depth is gained.

PROSPECTS FOR THE FUTURE

The early discoveries of gold and silver ore in Nevada were made by men whose zeal was fired by the days of '49, but their knowledge of ore deposits was very rudimentary, and their conception of a favorable outcrop was limited to an iron- or copper-stained quartz vein carrying gold and silver.

By the time of the great mining boom of the early 1900's, the prospectors were men of wider knowledge with the accumulated wisdom coming from the practical experience of their predecessors of several decades. More attention was paid to the base metals as was shown by the development of such districts as those of Ely, Yerington, and Goodsprings. However, most of the discoveries were made as before by hunters, sheep herders, cowboys, and Indians attracted to prominent and interesting outcrops.

During the last World War the demand for the ores of many metals resulted in a general increasing knowledge among the prospectors of mineralogy and geology. In the years that followed, this knowledge was extended to an ever-increasing number of nonmetallic ores.

As the years have gone by the rough-and-ready uneducated prospector who devoted his lifetime to his work is seldom seen. The present prospectors are mainly men who follow some other kind of work as their vocation, with prospecting as their avocation. They have a fair book knowledge of geology and mineralogy obtained from bulletins and schools for prospectors; and the application of this knowledge on field trips sustains their interest and often proves profitable. They have enthusiasm for discovery, but a reluctance to handle the pick and shovel. There are too many locations made and held for someone else to do the digging, as the locator in these times can find profitable work elsewhere.

Eighty years of prospecting over the State have about exhausted the possibilities of finding valuable undiscovered outcrops of pay ore, or at least to the extent where a prospector has little chance of obtaining a grub stake from storekeepers or professional men, or of gaining a satisfactory award for his efforts.

An increased price of a metal may make outcrops once discovered and abandoned of value again, as in the recent case of the Getchell mine in Humboldt County, or of scheelite and cinnabar outcrops abandoned after the first World War. Likewise, nonmetallic deposits of no value in the early years of the State have assumed greater importance with the passing years or in

a war emergency. Also, the steady mechanicalization of equipment for the rapid and low-cost mining of surface ore has made mines out of known outcrops formerly considered of no value.

New mines are not created by Mother Earth like an annual crop of grain or even like a venerable redwood forest. As the mines in a new country are in turn discovered and worked there remains a diminishing number, and these are the least obvious ones. Over many, Mother Earth has spread a conserving mantle of valley soil, loose rocks, or mountain vegetation.

Mr. S. Frank Hunt in 1922 expressed his idea of future prospecting this way: "It is patent to all that mere roving around over the surface in search of mines, is wasting time. The outcrops have about all been discovered. There is nothing in it any more for anybody; so another direction is indicated. The only right and remaining way is to dig down—go down after the ore. The future production of the metals largely depends on this line of work, and the outlook is splendid.

"Yet it is easier said than done, and it does not appeal to the imagination. The prospector and field man can ride and ramble around—and the going is fine—over a thousand miles of country in half the time and for half the expense of sinking a 100-foot prospect hole. It is going to hurt the prospectors and exploration concerns' feelings like h - - l to realize and admit they must begin to dig down."[56]

Mr. Hunt practiced what he preached as the Saturday Evening Post[57] tells the story: "The morning was warm. The loose rubble and the brush made the going hard, his crippled leg and the pain in his side and his seventy years slowed him up, but he persisted in prospecting the leached outcrop—in the winter of '31–'32 amid zero weather and in deep snow, when copper was a drug on the market, he persisted in sinking his shaft while suffering hardship, poverty, and ridicule, but sustained by his fixed faith in his geological deductions."

The hills of Nevada are dotted with the abandoned shafts and tunnels of men less fortunate than Mr. Hunt. A good share of these were predicated upon false assumptions or faith alone, without a fair geological conception of the chances taken. In other places an expensive diamond-drilling or shaft-sinking campaign has failed to materialize the hypothesis of excellently trained mining engineers and geologists that possible profitable

[56]Hunt, S. Frank, Mining Geology Outlined, Hunt Foundation, Mackay School of Mines, pp. 54–55. 1936.

[57]"The Story of the Rio Tinto Copper Strike," Saturday Evening Post, April 2, 1938.

ore bodies lay below. However, as time goes by the prospecting of the future must be more and more that of searching the surface and subsurface for geological and mineralogical indications of ore bodies below, with the use of scientific knowledge and instruments for their detection, or at least for indications, for the venturesome to take the risk of "going down."

Mr. Hunt knowing this and to do his small part for the future, established at the Mackay School of Mines the Hunt Foundation to aid in the training of students by making possible a closer correlation of book knowledge with field observation and experience.

Director Jay A. Carpenter of the Mackay School of Mines and the Nevada State Bureau of Mines believes: "This closer correlation of book knowledge with field observation and experience should be extended to the prospecting schools and in the special educational program for the return of soldiers of this World War whose interest lies in prospecting and mining.

"As the present mines in Nevada are being gradually worked out, new mines must be found and developed to maintain mining as our leading industry. To do this the State should render all possible practical aid to prospecting. As a paramount consideration, its officials should resist any move by the Interior Department to encroach upon the established right of freedom to locate, hold, and gain title to mineral lands upon the public domain, as this proven incentive of ownership and reward is necessary to encourage and foster the finding of new mines."*

*Written communication.

THE MINING DISTRICTS OF NEVADA*

By Henry G. Ferguson[1]

ABSTRACT

It is believed that four epochs of ore deposition are represented in Nevada; the earliest ore deposits are associated with granitic rocks, which in western Nevada were intruded near the close of the Jurassic and in eastern Nevada at the beginning of the Tertiary. Other ore deposits are associated with late Tertiary flows of two ages.

In western Nevada the ore deposits associated with granitic masses satellitic to the Sierra Nevada batholith are predominantly argentiferous quartz veins, similar in appearance to the auriferous veins of California. These, however, have been valuable only for their oxidized and enriched silver ores. In eastern Nevada base metal replacement deposits prevail. These have also produced silver from the oxidized zone, but in several districts base metal ores have proved workable in depth. It is thought that the difference between the two classes of deposits is a function of the different magmatic sources; that the western deposits are of late Jurassic or early Cretaceous age, dependent upon the Sierra Nevada batholith, while those in the eastern part of the State are of early Tertiary age. This implies that the western limit of the Tertiary intrusions is near the middle of the State.

Several of the important precious metal deposits associated with the late Tertiary lavas are clearly older than upper Miocene sediments, but others are younger than upper Miocene. In the ore of the older group of deposits silver exceeds gold by weight, while in those of Pliocene age gold is commonly in excess. The Miocene deposits have on the whole proved far more productive than those of the younger group.

From the available geologic data and a review of the history of production it is concluded that the western argentiferous quartz veins associated with granitic intrusives offer little hope of important future production, but on the other hand the eastern deepseated deposits may continue to be important producers of base metals; and that, of the near-surface deposits associated with Tertiary lavas the silver and silver-gold veins of Miocene age are likely to prove of more importance than the Pliocene gold-bearing veins.

*This paper is based on information available to 1927. I had hoped to revise it and incorporate the results of recent developments, but pressure of war work has prevented. A postscript has been added in which are noted a few additions and certain modifications of the conclusions stated in the main body of the paper.

[1]Geologist, U. S. Geological Survey.

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INTRODUCTION

The object of this paper is to present and discuss certain outstanding features in the geographic and geologic distribution of the ore deposits of Nevada. The writer's personal acquaintance with the region is chiefly within the area covered by the Hawthorne and Tonopah topographic maps embracing the area between latitude 38° and 39° and longitude 117° and 119°. For the remainder of the State, liberal use has been made of Lincoln's excellent compilation,[2] supplemented by consultation of the literature, as far as descriptions of the various districts are available. Lincoln's book is of especial value, as concise summaries of the geology, production data, and complete bibliographies accompany the descriptions of the various districts. In the following pages no attempt is made to give complete references but there is cited for each district the appropriate page references to Lincoln's book and reference is also given to the publication giving the most complete description of the district.

Of the 319 descriptions of mining districts of Nevada given by Lincoln several refer to districts whose major product is tungsten, mercury, manganese or nonmetallic minerals, which are not considered in the present paper; for others the data given are too scanty to permit even a guess as to their geologic classification. For 239 districts, however, which have produced gold, silver, lead, zinc or copper, enough geologic data are available to allow at least a tentative classification. Since, however, the object of the paper is to show only the major features of distribution and to speculate as to their causes, discussion will for the most part be confined to those districts which are credited by Lincoln with a production of over $1,000,000 gross.

MAJOR GEOLOGIC FEATURES

The following features of the geology of Nevada are of significance to the student of ore deposits. Paleozoic rocks occur throughout the State; the Paleozoic section in the eastern part contains a larger proportion of limestone members than in the west, but the Triassic and Jurassic strata in the western part of the State contain thick limestones and also lavas. In the west-central part, extending certainly as far to the east as the center of Nye County, the Paleozoic and Mesozoic sediments are strongly folded and cut by intrusive masses of granitic rocks. The great

[2] Lincoln, Francis Church, "Mining Districts and Mineral Resources of Nevada." Nevada Newsletter Publishing Co., Reno, 1923.

Sierra Nevada batholith which was intruded near the close of the Jurassic lies along the western border of the State. It is reasonable, therefore, to infer that the smaller areas of granitic rocks bordering it on the east, are, like those on its western flank in the California gold belt, satellitic to the main batholith and intruded at about the same time.

There is another belt of intense folding, accompanied by major thrusting, which parallels the eastern border of the State in western Utah, extends southwestward through Clark County, and enters California west of Goodsprings. Granitic intrusions also accompanied this folding. This folding and intrusion are considered to be of early Tertiary age. Butler[3] considers that the granitic rocks of the plateau region and the eastern part of the Great Basin in Utah were intruded during the early Tertiary. Nolan[4] has found in the Gold Hill district, Utah, close to the Nevada line, monzonite intrusions which are younger than folded sediments of probable Eocene age and Hewett[5] has likewise concluded that the granitic intrusives in the vicinity of the Goodsprings district are of Tertiary age. The intrusion of granitic rocks, therefore, appears to be not later than late Jurassic or early Cretaceous in the western part of the State and not earlier than the Eocene in the eastern and southern parts.

In the central part there are also many areas of granitic rocks, and for these no direct evidence of age is available. It may be that the locus of intrusion moved gradually eastward from the Sierra Nevada to the Rocky Mountain region and that the areas of granitic rocks, intermediate in position between the Sierra Nevada batholiths and the Tertiary batholiths to the east are also intermediate in time,[6] or there may have been two distinct and sharply separated episodes of granitic intrusion. Since, as far as known, there was no intermediate period of folding between the post-Jurassic revolution of the Sierra Nevada region and the much later folding in the eastern and southern parts of the State, the second hypothesis seems the more reasonable, and it is believed that the distribution of the ore deposits associated with granitic intrusions offers additional confirmatory evidence.

[3] Butler, B. S., "Ore Deposits of Utah," U. S. Geol. Surv. Prof. Paper 111, p. 99, 1920.

[4] Nolan, T. B., "The Gold Hill District, Utah," U. S. Geol. Surv. Prof. Paper (in preparation).

[5] Hewett, D. F., "The Goodsprings District, Nevada," U. S. Geol. Surv. Prof. Paper (in preparation).

[6] Lingren, W., "The Igneous Geology of the Cordilleras and its Problems: Problems of American Geology," p. 260, New Haven, 1915.

The youngest rocks of the State are lavas and nonmarine sediments ranging in age from the middle of the Tertiary to the Pleistocene. In central and southern Nevada areal reconnaissance has shown that sediments of upper Miocene age (Esmeralda formation) occur over wide areas and thus give a convenient datum for separation of the older and younger lavas. Similar sediments of Pliocene age are also present in parts of the State, particularly north of the fortieth parallel, and less abundantly in the south.

The lavas and sediments of post-granitic age are much faulted and locally highly tilted but major folding is lacking. There has been normal faulting on a large scale from some time prior to the upper Miocene to within Recent time. The characteristic desert range topography is due principally to faulting; the present relief is in large part the direct expression of movement on normal faults, but also in part due to rejuvenation of fault-scarps by erosion.

EPOCHS OF ORE DEPOSITION

Ore deposition accompanied both periods of granitic intrusion, and there are also many important deposits within the Tertiary lavas. The deeper-seated deposits associated with the granitic intrusives include contact-metamorphic deposits, and veins and replacement deposits in the intrusive and invaded rocks, and fall within the "mesothermal," "hypothermal," and "pyrometasomatic" classifications of Lindgren.[7] The younger deposits are commonly inclosed in the Tertiary lavas and near-surface intrusives, and are rarely found within the older rocks. These belong to the "epithermal deposits" of Lindgren's classification. It is thought that each class of deposits contains representatives of two distinct epochs of ore deposition. Although Mesozoic lavas are common in western Nevada, no ore deposits genetically connected with these lavas are known.

DEPOSITS ASSOCIATED WITH GRANITIC INTRUSIVES

Figure 1 shows the location of the more productive ore deposits of Nevada, which appear to be in more or less close association with granitic intrusives and are certainly older than the Tertiary lavas. They have been roughly classified according to total production, based on the estimates and production figures given by Lincoln, according to the type of the principal deposits (vein, replacement and contact-metamorphic) and according to the metal chiefly produced. The classification is not precise since complete production data are lacking for many districts, several districts contain ore deposits of different types and no district has produced

[7] Lindgren, W., "Mineral Deposits," 3d Edition, New York, 1928.

only a single metal. It is particularly difficult to draw a line between the silver- and lead-producing districts. It was found convenient to base the distinction on arbitrary ratios derived from

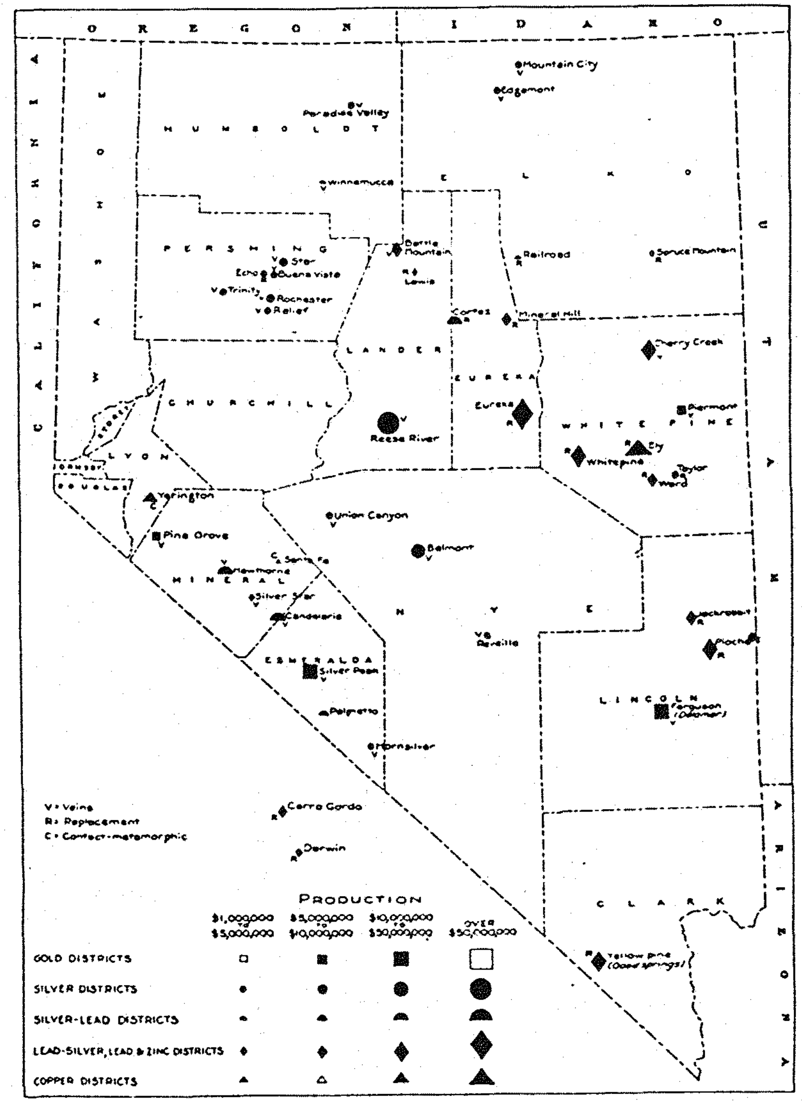

FIGURE 1. Map showing distribution of principal ore deposits in Nevada associated with granitic intrusives.

production figures. A district in which the production data show a ratio of ounces of silver to pounds of lead of 2 to 1 or greater is called for convenience a silver district. What is here called a silver-lead district is one in which this ratio is between 2 : 1 and

1 : 2, and a lead-silver or lead district one in which the ratio of ounces of silver to pounds of lead is less than 1 to 2.

It is evident from the map, that, taken as a whole, a different type of mineralization prevails in the east from that of the western part of the State. The western group of deep-seated deposits yielded principally silver with only minor amounts of base metals from enriched ore of quartz veins; and only a few districts, such as the copper camps of Yerington and Santa Fé and the lead-zinc districts of Cerro Gordo and Darwin in California east of the Sierra Nevada, have produced principally base metals. On the other hand, in eastern Nevada base metal deposits are the rule and, though many of the camps in their early days were important producers of silver from oxidized and enriched zones, the primary ore, wherever workable, and a large portion of the oxidized ore as well, has proved to be important principally for base metals, lead (with more or less primary silver), copper, or zinc. Mesothermal deposits in which the primary ore is valuable chiefly for silver are uncommon in the eastern part of the State. Table 1, in which a classification is made of all districts listed by Lincoln which appear to belong to this class, shows that the same relations hold true, though less decisively, for the less important districts.

TABLE 1

Distribution of Nevada Mining Districts Producing Ores of Prevolcanic Age

	Western Nevada.[1]						Eastern Nevada.[2]					
	Districts Producing Principally:						Districts Producing Principally:					
Value of Total Production.	Gold.	Silver.	Silver-lead.	Lead-silver, Lead and Zinc.	Copper.	Total.	Gold.	Silver.	Silver-lead.	Lead-silver, Lead and Zinc.	Copper.	Total.
Under $1,000,000	20	35	11	7	19	92	8	5	7	15	11	46
$1,000,000 to $5,000,000	0	8	1	2	1	12	1	2	1	1	0	5
$5,000,000 to $10,000,000	1	2	1	1	0	5	1	0	0	3	0	4
$10,000,000 to $50,000,000	1	2	2	0	1	6	0	0	0	4	0	5
Over $50,000,000	0	0	0	0	0	0	0	0	0	1	1	2
Total	22	47	15	10	21	115	10	7	8	24	12	61

[1] Washoe, Pershing, Humboldt, Storey, Ormsby, Douglas, Lyon, Churchill, Mineral, Lander, Nye, and Esmeralda Counties.

[2] Elko, Eureka, White Pine, and Clark Counties.

The difference in character between the ore deposits of the Pacific States and those of the Rocky Mountain region appears to hold true over a wide area. A compilation of total production of the deposits of this type would show a great preponderance of precious metal output from deposits dependent on the Sierra batholith and its satellites and a similar preponderance of base metal production from those of the Rocky Mountain region. The production statistics for 1918 analyzed and shown graphically in the World Atlas of Commercial Geology[8] bring out the same relations. The only important copper production west of the 117th Meridian is from Calaveras and Shasta counties, California, and the Yerington district, Nevada, amounting in all to only 4 percent of the country's production, while the major districts in the belt of early Tertiary batholiths and stocks between the 107th and the 115th meridians account for 79 percent of the 1918 copper output. Similarly west of the 117th meridian the only important lead and zinc deposits are those of Inyo County, California, which yielded one percent of the lead and less than one percent of the zinc production while major districts of the eastern belt gave 46 percent of the lead and 30 percent of the zinc. The veins and placers of the Sierra Nevada in 1918 yielded over 27 percent of the gold production, nearly all from the western side of the Sierra batholith. The similar veins in the older rocks whose content of supergene silver minerals made the fame of Nevada 60 years ago were no longer sufficiently productive to enter the picture to any extent. Rochester shows a silver production of one percent and Mineral County one percent, each of gold and silver, but this also includes output from late Tertiary ores. The precious metal production of the Rocky Mountain region, excluding the deposits of epithermal type such as those of Cripple Creek and the San Juan region, is nearly all a byproduct of the production of base metal districts, and for 1918 amounted to about 10 percent of the total for gold and about 60 percent for silver. Of course this relation does not hold true for small areas. There is a tendency to zonal distribution in individual areas both in eastern and western Nevada, with copper and gold within the intrusive or close to the contact, and lead and silver ores at a distance. Nor is this generalization consistent in detail with the results of the studies by Schofield[9] and Hanson[10] in

[8] "World Atlas of Commercial Geology." Part I. Mineral Production, U. S. Geological Survey. Plates 40 and 48, 1921.

[9] Schofield, S. J., "Geology and Ore Deposits of the Salmon River District, B. C." Canada Geol. Surv. Mem., 132, pp. 64–71, 1922.

[10] Hanson, George, "Zoning of Mineral Deposits in British Columbia." Trans. Roy. Soc. Canada, 3d ser., vol. 21, pt. 2, sec. 4, pp. 119–126, 1927.

British Columbia, and by Buddington[11] in southeastern Alaska.

The western deposits are most commonly well-defined quartz veins[12] which cut both the intrusives and the intruded rocks. In places, as in several of the Humboldt County districts,[13] there is a tendency for veins to be present in the noncalcareous rocks and irregular replacement deposits in the limestones, but at Belmont[14] sharply defined veins cross limestones. The gangue of the western veins is principally quartz with minor amounts of carbonate minerals. There appears to be no widespread carbonatization or sericitization of the adjoining wall rocks. The primary sulphides include pyrite, arsenopyrite, tetrahedrite, galena and sphalerite, jamesonite, and stibnite, and are argentiferous and slightly auriferous. The presence of abundant antimonial sulphides seems to be characteristic of many of the deposits in the western part of the State. In all of the districts which have had an important production, the valuable ore contained supergene silver minerals, and the primary sulphides have almost never proved workable.

Although gold-bearing veins also occur in many districts, only a few have proved to be of any commercial importance. The principal gold deposits are those of the Silver Peak district,[15] in which quartz veins and lenses associated with alaskite carry native gold with pyrite and galena. The ore of the Pine Grove district[16] appears to be of a similar nature, though here the production figures given by Hill show a larger amount of silver than gold, though the gold produced exceeds the silver in value. The workable silver ore appears to be of supergene origin. In districts where both gold- and silver-bearing veins occur, as at Rochester,[17] the auriferous veins appear to have been formed under higher temperature conditions. The gold-bearing veins of the Silver Peak district occur within or close to the intrusive, whereas

[11] Buddington, A. F., "Coincident Variations of Types of Mineralization and of Coast Range Intrusives," Econ. Geol., vol. 22, pp. 158–179, 1927.

[12] The term "vein" is here used in the sense of a tabular deposit discordant to the structure of the inclosing rocks and without connotation as to its mode of origin.

[13] Ransome, F. L., "Notes on Some Mining Districts in Humboldt County, Nevada," U. S. Geol. Survey, Bull. 414, 1909.

[14] Lincoln, pp. 160–161; Emmons, S. F., U. S. Geol. Expl. Fortieth Parallel, vol. 3, pp. 393–405, 1870; Spurr, J. E., "Quartz-Muscovite Rock from Belmont, Nevada." Amer. Jour. Sci., 4th ser., vol. 10, p. 355, 1900.

[15] Spurr, J. E., "Ore Deposits of the Silver Peak Quadrangle, Nevada," U. S. Geol. Survey Prof. Paper 55, pp. 34–74, 1906. Lincoln, pp. 81–82.

[16] Hill, J. M., "Some Mining Districts in Northeastern California and Northwestern Nevada," U. S. Geol. Surv. Bull. 594, pp. 133–141, 1915. Lincoln, pp. 148–149.

[17] Lincoln, pp. 213–215; Knopf, A., "Geology and Ore Deposits of the Rochester District, Nevada," U. S. Geol. Survey Bull. 762, pp. 42–53, 1924.

in the neighboring Palmetto district[18] the veins cutting the limestones and slates at a distance from the contact have yielded chiefly silver.

The only two districts in western Nevada whose production exceeds $1,000,000 which have produced chiefly copper are the Santa Fé and Yerington districts. The Yerington district[19] has had a considerable production, but it does not rank among the major copper districts of the country. The ore bodies are of the contact-metamorphic type. Pyrite and chalcopyrite occur in a gangue of pyroxene, garnet, and epidote as replacements of limestone. Secondary enrichment has not been important. The Santa Fé district[20] has been far less productive. The primary ore is similar in character to that of the Yerington, but the orebodies are small and irregular and have not proved productive below a relatively shallow zone of oxidation and enrichment.

The only lead and lead-zinc deposits of this general region which have been important producers are those of the Cerro Gordo and Darwin districts in Inyo County, California. In the Cerro Gordo district[21] large amounts of oxidized argentiferous lead ore and oxidized zinc ores have been mined from replacement deposits in limestone which was more or less dolomitized at the time of mineralization. The primary sulphides are galena with subordinate sphalerite, tetrahedrite, and pyrite. In the Darwin district[22] argentiferous galena occurs both in contact metamorphic deposits in altered limestone and in fissure veins crossing lime-silicate rock.

The prevalence of the vein type of deposit in western Nevada in contrast to the replacement type prevailing in the eastern part of the State was early noted by Raymond,[23] who quotes Clarence King's observations on the general lines of distribution of mining districts and calls attention to the difference in type between the veins of the Reese River (Austin) district and the irregular replacement deposits of White Pine (Hamilton). Ball[24] notes the prevalence of the vein type of deposit in southwestern Nevada.

[18] Lincoln, pp. 79–80; Spurr, J. E., *op. cit.*, pp. 86–87.

[19] Lincoln, pp. 133–137; Knopf, A., "Geology and Ore Deposits of the Yerington District, Nevada," U. S. Geol. Surv. Prof. Paper 114, 1918.

[20] Lincoln, pp. 153–154; Hill, J. M., *op. cit.*, pp. 157–171.

[21] Knopf, A., "A Geologic Reconnaissance of the Inyo Range and the Eastern Slope of the Southern Sierra Nevada, California," U. S. Geol. Surv. Prof. Paper 110, pp. 105–118, 1918.

[22] Knopf, A., "The Darwin Silver-lead Mining District, California." U. S. Geol. Surv. Bull. 580, pp. 1–18, 1915.

[23] Raymond, R. W., "The Geographical Distribution of Mining Districts in the United States," Trans. Amer. Inst. Min. Eng., vol. 1, p. 3, 1873.

[24] Ball, S. H., "A Geologic Reconnaissance in Southwestern Nevada and Eastern California," U. S. Geol. Surv. Bull. 308, pp. 44–46, 1907.

Spurr,[25] in his discussion of the ore deposits of Silver Peak, Reese River (Austin), Belmont, and southern Klondike, points out the similarity of the veins of these districts to the California gold veins. Lindgren[26] notes the same similarity in the older veins of the Santa Rosa Range, Humboldt County. The writer was also struck by the close resemblance of the veins of the Belmont, Union Canyon, Silver Star (Marietta), and minor districts of this type in the Hawthorne and Tonopah quadrangles to the California veins. These districts all have well-defined persistent veins of white coarse-grained quartz with patches of mixed sulphides. Other than the lower average gold content of the Nevada veins, the principal difference from the California veins seems to be that the alteration of the adjoining wall rock to carbonate and sericite which is common in California is not prominent in connection with the Nevada veins. The lack of primary gold on the Nevada side of the Sierra batholith is in part compensated by the prevailing deep zone of oxidation and enrichment which has permitted in the past a large production from surficially enriched silver ores.

The quartz veins of the California gold belt have produced many millions of dollars in gold, while the similar veins of western Nevada have been in general productive only of silver, and that only in the zone of oxidation and supergene enrichment. Difference in the extent of erosion, east and west of the crest of the Sierra does not seem an adequate explanation for the absence of gold in Nevada. The Nevada region has to some extent been protected from erosion by down-faulting along the present eastern front of the Sierra. This faulting took place at intervals during the Tertiary and Pleistocene, and the topographic expression of the Pleistocene faulting still persists. The Pleistocene faulting which has an average magnitude of not more than 2,000 feet, as measured by the difference in elevation between the Sierra summit and the summits of the Nevada ranges, may probably be left out of consideration, for some of the Nevada veins reach a pre-Pleistocene erosion surface which was probably once continuous over a wide area. The amount of earlier faulting was probably of something the same order of magnitude, and to this extent the outcrops of the Nevada veins reach a higher level than those of California. Also during the Cretaceous and early Eocene there may have been more active erosion on the California side than in Nevada. But it can be inferred from the Tertiary placer gravels, that the California veins retained their present character for a

[25] Spurr, J. E., "Genetic Relations of the Western Nevada Ores," Trans. Amer. Inst. Min. Eng., vol. 36, pp. 399–402, 1906.

[26] Lindgren, W., "Geology and Mineral Deposits of the National Mining District, Nevada," U. S. Geol. Surv. Bull. 601, p. 12, 1905.

considerable distance above their present outcrops. The amount of erosion represented by the Eocene auriferous gravels is probably of the order of magnitude of 1,000 or 2,000 feet. Lindgren[27] moreover describes auriferous gravel of pre-Chico (Lower Cretaceous) age, so that it is a fair assumption that the California veins retained their auriferous character for a considerable height, perhaps 4,000 or 5,000 feet, above their present outcrops. There seems to be no likelihood, therefore, that any significant difference in distance from the source due to less erosion of the Nevada veins can account for their lack of gold.

The California veins are almost everywhere accompanied by more or less replacement of the adjoining country rock by carbonates, generally ankerite, with more or less sericite or mariposite. This type of wall-rock alteration is not prominent, as far as the writer is aware, in the Nevada silver veins, although manganiferous ferrodolomite is the principal gangue mineral of the Candelaria veins,[28] and calcite and other carbonates are present in the veins of other districts. In the veins of the Alleghany district (California) studied by the writer[29] it is clear that ankerite is later than and replaces the quartz, and that the gold and several of the sulphides are also distinctly later than the quartz and contemporaneous with the ankerite. Howe[30] finds that at Grass Valley the gold and calcite are later than the quartz and were introduced after the quartz had been fractured. Hulin[31] has shown that gold is one of the last minerals of the veins of the Mother Lode.

Proof that the gold of the California veins was deposited at a later stage of mineralization, not present in Nevada, would not explain the difference between the California and Nevada veins if both derived all their minerals from the same magmatic source, and it would therefore be necessary to assume that the magma which formed the satellitic batholiths of western Nevada was deficient in gold; although these batholiths are in the same position relative to the central batholith as those on the California side and there seems to be no significant difference in the depth to which erosion has reached.

[27] Lindgren, W., "The Tertiary Gravels of the Sierra Nevada," U. S. Geol. Surv. Prof. Paper No. 73, p. 23, 1911.

[28] Knopf, A., "The Candelaria Silver District, Nevada," U. S. Geol. Surv. Bull. 735, p. 14, 1923.

[29] Ferguson, H. G., "The Alleghany District, California," U. S. Geol. Surv. Prof. Paper (in preparation).

[30] Howe, E., "The Gold Ores of Grass Valley, California," Econ. Geol., vol. 19, pp. 595–622, 1924.

[31] Hulin, Carlton D., "Structural Control of Ore Deposition," Econ. Geol., vol. 24, pp. 31–32, 1929.

In the California gold belt there are abundant basic rocks, gabbros, amphibolites, and serpentines which are older than the granitic intrusives. The fairly close association of serpentines and auriferous veins has led Lindgren[32] to suggest that the gabbros and peridotites and the albite-aplite dikes which accompanied these basic intrusions may have been a source of at least a part of the gold. The nearly complete absence of such basic intrusions in western Nevada is perhaps confirmatory evidence for Lindgren's suggestion. On the other hand no important basic intrusives occur in the Silver Peak distict, which has been the most important of the pre-Tertiary gold camps of western Nevada.

In eastern Nevada lead or lead-silver deposits are the most abundant. Several districts, such as Eureka,[33] yielded large amounts of oxidized silver ores in the years following their discovery, but have made their principal production from lead ores with a low silver content. The Jack Rabbit[34] and Pioche[35] produced much silver in the early days of mining, but silver has formed only a small fraction of the value of the recent production.

The White Pine district[36] was in its early days an important silver producer, but the supergene silver ores of Treasure Hill were distinct from the ores of the "lead belt" developed at a later date, which carry only a small amount of silver. The Yellow Pine (Goodsprings)[37] district in the southern part of the State is the only important district in which the production of zinc has been of more value than that of other metals. Ely[38] is an outstanding example of a deposit of disseminated copper ore of the type which prevails in the Rocky Mountain region. There are no other important copper districts in eastern Nevada, but in places where there are small areas of intrusives exposed, copper ores are present in the intrusive and the lead-silver or lead-zinc ores in the intruded sedimentaries at some distance from the contact. Gold-bearing veins have been mined in a few districts, but the

32 Lindgren. W., "Mineral Deposits," 3d edition, p. 627. New York, 1928.

33 Lincoln, pp. 88–93; Hague. A., "Geology of the Eureka District, Nevada," U. S. Geol. Surv. Monograph 20, 1892.

34 Lincoln, pp. 121–123; Westgate, L. G., and Knopf, A., "Geology of Pioche, Nevada and Vicinity," Bull. Amer. Inst. Min. and Met., 1647–I., 1927.

35 Lincoln, pp. 124–127; Westgate & Knopf, *op. cit.*

36 Lincoln, pp. 257–259; Larsh, W. S., "Mining at Hamilton, Nevada," Mines and Minerals, vol. 29, pp. 521–523, 1909.

37 Lincoln, pp. 29–33; Hewett, D. F., "The Goodsprings District, Nevada," U. S. Geol. Surv. Prof. Paper (in preparation).

38 Lincoln, pp. 245–251; Spencer, A. C., "Geology and Ore Deposits of Ely, Nevada." U. S. Geol. Surv. Prof. Paper 90, 1917.

Ferguson (Delamar)[39] district is the only one which has yielded a large production. In this district irregular impregnations of quartzite adjoining a fissure have yielded ore carrying silver and gold in the ratio of about 2 to 1.

There are three possible explanations for the prevailing difference in habit of the deep-seated ore deposits of western and eastern Nevada. The difference may be due to the fact that average depth of erosion is presumably less in the east than in the west, due to difference in age of intrusion, and that the western deposits therefore reflect conditions of higher temperature; or the greater proportion of limestone in the stratified rocks of the east may have influenced the form and content of the ore deposits; or the difference may be a function of the different age and source of the associated granitic intrusives. To the writer the last hypothesis is the most reasonable. Difference in temperature due to differences in the amount of erosion can hardly have been the controlling factor since, at the different heights to which the intrusives have risen in different regions, areas varying greatly in size are now exposed, so that differences in heat and pressure could not have been very important. The precious metal veins of western Nevada and California, as well as the base metal replacement deposits of eastern Nevada and the Rocky Mountain States tend to surround not the major batholiths but small areas of intrusives whose exposed area and position suggest that they are apically truncated stocks, generally satellitic to larger batholiths, and there seems to be no significant difference in the areas of such granite exposed in the east and west. Control by the wall rock may have been important since limestones form a larger proportion of the section in the east than in the west, but the vein type of deposit with sparse sulphides seems to prevail in the west even where limestone forms the country rock, whereas in the east, although the position of the deposits was naturally controlled by pre-existing fissures, the ore forming solutions were able to dissolve the country rock to a far greater extent and thus tend to occur as replacement deposits. The total content of metallic minerals is also far less in the western deposits than the eastern, but as regards their usefulness this has been compensated by the presence of primary gold in the California veins and of supergene silver minerals in the veins of western Nevada. It is therefore thought likely that this difference in habit of mineralization is a function of the different age and source of the associated intrusives, and the writer believes that two distinct metallogenetic

39 Lincoln, pp. 119–120: Emmons, S. F., "The Delamar and Hornsilver Mines," Trans. Amer. Inst. Min. Eng., vol. 31, pp. 658–675, 1902.

provinces are here represented, the western dependent upon intrusives of late Jurassic or early Cretaceous age, and the eastern on the early Tertiary intrusives of the Rocky Mountain region. The distinction between the two types of ore deposits is not sufficiently sharp to allow any definite statement as to how far to the west the early Tertiary intrusives extended. Inspection of analyses of the granitic rocks of the Sierra Nevada and the Rocky Mountain batholiths reveals no constant difference in composition, and direct geologic data on the age of the Nevada granites are almost completely lacking. Hewett[40] finds that in southern Nevada and southeastern California granitic rocks of probable Tertiary age extend as far west as the western border of the Ivanpah quadrangle (116th Meridian). In central Nevada the contrast between the Reese River and Belmont deposits on one hand and those of Eureka on the other, suggests the position for the western limit of the Rocky Mountain metallogenetic province in this part of the State. Since, as far as known, there is no wide belt free from intrusive rocks in central Nevada, it is to be supposed that overlap is somewhere present, but so far no evidence of this has been found.

DEPOSITS IN THE TERTIARY LAVAS

Deposits associated with Tertiary surficial lavas and shallow intrusions have yielded a large proportion of Nevada's output of gold and silver, but practically no base metals. It is thought that there are two distinct periods of late Tertiary mineralization, each characterized by certain distinctive features.

In Hawthorne and Tonopah quadrangles in western Nevada there are Tertiary lavas of varied composition older than the Esmeralda formation, and hence not later than upper Miocene in age; lavas, chiefly rhyolitic, of about the same age as the Esmeralda; later andesitic lavas and associated sediments of probable Pliocene age; and finally Pleistocene basalts. Recent reconnaissance indicates that the same sequence prevails in the Lowry Peak quadrangle, northeast of the Tonopah quadrangle, and in the Silver Peak region, south of Tonopah.

Ball's reconnaissance of southwestern Nevada[41] indicates a thick series of rhyolites with minor andesites older than the "Siebert Lake beds," which are now known to be a part of the Esmeralda formation and of upper Miocene age. As in the Hawthorne and Tonopah quadrangles, the Esmeralda formation

[40] Hewett, D. F. Personal communication.

[41] Ball, Sydney H., "A Geologic Reconnaissance in Southwestern Nevada and Eastern California," U. S. Geol. Surv. Bull. 308, p. 27 and pp. 31–35, 1907.

is overlain conformably by rhyolitic lavas. The succeeding Pliocene andesitic rocks do not appear to be present in the area covered by Ball's reconnaissance.

Reconnaissance study of the Hawthorne and Tonopah quadrangles and the results of detailed study of several other mining districts, indicate that the epithermal ore deposits of Tertiary age belong to two distinct periods, the older of pre-Esmeralda age, probably Miocene, and found only in the pre-Esmeralda lavas; and the younger, later than the rhyolitic and dacitic lavas which intrude and overlie the Esmeralda formation, but older than the andesitic series, and consequently of latest upper Miocene or earliest Pliocene age.

In the area covered by the Hawthorne and Tonopah quadrangles the productive veins of Tonopah,[42] Aurora,[43] and Rawhide[44] are confined to the lavas of pre-Esmeralda age. At the old mining camp of Bodie,[45] in California, but only 7 miles from the Aurora district, the lavas surrounding the camp appear to belong to the same post-Esmeralda series which at Aurora is later than the veins. According to Eakle and McLaughlin, however, the veins of Bodie outcrop in a small area of older andesite exposed by erosion of the later flows. This relation suggests contemporaneity of vein formation in the two neighboring camps.

There is evidence that deposits in other parts of Nevada are of the same age. Schrader finds the same relations at Wonder[46] as at Rawhide. The veins of Bullfrog[47] are in lavas mapped by Ball[48] belonging to the pre-Esmeralda (pre-"Siebert") series, though the authors of the Bullfrog bulletin consider that "the evidence for this conclusion is not so complete as might be desir-

[42] Lincoln. pp. 184–193; Spurr, J. E., "Geology of the Tonopah Mining District, Nevada," U. S. Geol. Surv. Prof. Paper 42, 1905; "Geology and Ore Deposition at Tonopah, Nevada," Econ. Geol., vol. 10, pp. 713–769, 1915.

[43] Lincoln, pp. 137–138; Hill, J. M., "Some Mining Districts in Northeastern California and Northwestern Nevada," U. S. Geol. Surv. Bull. 594, pp. 141–150, 1915.

[44] Lincoln, pp. 151–152; Schrader, F. C., "Ore Deposits of the Carson Sink Quadrangle, Nevada," U. S. Geol. Surv. Bull. (in preparation).

[45] Irelan, W., Eighth Annual Report of the State Mineralogist, California State Mining Bureau, pp. 382–400, 1888; Eakle, A. S. and McLaughlin, R. P., "Mines and Mineral Resources of Alpine Co., Inyo Co., and Mono Co.," Cal. State Min. Bur., pp. 131–156, 1917.

[46] Schrader, F. C., "Ore Deposits of the Carson Sink Quadrangle, Nevada," U. S. Geol. Surv. Bull. (in preparation).

[47] Lincoln, pp. 162–163; Ransome, F. L., Emmons, W. H., and Garrey, G. H., "Geology and Ore Deposits of the Bullfrog District, Nevada," U. S. Geol. Surv. Bull. 407, 1910.

[48] Ball, S. H., "A Geologic Reconnaissance of Southwestern Nevada and Eastern California," U. S. Geol. Surv. Bull. 308, pp. 180–181, 1907.

able."[49] At Jarbidge[50] the veins cut rhyolites of probable Miocene age which are overlain by barren rhyolites which Schrader considers as probably Pliocene.

Except Jarbidge, none of the mining districts of northern Nevada have been studied in sufficient detail to determine the age of the lavas and inclosing ore deposits with any certainty. In the area between latitudes 40° and 42° and longitudes 116° and 117° (including the Tuscarora[51] and Gold Circle[52] districts) studied by W. H. Emmons, the lavas, chiefly rhyolite with subordinate andesite, which contain the ore deposits, are older than the Pliocene Humboldt formation.[53] The lavas of the National district[54] are regarded by Lindgren[55] as probably Miocene in age.

Field work in the Hawthorne and Tonopah quadrangles as well as detailed studies of the two districts has shown that the deposits of Manhattan[56] and Round Mountain[57] are of post-Esmeralda age. The veins of several districts of minor importance are also in rocks, principally rhyolites, later than or contemporaneous with the Esmeralda formation. These include Divide,[58] Gilbert,[59] the gold veins of the Bell (Omco) district,[60] Fairplay (Goldyke, Atwood)[61] and the later gold-bearing veins of Tonopah.[62] Goldfield[63] is the only district outside of this area known to the writer in which ore deposition is certainly of post-Esmeralda age. The Oatman district[64] in Arizona, close to the Nevada line, seems to

[49] Ransome, F. L., et. al., *op. cit.*, p. 31.

[50] Lincoln, pp. 48–50; Schrader, F. C., "The Jarbidge Mining District, Nevada," U. S. Geol. Surv. Bull. 741, pp. 23–24, 1923.

[51] Lincoln, pp. 57–58; Emmons, W. H., "A Reconnaissance of the Mining Camps in Elko, Lander and Eureka Counties, Nevada," U. S. Geol. Surv. Bull. 408, 1910.

[52] Lincoln, pp. 45–46; Emmons, W. H., idem, pp. 48–57.

[53] Emmons, W. H., idem., pp. 34–35.

[54] Lincoln, pp. 100–101; Lindgren, W., "Geology and Mineral Deposits of the National Mining District, Nevada," U. S. Geol. Surv. Bull. 601, 1915.

[55] *Op. cit.*, p. 11.

[56] Lincoln, pp. 175–177; Ferguson, H. G., "Geology and Ore Deposits of the Manhattan District, Nevada," U. S. Geol. Surv. Bull. 723, 1924.

[57] Lincoln, pp. 180–181; Ferguson, H. G., "The Round Mountain District, Nevada," U. S. Geol. Surv. Bull. 725, pp. 383–406, 1921.

[58] Lincoln, pp. 64–66; Knopf, A., "The Divide Silver District, Nevada," U. S. Geol. Surv. Bull. 715, pp. 147–170, 1921.

[59] Ferguson, H. G., "The Gilbert District, Nevada," U. S. Geol. Surv. Bull. 795, pp. 125–145, 1927.

[60] Lincoln, pp. 138–140; Knopf, A., "Ore Deposits of Cedar Mountain, Nevada," U. S. Geol. Surv. Bull. 725, pp. 361–382, 1921.

[61] Lincoln, p. 167.

[62] Spurr, J. E., "Geology of the Tonopah Mining District, Nevada," U. S. Geol. Surv. Prof. Paper 42, p. 99, 1905.

[63] Lincoln, pp. 67–73; Ransome, F. L., "The Geology and Ore Deposits of Goldfield, Nevada," U. S. Geol. Surv. Prof. Paper 66, 1909.

[64] Ransome, F. L., "Geology of the Oatman District, Arizona," U. S. Geol. Surv. Bull. 743, 1923.

be of similar character, but the age of ore deposition, except that the inclosing lavas are probably of middle or late Tertiary age, is not definitely known.

TABLE 2

Classification of Nevada Mining Deposits in Tertiary Lavas

Value of Total Production.	Silver and Silver-gold Districts, by Counties.															Gold Districts, by Counties.								
	Clark.	Churchill.	Elko.	Esmeralda.	Eureka.	Humboldt.	Lander.	Lincoln.	Lyon.	Mineral.	Nye.	Pershing.	Storey.	Washoe.	Total.	Clark.	Esmeralda.	Eureka.	Lincoln.	Lyon.	Mineral.	Nye.	Pershing.	Total.
Under $1,000,000	0	2	2	1	1	1	0	1	2	1	12	2	0	1	26	1	1	1	1	1	1	5	4	15
$1,000,000 to $5,000,000....	2	0	3	1	0	1	1	0	1	1	2	1	0	0	13	0	0	0	0	0	0	2	0	2
$5,000,000 to $10,000,000...	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
$10,000,000 to $50,000,000...	0	0	1	0	0	0	0	1	0	1	1	0	0	0	3	0	0	0	0	0	0	0	0	0
Over $50,000,000	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	1	0	0	0	0	0	0	1
Total........	2	3	6	2	1	2	1	2	3	3	15	3	1	1	45	1	2	1	1	1	1	7	4	18

Figure 2 shows the distribution of the more productive late Tertiary deposits of Nevada, with the principal metal produced and the age, where known; and Table II is an attempt at classification on the basis of predominant metal content of all the districts mentioned by Lincoln which appear to lie within or to be closely associated with the Tertiary lavas. The table is probably considerably in error as regards the grouping of many of the less important districts, owing to insufficient data. Available information is too slight to attempt a classification on an age basis, but it may be said that Divide is the only district producing principally silver known to belong to the younger group. The table suggests that the chances for survival to the point of $1,000,000 production are much better for the silver and silver-gold deposits than for the gold. There is a suggestion of regional grouping, of the silver and silver-gold districts in the north and west central parts of the State, and of the gold deposits in two groups centering in Nye and Pershing Counties. The areal distribution of the Tertiary lavas of various ages is not sufficiently known to permit any inference as to possible significance of this grouping.

Although the ore deposits of these two periods of epithermal deposition closely resemble one another in certain general features and are different in character from the older deposits considered in the first part of the paper, yet there are certain points of constant difference between them.

The most striking is the predominance of silver in the deposits associated with pre-Esmeralda lavas and of gold in the younger deposits. Several of the districts considered to belong to the older group, such as Aurora, Bodie, Rawhide, Jarbidge, and Na-

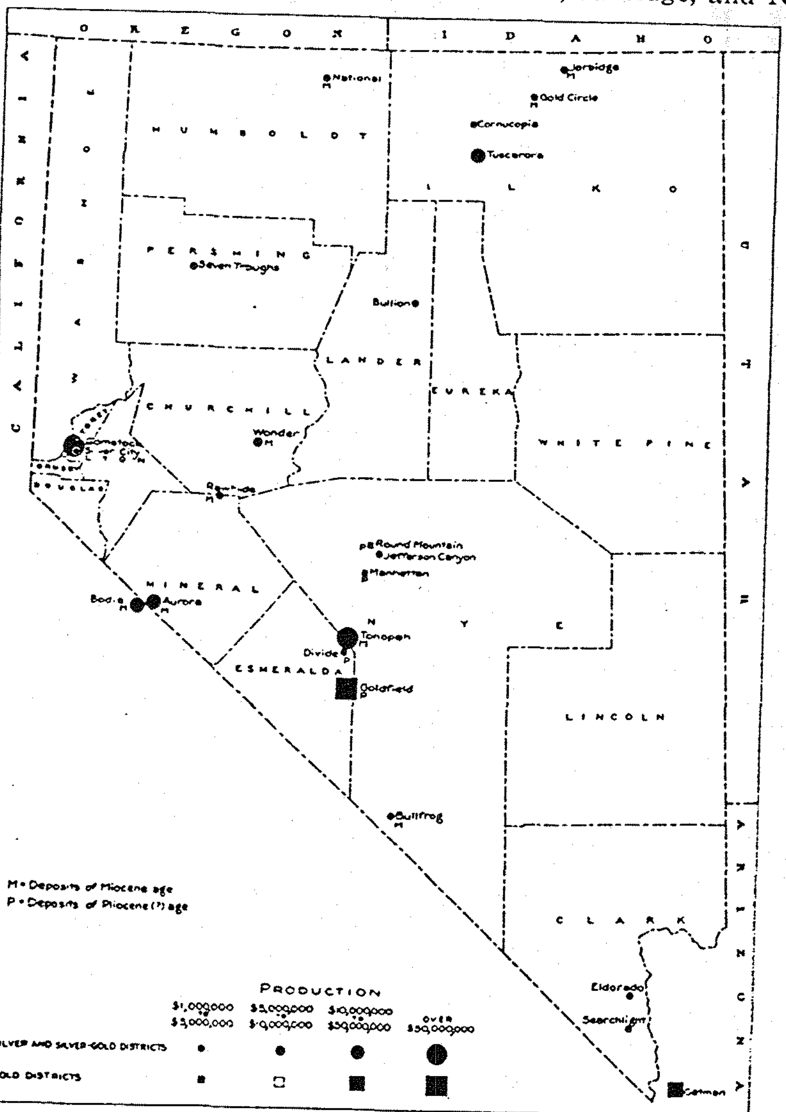

FIGURE 2. **Map showing distribution of principal ore deposits in Nevada associated with Tertiary lavas**

tional, are gold camps, but in all of these the bulk of the silver produced exceeds that of the gold. The ratio by weight of gold to silver as shown by production records is about 1: 14 for Aurora,

1: 8 for Bodie, 1: 15 for Rawhide, 1: 1½ for Jarbidge. For the bulk of the production from National the ratio was about 1: 50, the same as at Tonopah, but in the rich gold shoot large amounts of electrum, with a value of $9 to $11 an ounce, greatly increased the total gold produced, though not to the point of excess over silver. The production records of the post-Esmeralda deposits, on the other hand, largely show an excess of gold over silver, commonly in about the ratio of 7 ounces of gold to 3 of silver. The Divide district[65] is the only exception, and here the high silver content is the result of supergene enrichment. Gold-bearing veins of post-Esmeralda age are also present in this district and have been worked to some extent.

Certain mineralogical features are also distinctive. In the pre-Esmeralda group manganiferous calcite or rhodochrosite is commonly an abundant gangue mineral. Primary silver minerals, chiefly argentite, are also characteristic of the older deposits, but are lacking in the younger. Primary gold is present in both classes of veins, but in the older group it is in the form of electrum, about equal parts gold and silver, while in the younger deposits the proportion of silver is much less and native gold is generally the only valuable mineral. For most districts the mineralogy of the younger veins is much simpler than of the older. Most of the younger deposits are veins of comby quartz with pyrite and free gold, but in some of the younger deposits, such as those of Goldfield and the limestone ores of Manhattan, the mineralogy is very complex. Propylitic alteration of the wall rock is more characteristic of the older group than of the younger. The peculiar tabular quartz, pseudomorphous after calcite or originally intergrown with calcite, is common to both classes of epithermal deposits. On the whole, the older veins are more continuous and better defined than the younger. The ore shoots tend to be larger, and though sensationally rich primary ore is less commonly encountered, the pre-Esmeralda deposits have proved on the whole larger producers and have been productive to a greater average depth than the younger. Spurr has pointed out the similarity of Comstock and Tonopah, and if the criteria for distinction between the two periods of ore deposition are valid, Comstock[66] certainly belongs to the earlier rather than the later

[65] Knopf, A., "The Divide Silver District, Nevada," U. S. Geol. Surv. Bull. 715, pp. 147–170, 1921.

[66] Lincoln, pp. 222–233; Becker, G. F., "Geology of the Comstock Lode and the Washoe District," U. S. Geol. Surv. Monograph 3, 1882; Reid, J. A., "The Structure and Genesis of the Comstock Lode, Calif.," Cal. Univ. Dept. Geol. Bull., vol. 4, pp. 177–199, 1905; Bastin, "Bonanza Ores of the Comstock Lode," U. S. Geol. Surv. Bull. 735, pp. 41–63, 1922.

period. The geologic map and sections seem to indicate that the "later hornblende andesite" at Comstock is later than the vein,[67] but other than this no geologic data as to its age within the Tertiary is available. The Silver City district[68] is geologically a continuation of the Comstock district. No details are given as to mineralogy, but production records show a slight excess of gold over silver, possibly due in part to placer output.

It is thought likely that the older type of epithermal deposits of which Tonopah, Aurora, and probably Comstock are representative is of widespread occurrence throughout western North America, though as yet there is no evidence available indicating that this mineralization took place at approximately the same date throughout. Spurr[69] notes the similarity of the Tonopah district to Comstock and to the Silver City and De Lamar districts of Idaho and Pachuca in Mexico, and notes the points of similarity to districts carrying veins in Tertiary lavas in Peru, Chile, Japan, Sumatra, and New Zealand, and suggests the existence of a "major Pacific Tertiary petrometallographic zone." Of the two periods of late Tertiary ore deposition it is the ore deposits of the earlier period (probably Miocene) which are the Nevada representatives of this widespread metallogenetic epoch. The younger (probably Pliocene) gold deposits appear to be of only local and sporadic occurrence.

Presumably the major differences between the deposits formed in association with granitic intrusives considered in the preceding section and those associated with the surface lavas are due to the greater temperature of formation of the former, and to the longer continuance of high temperatures owing to the great distance below the surface at which the intrusive consolidated. At a guess, the older deep-seated deposits may have formed at depths of from less than 4,000 to over 10,000 feet below the surface and those associated with late Tertiary lavas from a minimum depth of only a few hundred feet to depths of about 3,000 feet below the surface. Presumably on the average the post-Esmeralda veins have suffered less erosion than the earlier Tertiary veins, but a comparison of the data on erosion from districts which have been studied in detail indicates too great a degree of overlap in the amount of erosion of pre-Esmeralda and post-Esmeralda deposits for difference in depth of formation to have been the controlling factor. At Tonopah, Aurora, and Bodie the small areas of pre-Esmeralda volcanics exposed indicate that the amount of erosion

[67] Cf. sheet V of Atlas accompanying Monograph 3. U. S. Geol. Survey.
[68] Lincoln, pp. 131–132.
[69] *Op. cit.*, pp. 273–279.

since the upper Miocene must have been small, probably not over a few hundred feet at most. No data are available which would furnish a measure of the pre-Esmeralda erosion. The lacustrine and terrestrial deposits of the Esmeralda formation covered the site of Tonopah, but Aurora may have been undergoing erosion during this period, and a hint is thus offered as to the reason for the exhaustion of the known Aurora ore bodies at less depth than those of Tonopah. Spurr[70] estimates that the main ore deposition at Tonopah took place at a depth of less than 2,000 feet. Lindgren[71] gives minimum figures of 1,000 and 2,700 feet for the National district, the former for the veins on Buckskin Mountain, based on the difference in elevation between their outcrops and the summit of Buckskin Peak; the latter represents the difference in elevation between Buckskin Peak and the outcrop of the National vein. Certainly this must be some hundreds of feet less than the actual depth at the time of vein formation, for no allowance is made for Pliocene erosion.

Estimates for the depth of formation of the post-Esmeralda deposits show a considerable overlap in range with those of Miocene age. Ransome[72] has calculated that at Goldfield the erosion of the part of the district containing the principal ore bodies was not more than 1,000 feet and may have been much less (to a minimum of something over 300 feet) and to this some 1,500 feet may be added for the vertical range of ore deposition. But such data as exist for Round Mountain and Manhattan indicate a greater depth. The old erosion surface on the crest of the Toquima Range is cut on lavas of the same age as those which contain the veins of Round Mountain and the veins in the lavas north of Manhattan, and the later andesitic lavas are lacking. This old surface is over 2,000 feet above the outcrop of the Gold Hill veins at Manhattan and over 2,500 feet above the Round Mountain veins, and about 3,000 feet above the deepest productive work at both camps. Certainly several hundred feet in addition must be allowed for the erosion interval which ended with the formation of this surface. Ransome[73] considers that the ore shoots of the Oatman (Arizona) veins could not have been formed more than about 3,000 feet below the surface. All such

[70] Spurr, J. E., "Geology and Ore Deposition at Tonopah, Nevada," Econ. Geol., vol. 10, p. 761, 1915; "Ore Magmus," vol. 1. p. 293. 1923.
[71] U. S. Geol. Serv. Bull. 601, p. 33.
[72] U. S. Geol. Surv. Prof. Paper 66, p. 174.
[73] Ransome, F. L., "Geology of the Oatman District, Arizona," U. S. Geol. Surv. Bull. 743, p. 55. 1923.

estimates include factors which are hard to evaluate and consequently are more or less indefinite, but it seems probable that the depth of the zones of ore deposition of the two types of deposits overlapped to a considerable extent, and that therefore the probably somewhat greater average erosion of the deposits of the earlier group is not alone capable of explaining the differences observed.

There must have been other causes operating to produce the widespread mineralization of pre-Esmeralda age with predominant silver. and the later and sporadic gold-bearing veins. In many districts the veins are in lava flows rather than intrusions and presumably did not derive their contents from the inclosing lavas, but both vein minerals and lavas were divided from a deeper source. As far as can be judged from available descriptions there is no characteristic difference in the character of lavas associated with the veins of the two periods. Since, as at Tonopah, deposits belonging to the two periods occur in the same district, the possibility of derivation of gold from deep-seated older basic rocks in the manner suggested in the speculation as to the gold of the California veins is not here applicable. In several of the districts containing late Tertiary gold veins, the ore, and apparently also the veins, fail in depth with a change of rock. For the Oatman district, Ransome[74] suggests a dependence of the ore on the flow inclosing the veins. At Goldfield the ore does not appear to continue into the slates below the lavas, but at Manhattan the principal production has come from ore deposits of post-Esmeralda age in the Cambrian schists and limestones. It is concluded, therefore, that the persistent difference between the Nevada epithermal deposits of pre-Esmeralda age and the younger veins cannot be due alone to depth or degree of heat at the time of formation; and it is inferred that this difference is a function of the character of the source from which the two classes of deposits are derived.

ECONOMIC CONSIDERATIONS

The propositions advanced in the preceding sections are admittedly speculative, but, if valid, they have certain economic bearings, especially on the chances of discovering new districts and of profitably exploring known deposits in depth.

[74] Ransome, F. L., "Progress in Economic Geology." Econ. Geol., vol. 23, p. 121, 1928. In this paper the Mogollon district is cited as another example of this tendency. This appears to the writer to be ill-chosen since at Mogollon the productive portions of the veins cut a succession of lavas of different ages and composition, and exploration has shown that the veins continue well defined to depths at least 300 feet below the exhausted ore shoots. Cf. U. S. Geol. Surv. Bull. 783.

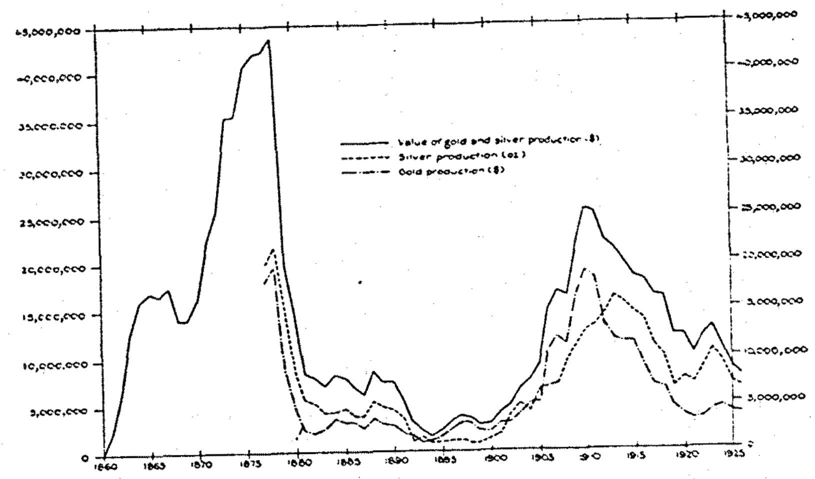

FIGURE 3. Graph showing production of gold and silver in Nevada.

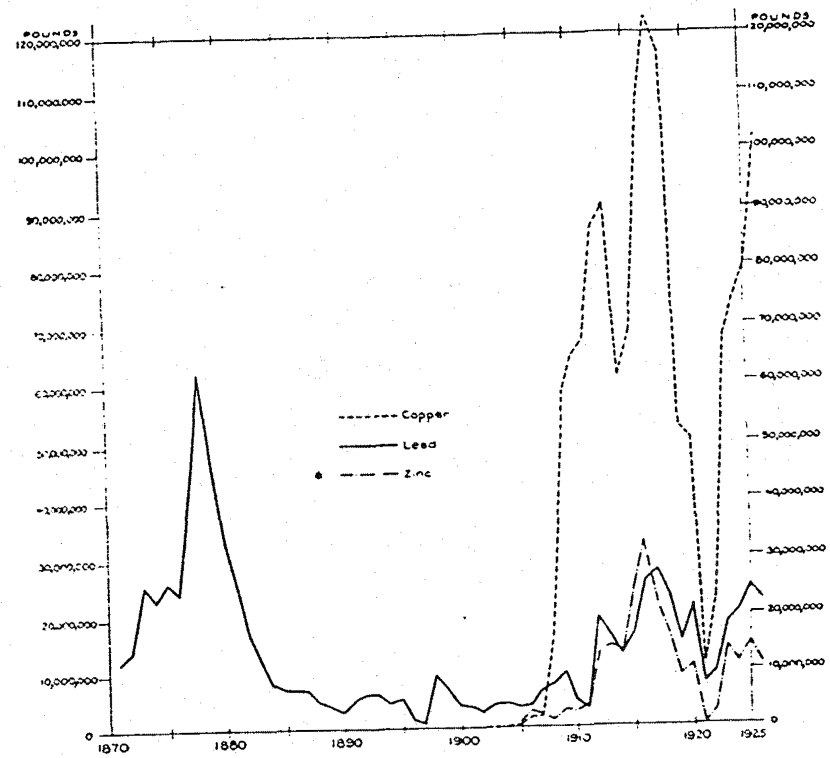

FIGURE 4. Graph showing production of copper, lead, and zinc in Nevada.

Figures 3 and 4, based on data derived from Lincoln and the annual Mineral Resource chapters, show the trend of mineral production in Nevada.

Mining in Nevada began in the early 'fifties; the prospectors were mostly gold miners from California, unfamiliar with silver ores, and it was not until 1859 that important mining of the rich Comstock ores began. The next discoveries were in districts such as Reese River (1862), where the prominent vein outcrops made prospecting easy and the rich silver ores could be treated by amalgamation. The replacement deposits richer in lead and with a less familiar type of outcrop did not come into production until about 1869, when local smelters began to be built. As noted above, the chief value of the silver veins of the Reese River type was due to the presence of supergene silver minerals, and secondary silver ores were an important item in the early production of the eastern lead-silver replacement deposits. The Comstock district appears to have been the only district in which primary silver ores were mined in the early period. The cream was soon skimmed and the catastrophic fall in production which coincided with the panic of 1879 was merely the accentuation of an inevitable decline.

Mining in Nevada almost ceased during the decade from about 1890 to 1900, but a second period of production began with the accidental discovery of Tonopah in 1900. This discovery turned the attention of prospectors to types of outcrops hitherto neglected, and within a few years a large number of gold and silver districts, chiefly within the Tertiary lavas, had become producers. The older silver-bearing veins of western Nevada received their share of attention but did not join to any extent in this renewed production. Important discoveries of secondary silver ore were made in the Rochester district, but on the whole, although attempts were made to reopen mines in nearly every district which had been an important silver producer in the early days, it was found that the early miners had overlooked little in the way of secondary ore, and even with the high prices prevailing for silver between 1917 and 1923 the older silver-bearing veins did not make any important production. Nevertheless these attempts, though generally not profitable, added to the total silver production.

This second period of precious metal production never reached the magnitude of output of the early days, and since 1911 for gold and 1913 for silver the output has shown a fairly steady decline. At about the same time as the new discoveries of precious metal

deposits, improvements in the technique of mining and treatment initiated a renewed production of lead and zinc, from the old camps of eastern Nevada of which Pioche, Yellow Pine, and Eureka were among the most important, and made possible the mining of the Ely copper ores. The war prices stimulated copper production from a number of copper districts, including Yerington and Santa Fé, and there was also some production of copper ores from districts whose principal ores were valuable for lead or zinc, such as Battle Mountain and Yellow Pine. These smaller districts did not recover from the depression of 1921, and in recent years the copper production of the State has been essentially that of the Ely district.

The recent lead output has not attained anything like the magnitude of the early period of production, but on the other hand lead mining has so far shown an ability to respond to favorable prices and as yet gives no indication of a decline like that of the precious metal production. According to the analysis of production given in Mineral Resources,[75] 56 percent of the production of lead for the period 1917–1926 was derived from "lead ore," 19 percent as concentrates from "dry and siliceous ore," and 23 percent from "zinc ore and lead-zinc ore."

Zinc production, chiefly from the Yellow Pine district, became important in 1912 and increased greatly under the stimulus of war prices. In spite of the lower prices in 1919 and succeeding years the output has kept at about the 1912 level.

In considering the possibilities for future production from the State it is of course necessary to make many assumptions any one of which, if invalid, will vitiate the entire argument. Nevertheless, on the basis of the foregoing geological and historical data certain deductions of possible economic importance may be drawn. The western silver-bearing veins of the California type generally have prominent outcrops and the chances for new discoveries are therefore small, although Rochester is an example of the recent discovery of deposits of this type which were overlooked by the first generation of miners. Nor is it likely, unless great advances in technique of mining and treatment are made, that the deep working of the known veins will prove profitable since the old production came from highly enriched supergene ores. In the Reese River district, which had a production of over $50,000,000, the vertical productive depth was not over 500 feet.[76] Veins of

[75] Gerry, C. N., "Gold, Silver, Copper, Lead and Zinc in Nevada in 1926." U. S. Bur. Mines, Min. Res. of the U. S., Part 1, p. 518, 1928.

[76] Hill, J. M., "Some Mining Districts in California and Nevada," U. S. Geol. Surv. Bull. 594, p. 113, 1914.

this type whose apices are buried beneath late Tertiary lava or deep valley fill doubtless await discovery, but it is doubtful whether these are favorably situated so as to have received the necessary supergene enrichment. Such veins were exposed to erosion and the action of supergene waters during part of the Tertiary, and the preservation of zones of Tertiary enrichment is of course possible, and intensive studies of the paleophysiography of such districts might point out favorable areas. Knopf[77] considers that in the Rochester district, the only camp of this type in which consideration has been given to the application of physiography to the study of ore deposits, the enrichment dates from the early part of the Pleistocene.

Of the copper deposits of the State, the most productive, Ely, is the only example of a deposit of disseminated ore. The others consist for the most part of contact metamorphic deposits and to a less extent of copper-bearing veins within or close to the intrusive. Except for Ely, the copper camps of Nevada have not been able to make any significant production except under the stimulus of unusually high prices. At Ely supergene enrichment makes the greater part of the ore, but the large reserves insure future production. Some of the other districts have potentialities of moderate future production at high prices.

The eastern lead-silver deposits of the replacement type, like the silver veins of the west, may be supposed to have essentially exhausted the silver-rich surficial ores. Although their outcrops are in general less prominent than those of the western quartz veins, the State has been so well prospected that the chance for important new discoveries is probably small. The same conditions prevail as in the west as to possibility of enrichment of such deposits to be found beneath the later lavas, or valley fills. In the eastern replacement deposits, however, in contrast to the western veins, partly oxidized base metal ores below the zone of silver enrichment, and in places primary ores, have proved important producers of lead and zinc, especially since selective flotation has rendered mixed sulphide ores available. The production graph given by Knopf for the Pioche region[78] shows early production of the enriched ores followed by a long period of stagnation and recent revival. Eureka, Cortez, and White Pine have had similar histories. It is believed, therefore, that the

[77] Knopf, A., "Geology and Ore Deposits of the Rochester District, Nevada," U. S. Geol. Surv. Bull. 762, p. 44, 1924.

[78] Westgate, L. G., and Knopf, A., "Geology of Pioche, Nevada, and Vicinity," Bull. Am. Inst. Min. Eng., 1647-I., p. 13, 1927.

type of deposit prevailing in eastern Nevada, which has in the past yielded secondary silver ores, offers a better chance for the development of workable base metal ores than do the veins in the pre-Tertiary rocks of the western part of the State.

Several of the silver and silver-gold veins in the Tertiary lavas such as those of Comstock, Aurora, and Tuscarora were discovered and largely exhausted during the early period of production. Others, such as those of Tonopah and Wonder, escaped observation until the recent revival, either on account of the inconspicuous nature of their outcrops or because they occurred in rocks not supposed to be productive. The Pliocene gold deposits such as Goldfield, Manhattan, and Round Mountain were all discovered during the recent period of activity. The chances for important new discoveries do not seem great when one recollects the intensive prospecting which followed the discoveries of Tonopah and Goldfield. But spectacular gold ore outcropped at Manhattan only a few feet from one of the main roads leading to the old silver camp of Belmont, and the outcrops of the veins of Tonopah and Goldfield remained unconsidered in a region which was vigorously prospected between 1860 and 1880, so it would be hazardous to assume that other inconspicuous outcrops of rich veins do not await future discovery.

The gold veins in the late Tertiary lavas have in general less conspicuous outcrops, and the chances for new discoveries of deposits of this type are probably better than for discoveries of silver or silver-gold veins, but, if the data given in Table II are significant, such discoveries are less likely to develop into producing districts.

Supergene enrichment has not been as important in the silver-gold deposits in the lavas as in the older argentiferous quartz veins, although the near-surface bonanzas of Comstock and the oxidized and enriched ores of Bullfrog, Wonder, and Tuscarora have yielded a considerable production. Practically all the production from Tonopah and Aurora and the smaller camps shown in Figure 2, as well as a considerable proportion of that from Comstock, has been from primary ore. The deficiency in oxidation and enrichment in deposits of this type as compared with the older argentiferous quartz veins may be due to the lower content of pyrite and to the lower degree of permeability of these generally finer-grained veins and perhaps also in some part to enrichment of the older veins during part of the Tertiary, before the lavas that contain the later veins were erupted. Since secondary enrichment is not a very important factor in determining the workability of veins of this type, it follows that future discoveries of such veins beneath later lavas or sediments or beneath valley fill may yield workable deposits. At Tonopah productive veins in the older lavas have been mined for considerable distances beneath the later barren formations. The close proximity of Aurora and Bodie suggests a chance for such discoveries. In both these camps the productive veins outcrop in small areas of the older andesites surrounded by later barren lavas. The distance between the two is not even seven miles, but blind exploration beneath the barren lava separating the two would be a long chance without more detailed geologic knowledge than we possess at present.

Since the zone of original deposition is relatively thin in deposits of this type, much depends on the amount of erosion that has taken place. It has been suggested that the greater depth of the ore at Tonopah than at Aurora may be due to the fact that Tonopah was in an area of sedimentation during Esmeralda time, while at the same time the Aurora veins were presumably being eroded. Studies of the regional geology directed towards estimating the amount of both Tertiary and Pleistocene erosion may in places prove helpful in determining the probability of persistence of this type of ore deposit in depth.

In several districts containing gold veins of Pliocene age such as Manhattan, Round Mountain, and Gilbert there seems to be a distinct association of the ore with intrusive rhyolites or dacites which cut the Esmeralda sediments, but this association is apparently lacking in other districts so cannot be regarded as of much value as a guide to possible discovery. Supergene enrichment is responsible for the silver ores of Divide and has apparently been of some importance in the gold ores of Round Mountain, but in the other districts containing Pliocene deposits all the production has been from primary ores, therefore a vein beneath a capping of later lava or valley fill may be as productive as one which outcrops at the surface. Since the range of original deposition was certainly no greater than that of the Miocene deposits and was probably less, it follows that estimation of the amount of probable erosion is equally valuable. With these deposits the problem is somewhat simpler because the time since their formation is shorter.

In conclusion, this study of the available data on the geology of Nevada ore deposits suggests: (1) that the argentiferous veins of pre-Tertiary age in western Nevada offer little hope of new discoveries or of greatly increased production from known deposits

under present conditions of mining and metallurgical technique, (2) that increased copper production, aside from the Ely district, will probably only be available under the stimulus of higher prices, (3) that the lead-silver replacement deposits of early Tertiary age in eastern Nevada offer fair prospects for the continued production of lead and zinc and for the discovery of primary ore valuable for lead or lead and zinc, (4) that the chances for new discoveries of deposits in the Tertiary lavas are more favorable than for the older deposits, (5) that of such possible discoveries those of silver or silver-gold ore of pre-Esmeralda age have a better chance for persistence than those of the Pliocene gold-ore type, and (6) that workable ore in veins in the Tertiary lavas generally persists below the zone of supergene enrichment.

U. S. Geological Survey,
Washington, D. C.

POSTSCRIPT*

The assumption of two separate and distinct periods of folding, granitic intrusion, and consequent ore deposition is perhaps stated more definitely than is justified. The following quotations from Nolan present the opposite point of view:

"A large proportion of the interested geologists have assumed that these structural features (major folds and thrusts) were formed during a single short orogenic epoch which was either contemporaneous with the Late Jurassic deformation of California or with the Laramide of the Rocky Mountains. Relatively recent geologic work in the province now seems to indicate that these assumptions have doubtful validity and that orogenic activity has probably persisted in one place or another over a considerable length of time, starting as early as the middle of the Lower Jurassic and continuing into the Eocene."[1]

"The absence of any Mesozoic sedimentary rocks younger than Lower Jurassic in western and central Nevada prevents any direct contributions from that region to help in answering the question of the age of the numerous stocks that are so widely distributed. Some of them are doubtless late Jurassic age, but if Lindgren's correlation for the Cordilleran region of intrusion with orogenic stress is accepted, it is possible that emplacement of the stocks occurred at different times from the Late Lower Jurassic into the Tertiary period."[2]

It is thought, however, that the facts presented here (pp. 80–89) justify the separation of the Nevada deposits associated with deep-seated intrusives into two distinct metallogenetic provinces (or epochs), and that the conclusions regarding them (pp. 89–90, 105) are, on the whole, valid.

The Delamar (Ferguson) district (p. 89 and Figure 1) has been shown by Callaghan[3] to belong to the Tertiary silver-gold group. Removal from Figure 1 and Table 1 gives a sharper separation between the eastern and western types of Nevada deep-seated deposits.

The Reese River (Austin) district is erroneously credited with

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[1] Nolan, T. B. The Basin and Range Province in Utah, Nevada, and California. U. S. G. S. Prof. Paper 197-D, p. 177, 1943.

[2] *Op. cit.*, pp. 162–163.

[3] Callaghan, Eugene. Geology of the Delamar District, Lincoln County, Nevada. Univ. Nevada Bull., vol. 31, No. 5, 1937.

a production of over $50,000,000 (Figure 1). Gross production has probably been something over $18,000,000.[4]

Recent paleontological work has shown that the sediments referred to as the Esmeralda formation (pp. 80, 90, 91) contain fossils of Lower Pliocene as well as Upper Miocene age; this formation is therefore not as good an age indicator as had been inferred. It remains true, however, the silver-gold and silver districts have been on the whole larger producers and seem to be generally older than the more erratic and for the most part less productive districts producing generally gold in excess of silver.

The Delamar district[5] should have been included among the silver-gold districts of Tertiary age (ratio Au: Ag about 1 to 2 or 3).

Other minor points which should be noted (p. 95): Ratio of gold to silver for Tonopah is between 1 to 85 and 1 to 100, not 1 to 50 as stated.[6] Nolan's data show the largest proportion of gold in the bullion for the upper (central) part of the productive zone.[7]

The vein of the Omco mine in Cedar Mountain (p. 92) is definitely older than the sediments, here of probable Pliocene age, that were deposited across the outcrop of the vein.

Nolan[8] has shown that there was a single period of mineralization at Tonopah, so the reference (p. 92) to "the later gold-bearing veins of Tonopah" is inapplicable.

Possibly, if the old deposits of the National district are genetically related to the cinnabar-bearing sinter of Buckskin Mountain their age may be younger than Miocene.[9]

An important group of deposits of probable late Tertiary age not mentioned in the foregoing summary is the group of tungsten-silver and gold veins of the Silver Dyke and Camp Douglas districts near Mina in Mineral County.

The Getchell deposit in northern Nevada has been recently developed. The presence of realgar and orpiment suggest a

[4] Couch, B. F., and Carpenter, J. A., Nevada's metal and mineral production: Univ. Nevada Bull., vol. 37, No. 4, p. 73, 1943.

[5] Callaghan, E., Geology of the Delamar District, Lincoln County, Nevada: Univ. Nevada Bull., vol. 31, No. 5, 1937.

[6] Nolan, Thomas B., The underground geology of the Tonopah mining district. Univ. Nevada Bull., vol. 29, No. 5, p. 45, 1935.

[7] *Op. cit.*, pl. 3.

[8] Univ. Nevada Bull., vol. 24, No. 4, 1930, and Univ. Nevada Bull., vol. 29, No. 5, p. 9, 1935.

[9] Roberts, R. J. Quicksilver deposit at Buckskin Peak. U. S. G. S. Bull. 922-E, p. 123, 1940.

similarity to the Manhattan deposits of late Tertiary age, but according to Hardy[10] "the gold mineralization was associated with the early Tertiary period of andesitic intrusion. The deposits are of the overlapping epithermal-mesothermal type. The gold-free arsenic mineralization in which the arsenic was deposited in the form of realgar and orpiment with other low-temperature sulphides was of late Tertiary age."

The minerals of the early stage at Getchell include pyrite, arsenopyrite, pyrrhotite, sphalerite, galena, chalcopyrite, and electrum, and the doré bullion contains a minute amount of selenium. Late-stage minerals include stibnite, realgar, and orpiment.[11]

[10] Hardy, Roy A. Geology of the Getchell Mine. Am. Inst. Min. and Met. Eng. Trans., vol. 144, pp. 149–150, 1941.

[11] *Op. cit.*, p. 150.

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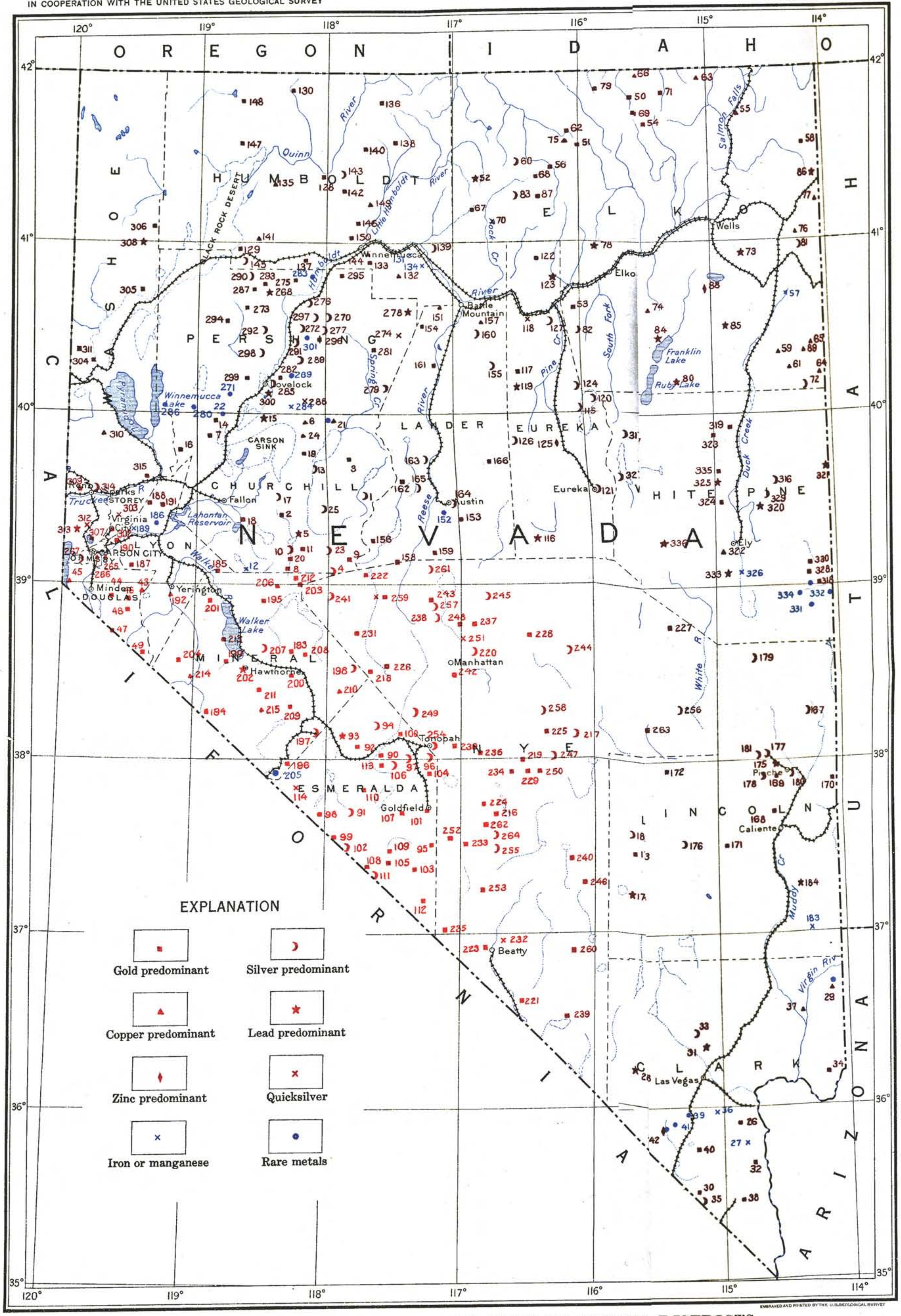

MAP OF NEVADA SHOWING LOCATION OF MINING DISTRICTS

Scale $\frac{1}{2500000}$

APPROXIMATELY 40 MILES TO 1 INCH

25 0 25 50 75 100 Miles

25 0 25 50 75 100 Kilometers

1932

LIST OF MINING DISTRICTS

CHURCHILL COUNTY

1. Alpine (Clan Alpine) — Silver
2. Bell Mountain — Gold
3. Bernice — Gold
4. Broken Hills (Quartz Mountain) — Silver
5. Chalk Mountain — Lead
6. Copper Kettle — Copper
7. Desert (White Plains) — Gold
8. Eagleville (Hot Springs) — Gold
9. Eastgate — Gold
10. Fairview — Silver
11. Gold Basin — Gold
12. Holy Cross (Fallon, Terrell) — Manganese
13. I. X. L. (Silver Hill) — Silver
14. Jessup — Gold
15. Lake — Lead
16. Leete — Gold
17. Mountain Wells (La Plata) — Silver
18. Sand Springs — Gold
19. Shady Run — Gold
20. South Fairview — Gold
21. Table Mountain (Boyer, Cottonwood Canyon, Bolivia) — Nickel
22. Toy (Browns) — Tungsten
23. Westgate — Silver
24. White Cloud (Coppereid) — Copper
25. Wonder (Hercules) — Silver

CLARK COUNTY

26. Alunite (Railroad Pass, Vincent) — Gold
27. Black Mountains — Iron
28. Charleston — Lead
29. Copper King (Bunkerville, Great Eastern, Key West) — Copper
30. Crescent — Gold
31. Dike — Lead
32. Eldorado (Colorado, Nelson) — Gold
33. Gass Peak — Silver
34. Gold Butte — Gold
35. Ivanpah — Silver
36. Las Vegas — Manganese
37. Logan (St. Thomas, Muddy Mountains) — Copper
38. Searchlight — Gold
39. Sloan — Radium
40. Sunset (Lyons) — Gold
41. Sutor — Radium
42. Yellow Pine (Goodsprings, Potosi) — Zinc

DOUGLAS COUNTY

43. Buckskin — Copper
44. Gardnerville (Eagle) — Gold
45. Genoa — Copper
46. Mount Siegel — Gold
47. Mountain House (Holbrook, Pine Nut) — Gold
48. Red Canyon (Silver Lake) — Gold
49. Silver Glance (Wellington) — Gold

ELKO COUNTY

50. Alder — Gold
51. Aura (Bull Run, Centennial, Columbia) — Gold
52. Burner — Lead
53. Carlin — Gold
54. Charleston (Copper Mountain, Cornwall) — Gold
55. Contact (Kit Carson, Porter, Salmon River) — Copper
56. Cornucopia — Gold
57. Decoy — Manganese
58. Delano (Delno) — Gold
59. Delker — Copper
60. Divide — Silver
61. Dolly Varden (Mizpah, Granite) — Copper
62. Edgemont (Centennial) — Gold
63. Elk Mountain — Copper
64. Ferber — Copper
65. Ferguson Spring (Allegheny) — Copper
66. Gold Basin (Rowland) — Copper
67. Gold Circle (Midas, Summit) — Gold
68. Good Hope — Gold
69. Island Mountain (Gold Creek) — Gold
70. Ivanhoe — Quicksilver
71. Jarbidge — Gold
72. Kinsley — Silver
73. Lafayette — Lead
74. Lee — Copper
75. Lime Mountain (Deep Creek) — Copper
76. Loray (Luray, Leroy) — Copper
77. Lucin — Copper
78. Merrimac (Lone Mountain) — Lead
79. Mountain City (Cope, Van Duzer) — Gold
80. Mud Springs (Medicine Springs) — Lead
81. Proctor — Silver
82. Railroad (Bullion) — Silver
83. Rock Creek (Falcon) — Silver
84. Ruby Valley (Smith Creek) — Lead
85. Spruce Mountain — Lead
86. Tecoma — Lead
87. Tuscarora — Gold
88. Warm Creek — Zinc
89. White Horse — Copper

ESMERALDA COUNTY

90. Alpine — Gold
91. Argentite — Silver
92. Castle Rock — Gold
93. Coaldale — Lead
94. Crow Springs — Silver
95. Cuprite — Gold
96. Divide — Silver
97. Dolly — Silver
98. Dyer — Gold
99. Fesler (Windypah) — Gold
100. Gilbert (Desert) — Gold
101. Goldfield — Gold
102. Good Hope — Silver
103. Hornsilver (Lime Point) — Gold
104. Klondyke (Southern Klondyke) — Gold
105. Lida (Alida Valley, Tule Canyon) — Gold
106. Lone Mountain (West Divide) — Silver
107. Montezuma — Gold
108. Palmetto — Gold
109. Railroad Springs — Gold
110. Silver Peak — Gold
111. Sylvania (Green Mountain) — Silver
112. Tokop (Gold Mountain, Bonnie Clare, Oriental Wash) — Gold
113. Weepah — Gold
114. White Mountains (Fish Lake Valley) — Quicksilver

EUREKA COUNTY

115. Alpha — Silver
116. Antelope — Lead
117. Buckhorn — Gold
118. Beowawe — Quicksilver
119. Cortez (Bullion Hill, Mount Tenabo) — Silver
120. Diamond — Silver
121. Eureka (Pinto, Prospect, Ruby Hill, Secret Canyon, Silverado, Spring Valley) — Silver
122. Lynn — Gold
123. Maggie Creek (Schroeder) — Lead
124. Mineral Hill — Silver
125. Mount Hope — Zinc
126. Roberts — Silver
127. Safford (Barth, Palisade) — Silver

HUMBOLDT COUNTY

128. Amos (Awakening, Slumbering Hills) — Gold
129. Black Rock — Gold
130. Disaster — Gold
131. Golconda — Manganese
132. Gold Run — Copper
133. Grandpap — Gold
134. Iron Point — Manganese
135. Jackson Creek — Copper
136. National — Gold
137. New Central — Gold
138. Paradise Valley (Mount Rose, Spring City) — Gold
139. Preble (Potosi) — Silver
140. Rebel Creek (New Goldfields, Willow Creek) — Gold
141. Red Butte — Copper
142. Sherman — Gold
143. Shon — Silver
144. Sonoma Mountain (Harmony) — Copper
145. Sulphur (Rabbit Hole) — Silver
146. Ten Mile — Gold
147. Varyville (Columbia) — Gold
148. Warm Springs (Vicksburg, Ashdown, Pueblo) — Gold
149. Willow Point — Copper
150. Winnemucca (Barrett Springs) — Gold

LANDER COUNTY

151. Battle Mountain (Bannock, Copper Basin, Copper Canyon, Cottonwood Creek, Galena, Rocky Canyon) — Copper
152. Big Creek — Antimony
153. Birch Creek — Gold
154. Buffalo Valley — Gold
155. Bullion (Campbell, Lander, Tenabo) — Silver
156. Gold Basin — Gold
157. Hilltop (Kimberly, Mayesville) — Copper
158. Jackson (Gold Park) — Gold
159. Kingston (Bunker Hill, Santa Fe, Summit, Victorine) — Gold
160. Lewis (Dean, Mud Springs, Pittsburgh) — Silver
161. McCoy — Gold
162. New Pass — Gold
163. Ravenswood (Shoshone) — Silver
164. Reese River (Amador, Austin, Yankee Blade) — Silver
165. Skookum — Silver
166. Spencer — Gold

LINCOLN COUNTY

167. Atlanta (Silver Park, Silver Springs) — Silver
168. Chief (Caliente) — Gold
169. Comet — Gold
170. Eagle Valley (Fay, Stateline) — Gold
171. Ferguson (Delamar) — Gold
172. Freiberg (Worthington) — Gold
173. Gold Range — Gold
174. Groom — Lead
175. Highland — Lead
176. Hiko (Pahranagat) — Silver
177. Jack Rabbit (Bristol) — Silver
178. Lone Mountain — Silver
179. Patterson (Cave Valley, Geyser) — Gold
180. Pioche (Ely) — Silver
181. Silverhorn — Silver
182. Tem Piute — Silver
183. Vigo — Manganese
184. Viola — Lead

LYON COUNTY

185. Benway — Gold
186. Churchill — Tungsten
187. Como (Palmyra, Indian Springs) — Gold
188. Ramsey — Gold
189. Red Mountain — Iron
190. Silver City (Chinatown, Dayton, Devils Gate, Gold Canyon) — Gold
191. Talapoosa — Gold
192. Yerington (Ludwig, Mason) — Copper

MINERAL COUNTY

193. Acme (Fitting) — Gold
194. Aurora (Cambridge, Esmeralda) — Gold
195. Bovard (Copper Mountain, Rand) — Gold
196. Buena Vista (Basalt, Mount Montgomery, Oneota) — Gold
197. Candelaria (Belleville, Columbus) — Silver
198. Cedar Mountain (Bell, Omco, Simon) — Silver
199. East Walker (Mount Grant) — Gold
200. Garfield — Gold
201. Granite (Mountain View, Reservation) — Gold
202. Hawthorne (Lucky Boy, Pamlico) — Lead
203. King — Gold
204. Pine Grove (Rockland, Wilson) — Gold
205. Queens — Tungsten
206. Rawhide (Regent in Churchill County) — Gold
207. Ryan Canyon — Silver
208. Santa Fe (Luning, Kinkead) — Gold
209. Silver Star (Black Mountain, Gold Range, Marietta, Mina) — Gold
210. Sodaville (Pilot Mountain) — Copper
211. Sulphide — Gold
212. Sunnyside (Hot Springs) — Gold
213. Walker Lake (Buckley, Cat Creek) — Gold
214. Washington — Copper
215. Whiskey Flat — Copper

NYE COUNTY

216. Antelope — Gold
217. Arrowhead — Silver
218. Athens — Gold
219. Bellehelen — Gold
220. Belmont (Philadelphia, Silver Bend) — Silver
221. Big Dune (Lee) — Gold
222. Bruner (Phonolite) — Gold
223. Bullfrog (Beatty, Pioneer, Rhyolite) — Gold
224. Cactus Springs — Gold
225. Clifford — Gold
226. Cloverdale (Golden, Republic) — Gold
227. Currant — Gold
228. Danville — Gold
229. Eden (Gold Belt) — Gold
230. Ellendale — Gold
231. Fairplay (Atwood, Goldyke) — Gold
232. Fluorine (Bare Mountain, Telluride) — Quicksilver
233. Gold Crater — Gold
234. Golden Arrow (Blakes Camp) — Gold
235. Grapevine — Gold
236. Hannapah (Silverzone, Volcano) — Gold
237. Jefferson Canyon (Concordia, Green Isle) — Gold
238. Jett — Silver
239. Johnnie — Gold
240. Kawich (Gold Reed) — Gold
241. Lodi (Ellsworth, Mammoth, Marble, Quartz Mountain) — Silver
242. Manhattan — Gold
243. Millett (North Twin River) — Gold
244. Morey — Silver
245. Northumberland — Silver
246. Oak Springs — Gold
247. Reveille — Silver
248. Round Mountain — Gold
249. San Antone (Royston, San Antonio) — Silver
250. Silverbow — Gold
251. Spanish Belt — Quicksilver
252. Stonewall Mountain — Gold
253. Tolicha (Monte Cristo) — Gold
254. Tonopah — Silver
255. Trappmans — Silver
256. Troy (Irwin Canyon, Nyala) — Silver
257. Twin River — Silver
258. Tybo (Hot Creek, Keystone) — Silver
259. Union (Berlin, Ione) — Quicksilver
260. Wahomie — Gold
261. Washington — Silver
262. Wellington (O'Briens) — Gold
263. Willow Creek — Gold
264. Wilsons — Silver

ORMSBY COUNTY

265. Carson River — Copper
266. Delaware (Sullivan) — Copper
267. Voltaire (Eagle, Washoe Valley) — Silver

PERSHING COUNTY

268. Antelope (Cedar) — Lead
269. Black Knob — Antimony
270. Buena Vista (Unionville) — Silver
271. Copper Valley (Ragged Top) — Tungsten
272. Echo (Rye Patch) — Silver
273. Farrell (Stone House) — Gold
274. Gold Banks — Quicksilver
275. Haystack — Gold
276. Imlay (Humboldt, Prince Royal, Eldorado) — Silver
277. Indian — Silver
278. Iron Hat — Lead
279. Jersey — Silver
280. Juniper Range — Tungsten
281. Kennedy — Gold
282. Loring (Lovelock, Willard) — Gold
283. Mill City (Central) — Tungsten
284. Mineral Basin — Iron
285. Muttleberry — Silver
286. Nightingale — Tungsten
287. Placerites (Rabbit Hole) — Gold
288. Relief — Quicksilver
289. Rochester (Nenzel, Oreana) — Silver
290. Rosebud — Silver
291. Sacramento — Silver
292. San Jacinto — Silver
293. Scossa — Gold
294. Seven Troughs — Gold
295. Sierra (Sunshine, Dun Glen, Chafey, Oro Fino) — Gold
296. Spring Valley (Fitting, American Canyon) — Gold
297. Star (Santa Clara) — Silver
298. Trinity (Arabia, Oreana) — Silver
299. Velvet — Gold
300. Wild Horse — Lead
301. Wrights Canyon — Tungsten

STOREY COUNTY

302. Comstock (Virginia City, Gold Hill, Silver Star, Flowery) — Gold
303. Red Mountain (Castle Peak) — Quicksilver

WASHOE COUNTY

304. Cottonwood (Round Hole) — Gold
305. Deep Hole — Gold
306. Donnelly (Gerlach) — Gold
307. Jumbo (West Comstock) — Gold
308. Leadville — Lead
309. Peavine (Reno, Crystal Peak) — Gold
310. Pyramid — Copper
311. Sheephead — Gold
312. Steamboat Springs — Quicksilver
313. Washoe (Galena) — Lead
314. Wedekind — Silver
315. White Horse (Olinghouse) — Gold

WHITE PINE COUNTY

316. Aurum (Muncy Creek, Queen Springs, Ruby Hill, Schellbourne, Schell Creek) — Silver
317. Bald Mountain — Silver
318. Black Horse — Gold
319. Cherry Creek (Egan Canyon) — Gold
320. Duck Creek (Success) — Lead
321. Eagle (Kern, Pleasant Valley, Regan, Tungstonio) — Lead
322. Ely (Robinson) — Copper
323. Gold Canyon — Gold
324. Granite (Steptoe) — Gold
325. Hunter — Lead
326. Nevada — Manganese
327. Newark (Strawberry) — Silver
328. Osceola — Gold
329. Piermont — Silver
330. Sacramento — Gold
331. Shoshone (Minerva, Lexington) — Tungsten
332. Snake (Bonita) — Tungsten
333. Taylor (Ward) — Lead
334. Tungsten (Hub, Lincoln) — Tungsten
335. Warm Springs — Gold
336. White Pine (Hamilton) — Lead