Jasperoid in the United States— Its Characteristics, Origin, and Economic Significance

GEOLOGICAL SURVEY PROFESSIONAL PAPER 710

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By T. G. LOVERING

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Jasperoid consists dominantly of quartz replacing older host rocks, commonly limestone or dolomite. It is a useful ore guide in many mining districts

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By T. G. LOVERING

ABSTRACT

Jasperoid is a rock composed dominantly of silica, most commonly quartz, that has formed largely by epigenetic replacement. It is a common product of hydrothermal alteration of carbonate rocks in many mineralized areas.

Although jasperoid in the United States is most abundant in limestone and dolomite, it also occurs in shale, mudstone, extrusive igneous rocks, and metamorphic rocks. Most bodies of jasperoid are localized along faults, fracture zones, and shear zones, and they spread laterally from such conduits through beds of favorable lithology or permeability, or beneath impermeable caprocks. In many mining districts of the Western United States, the jasperoid bodies seem to be both spatially and genetically related to siliceous igneous intrusives.

Individual bodies of jasperoid range in size from pods a few feet in diameter to masses more than a quarter of a mile in their greatest dimension. Many form crosscutting veins or reefs; others form concordant mantos or sheets. Some are lenticular, and some are extremely irregular in shape with many projecting apophyses.

Large masses of jasperoid characteristically form prominent rugged outcrops that shed a talus of angular broken blocks. They tend to be strongly brecciated and recemented by younger quartz. The rock is fine grained to aphanitic in texture; the coarser varieties resemble fine-grained quartzite, and the finer varieties resemble chert. Vugs are commonly abundant and conspicuous. Jasperoid in most outcrops is oxidized and is stained by iron oxides in various shades of brown, yellow, and red. Unoxidized jasperoid is predominantly gray or black. Some jasperoid retains both the color and texture of the host rock, and is distinguishable only by its greater hardness. Some masses of jasperoid have sharp contacts with unreplaced host rocks; others grade into the host through a transition zone of tiny irregular quartz veinlets and disseminated quartz grains.

Quartz in jasperoid displays a variety of microtextures. The two most common are irregularly interlocking grain boundaries, comparable to xenomorphic texture in igneous rocks, and extremely irregular sinuous boundaries with individual grains interlocking like the pieces of a jigsaw puzzle. A less common texture, which seems to be confined to jasperoid and which may be used to distinguish it from other forms of quartz, consists of randomly oriented euhedral to subhedral quartz laths that form a reticulated net, with the interstices filled by interlocking anhedral grains.

Although jasperoid is composed predominantly of quartz, only a few varieties are composed entirely of quartz. The most common of nearly 100 observed accessory minerals are allophane, barite, calcite, chalcedony, dolomite, goethite, hematite, hydromica, jarosite, kaolinite, limonite, opal, pyrite, sericite, tourmaline, and zircon. Some accessory minerals are unreplaced inclusions in, or remnants of, host rock. A few are nearly contemporaneous with the matrix quartz, but most are younger than the matrix quartz and form crosscutting veinlets, vug fillings, or oxidation pseudomorphs of older minerals.

Chemical analyses of selected samples indicate that typical jasperoid consists of about 80–99 percent silica; the remainder is mostly iron, aluminum, calcium, magnesium, and water, in varying proportions. Forty-three elements were detected, by spectrographic analyses, in one or more of 200 samples; of these elements, only silicon, aluminum, iron, magnesium, calcium, titanium, manganese, barium, chromium, copper, nickel, strontium, and vanadium were detected in most of the samples.

The prerequisites to the formation of jasperoid are (1) an adequate source of silica, (2) solutions that can transport silica to the site of deposition, (3) an environment at this site that inhibits the solubility of silica and promotes solution of host rock, and (4) reaction rates that cause the host rock to dissolve at least as fast as silica precipitates.

Possible sources of silica are (1) a cooling magma at depth contributing juvenile siliceous emanations, (2) silica-bearing rocks above or below the host rock, and (3) silica disseminated through the host rock itself.

The capacity of an aqueous fluid to transport silica depends largely on the form of silica available, and on the temperature, pressure, and chemical composition of the system. Although hydrothermal fluids are generally capable of transporting silica in higher concentrations than is cool water, ground water can also transport large quantities of silica under the proper conditions during a longer period of time.

Ionic solubility of silica varies directly with the fluid density of the solvent. At low temperature, saturation with respect to ionic silica is low in strongly acid solutions, increases slightly in weakly acid solutions, declines to a minimum in neutral solutions, rises in slightly alkaline solutions, and rises rapidly in strongly alkaline solutions. Dispersed silica sols tend to be stable at low pH; consequently, acid solutions are capable of transporting large quantities of silica.

The silica content of natural waters ranges from a low of about 6 parts per million in sea water to a high of several hundred parts per million in thermal springs of volcanic origin. The concentration of silica in natural water seems to be largely independent of the total dissolved solids in the water.

Precipitation of silica can result from (1) decrease in fluid density, (2) evaporation of the solvent, (3) neutralization of acid or alkaline waters, (4) contact with a solid form of silica, (5) changes in the concentration of certain dissolved salts, (6) the mingling of dispersed sols with opposite electrical charges, or (7) a combination of these factors. Iron and aluminum promote precipitation of silica from acid solutions, and barium and fluorine promote its precipitation from alkaline solutions. Sodium chloride causes silica to precipitate from supersaturated solutions and to dissolve in undersaturated solutions. Increases in temperature and pressure accelerate the conversion of silica gel to quartz.

Although some jasperoid bodies probably result from solution of host rock at an early stage and from precipitation of silica in the resulting voids at a later stage, the common preservation of original host rock textures in replacing jasperoid furnishes evidence that simultaneous solution of host rock and precipitation of silica by the same solution must also be an important process in the formation of such bodies.

If a hot aqueous silica-bearing fluid containing dissolved CO_2 and NaCl rose under pressure along an insulated conduit into a layer of carbonate rocks that was highly permeable, the resulting rapid change in physical and chemical environment would be conducive to this type of volume-for-volume replacement. Both carbonic acid and sodium chloride increase the solubility of carbonate rocks. The rising pH of the solution resulting from reaction with these rocks, and the drop in both temperature and pressure as the solution spread from the feeding conduit through the permeable zone, would tend to supersaturate the solution with silica. The presence of sodium chloride would, however, inhibit such supersaturation and cause the excess silica to precipitate as the carbonate rock dissolved. If the silica precipitated as a gel rather than as crystalline quartz, the rate of replacement would decline as the reaction became dependent on diffusion of solution through the thickening gel layer. However, the higher temperature of solutions on the inlet side of the system would promote rapid conversion of silica gel to quartz. The loss in volume resulting from such a conversion would open new channels for solutions to move toward the reaction interface with the host rock. If silica precipitated directly as quartz disseminated through the host, solutions could continue to flow along intergrain boundaries and tiny fractures in the host rock and the growing nuclei of quartz within it.

The appearance, texture, mineralogy, and composition of ore-related jasperoid samples from many different localities were studied and compared statistically with the same attributes of non-ore-related samples. Characteristics found to be significantly more common in ore-related samples include phaneritic texture, abundant vugs, brown color, highly variable grain size, reticulated microtexture, the presence of goethite, jarosite, pyrite, and >0.00015 percent Ag, >0.0015 percent Pb, >0.015 percent Zn, >0.003 percent Cu, >0.0007 percent Mo, >0.15 percent As, >0.0007 percent Ga, >0.0007 percent In, >0.0015 percent Sn, >1.5 percent Fe. Characteristics found to be significantly more common in samples not associated with ore are red color, jigsaw-puzzle microtexture, and the presence of yellow limonite, montmorillonite, hydromica, sericite, and >0.01 percent Mg.

Numerical scores were awarded to each characteristic according to its statistical level of significance, and the scores were summed for each sample in both groups. More than 90 percent of the ore-related samples yielded scores of ≥ 5, and more than 90 percent of the non-ore-related samples yielded scores of ≤ 5.

Each of the nine major jasperoid-bearing mining districts in the United States has yielded ore worth at least $100 million. These districts, in order of decreasing production, are Tri-State, Clifton-Morenci, Bisbee (Warren), Ely (Robinson), Leadville, Tintic, Gilman, Aspen, and Eureka. The distribution and characteristics of jasperoid in each of these districts are discussed in some detail. Information on jasperoid in 99 other mining districts and mineralized areas in the United States is summarized more briefly, and 97 other occurrences of jasperoid or silicified rock that may be jasperoid are named and located.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The common association of bodies of silicified rocks (jasperoid) with replacement ore deposits in mining districts of the Western United States prompted this investigation. The major objectives are twofold: first, to establish criteria for distinguishing jasperoids that are closely associated with replacement ore bodies (favorable jasperoids) from similar siliceous bodies that are unrelated to ore (unfavorable jasperoids and cherts); second, to obtain information on the physical and chemical nature of jasperoid as a rock type and on the environment in which it forms.

Much of the information has been derived from geologic literature, and most of the rest, from examination and analysis of jasperoid samples contributed by my colleagues.

DEFINITION OF "JASPEROID"

Although the term "jasperoid" has been established in the literature since the late 19th century, some confusion still exists as to its exact meaning. This confusion is due in part to the many names that have been applied to jasperoids. These include blout, flint, quartz, jasper, hornstone, chert, secondary chert, hydrothermal chert, limestone quartzite, ozarkite, cherokite, silicified limestone, and silicified dolomite.

The term "jasperoid" was first introduced by Spurr (1898, p. 219–220), who wrote:

> Jasperoid may then be defined as a rock consisting essentially of cryptocrystalline, chalcedonic, or phenocrystalline silica, which has formed by the replacement of some other material, ordinarily calcite or dolomite. This jasperoid may be white or various shades of red, gray, brown, or black, the colors resulting from different forms of iron in varying proportions.

Lindgren (1901, p. 678), in his report on metasomatic processes in fissure veins, wrote as follows:

> Many tiny quartz grains first appear scattered through the rock, chiefly along areas of slight shearing or fracture. Here and there appear long slender quartz crystals entirely surrounded by fresh limestone. As silicification proceeds, the slender crystals multiply, forming a characteristic network, sometimes enclosing small areas of calcite which are sprinkled with small, irregular quartz-grains of varying size, in which

> the retiform structure is still apparent, and which rock resembles a chert or a fine-grained and altered quartzite, and is generally somewhat porous, drusy, and also often colored red or yellow. In structure, appearance, and origin, this cherty rock is identical with the jaspers of Lake Superior. Mr. Spurr proposes "jasperoid" as a term for this rock, consisting essentially of cryptocrystalline, chalcedonic or phanero-crystalline silica formed by the replacement of other rocks, chiefly limestone.

Lindgren did not stipulate an origin due to the agency of circulating water, as did Spurr. Further confusion regarding the definition of the term "jasperoid" is caused by the fact that both Lindgren and Spurr regarded the jasper of the Lake Superior region as being a jasperoid. Van Hise and Leith (1911, p. 124, 556), in their famous monograph on the geology of this region, did not commit themselves to a replacement origin for the jasper, and regarded the interbedded iron ore as syngenetic. In an investigation of the Ironwood Iron-Formation, Huber (1959, p. 111–113) stated that the jasper is primary.

The characteristic features of jasperoid described by Lindgren are evident in much of the jasperoid from the type locality at Aspen, Colo., but some of them are not apparent in many rocks called jasperoids by later investigators in other areas. Smith and Siebenthal (1907, p. 14) applied the term to the dense black siliceous rock in the Joplin district, Missouri-Kansas, which is commonly associated with the galena and sphalerite ore bodies. Soon afterward, Irving (1911, p. 630–631) described gold-bearing jasperoid bodies in the Black Hills of South Dakota whose contacts with the enclosing dolomite are knife-edge sharp. Duke (1959) defined jasperoid as "any rock which is composed mostly of secondary silica."

There seems to be general agreement on two points: (1) jasperoids are composed predominantly of silica, which in most places is in the form of aphanitic to fine-grained quartz, and (2) jasperoids form by replacement of the enclosing rock. For this study, I return to Spurr's definition (1898) by restricting the usage of the term "jasperoid" to mean "an epigenetic siliceous replacement of a previously lithified host rock." Jasperoid, thus defined, excludes syngenetic or diagenetic forms of silica, such as primary chert and novaculite.

ACKNOWLEDGMENTS

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DISTRIBUTION OF JASPEROID

GEOGRAPHIC DISTRIBUTION

Jasperoid bodies have been recognized and reported from more than 200 mining districts and mineralized areas in the United States (fig. 1), and they undoubtedly occur in many more areas. Bodies of jasperoid that are apparently unrelated to commercial ore deposits are also common throughout large areas of the Western United States, but because most of them are small, widely scattered, and of no known economic importance, they rarely are shown on small-scale regional geologic maps. Thus, the localities shown on figure 1 probably represent less than half the actual jasperoid localities in the United States.

Many of the known localities are concentrated in certain areas, or jasperoid provinces; others are widely scattered. Jasperoid provinces may be of significance in broad-scale economic exploration programs because they represent regions within which jasperoid seems to be associated with ore. These provinces, shown in figure 1, are: (1) a large area in eastern Nevada and western Utah, (2) an area west and southwest of Tonopah, Nev., extending southward into California, (3) an area in central Colorado surrounding Leadville, (4) a long narrow area in southwestern New Mexico extending from Magdalena southward to the Mexican border, (5) the Tri-State "district" (in reality a very large region of many "districts," as the term is used in the West) surrounding the common corner of Kansas, Oklahoma, and Missouri, and (6) the lead-zinc "district" of northern Arkansas. In each of these provinces are many districts in which jasperoid bodies are associated, both genetically, and spatially, with sulfide ore deposits. It is also noteworthy that major mining districts lie near the center of many of these provinces, for example, Ely, Nev., Leadville, Colo., and the "Picher Field," Okla.

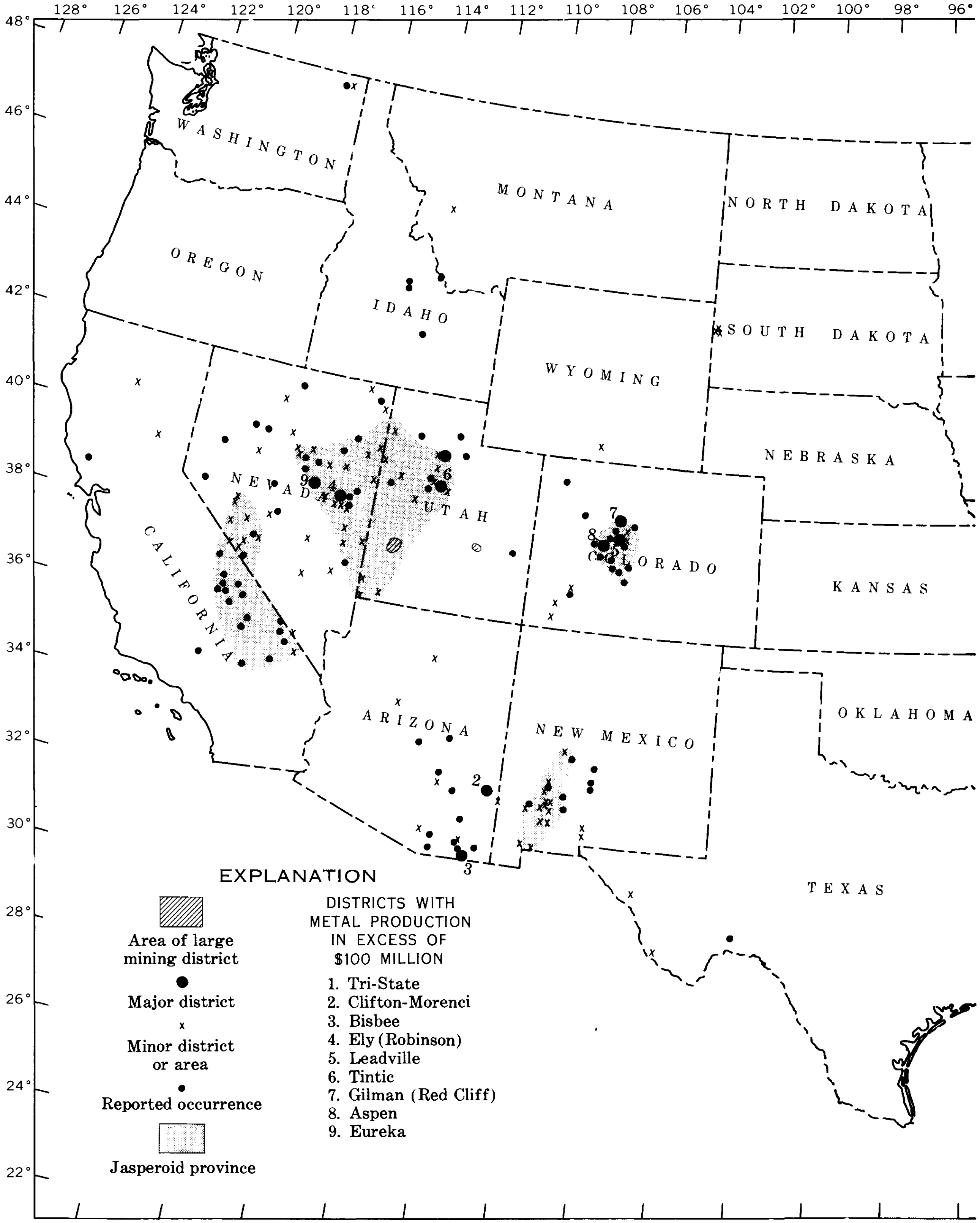
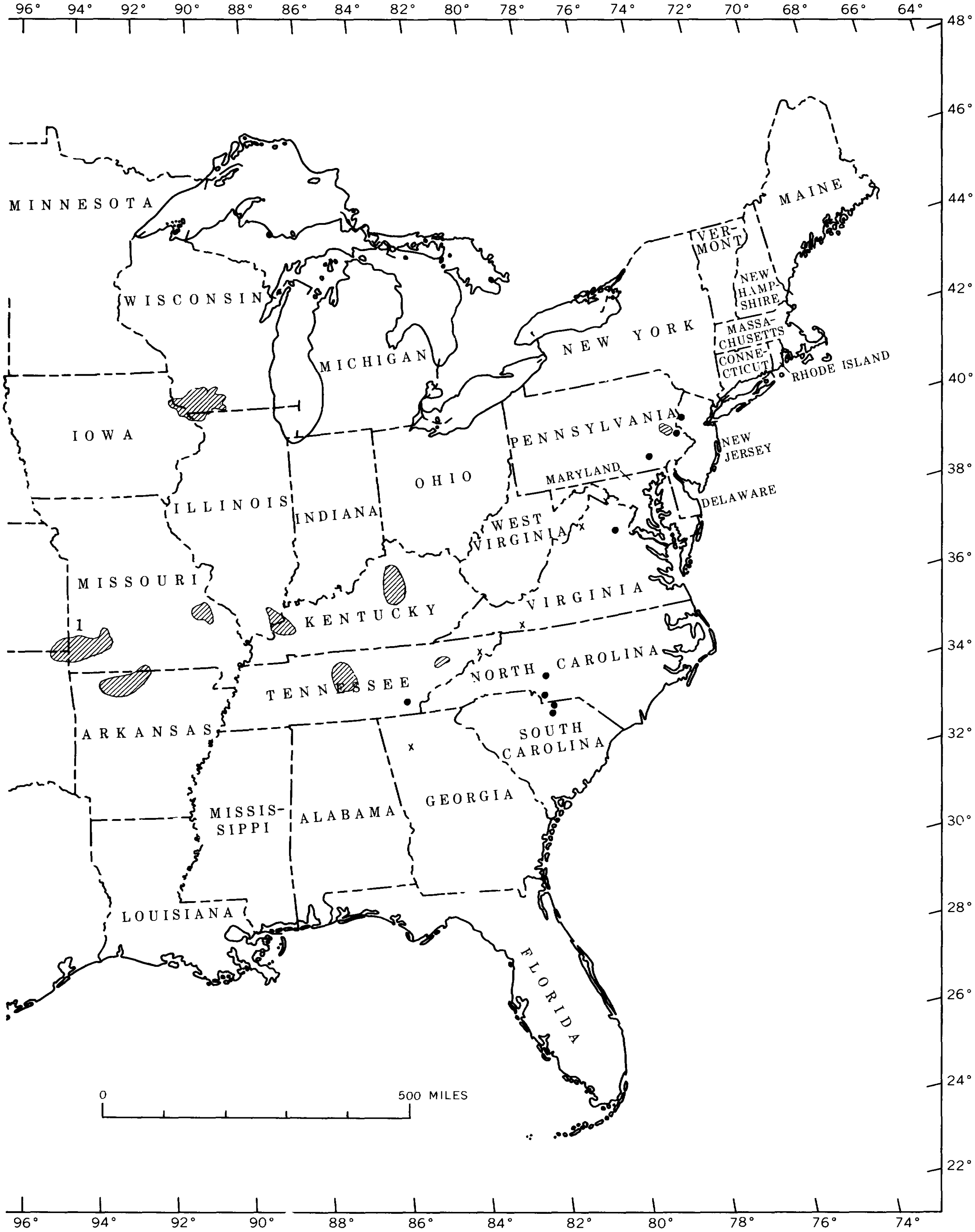


FIGURE 1.—Jasperoid-bearing localities and



provinces of the conterminous United States.

In the Eastern United States the scarcity of jasperoid-bearing mining districts may reflect a scarcity of such districts with readily silicified host rocks and may also reflect a lack of published information on jasperoid in certain districts where jasperoid does exist.

Many jasperoid-bearing mining districts in other countries have been reported in the literature. A few of these are listed below.

Central and South America, Antilles
- Sierra Mojada district, Coahuila, Mex.
- Santa Barbara district, Chihuahua, Mex.
- Santa Eulalia district, Chihuahua, Mex.
- Colquijirca mine near Cerro de Pasco, Peru
- Eastern Cuba
- Western Haiti

Europe
- Vosges Mountains, France
- Rosia district, Tuscany, Italy
- Kostajnika district, Southern Croatia, Yugoslavia

Africa
- Anti-Atlas Mountains, Morocco
- Tsumeb district, South-West Africa
- Postmasburg district, Cape Province
- Pilgrims Rest district, North-East Transvaal

Australia
- Tasmania

Asia
- Tienpaoshan district, Sinkiang Province, China
- South Fergana district, Uzbek, USSR
- Kara Tau Mountains, Kazak, USSR

GEOLOGIC DISTRIBUTION

HOST ROCK

Rocks vary greatly in their susceptibility to replacement by silica. The most susceptible rocks are limestone and dolomite; shale and siltstone are also replaceable, although considerably less so than the calcareous rocks. Siliceous hypabyssal and extrusive igneous rocks and pyroclastics have a susceptibility to replacement by silica comparable to that of shale. Plutonic igneous rocks and metamorphic rocks, except for marble and metavolcanic rocks, appear to be most resistant to siliceous replacement. Sandstones and conglomerates that are impregnated with silica and brecciated rocks that are recemented by silica are, by definition, not jasperoids.

Most of the jasperoid bodies reported in the geologic literature have formed by the replacement of limestone or dolomite. Commonly, other rock types that have been jasperoidized are closely associated with similarly altered calcareous rocks.

Jasperoids occur in host rocks of all ages, from Precambrian to Tertiary; however, the greatest concentration of jasperoid bodies in the Western United States is in rocks of Devonian, Mississippian, and Pennsylvanian ages. Probably, this concentration merely reflects the fact that calcareous rocks of these ages cover a considerably larger area of the Western United States than do calcareous rocks of any other age.

STRUCTURAL CONTROL

Most jasperoid bodies are localized along zones of structural disturbance, such as breccia zones, shear zones, and faults, and this structural control is the best criterion for distinguishing jasperoid from chert or novaculite. Channelways created by these zones of structural weakness provide the plumbing system through which the silica-bearing solutions gain access to the host rocks. In other localities a relatively impermeable caprock has caused widespread lateral migration of silicifying solutions at the contact, resulting in a jasperoid blanket conformable with the host rock. Such bodies may closely resemble bedded chert on the outcrop, but they can be identified as jasperoids by such features as local silicification of the caprock, transgression of the bedding, or by the presence of feeding channels. Layers of jasperoid may also form by selective replacement of certain favorable beds in a carbonate series. The jasperoid in this type of deposit closely resembles bedded chert, but it can be distinguished from chert by the following criteria: (1) jasperoid beds are localized in a relatively small area, in contrast to the broad regional distribution of bedded cherts, and (2) such jasperoid layers commonly grade laterally into larger masses with evident structural control. Jasperoid blankets may also form in the permeable zone along a buried erosion surface, and jasperoid may replace limestone adjacent to old drainage channels and sinkholes beneath such a surface.

Jasperoid deposits are most prevalent in the vicinity of intrusive bodies of igneous rocks, to which they are genetically related. The presence of an intrusive mass, however, is not a prerequisite for the occurrence of jasperoid. Large masses of jasperoid are found far removed from any known intrusive stocks—for example, in the Tri-State district of Kansas, Oklahoma, and Missouri.

GEOLOGIC AGE

The laboratory methods of geochronology that have been applied to plutonic and hypabyssal igneous rocks cannot be applied to jasperoids, and their age is therefore difficult to determine. Most of the jasperoid bodies whose distribution is shown in figure 1 are presumed to be of "Laramide" age (late Mesozoic or early Cenozoic). Jasperiod masses of known Precambrian age have been reported from the Jerome district and the Fort Apache iron district of north-central Arizona, and from Tasmania, Australia; rounded detrital pebbles of jasperoid, presumably of Permian age, have been found in the Triassic Shinarump Member of the Chinle Formation and in the Jurassic Morrison Formation in the northern Colorado Plateau; and jasperoid replaces Tertiary marine limestones and associated volcanic rocks in Cuba and Haiti (Goddard and others, 1947, p. 34–37; Park, 1942, p. 81–82, 92–93). There is a suggestion that jasperoid bodies may be forming today beneath some of the hot springs in the Yellowstone Basin. The waters of some of these springs are rich in calcium bicarbonate and deficient in silica; these chemical characteristics strongly indicate contact with carbonate rocks at depth, and it seems a reasonable hypothesis that they lost silica to these rocks as they leached calcium carbonate (D. E. White, written commun., 1957).

PHYSICAL PROPERTIES OF JASPEROID

MEGASCOPIC FEATURES

Jasperoid varies widely in physical appearance; commonly, a single body contains several distinguishable varieties of jasperoid with distinctive colors, textures, and assemblages of associated minerals.

COLOR

Many jasperoids range in color from white through various shades of gray to coal black; this is particularly true of unoxidized varieties. An iron content of 0.1–1 percent generally is sufficient to impart various shades of brown, yellow, orange, and, less commonly, red and pink to most oxidized jasperoid outcrops. Less colorful outcrops are common in areas where the iron content of the jasperoid is unusually low, or where the jasperoid is so dense that little or no oxidation of the iron present has taken place. In some jasperoid the pigmentation is primary and colors the rock below the zone of surface oxidation.

The relative frequency of various color occurrences in my suite of oxidized jasperoid samples, from more than 50 localities, is shown in table 1. Most of the samples are mottled, veined, streaked, or banded with more than one color, which accounts for the total of the various colors being higher than the total number of samples. The prevailing colors of fresh exposures of oxidized jasperoid are shades of gray, followed by light to medium brown and orange. The prevailing colors of weathered jasperoid are medium brown, light brown, and orange, followed by dark brown, reddish brown, and dark gray. Red and pink jasperoids are relatively uncommon, as may be seen in table 1.

TABLE 1.—*Colors of fresh and weathered surfaces of oxidized hypogene jasperoid samples from more than 50 localities in the United States*

[The 12 most common colors are listed, in order of decreasing frequency of occurrence]

Fresh surface (267 samples)		Weathered surface (205 samples)	
Color	Number of samples	Color	Number of samples
1....Medium gray	109	1....Medium brown	68
2....Medium brown	56	2....Light brown	47
3....Dark gray-black	54	3....Orange	40
4....Light brown	54	4....Medium gray	25
5....Orange	52	5....Dark brown	23
6....White to light gray	35	6....Reddish brown	22
7....Reddish brown	27	7....Dark gray-black	20
8....Yellow	24	8....Dark red	16
9....Medium red	23	9....White to light gray	14
10....Pink	22	10....Yellow	11
11....Dark red	20	11....Medium red	10
12....Olive gray	20	12....Olive gray	10

My collection contains only 35 samples of unoxidized jasperoid, from 15 localities. Dark gray is the predominant color of this suite, followed by medium gray and white. Individual specimens also show various shades of olive gray, brown, yellowish gray, and grayish orange.

I also have 11 samples of supergene jasperoid that are gradational into siliceous gossans. These samples are a variety of dark colors, including dark gray, dark brown, dark yellowish orange, dark reddish brown, and dark red.

TEXTURE

Jasperoid bodies are resistant to weathering and commonly exhibit prominent rough outcrops (fig. 2A). Where their distribution is controlled by faults, these outcrops tend to stand up as uneven walls or "reefs." Jasperoid is both hard and brittle and therefore is commonly highly fractured and brecciated in zones of structural instability. This shattering causes both characteristic rough outcrops and aprons of angular sharp-edged talus blocks below such outcrops. Gilluly (1932, p. 98) described jasperoid bodies, in the Mercur and Ophir districts of Utah, as being cut by many randomly curved and slickensided fracture surfaces that terminate abruptly at the contact with the country rock, suggesting differential movement of blocks within the body after its solidification.

Another distinctive feature of jasperoid exposures in many districts is the abundance of vugs. These range in size from microscopic openings to

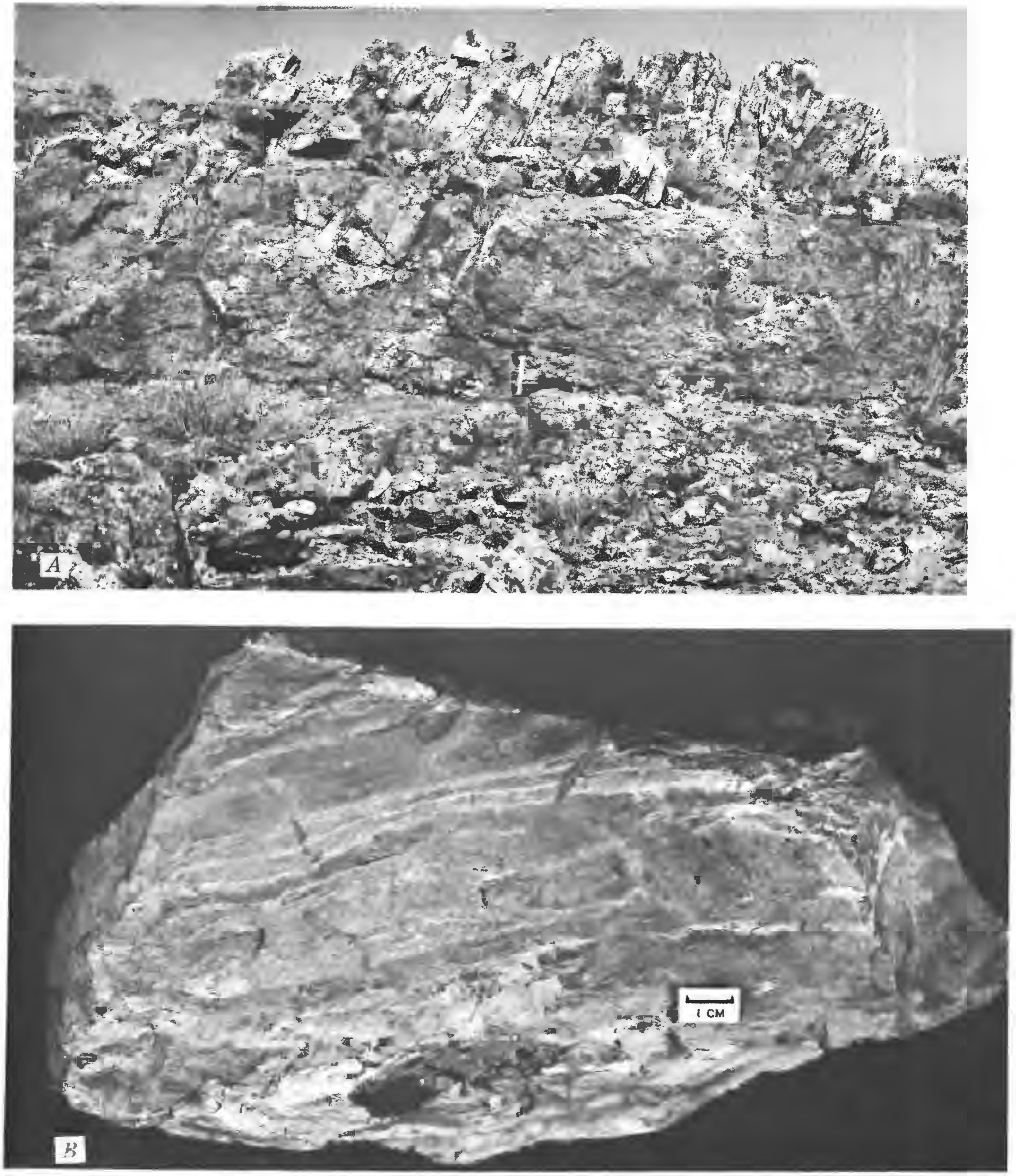


FIGURE 2.—*A*, Typical outcrop of jasperoid, Lake Valley district, New Mexico (photograph by E. J. Young). *B*, Hand specimen of jasperoid showing preservation of primary bedding texture.

cavities several inches in diameter. The larger vugs characteristically are lined with crystals of quartz or calcite. Vugs in jasperoid commonly show a random orientation and distribution, but many are restricted to well-defined zones. Locally, they have a strong preferred orientation, forming lenticular voids parallel to the walls of the jasperoid mass in which they occur.

Many jasperoid bodies have sharp, well-defined contacts with their host rocks. Some have transitional contacts, grading outward through a zone of unreplaced fragments of host rock in jasperoid into a zone of shattered host rock cut by anastomosing veinlets of jasperoid, and finally into a zone of quartz grains or slender, doubly terminated quartz crystals randomly disseminated through the host. Others are bordered by a zone of soft friable carbonate rock, which breaks down on weathering so that the contact is not exposed at the surface.

In some places jasperoid differs strikingly in appearance and texture from its host. Elsewhere, the color, texture, and primary bedding of the host rock are faithfully preserved in the replacing jasperoid (fig. 2*B*). Extensive bodies composed exclusively of a single homogeneous type and generation of jasperoid are rare. Most jasperoid masses consist of several distinct varieties of jasperoid, in which the oldest generation has been fractured or brecciated and then recemented by a second generation. This second generation, in turn, has been cut by a third generation, and so on, so that it is not uncommon to find five or more distinct ages and types of jasperoid in large exposures. In most such bodies, only the oldest generation is a true jasperoid, strictly speaking, formed by replacement of the host. The younger generations have merely filled fractures, without replacement. It is customary, however, to refer to the entire mass as jasperoid.

The typical texture of jasperoid is aphanitic, almost glassy, but fine-grained phaneritic jasperoid with a "sugary" texture is common in some areas. Locally, jasperoid with an average grain size of as much as 1 millimeter is found. In mining districts where relatively coarse grained jasperoid forms the host rock for disseminated sulfide minerals, or where jasperoid is disseminated in a carbonate host rock, leaching in the zone of oxidation has produced light friable porous masses of "honeycomb quartz." Such masses from the Lowell mine at Bisbee, Ariz., were described by Ransome (1904, p. 131) and from the Bingham district, Utah, by Boutwell (1905, p. 68, 118, 202).

ASSOCIATED MINERALS

Jasperoid that constitutes the host rock for ore bodies commonly contains a wide variety of visible accessory ore minerals. Considerably fewer minerals, recognizable in hand specimen, are common in oxidized jasperoid not closely associated with ore. They are chalcedony, calcite, dolomite, hematite, limonite, "manganese oxides," and, more rarely, pyrite, fluorite, barite, siderite, opal, chlorite, and apatite. These minerals occur either disseminated through the jasperoid matrix or concentrated in veinlets and on the walls of vugs.

Primary jasperoid, produced by hydrothermal alteration, commonly exhibits oxides of iron and manganese as surface stains and fracture coatings, and, locally in the zone of oxidation, it contains scattered iron oxide pseudomorphs after original sulfides. Secondary or supergene jasperoid, produced by siliceous alteration from ground water during weathering and oxidation of an ore body, commonly contains oxides of iron and manganese intimately mixed with, and disseminated through, the siliceous matrix; it rarely exhibits sulfide pseudomorphs.

MICROSCOPIC FEATURES

Thin sections of jasperoid, examined with a petrographic microscope, exhibit considerable variation in grain size, a wide range of textures, and a much more extensive suite of accessory minerals than is visible to the naked eye. A jasperoid sample that in hand specimen appears to be simple, dense, and relatively homogeneous may reveal, when examined under the microscope, a complex history, starting with replacement, followed by successive brecciation and recementation, and ending with weathering and oxidation.

GRAIN SIZE

The mean grain size and size range of grains in recognizable distinct varieties of jasperoid in 200 thin sections were recorded and plotted on a scatter diagram (fig. 3). Size range was recorded as the ratio of the mean diameter of the largest grains to that of the smallest. The high concentration of points in the lower left corner of this diagram shows that jasperoid is commonly very fine grained, having a mean grain size of <0.05 mm, and is relatively homogeneous, with a ratio of largest grain to smallest grain of $<10{:}1$. It is the abundance of this type of jasperoid that makes it so difficult to distinguish between jasperoid and chert in hand specimens. The nature of the mean size and size-range distributions of these samples is further shown by the histograms in figure 4. The class intervals chosen

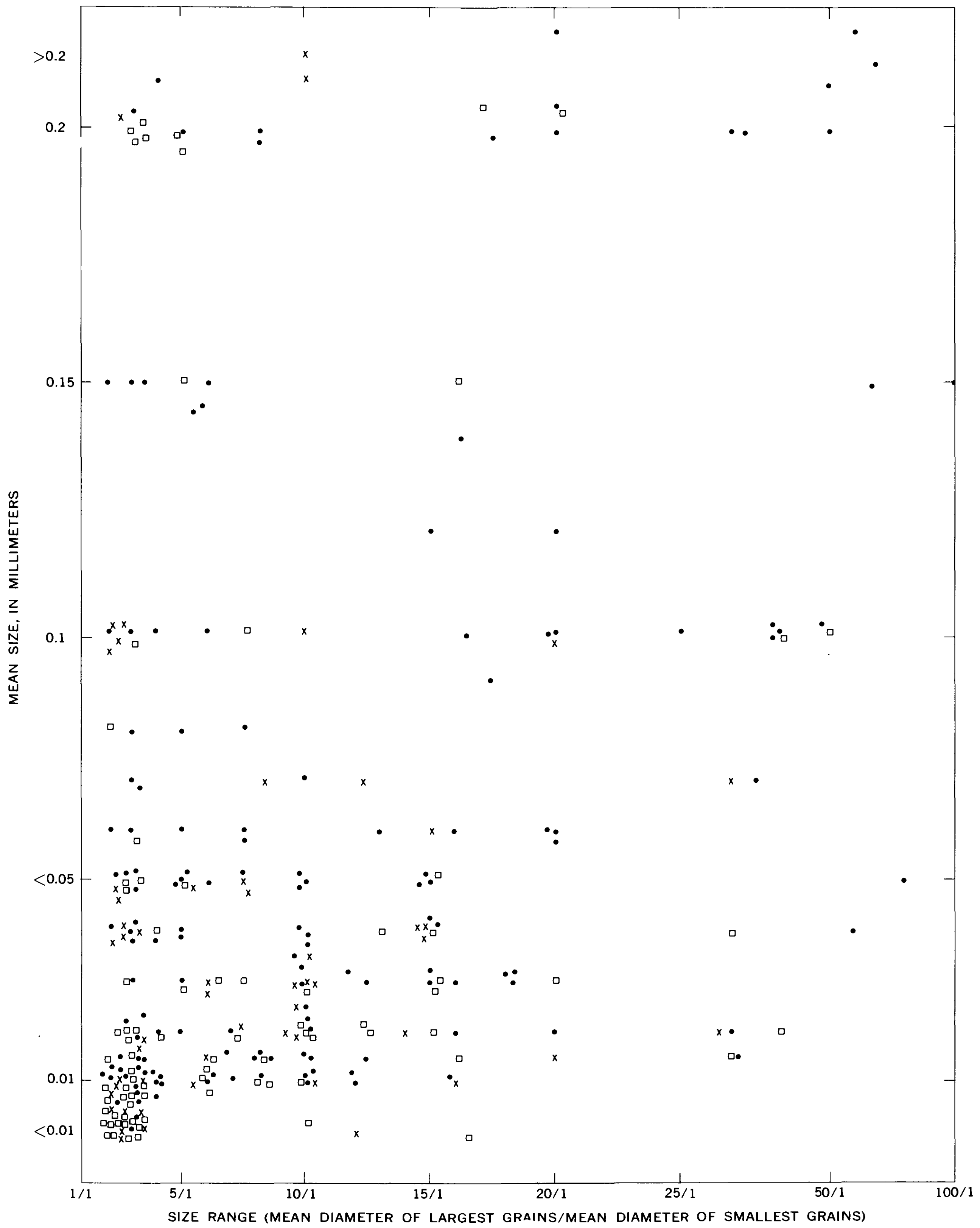


FIGURE 3.—Mean size and size range of jasperoid grains in 200 samples. □, unfavorable; ●, favorable; ×, not known.

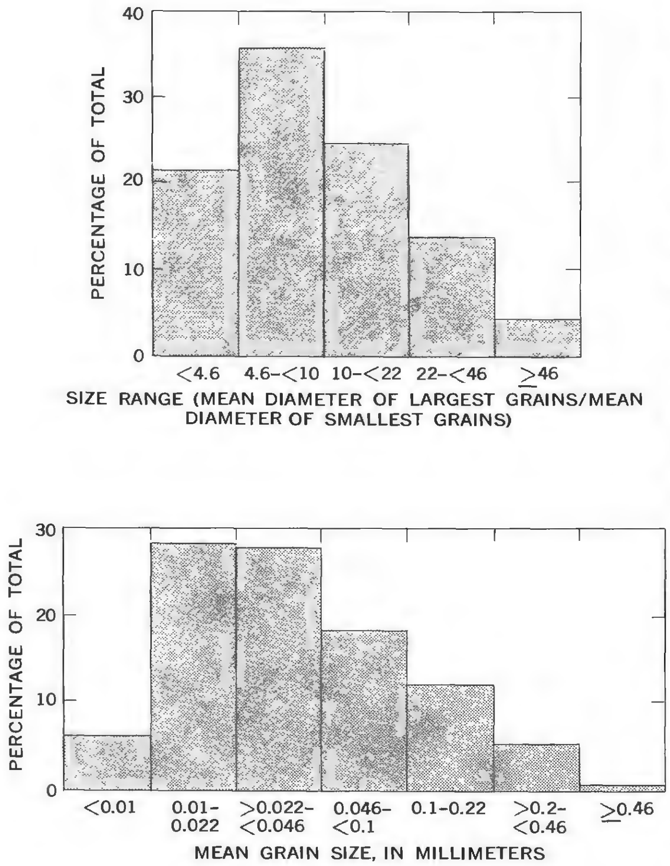


FIGURE 4.—Frequency distribution of mean size and size range of jasperoid grains.

for these histograms are approximately equal on a logarithmic scale, except for the two open-end classes. The resulting distributions after the logarithmic transformation still show a pronounced positive skewness, thus emphasizing that most jasperoid is extremely fine grained and relatively homogeneous.

FABRIC TEXTURE

The shapes of jasperoid grains and their mutual boundaries produce several different characteristic textural patterns.

One of the most common microtextures in jasperoid consists of highly irregular grains that are tightly interlocked—in somewhat the same way as are the pieces of a jigsaw puzzle (fig. 5). This texture is typical of extremely fine grained and relatively homogeneous varieties of jasperoid, and probably represents the crystallization of an original silica gel into quartz. Relatively coarse grained jasperoid may also exhibit "jigsaw-puzzle" texture. Such coarse jigsaw-puzzle jasperoid is commonly associated with masses of fibrous chalcedony, filling voids in an older generation of jasperoid.

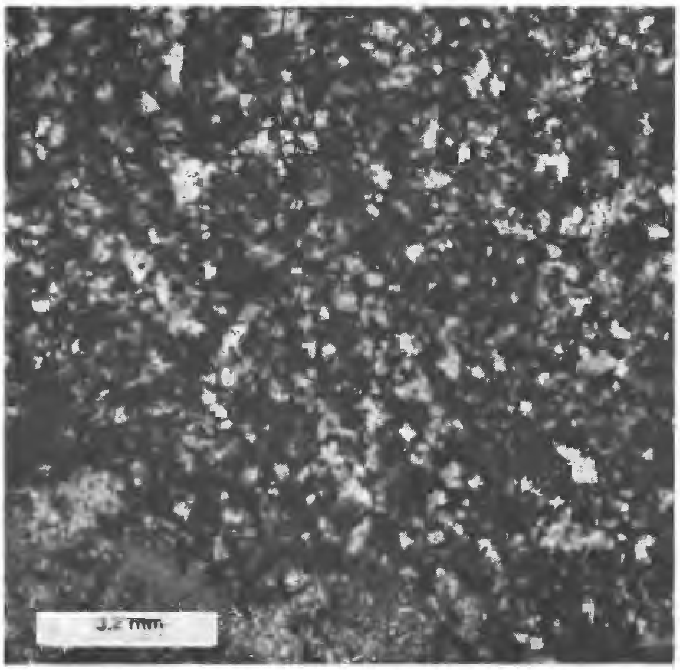


FIGURE 5.—Typical jigsaw-puzzle texture in aphanitic jasperoid. Crossed polars. × 100.

Jasperoid grains that are somewhat irregular at their boundaries but lack the deep sinuous indentations and amoeboid forms that characterize the jig-

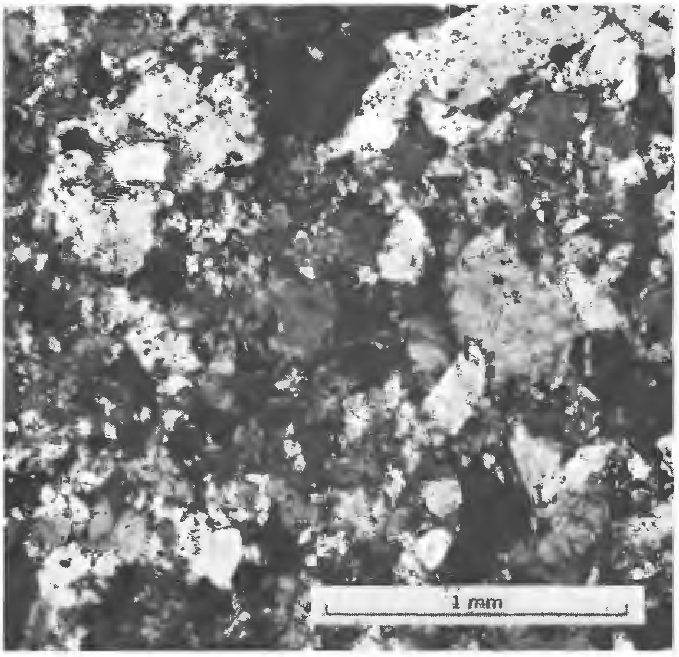


FIGURE 6.—Typical xenomorphic texture in coarse-grained heterogeneous jasperoid. Crossed polars. × 40.

saw-puzzle texture produce a textural pattern very similar to the xenomorphic texture commonly observed in nonporphyritic igneous rocks. This texture is characteristic of many jasperoids that have a heterogeneous grain-size distribution in which smaller grains form inclusions in, or fill interstices between, larger grains (fig. 6), and it may also occur in jasperoids that have relatively homogeneous grain-size distribution. Textural gradations from jigsaw puzzle to xenomorphic are common within a single jasperoid type, and these two textural varieties characterize most jasperoids.

The granular texture that is typical of fine-grained detrital sedimentary rocks is also found in a few jasperoids of replacement origin. The grains are all about the same size, are nearly equant, and have smooth, simple boundaries (fig. 7*A*). Rarely, when the individual granules are examined under the microscope with crossed nicols, they do not extinguish as a unit but show a peculiar hourglass type of extinction in which different quadrants of a granule extinguish in different positions (fig. 7*B*). Granular texture is relatively rare in jasperoid, although it is characteristic of silicified siltstone, which may be indistinguishable from jasperoid in hand specimens.

Masses or veinlets of jasperoid quartz that have formed from original chalcedony may exhibit a peculiar "feathery" texture (fig. 8*A*) or a "cross-fiber" texture, suggestive of chrysotile veinlets in serpentine of the type shown in figures 8*B* and *C*. These textures in quartz are rare, however, because chalcedony seems to be a stable mineral in most jasperoids.

Another type of texture that is common in the coarser grained varieties of jasperoid consists of abundant elongated grains with a length-to-width ratio of 3:1 or greater. Such grains are elongated parallel to the *c* axis, and some show crystal faces. They are randomly distributed in a matrix of smaller, nearly equant, anhedral grains, and commonly give the appearance of a crude mesh or network. This reticulated texture (fig. 9) is useful in distinguishing jasperoid from other siliceous bodies, such as chert and novaculite, because it seems to be peculiar to jasperoid. Unfortunately, only a relatively small proportion of jasperoids has this texture; therefore, its absence in a sample cannot be considered as evidence that the rock is not a jasperoid. The origin of reticulated texture in jasperoid has been discussed by Lindgren (1901, p. 678; quoted on p. 2 of present report). His statements therein appear to be valid, except for the implication that all jasperoids form in a manner that produces this texture; actually, only a small proportion of them seem to do so. The presence of reticulated texture in jasperoid is evidence of the original deposition of silica as crystalline quartz rather than as a colloidal gel and is most common in bodies whose contacts with the host rock are gradational.

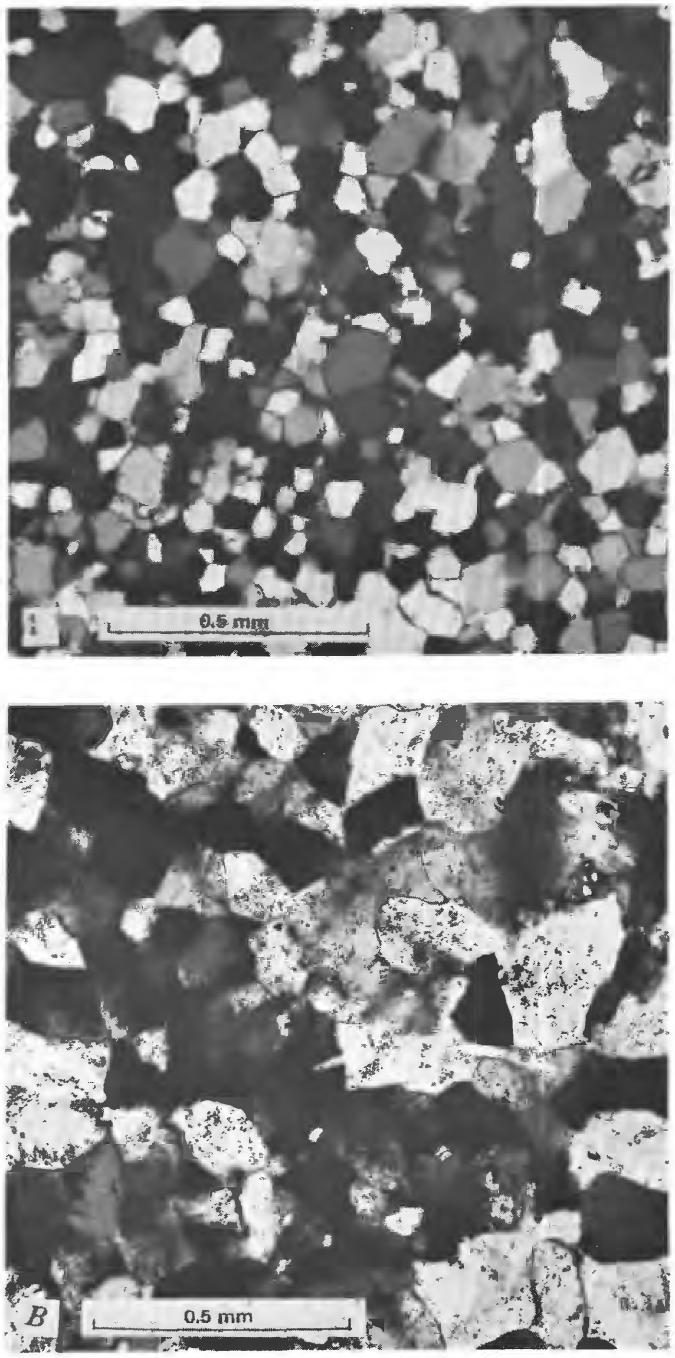


FIGURE 7.—Granular texture. *A*, Granular texture in Precambrian jasperoid. Crossed polars. × 68. *B*, Granular jasperoid with hourglass extinction. Crossed polars. × 68.

The first phase in the formation of this type of

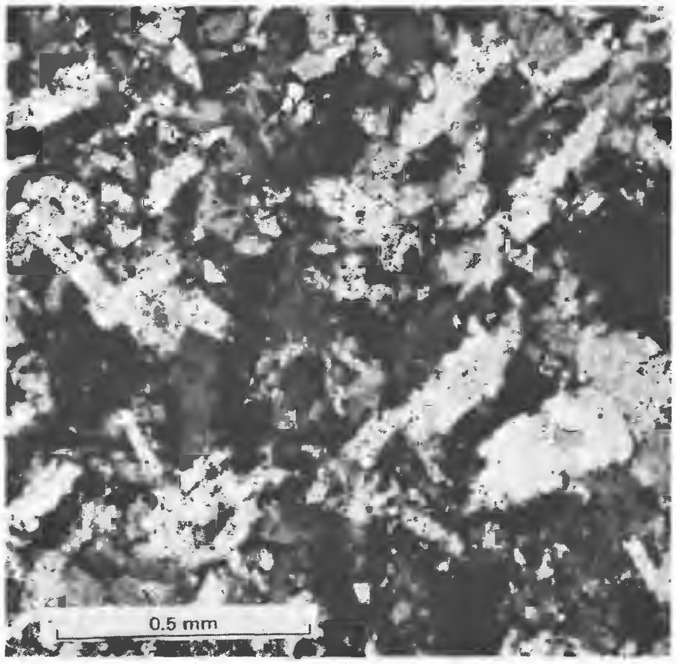


FIGURE 9.—Reticulated texture in jasperoid. Crossed polars. × 68.

jasperoid is commonly a recrystallization or marmorization of limestone that results in the formation of numerous coarse grains of calcite. Accompanying, or closely following, this recrystallization is the formation of small grains and slender euhedral crystals of quartz randomly scattered through the calcite (fig. 10A). As silicification proceeds, there is a selective replacement, outward from tiny fractures (fig. 10*B*), of the smaller calcite grains by fine-grained aggregates of anhedral quartz. Finally, only irregular remnants of the coarse calcite grains remain as inclusions in the jasperoid matrix (fig. 10*C*). The jasperoid quartz formed by this process is commonly clouded by tiny dust-sized particles of calcite, a few microns in diameter (fig. 11). These particles are characteristically round or oval in section, and, rather than being tiny unreplaced remnants of the original host rock, they appear to have exsolved as the quartz crystallized. Such carbonate particles are also found in jasperoid that has jigsaw-puzzle and xenomorphic textures. Wherever the particles occur, they provide evidence of the origin of the enclosing quartz by replacement of a carbonate host rock.

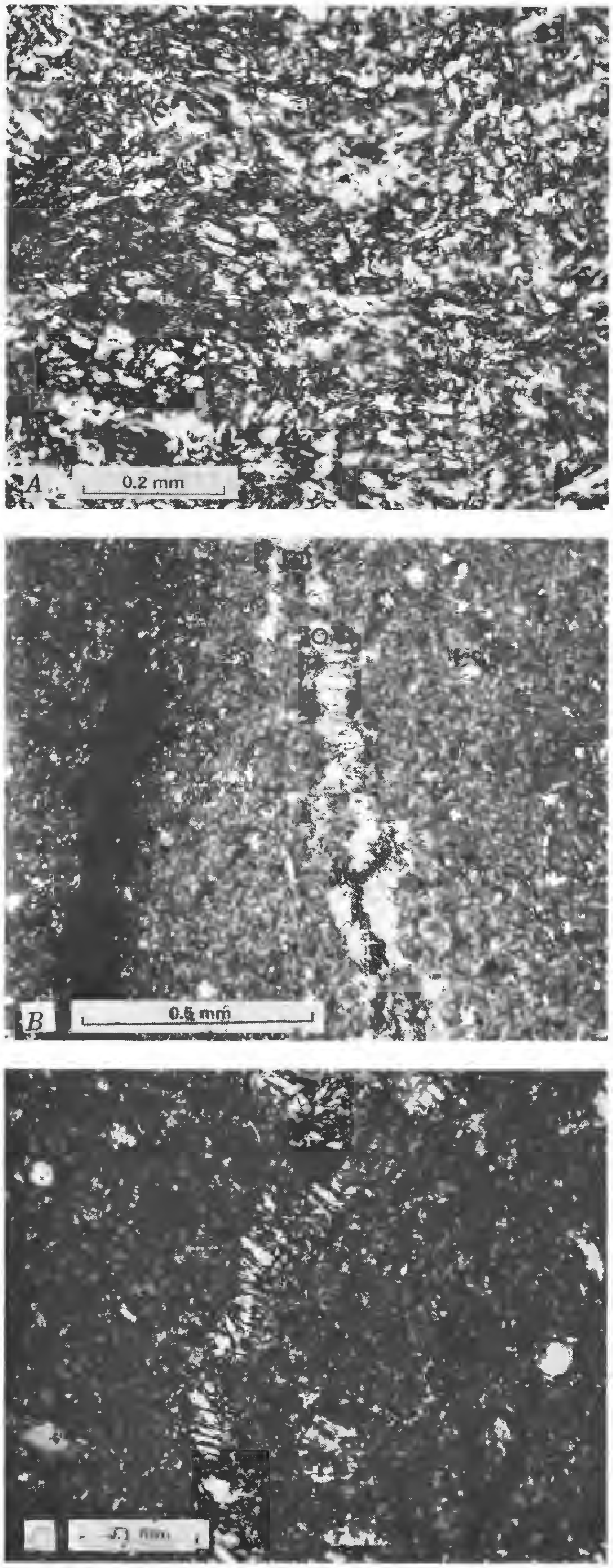


FIGURE 8.—Feathery and fibrous textures. *A*, Feathery texture in jasperoid quartz recrystallized from chalcedony. Crossed polars. × 100. *B*, "Crossfiber" texture in quartz veinlet (Q). Crossed polars. × 68. *C*, Detail of quartz veinlet shown in *B*. Crossed polars. × 170.

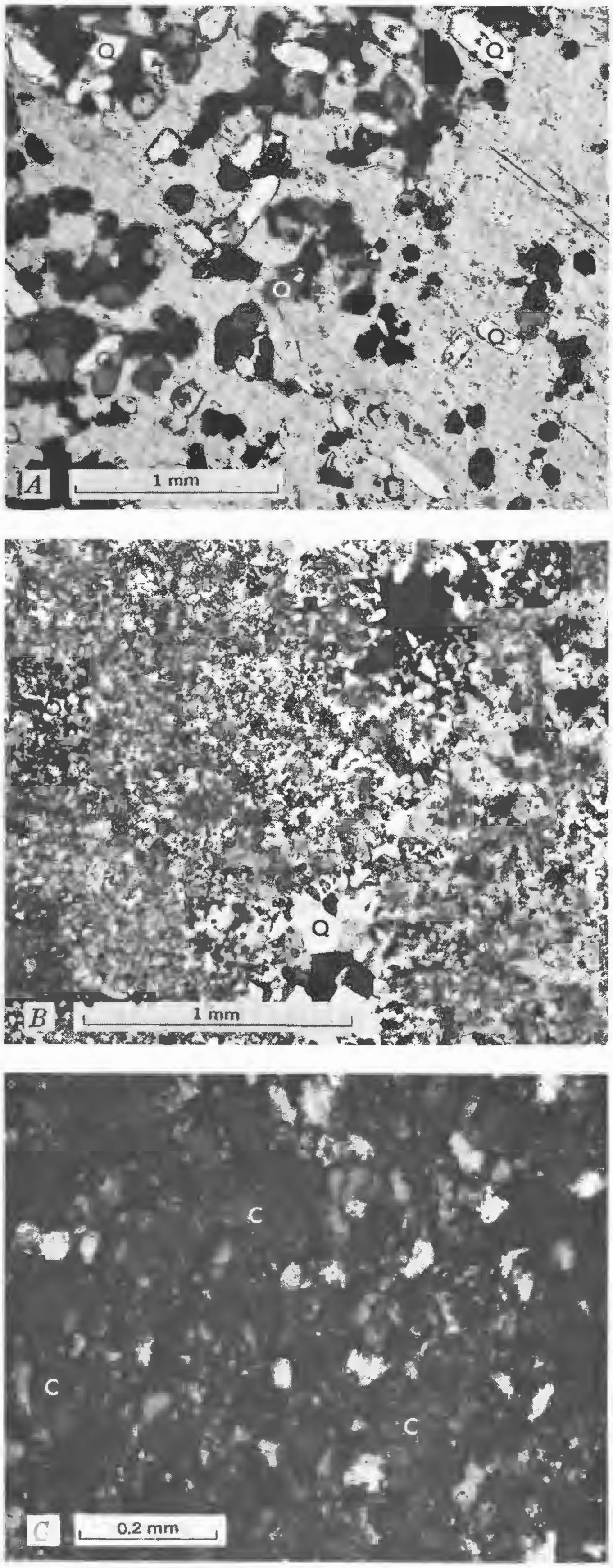


FIGURE 10.—Stages in the replacement of limestone by jasperoid. *A*, First stage, disseminated quartz grains and crystals (Q) in a matrix of coarse recrystallized calcite. Crossed polars. × 30. *B*, Second stage, selective replacement of smaller calcite grains by fine-grained anhedral quartz aggregates (Q). Crossed polars. × 40. *C*, Third stage, remnants of coarse calcite (*C*) in a jasperoid matrix. Crossed polars. × 100.

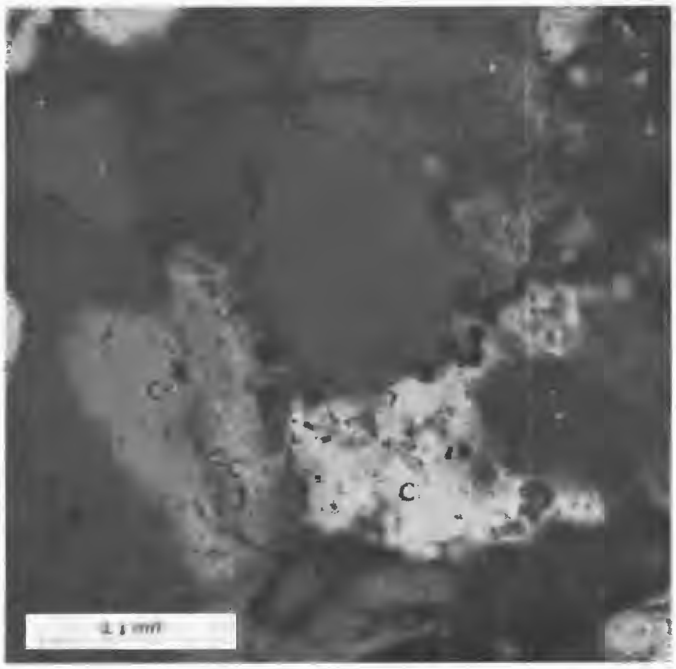


FIGURE 11.—Typical calcite dust-sized particles in jasperoid. Crossed polars. × 250.

The replacement process just outlined is common in limestone, but for some reason the growth of euhedral quartz crystals seems to be inhibited by a dolomitic host rock, although the recrystallization of the host rock and the selective replacement of smaller grains by aggregates of anhedral quartz (fig. 12) proceed in a manner similar to that outlined for limestone. Dolomite is more resistant to replacement by silica than is limestone, and unreplaced original dolomite crystals may be preserved in a completely jasperoidized limestone (fig. 13). Where aphanitic jasperoid, of the type shown in figure 5, comes in contact with a carbonate host rock, that contact is normally sharp and well defined (fig. 14), in contrast to the gradational contacts just discussed. Sharp contacts of this type probably are indicative of rapid precipitation of silica, as a gel, from solutions that were highly supersaturated with silica.

Evidence of the colloidal origin of some jasperoid may be preserved in delicate repeated colloform

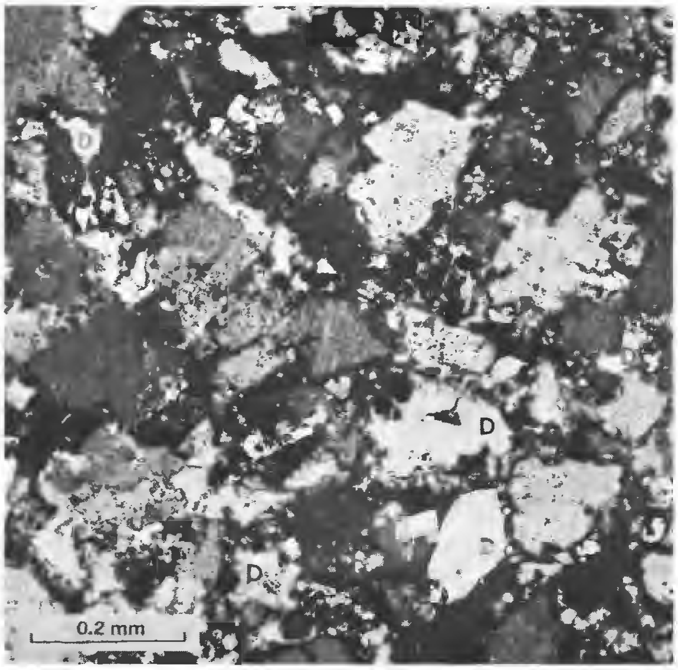


FIGURE 12.—Incipient jasperoid in dolomite (note similarity to fig. 10*B*). Crossed polars. × 100.

bands, which bear no relation to existing grain boundaries or textural variations and which disappear under crossed nicols (fig. 15). This type of texture has its counterpart in zonally arranged inclusions of allophane or carbonate particles that preserve the euhedral outlines of original seed crystals of quartz in a mass composed of an aggregate of coarse anhedral grains (fig. 16). These zoned inclusions around euhedral cores provide good evidence that the early jasperoid was deposited directly as quartz rather than as a gel. They are most common in late quartz that fills veinlets or voids in an older generation of matrix jasperoid, but they may also occur within a matrix of coarse jasperoid.

Where more than one generation of quartz is present in a jasperoid, as is generally true, the younger generations are commonly coarser grained and more heterogeneous than the oldest generation (fig. 17); but in some jasperoids the younger quartz is finer grained than the matrix (fig. 18). Some chert layers in limestone are locally brecciated and recemented by younger quartz (fig. 19).

ACCESSORY MINERALS

The accessory minerals associated with jasperoid quartz may be divided into three groups on the basis of their age relative to the main period of silicification. These groups are (1) early—older minerals, remnants of unreplaced host rock or accessory minerals from the host rock preserved in the jasperoid; (2) contemporary—minerals formed penecontemporaneously with silicification of the host rock; and (3) late—the large group of minerals that were

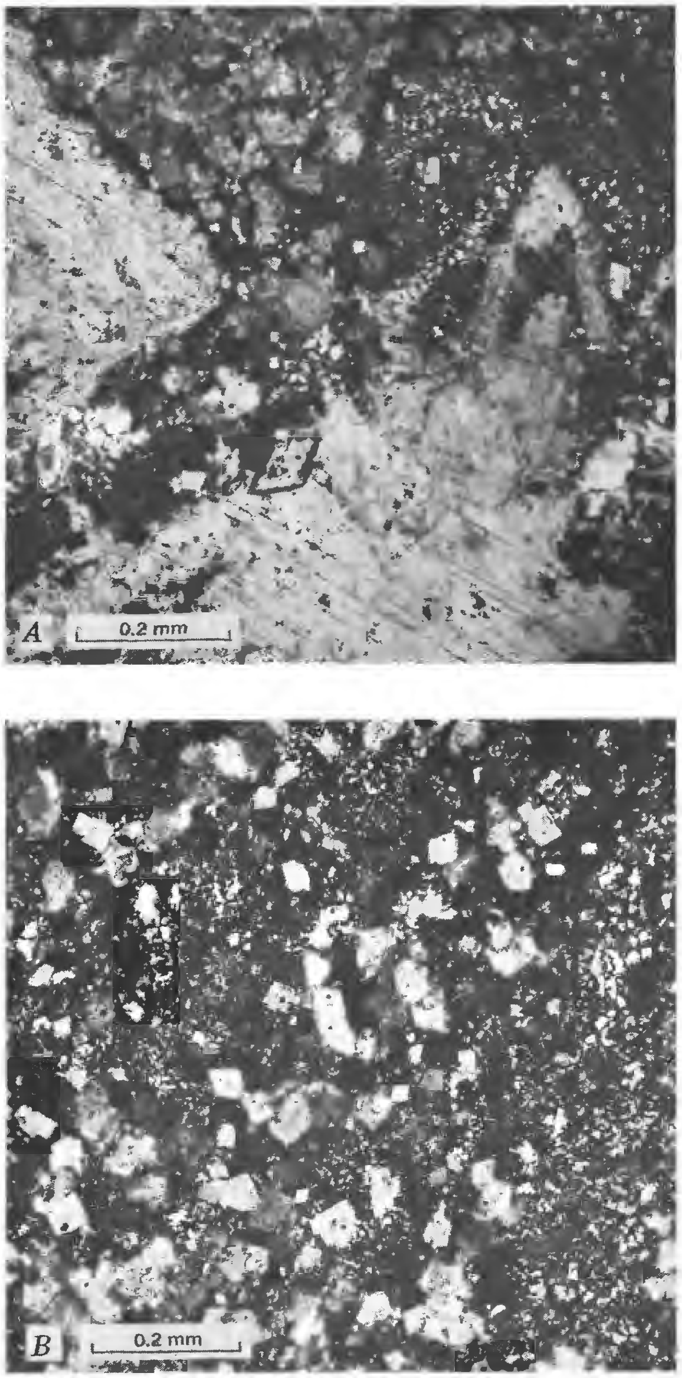


FIGURE 13.—Selective replacement of calcite containing dolomite, by jasperoid. *A*, Dolomite rhomb in coarse calcite remnant in jasperoid matrix. Crossed polars. × 100. *B*, Disseminated dolomite rhombs in jasperoid matrix, which has replaced calcite (same section as that shown in *A*). Crossed polars. × 100.

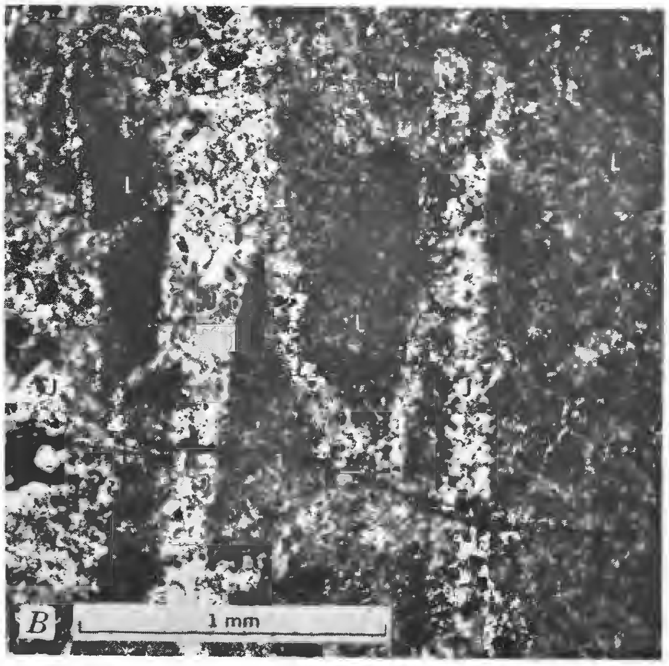


FIGURE 14.—Jasperoid contact with limestone. *A*, Abrupt contact between jasperoid (J) and limestone (L), showing later brecciation and cementation by coarse calcite (C). Specimen from the Egan Range, Nev. Natural size. *B*, Jasperoid (J) contact with limestone (L). Same specimen as that shown in figure *A*. Crossed polars. × 40.

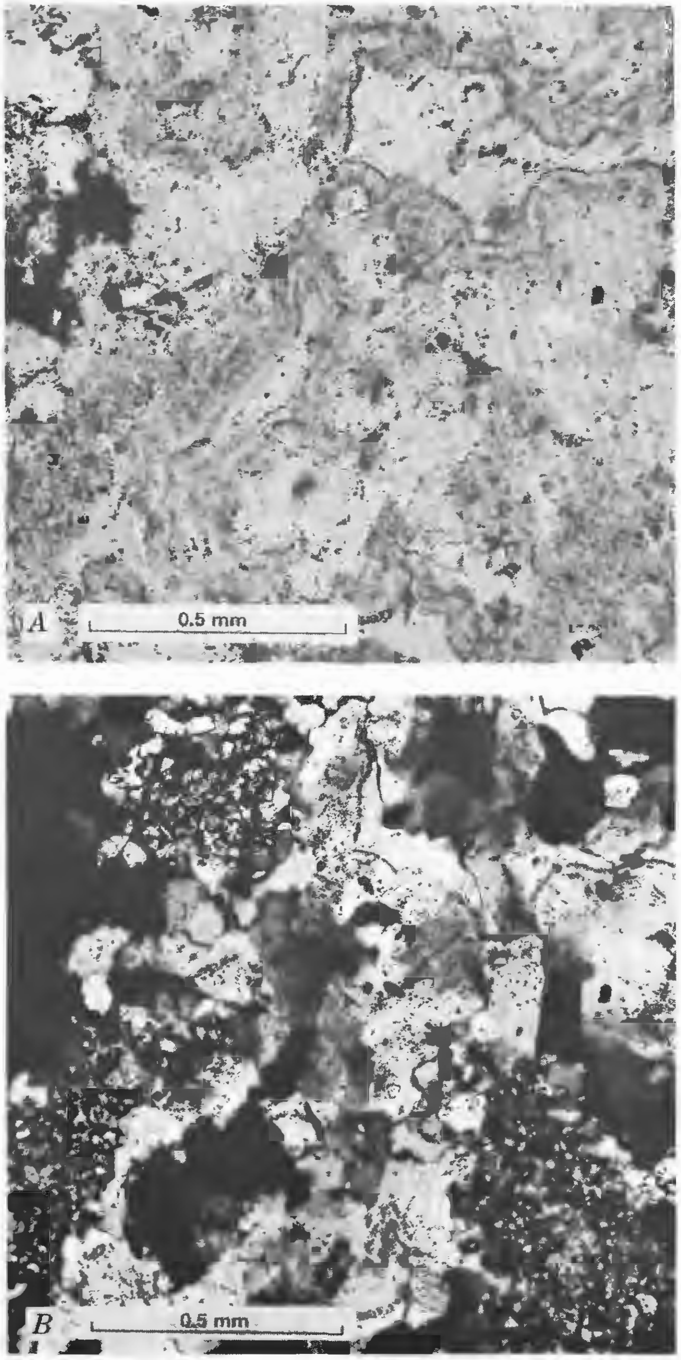


FIGURE 15.—Ghost colloform banding. *A*, Plane polarized light. × 68. *B*, Crossed polars. × 68.

emplaced after the initial silicification; this group includes both minerals deposited from late hypogene hydrothermal solutions and strictly supergene minerals formed as a result of weathering and oxidation. The distinction between the two categories of minerals included in the third group may be clear where both outcrop samples and samples taken from

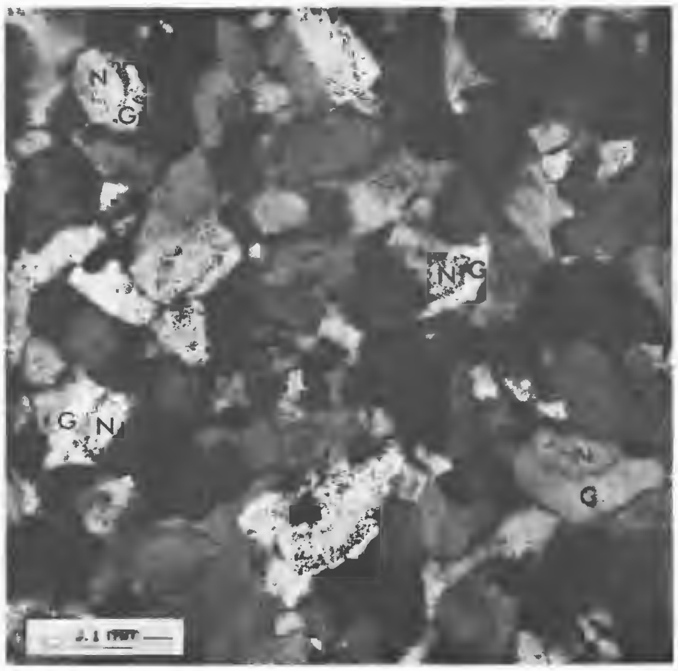


FIGURE 16.—Zoned allophane inclusions outlining original quartz crystal nuclei (N) and growth stages (G), in coarse xenomorphic jasperoid. Crossed polars. × 170.

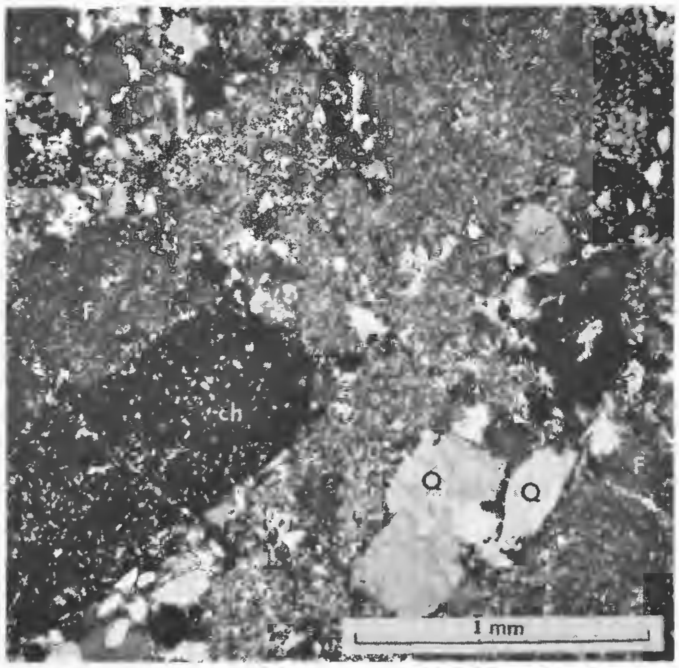


FIGURE 17.—Chert (ch) and fine-grained jasperoid (F) cemented by coarser grained jasperoid (C), with late coarse quartz (Q). Crossed polars. × 40.

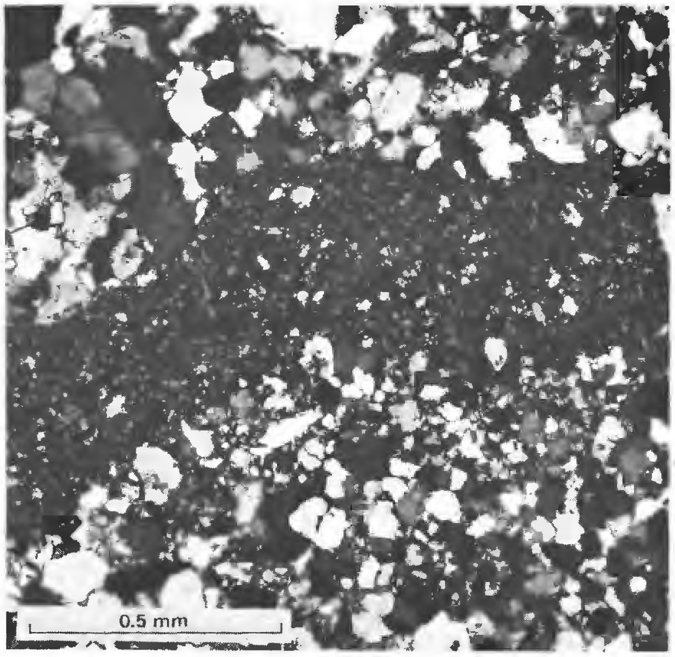


FIGURE 18.—Veinlet of fine-grained quartz cutting coarse-grained jasperoid matrix. Crossed polars. × 68.

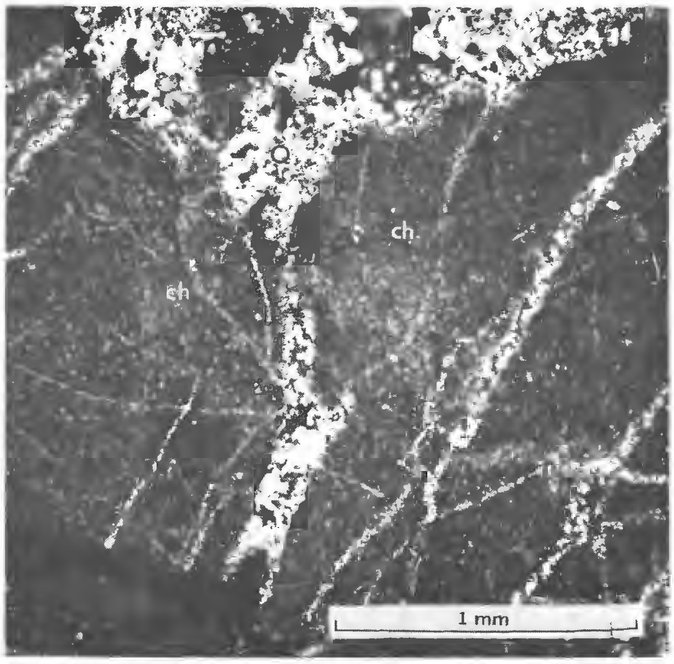


FIGURE 19.—Brecciated chert (ch) cut and cemented by coarser quartz (Q). Crossed polars. × 40.

below the zone of oxidation are available from the same jasperoid body; however, this distinction becomes much more difficult to make where only the outcrop can be sampled. Most of the samples I studied are outcrop samples; hence, I made no attempt to differentiate between these two categories. Table 2 gives the paragenesis, in terms of these three groups, of accessory minerals that I identified in thin sections of 250 jasperoid samples collected from about 40 different mining districts and unmineralized localities.

ALLOPHANE

Allophane is a common, though minor, constituent of jasperoid quartz. It forms tiny inclusions, a few microns in diameter, embedded in the quartz grains. Where more than one generation of quartz is present, the allophane is most highly concentrated in the oldest generation. Allophane particles may be zoned either in hexagonal patterns around original quartz crystal cores (fig. 16) or in wavy colloform patterns (fig. 15*A*). These zonal patterns, where present, are useful indicators of the form in which the silica was originally deposited; colloform patterns suggest crystallization of jasperoid from a colloidal silica gel, whereas hexagonal patterns indicate deposition of silica directly in the form of quartz crystals.

ANKERITE

Ankerite is very sparse in jasperoid, but where it occurs, it is in the form of relict inclusions. It is indicative of a hydrothermal carbonate phase of host-rock alteration preceding silicification.

BARITE

Barite is relatively common in jasperoids, particularly those associated with ore deposits; however, in regions characterized by abundant barite, such as north-central Nevada, it is found in jasperoid bodies far removed from sulfide deposits. It may form granular aggregates or euhedral crystals older than the quartz, it may be disseminated through the matrix in small grains deposited penecontemporaneously with the silica, or it may be present in younger masses and veinlets (fig. 20) and as crystals that line vugs.

BEIDELLITE (?)

Small aggregates and disseminated particles of a mineral belonging to the montmorillonite group, tentatively identified as beidellite, were observed in a few jasperoid samples. This mineral is approximately contemporaneous with the matrix quartz in which it occurs; but positive identification could not be made with the petrographic microscope, and the mineral is not sufficiently abundant to furnish a sample for X-ray identification.

TABLE 2.—*Accessory minerals found in jasperoids during the present study, together with their composition, relative age, and relative abundance*

[The minerals were identified, by T. G. Lovering, in thin sections of 250 jasperoid samples collected from about 40 mining districts and unmineralized localities]

Mineral	Composition	Age and relative abundance [1]		
		Early	Contemporary	Late
Allophane	Al_2O_3, SiO_2, nH_2O		X	
Ankerite	$CaO \cdot (Mg,Fe)O \cdot 2CO_2$	x		
Barite	$BaO \cdot SO_3$	x	x	x
Beidellite?	$Al_2O_3 \pm SiO_2 \cdot 3 \pm H_2O$		x	
Biotite	$K_2O \cdot 4(Mg,Fe)O \cdot 2(Al,Fe)_2O_3 \cdot 6SiO_2 \cdot H_2O$	x		
Brochantite	$HCuO \cdot SO_3 \cdot 3H_2O$			x
Calcite	$CaO \cdot CO_2$	X	x	x
Carbon	C	x	x?	
Cerussite	$PbO \cdot CO_2$			x
Chalcedony	SiO_2	x	x	x
Chalcopyrite	$CuFeS_2$		x	
Chlorapatite	$9CaO \cdot 3P_2O_5 \cdot CaCl_2$	x		
Chlorite	$H_4Mg_3Si_2O_9$–$H_4Mg_2Al_2SiO_9$	x		x
Dickite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	x		
Dolomite	$CaO \cdot MgO \cdot 2CO_2$	x	x?	
Epidote	$Ca_2(Al,Mn,Fe)_3Si_3O_{12}(OH)$	x		
Fluorite	CaF_2			x
Galena	PbS		x	x
Glauconite	SiO_2,Al_2O_3,Fe_2O_3,FeO,MgO,K_2O,H_2O	x		
Goethite	$Fe_2O_3 \cdot H_2O + nH_2O$		x	x
Halloysite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$			x
Hematite	Fe_2O_3	x	x	x
Hydromica	$(Al,Fe)_2(Al,Si)_4 \cdot K<\cdot5(OH)_2 \cdot nH_2O$		X	
Jarosite	$K_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$			x
Kaolinite	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$	X	x	x
Limonite	$Fe_2O_3 \cdot nH_2O$		x	x
Lussatite	$SiO_2 \cdot nH_2O$ (?)			x
Magnetite	$Fe_2O_3 \cdot FeO$	x	x	
Malachite	$2CuO \cdot CO_2 \cdot H_2O$			x
"Manganese oxide"	MnO,Mn_2O_3,$\pm nH_2O$			X
Microcline	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	x		x
Montmorillonite	$MgO \cdot Al_2O_3 \cdot 4SiO_2 \cdot nH_2O$		x	x
Muscovite	$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	x		
Nontronite	$(Ca,Mg)O \cdot 2Fe_2O_3 \cdot 8SiO_2 \cdot 7 \pm H_2O$			x
Opal	$SiO_2 \cdot nH_2O$			x
Orthoclase	$K_2O \cdot Al_2O_3 \cdot SiO_2$	x		
Plagioclase	$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$–$CaO \cdot Al_2O_3 \cdot 2SiO_2$	x		
Pyrite	FeS_2	x	X	x
Quartz	SiO_2	x		X
Sericite	$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$		X	
Siderite	$FeO \cdot CO_2$	x		
Smithsonite	$ZnO \cdot CO_2$			x
Sphalerite	ZnS		x	x
Sphene	$CaO \cdot TiO_2 \cdot SiO_2$	x		
Stibiconite	$Sb_2O_4 \cdot nH_2O$?			x
Tourmaline	$Na_2O \cdot 8FeO \cdot 8Al_2O_3 \cdot 4B_2O_3 \cdot 16SiO_2 \cdot 5H_2O$	x	x	
Tremolite	$2CaO \cdot 5MgO \cdot 8SiO_2 \cdot H_2O$			x?
Wulfenite	$PbO \cdot MoO_3$			x
Zircon	$ZrO_2 \cdot SiO_2$	x		

[1] X, major accessory; x, minor accessory.

BIOTITE

Biotite is very sparse in jasperoid, and where it occurs, it seems to be a relict mineral older than the enclosing quartz.

BROCHANTITE

Brochantite is present in minor amounts, as a late mineral, in veinlets cutting jasperoid in the oxidized zone of some copper districts. In one sample from the Bisbee district, Arizona, brochantite lines the walls of a veinlet that is filled with still younger supergene quartz.

CALCITE

Calcite is the major constituent of the most common host rock for jasperoid and is present in nearly all jasperoid bodies. Very fine grained limestones are in many places recrystallized into coarsely crystalline calcite adjacent to jasperoid bodies, and relict grains and breccia fragments of unreplaced calcite and limestone are common in these bodies. Where replacement of the host rock is more nearly complete, tiny particles of calcite are locally preserved in the quartz (fig. 11). These particles may

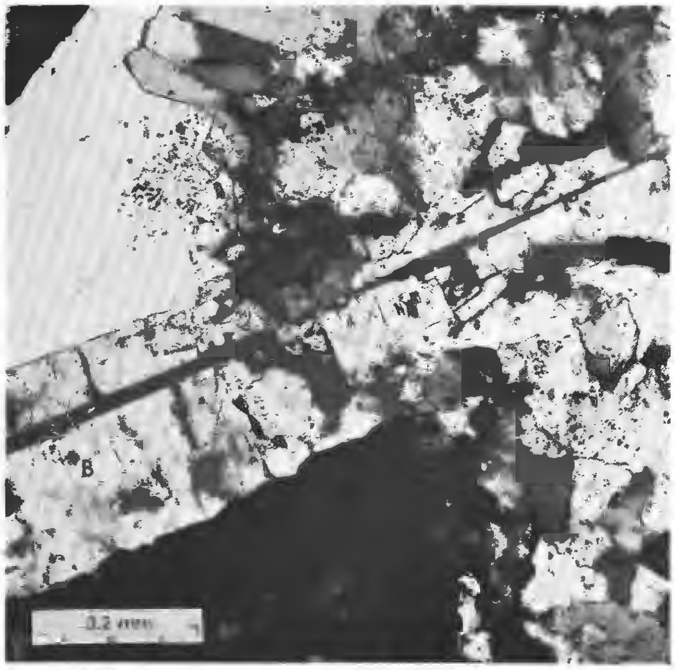


FIGURE 20.—Barite veinlet (B) cutting jasperoid. Crossed polars. × 100.

be concentrated in patterns, similar to those for allophane, that indicate the form in which the silica was deposited, or they may be randomly distributed. Late calcite fills veinlets that cut the matrix or forms layers that coat vugs. Much of this late calcite may be of supergene origin, deposited in cavities by circulating ground water, but some was probably deposited by late hydrothermal solutions.

CARBON

Amorphous, opaque, very dark brown or black organic material occurs in some jasperoids. It may be present as irregular masses or as streaks or particles disseminated in the matrix quartz, or it may be concentrated along grain boundaries. In some places it is concentrated in a zone adjacent to the host rock in which abundant relict grains of unreplaced calcite or dolomite remain. Most of this organic material in jasperoid represents an inert impurity inherited from the host. The carbon particles disseminated in some jasperoids however, may have been introduced and deposited by the silicifying solutions.

CERUSSITE

Cerussite, a constituent of lead ore-bearing jasperoid, occurs in the zone of oxidation. It is an alteration product of galena, and commonly forms either pseudomorphs of galena crystals or alteration rims around relict grains of galena.

CHALCEDONY

Chalcedony is abundant in jasperoid. It forms spherulites and irregular masses that are penecon-

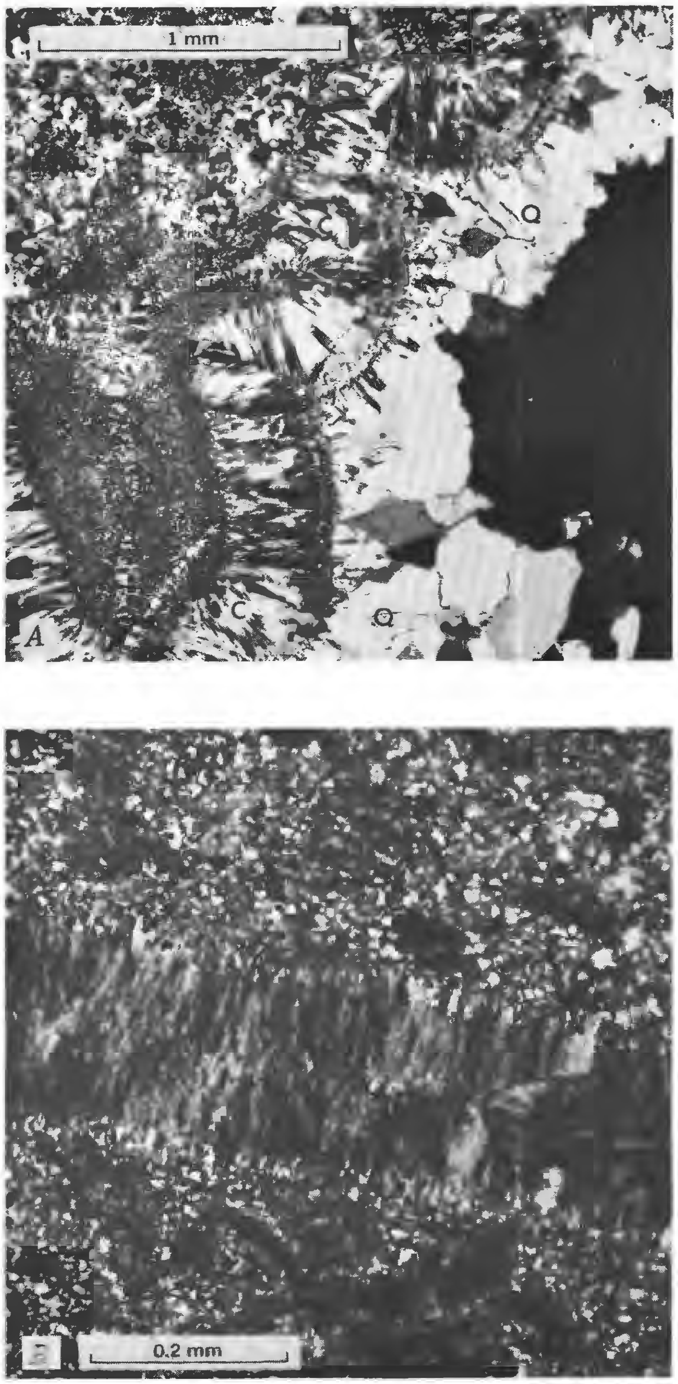


FIGURE 21.—Chalcedony. *A*, Chalcedony (C) transitional into late quartz (Q), lining a vug. Crossed polars. × 40. *B*, Veinlet of fibrous chalcedony cutting aphanitic jasperoid. Crossed polars. × 130.

temporaneous with the jasperoid quartz matrix (fig. 21*A*,*B*), but more commonly it fills veinlets and lines cavities (fig. 21*A*,*B*) in the jasperoid. Rarely, breccia fragments of chalcedony are enclosed in the matrix. Sparse and peculiar feathery or fibrous forms of jasperoid quartz appear to have formed from the dehydration of original chalcedony (fig. 8*A*). Chalcedony is more abundant in fine-grained jasperoid than in the coarser varieties.

CHALCOPYRITE

Chalcopyrite, like galena, occurs locally in unoxidized samples of productive jasperoid. It is characteristically slightly younger than the first generation of matrix silica.

CHLORAPATITE

Rounded grains of chlorapatite, older than the matrix jasperoid, are present in some samples from the Ely district, Nevada. An unusual sample from the Shirley Basin, Wyo., contains, as a major constituent, an aphanitic uraniferous chlorapatite that is associated with veinlets of younger chalcedony. This mineral is rarely present in jasperoids.

CHLORITE

Chlorite is a sparse relict mineral in jasperoid. It also occurs locally as a late hydrothermal mineral in the jasperoids of some major districts. T. S. Lovering (1949, p. 39) reported abundant younger chlorite in some jasperoid from the Tintic district, Utah, where it formed close to the mineralizing conduits.

DICKITE

Dickite was sufficiently abundant for identification in only one thin section, and there it appeared to be older than the matrix quartz. It is highly probable, however, that minor amounts of dickite are intimately associated with kaolinite in other specimens, but the mineral was not recognized because of the similarity of its optical properties to those of kaolinite.

DOLOMITE

Dolomite, like calcite, is a very abundant constituent of jasperoid. It generally appears as unreplaced remnant grains and aggregates in jasperoid masses that replace a dolomitic host rock. Another common mode of occurrence is as tiny euhedral rhombs disseminated through the matrix. These rhombs may have been deposited at the same time as the silica, or they may be relicts from the selective replacement of limestone in which they were originally embedded (fig. 13). Veinlets of late dolomite that cut jasperoid are extremely sparse. Late carbonate, in jasperoid that replaces dolomite, is generally calcite rather than dolomite.

EPIDOTE

Although epidote is a common constituent of the higher temperature lime silicate rocks, it is extremely sparse in jasperoid. It was identified in only one thin section, where it is present as small corroded grains in a brecciated zone that was later silicified.

FLUORITE

Fluorite is relatively sparse in jasperoid, but where it does occur, it is generally a late hypogene mineral in the form of veinlets that cut the matrix, or as masses that enclose grains and aggregates of early jasperoid quartz. Locally, it lines vugs and cavities in the matrix.

GALENA

Below the zone of oxidation, bodies of jasperoid that are host rocks for sulfide ore commonly contain disseminated grains and crystals of galena associated with pyrite. In most of these occurrences, the sulfides are clearly introduced after the silicification of the host rock. Locally, deposition of silica and sulfides may have been contemporaneous. Galena is rarely formed before the enclosing quartz.

GLAUCONITE

Glauconite was identified in only one sample, and there it is present as tiny rounded grains in a fragment of silicified sandstone incorporated in a matrix of coarse quartz.

GOETHITE

Goethite is common in oxidized jasperoids, where it forms late veinlets and irregular masses. It also rims vugs, or it may be disseminated as tiny grains through the matrix quartz. Crystalline orange goethite is commonly associated with amorphous isotropic brown or yellow limonite with hematite, and less commonly, with jarosite. It is generally a very late mineral, younger than both the matrix quartz and the limonite; however, in the relatively few samples in which it is disseminated through the quartz matrix it appears to be contemporaneous in origin with the silica and is indicative of supergene jasperoid. Sharp euhedral pseudomorphs of goethite after pyrite are common in jasperoid outcrops in

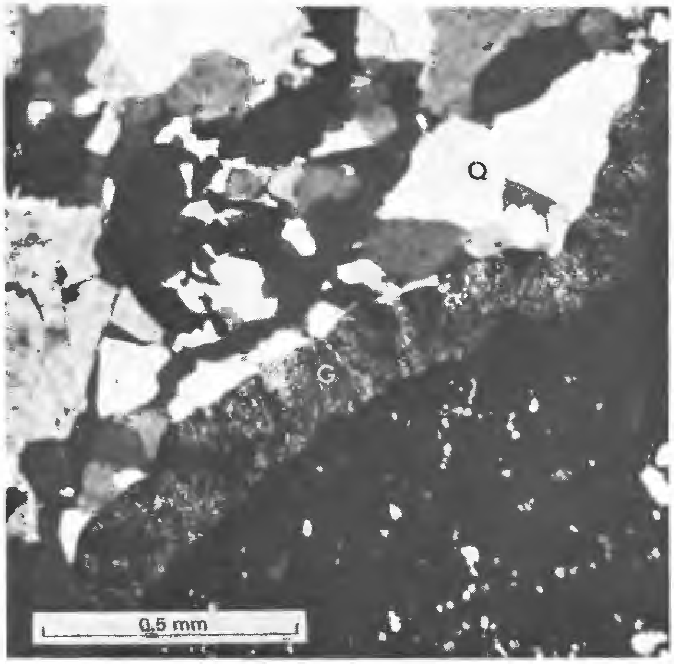


FIGURE 22.—Goethite (G) lining vugs filled with coarse supergene quartz (Q), in limonite gossan (black). Crossed polars. × 68.

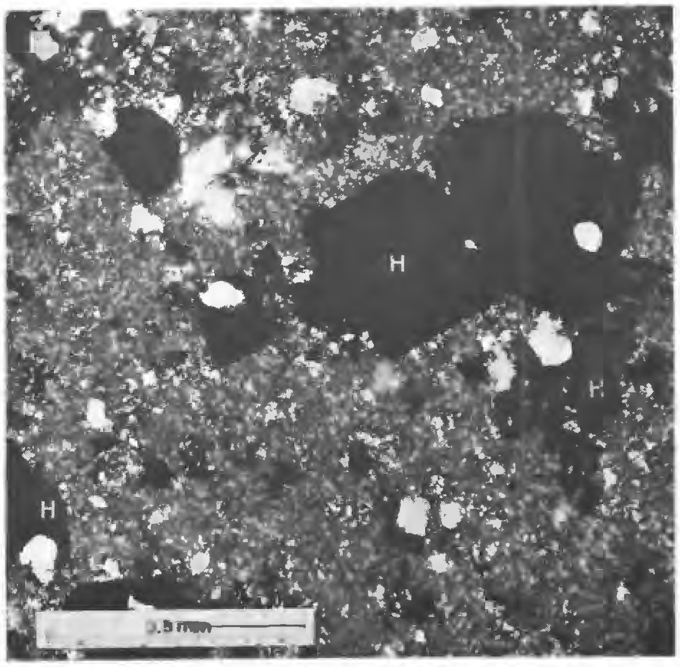


FIGURE 23. Hematite (H) pseudomorphous after pyrite in oxidized jasperoid. Crossed polars. × 68.

mineralized areas, but similar pseudomorphs of limonite or jarosite are sparse. In some samples, vugs, cavities, and veinlets are rimmed with orange goethite and are filled with younger coarse xenomorphic quartz (fig. 22). The fact that the introduction of this quartz did not result in the conversion of goethite to hematite indicates that such quartz may form at low temperatures. Indeed, in many places there is strong evidence that it was deposited by downward-percolating surface waters during weathering and oxidation of the outcrop.

HALLOYSITE

Halloysite is a sparse late mineral that accompanies kaolinite. It lines vugs and fills fractures.

HEMATITE

Like goethite, hematite is abundant in the oxidized parts of some jasperoid bodies, to whose outcrops it imparts a characteristic deep-red color, it is generally a late mineral that fills fractures and permeates the rock along quartz-grain boundaries, and it commonly forms good pseudomorphs after original pyrite crystals (fig. 23). Unlike goethite, however, hematite occurs in many samples as an early hypogene mineral, either coprecipitated with original silica and disseminated through the resulting jasperoid, or as irregular masses cut by later jasperoid quartz. In most samples that contain both hematite and goethite the hematite is older, but in some samples the two minerals seem to be nearly contemporaneous. Hematite that is definitely younger than associated goethite is very rare. According to Tunell and Posnjak (1931), goethite is unstable above 130°C. There is ample evidence, however, that either hematite or goethite can form at low temperatures. Iron oxide, like silica, apparently may be precipitated at relatively low temperatures—either as a colloidal hydrosol or directly in anhydrous form. Once it is precipitated as hematite it is stable, but the hydrosol may crystallize into goethite, maintain its amorphous form, and partly desiccate to form limonite, or, depending on its environment after deposition, it may even undergo complete dessication to form hematite.

HYDROMICA

Hydromica is a common constitutent of early hypogene jasperoid quartz, through which it may be disseminated. Sericite normally accompanies the hydromica, and has the same habit of occurrence. Most of the hydromica in jasperoid apparently precipitated concurrently with the early silica, but locally it occurs in older clay pockets and lenses. It is much less abundant in younger generations of jasperoid quartz, and has not been observed as a late, postsilica mineral.

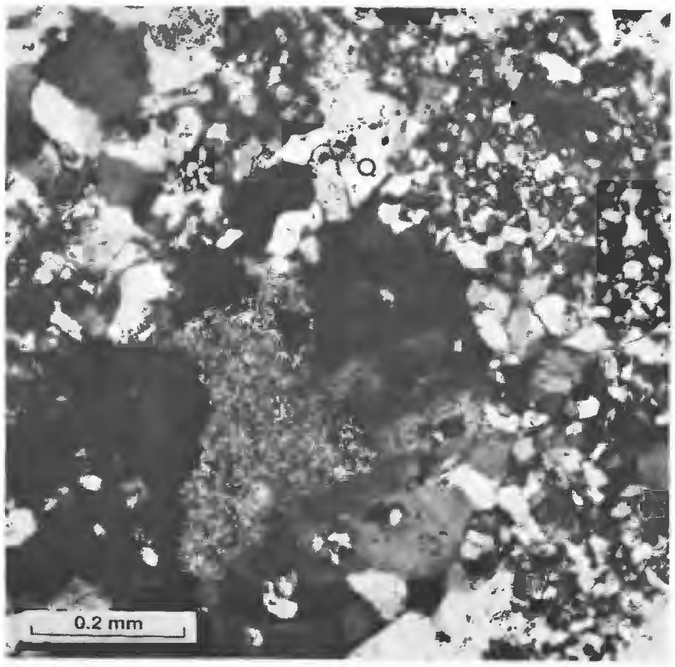


FIGURE 24.—Jarosite inclusion (J) in late coarse quartz (Q), filling fractures and cavities in jasperoid. Crossed polars. × 100.

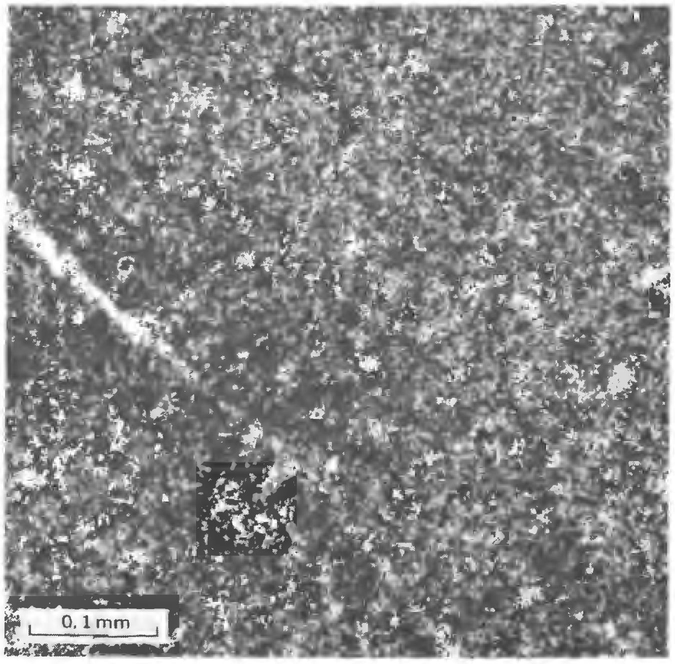


FIGURE 25.—Limonite particles disseminated through aphanitic jasperoid. Crossed polars. × 170.

JAROSITE

The oxidation of pyrite in, or adjacent to, jasperoid bodies in arid regions commonly causes the precipitation of jarosite from the acid potassium-bearing sulfate waters. Jarosite—in veinlets and as vug coatings, disseminated granules, and irregular masses—accompanies goethite, hematite, and limonite in weathered jasperoid (fig. 24). Massive jarosite only rarely forms the matrix for breccia fragments of jasperoid. In many places jarosite is clearly derived from the alteration of pyrite, but it has not been observed as a direct pseudomorph of pyrite crystals. Jarosite is a late supergene mineral, generally even later than associated goethite.

KAOLINITE

Kaolinite is a major constitutent of relict clay pockets and lenses that are incorporated in silicified breccias or are inherited from impure argillaceous carbonate rocks. It may also be associated, in minor amounts, with hydromica and sericite introduced contemporaneously with the silica. It is locally a late mineral, occurring with halloysite, coating vugs, and filling fractures in the matrix quartz. It is not abundant in most jasperoids.

LIMONITE

The amorphous isotropic forms of hydrous iron oxide that are abundant as stains and fracture coatings on outcrops, and in the oxidized zone beneath, have been lumped together under the heading of "limonite." These limonites are normally some shade of brown, ranging from a dark chocolate brown to light tan, but some are yellow or orange. In some supergene jasperoids, limonite particles are evenly disseminated through the groundmass and contemporaneous with it (fig. 25). Rarely, limonite inclusions are present in younger jasperoid quartz. In most samples, however, it is definitely later than the quartz, and it coats fractures and lines vugs. Limonite normally is associated with late hematite, goethite, and jarosite, but in many jasperoid samples it is the only iron mineral present. The reason for the wide variation in the color of limonite is not known, although the dark-brown varieties seem to be most commonly derived from the oxidation of sulfides, particularly copper-iron sulfides.

LUSSATITE

Lussatite, a very sparse form of silica, has the refractive indices of opal and the birefringence of quartz (fig. 26). It is fibrous, has positive elongation and parallel extinction, and gives a disorder cristobalite pattern on X-ray. Rogers and Kerr (1942, p. 190) regarded it as probably a mixture of fibrous chalcedony and opal. In Dana's "A textbook of Mineralogy, 4th ed." (Ford, 1932, p. 473), lussatite is mentioned as having a structure like chalcedony, but the opposite sign, and the specific gravity and refractive index of opal. According to Frondel (1962, p. 280–281), lussatite is a fibrous form of low-temperature cristobalite with a composition similar to that of opal but containing less water. In the present study, lussatite was observed in two samples—a jasperoid breccia from the Ely Limestone in the Ely district, Nevada, and a silicified siltstone sample from the Deadwood Formation in the southwestern part of the Lead district, South Dakota. In the first sample, fragments of jasperoid are cemented by vuggy limonite and goethite, in a vein about 3 inches wide, between walls of opal; open vugs in the limonite are rimmed with orange goethite, and the goethite is encrusted with a thin film of lussatite. In the sample from the Deadwood Formation a succession of narrow bands, suggestive of Liesegang bands, consists of goethite and chalcedony. The goethite in these bands is full of microvugs that are lined with lussatite. In both, the occurrence of lussatite as a very late incrustation on goethite suggests that it was deposited at low temperature, probably from downward-moving surface waters.

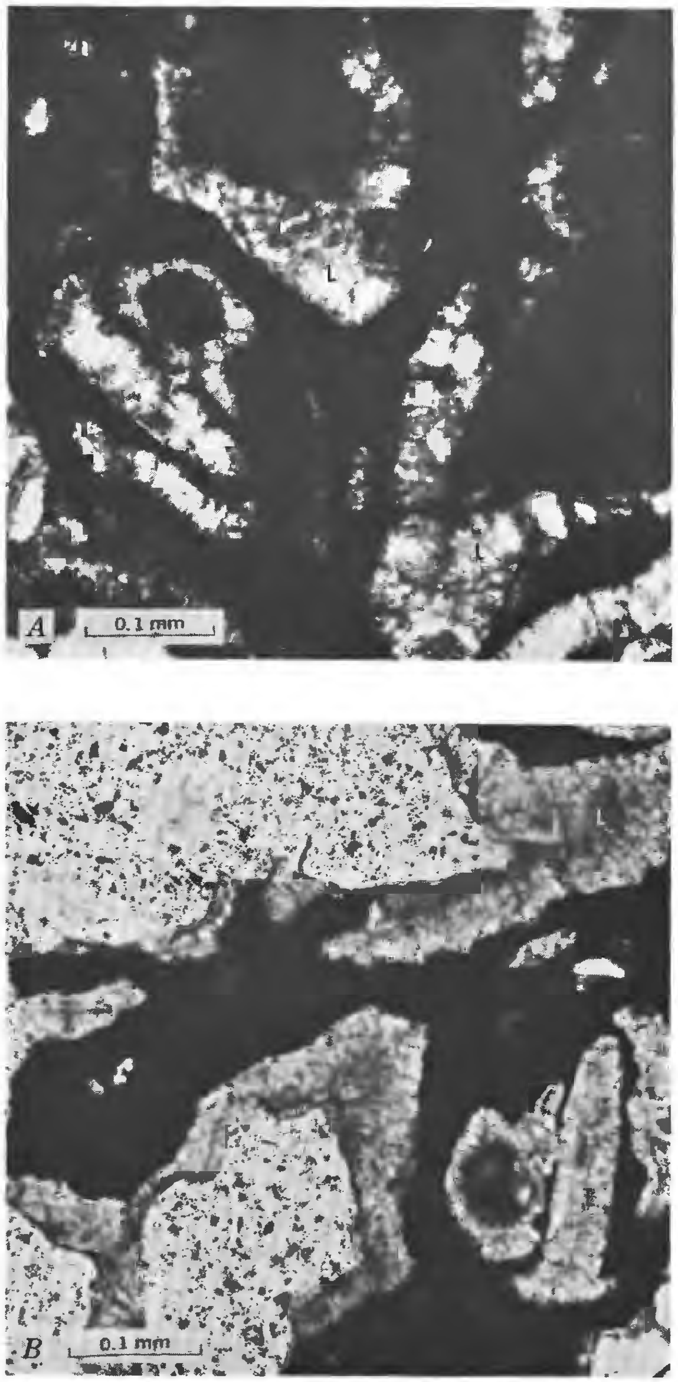


FIGURE 26.—Lussatite (L) lining vug in goethite, showing fibrous character. *A*, Crossed polars. × 170. *B*, Same field, with stage rotated. Plane polarized light. × 170.

MAGNETITE

Magnetite is a very sparse constitutent of hypogene jasperoids. It occurs as small rounded grains and short irregular veinlets in a fine-grained siliceous dolomite, which is locally replaced by jasperoid quartz, in the Pahasapa Limestone in the northern Black Hills of South Dakota. This magnetite is older than the jasperoid.

MALACHITE

Malachite is associated with jarosite, goethite, and brown limonite as an oxidation product from

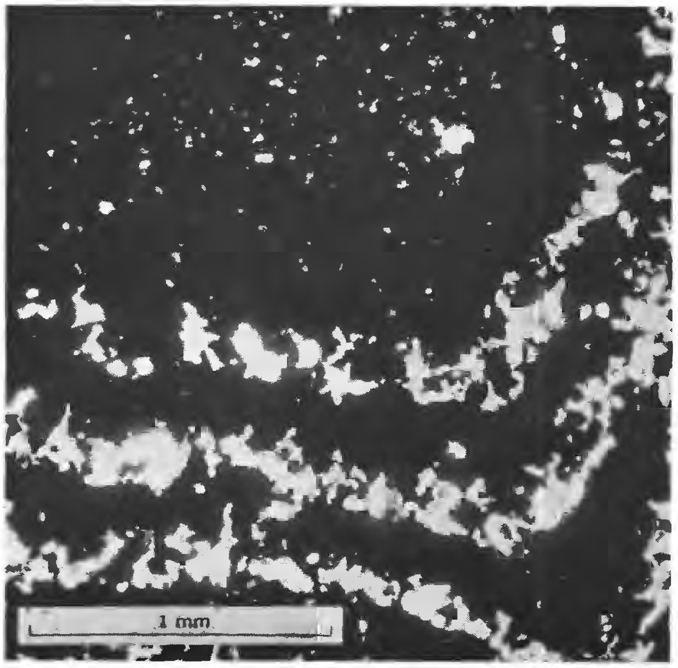


FIGURE 27.—Fine-grained supergene jasperoid impregnated with manganese oxide (black areas). Crossed polars. × 40.

the weathering of copper sulfide-bearing jasperoid. In most places it fills fractures and coats fractures, and it appears to be younger than the associated supergene iron minerals. Locally, it forms crystals embedded in remnant masses of recrystallized limestone or dolomite, in a matrix of jasperoid quartz.

"MANGANESE OXIDES"

Aphanitic, black, opaque, supergene manganese oxides are abundant in a few oxidized jasperoids in mineralized areas. These normally are too finely divided to permit optical identification of the mineral species present. They characteristically impregnate the matrix quartz of supergene jasperoid (fig. 27), and are associated with limonite and goethite. They range in size from thin films to large irregular masses containing scattered quartz grains. In some places these masses are fractured and veined with younger quartz.

MICROCLINE

Most microcline found in jasperoids occurs as relict grains or crystals, inherited from the host rock, or as small angular breccia fragments. A few jasperoids, in the outer part of a contact-metamorphic zone surrounding an intrusive, however, contain younger microcline in veinlets that cut the jasperoid. Where this happens, the jasperoid matrix normally is impregnated with sericite.

MONTMORILLONITE

Montmorillonite is not a common constituent of jasperoid. It is occasionally observed in the form of tiny disseminated particles that cloud the matrix quartz, or more rarely, as a filling in late veinlets that cut the matrix.

MUSCOVITE

Rarely, coarse flakes of muscovite are incorporated in jasperoid breccias, or they are inherited from micaceous rocks that have been replaced by jasperoid.

NONTRONITE

Nontronite that occurs in jasperoids is, like halloysite, predominantly of supergene origin. Thin veinlets of nontronite cut jasperoid quartz in the zone of oxidation. The mineral also lines vugs and open cavities. In some samples it is associated with late calcite and goethite.

OPAL

Opal is a sparse, late, minor constitutent of jasperoid. It fills veinlets and coats cavities in association with chalcedony and goethite, and is commonly of supergene origin. In one sample of supergene jasperoid, opal takes the place of quartz as the major silica mineral in the matrix. Here, the opaline groundmass contains disseminated red hematite and is cut by veinlets of hematite and of chalcedony (fig. 28). This opal replaced dolomite at the base of a volcanic flow.

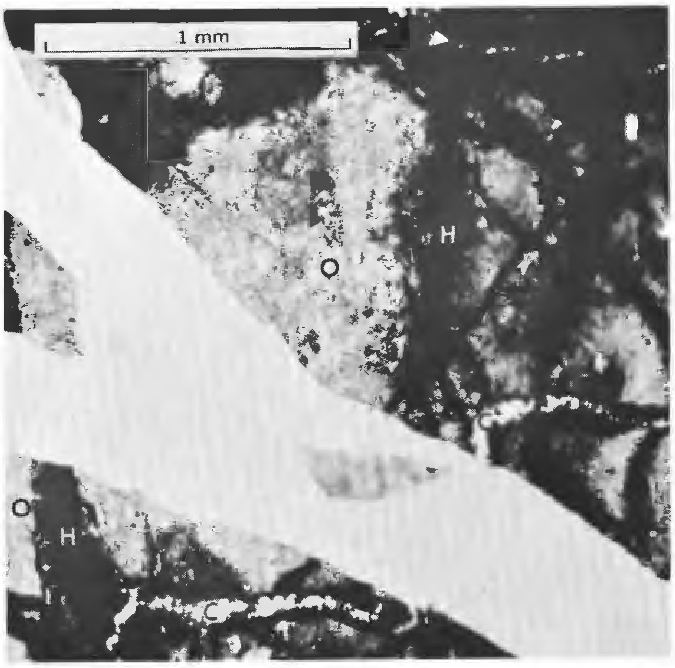


FIGURE 28.—Opal groundmass (O), cut by hematite veinlets (H) and younger chalcedony veinlet (C). Plane polarized light. × 40.

ORTHOCLASE

Orthoclase, like microcline, locally occurs as breccia fragments, or as unreplaced inclusions, in a silicified matrix. It is very sparse, and has not been found as a contemporaneous or younger constitutent of jasperoid.

PLAGIOCLASE

The remarks made about orthoclase apply equally to plagioclase. Where remnant inclusions of plagioclase do occur, they normally show sericitic alteration.

PYRITE

Pyrite is a common but not abundant constitutent of unoxidized jasperoids. Most pyritic jasperoids are spatially and genetically related to sulfide ore bodies in mining districts. However, pyrite also occurs as an early mineral in a considerable number of jasperoids that apparently are unrelated to any other sulfide mineralization, and therefore its presence cannot be regarded as a reliable guide to ore. Pyrite is predominantly contemporaneous with, or slightly younger than, the oldest generation of matrix quartz. In a few samples, pyrite occurs as an aphanitic colloidal precipitate, contemporaneous with the silica matrix (fig. 29). Pyrite in jasperoid generally crystallizes in cubic form, and in oxidized samples its former presence is shown by masses of cubic hematite or goethite or by square pits. In aphanitic, "cherty"-looking, barren jasperoid, pyrite may occur as tiny well-formed cubes, a few hundredths of a millimeter in diameter, evenly disseminated through the matrix and apparently contemporaneous with it. A similar occurrence of pyrite has been observed in fresh drill-hole samples of Arkansas Novaculite, in which both pyrite and quartz appear to have formed from a syngenetic marine chemical precipitate (fig. 30). Neither pyrite nor its pseudomorphs have been observed in supergene jasperoid.

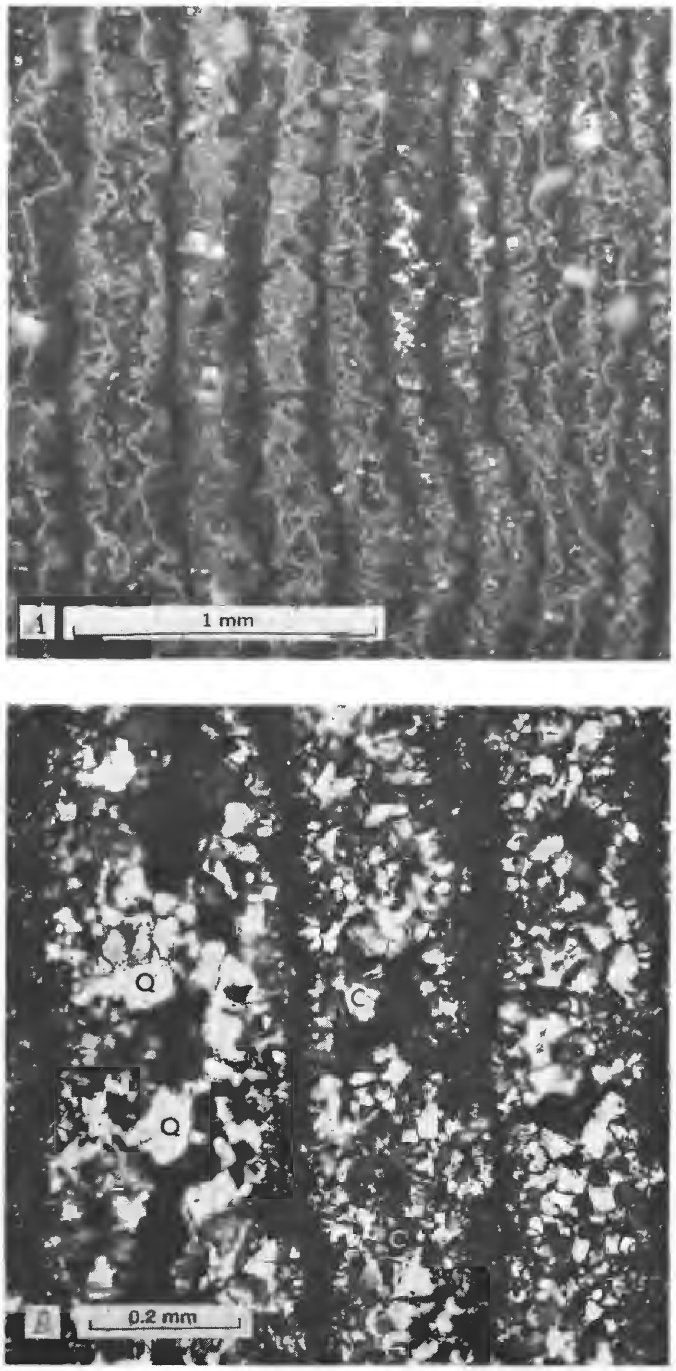


FIGURE 29.—Alternating colloform bands of pyrite and chalcedonic jasperoid. *A*, Colloform banding. Dark bands are largely pyrite. Reflected light. × 40. *B*, Enlargement showing abundance of chalcedony (C) in some silica bands, and quartz (Q) in others. Black bands are largely pyrite. Crossed polars. × 100.

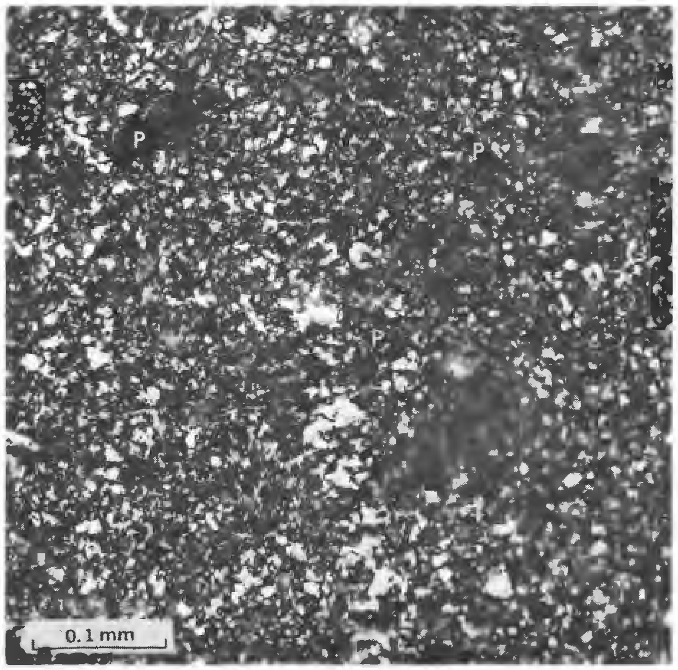


FIGURE 30.—Small pyrite grains (P) disseminated in Arkansas Novaculite. Crossed polars. × 170.

QUARTZ

The major constituent of nearly all jasperoids is quartz. It occurs both as a replacement and as an accessory mineral. Older quartz grains, inherited after the replacement of a sandy dolomite or limestone, are commonly found in jasperoids. Many of these grains show zonal overgrowths of jasperoid silica in optical continuity with the grain (fig. 31). Quartz of nonreplacement origin commonly fills veinlets that cut the matrix, or it forms well-formed crystals that line vugs and cavities. Some of these crystals are long, slender, and prismatic, but most are short and stubby or show only the pyramidal

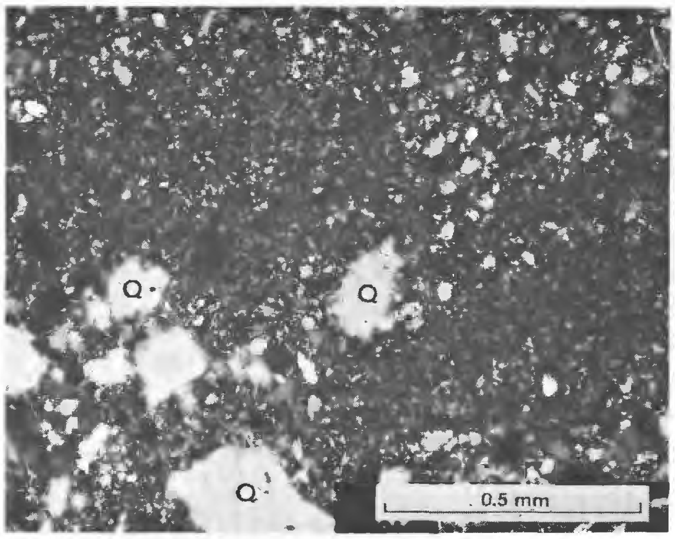


FIGURE 31.—Quartz grain inclusions (Q) in jasperoid, showing accretionary overgrowths of jasperoid silica in optical continuity. Crossed polars. × 68.

terminations. The theory that quartz may be precipitated directly from cold water as relatively coarse grained aggregates, or as crystals, is substantiated by its presence in these forms in veinlets in, and crusts on, supergene minerals such as goethite (fig. 22) and brochantite.

SERICITE

Sericite is a common constituent of the earliest generation of hypogene jasperoid quartz. It is characteristically present in the form of tiny shreds and flakes which are randomly disseminated through the groundmass and which seem to have been introduced with the replacing silica. Sericite may also be present in pockets of older clay, or as an alteration product in relict feldspar. It is notably less abundant in younger generations of quartz that cuts the matrix. It is commonly associated with hydromica and, locally, with kaolinite. The prevalence of sericite in association with hypogene jasperoid suggests that potassium is a major constituent of the silica-bearing solutions that are responsible for the replacement by which this jasperoid formed.

SIDERITE

Siderite, like ankerite, is very sparse in jasperoid. It locally occurs in the form of relict grains and masses in the matrix, indicating an iron carbonate phase of rock alteration that preceded silicification. Rarely, it fills veinlets younger than the jasperoid quartz.

SMITHSONITE

Grains of sphalerite in ore-bearing jasperoid are locally replaced by smithsonite in the zone of oxidation, but, more commonly, the sphalerite either remains in its original form or is leached away entirely or is replaced in part by hemimorphite and jasperoid.

SPHALERITE

In many mining districts hypogene jasperoid forms a siliceous gangue for sphalerite ore. Normally, sphalerite is slightly younger than the quartz, but it may also be of about the same age. It is most commonly associated with pyrite and galena.

SPHENE

Small rounded detrital grains of sphene, originally present in the host rock, at places occur as relict inclusions in the replacing jasperoid.

STIBICONITE (?)

An aphanitic yellowish-brown antimony mineral that has a high index of refraction is a major constitutent of a jasperoid sample from the Taylor district, Nevada. It forms irregular massive inclusions in a jasperoid breccia that shows several periods of silicification. The mineral appears to be approximately contemporaneous with the youngest generation of quartz, and is probably a supergene alteration product of stibnite, which is relatively common in this district, although none was observed in the sample. This mineral has been tentatively identified as the hydrous antimony oxide stibiconite, which was reported from the Mercur district, Utah, by Gilluly (1932, p. 116), and from Kostajnika, Yugoslavia, by Beck (1905, p. 581) under the name "antimony ochre."

TOURMALINE

Tourmaline, like sphene, in most places occurs in the form of rounded detrital grains inherited from the host rock. In a few places, however, tourmaline appears as tiny slender euhedral crystals that seem to have formed at about the same time as the quartz matrix in which they are embedded.

TREMOLITE

Tremolite, in association with diopside and coarse-grained calcite, is locally found in the outer fringe of contact metamorphic zones surrounding intrusive rocks, in veinlets that cut dense aphanitic siliceous rocks. Some of these siliceous rocks may be jasperoid, but most of them probably are chert.

TABLE 3.—*Jasperoid-associated minerals reported in the literature other than those discussed in the text*

Mineral	Composition	Locality		Reference
		District	State or country	
Aragonite	$CaO \cdot CO_2$	Mercur-Ophir	Utah	Gilluly (1932, p. 116).
		Organ	New Mexico	Dunham (1935, p. 126–129).
		Tri-State	Oklahoma, Kansas, Missouri.	Weidman (1932, p. 68).
Argentite	Ag_2S	Georgetown	New Mexico	Anderson, E. C. (1957, p. 67).
		Horseshoe-Sacramento	Colorado	Butler and Singewald (1940, p. 809).
		Mercur-Ophir	Utah	Gilluly (1932, p. 116).
		Mineral Hill	Nevada	Emmons, W. H. (1910, p. 97).
		Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
Arsenopyrite	$FeAsS$	Gold Hill	Utah	Nolan (1935, p. 102–103).
		Manhattan	Nevada	Ferguson (1921, p. 15).
Aurichalcite	$7(Zn,Cu)O \cdot 3CO_2 \cdot 4H_2O$	Mercur-Ophir	Utah	Gilluly (1932, p. 116).
Azurite	$3CuO \cdot 2CO_2 \cdot H_2O$	do	do	Do.
		Mineral Hill	Nevada	Emmons, W. H. (1910, p. 97).
		Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
		Pilgrims Rest	South Africa	Beck (1905, p. 576–577).
		Tutsagubet	Utah	Butler, Loughlin, Heikes, and others (1920, p. 595).
Bismite (Bismuth Ochre)	$Bi_2O_3 \cdot 3H_2O$ (?)	Pilgrims Rest	South Africa	Beck (1905, p. 576–577).
Cerargyrite	$AgCl$	Georgetown	New Mexico	Anderson, E. C. (1957, p. 67).
		Lake Valley	do	Harley (1934, p. 176–178).
		Mercur-Ophir	Utah	Gilluly (1932, p. 116).
		Mineral Hill	Nevada	Emmons, W. H. (1910, p. 97).
		Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
Chalcocite	Cu_2S	Ely	Nevada	Spencer (1917, p. 99).
		Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
Chrysocolla	$CuO \cdot SiO_2 \cdot nH_2O$ (?)	Lucin	Utah	Butler, Loughlin, Heikes, and others (1920, p. 493).
		Mercur-Ophir	do	Gilluly (1932, p. 116).
		Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
Cuprite	Cu_2O	Lucin	Utah	Butler, Loughlin, Heikes, and others (1920, p. 493).
Enargite	$Cu_2S \cdot 4CuS \cdot As_2S_3$	Colquijirca	Peru	McKinstry (1936, p. 622).
Freibergite	$5(Cu,Ag)_2S \cdot 2(Cu,Fe)S \cdot 2Sb_2S_3$	Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
Gold	Au	Bull Valley	Utah	Butler, Loughlin, Heikes, and others (1920, p. 598).
		Kingston	New Mexico	Harley (1934, p. 98).
		Pilgrims Rest	South Africa	Beck (1905, p. 576–577).
		Terry	South Dakota	Irving (1911, p. 631).
Gypsum	$CaO \cdot SO_3 \cdot 2H_2O$	Mercur-Ophir	Utah	Gilluly (1932, p. 116).
Luzonite	$Cu_2S \cdot 4CuS \cdot As_2S_3$	Colquijirca	Peru	McKinstry (1936, p. 622).
Manganite	$Mn_2O_3 \cdot H_2O$	Postmasburg	South Africa	Du Toit (1933, p. 113).
Manganocalcite	$(Ca,Mn)O \cdot CO_2$	Kingston	New Mexico	Harley (1934, p. 98).
		Ouray	Colorado	Burbank (1940, p. 207).
Manganosiderite	$(Fe,Mn)O \cdot CO_2$	Leadville	do	Emmons, Irving, and Loughlin (1927, p. 218).
Marcasite	FeS_2	Colquijirca	Peru	Lindgren (1935, p. 334).
		Tri-State	Oklahoma, Kansas, Missouri.	Weidman (1932, p. 68).
Melaconite	CuO	Mercur-Ophir	Utah	Gilluly (1932, p. 116).
Orpiment	As_2S_3	Manhattan	Nevada	Ferguson (1921, p. 15).
		Mercur-Ophir	Utah	Gilluly (1932, p. 116).
Pearceite	$8Ag_2S \cdot As_2S_3$	Ouray	Colorado	Burbank (1940, p. 207).
Plumbojarosite	$PbO \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$	Mercur-Ophir	Utah	Gilluly (1932, p. 116).
		Tutsagubet	do	Butler, Loughlin, Heikes, and others (1920, p. 598).
Pyrargerite	$3Ag_2S \cdot Sb_2S_3$	Ouray	Colorado	Burbank (1940, p. 207).
Pyromorphite	$9PbO.3P_2O_5 \cdot PbCl_2$	Mineral Hill	do	Emmons, W. H. (1910, p. 97).
Pyrrhotite	$Fe_{1-x}S$	Ely	Nevada	Spencer (1917, p. 116).
Realgar	AsS	Manhattan	do	Ferguson (1921, p. 15).
		Mercur-Ophir	Utah	Gilluly (1932, p. 99).
Rhodochrosite	$MnO \cdot CO_2$	Bingham	do	Boutwell (1905, p. 160).
		Kingston	New Mexico	Harley (1934, p. 98).
		Ouray	Colorado	Burbank (1940, p. 207).
		Phillipsburg	Montana	Emmons and Calkins (1913, p. 213–219).
Rhodonite	$(Mn,Mg,Fe,Ca)MnSi_2O_6$	Diadem Lode	California	Turner (1899, p. 389).
Scorodite	$Fe_2O_3 \cdot As_2O_5 \cdot 4H_2O$	Mercur-Ophir	Utah	Gilluly (1932, p. 116).
Senarmantite	Sb_2O_3	Kostajnika	Yugoslavia	Beck (1905, p. 578–580).
		Rosia	Italy	Do.
Silver	Ag	Colquijirca	Peru	Lindgren (1935, p. 334).
		Georgetown	New Mexico	Anderson, E. C. (1957, p. 67).
		Lake Valley	do	Harley (1934, p. 176–178).
Stibnite	Sb_2S_3	Cortez	Nevada	Emmons, W. H. (1910, p. 103–104).
		Kostajnika	Yugoslavia	Beck (1905, p. 578–581).
		Manhattan	Nevada	Ferguson (1921, p. 15).
		Mercur-Ophir	Utah	Gilluly (1932, p. 99).
		Rosia	Italy	Beck (1905, p. 581).
Stromeyerite	$(Ag,Cu)_2S$	Colquijirca	Peru	Lindgren (1935, p. 334).
		Cortez	Nevada	Emmons, W. H. (1910, p. 103–104).
Sulfur	S	Kostajnika	Yugoslavia	Beck (1905, p. 578–581).
		Mercur-Ophir	Utah	Gilluly (1932, p. 116).
		Rosia	Italy	Beck (1905, p. 581).
Sylvite	KCl	Ely	Nevada	Spencer (1917, p. 63).
Tennantite	$5Cu_2S \cdot 2(Cu,Fe)S \cdot 2As_2S_3$	Cartersville	Georgia	Kesler (1950, p. 48).
		Colquijirca	Peru	Lindgren (1935, p. 334).
		Horseshoe-Sacramento	Colorado	Butler and Singewald (1940, p. 809).
Tetrahedrite	$5Cu_2S \cdot 2(Cu,Fe)S \cdot 2Sb_2S_3$	Bingham	Utah	Boutwell (1905, p. 160).
		Cortez	Nevada	Emmons, W. H. (1910, p. 103–104).
		Gold Hill	Utah	Nolan (1935, p. 153).
		Mineral Hill	Nevada	Emmons, W. H. (1910, p. 97).
		Ouray	Colorado	Burbank (1940, p. 207).
		Stockton	Utah	Butler, Loughlin, Heikes, and others (1920, p. 372).
Wittichenite	$3Cu_2S \cdot Bi_2S_3$	Colquijirca	Peru	Lindgren (1935, p. 334).

WULFENITE

Wulfenite has been observed in jasperoid from only one locality, the Seventy Nine mine in the Banner district, Arizona. Here, it forms crystals, associated with goethite, that line vugs in a jasperoid body that crops out near the entrance to the mine.

ZIRCON

Small rounded grains of zircon, associated with tourmaline, sphene, and other detrital minerals, are commonly preserved in jasperoid that has resulted from the silicification of siltstone and impure carbonate rocks.

OTHER MINERALS

Other minerals which are locally associated with jasperoid and which have been reported in the literature are listed in table 3. It is noteworthy that most of these minerals are those characteristic of shallow epithermal deposits. They consist largely of salts of Ag, As, Bi, Cu, Mn, Pb, and Sb.

OTHER PHYSICAL PROPERTIES

Studies were made of the density, porosity, and response to differential thermal analysis of some representative jasperoid samples in order to (1) estimate the nature of the distribution of these properties in jasperoid and (2) ascertain whether variations in any of them could be useful in distinguishing barren jasperoid bodies from those related to ore. The results of this second phase of the investigation will be discussed in a subsequent chapter of this report.

DENSITY AND POROSITY

Bulk and powder density determinations were made on 124 jasperoid samples representing 19 districts. The porosity of the sample (in percent) was calculated from the equation,

$$\text{Porosity} = \left[1 - \left(\frac{\text{Bulk density}}{\text{Powder density}} \right) \right] \times 100.$$

The observed range of powder densities is 2.50–3.61; that of porosities is from <1 to 17 percent. The frequency distributions for both density and porosity are distinctly skewed with modes in the low values (fig. 32). The sample frequency distribution for density approximates a log normal distribution, truncated in the low values. The distribution of sample porosity data is highly irregular.

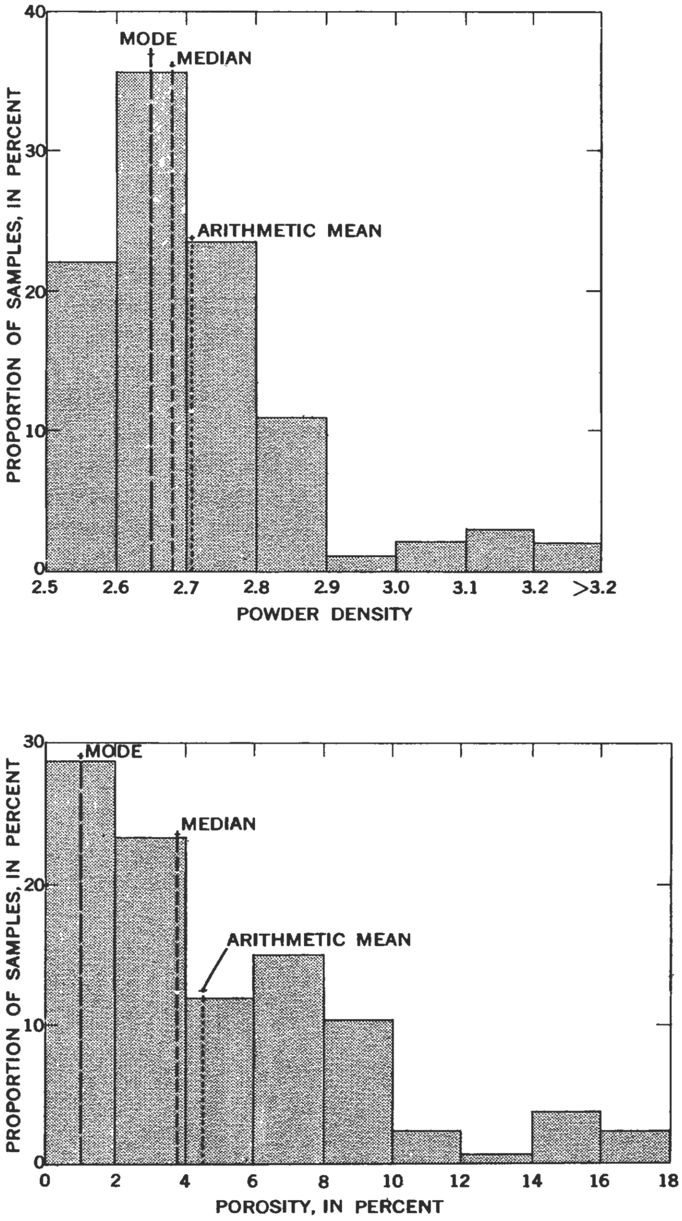


FIGURE 32.—Histograms showing distributions of density and porosity in 124 jasperoid samples.

The relatively large number of jasperoid samples with powder densities in the range 2.5–2.6 is surprising, because the major identifiable minerals in jasperoid (quartz, chalcedony, calcite, dolomite, limonite, kaolinite, sericite) all have specific gravities >2.6.

Many of the extremely fine grained cherty varieties of jasperoids may contain appreciable quantities of air or water trapped in submicroscopic pores, along fractures and grain boundaries, and in fluid inclusions, or the anomalously low birefringence of some of these varieties may reflect, in part, the presence of cristobalite or opal granules too small for identification but sufficiently abundant to lower the density of the rock. However, differential thermal analysis of some of these low-density samples did not confirm the presence of abundant pore water, opal, or cristobalite.

The experimental error factor in these density determinations was appreciable, and may have been sufficient to account for the low-density values. The likelihood that these low values are due entirely to experimental error is considerably reduced, however, by the fact that some of them are based on independent determinations on replicate splits of the same sample made in different laboratories. The porosity values calculated from the ratios of two separate density determinations, both of which were subject to considerable analytical error, must be regarded as rough approximations. It is doubtful, however, that refinements in the determination of sample porosity would alter the general observation that dense jasperoid of low porosity is considerably more abundant than jasperoid of high porosity.

DIFFERENTIAL THERMAL ANALYSIS

Differential thermal analyses (hereafter referred to as DTA) were made on 12 selected jasperoid samples and on two chert samples in order to (1) test the theory that chert and aphanitic cherty jasperoid may contain appreciable quantities of opaline silica, (2) determine whether the DTA curves for syngenetic chert differed from those for jasperoid, and (3) ascertain whether the presence of finely divided sulfides, or their alteration products, in jasperoid would produce diagnostic peaks on the curves. All samples were run on a portable DTA apparatus, after calibration of the cells with a standard montmorillonite sample.

Most of the jasperoid samples and one chert sample gave endothermic peaks at various temperatures between 100° and 800°C, but no consistent pattern was apparent. One jasperoid sample known to contain opal as a major constitutent showed, as expected a strong endothermic peak at about 100°C. A pyritic sample showed an endothermic peak at about 650°C, and a sample containing much sphalerite showed a similar peak at about 750°C. Some samples that consist predominantly of aphanitic silica proved to be inert, but other samples of similar composition gave a pronounced isolated endothermic peak in the range of 500°–550°C. This range is too broad, and the peak too strong, to mark the inversion of α quartz to β quartz. The presence of this peak is difficult to interpret in terms of the known mineralogy of the samples. It comes at too high a temperature to mark the dehydration of clay minerals or hydrous iron oxides, and at too low a temperature to be caused by the breakdown of calcite or dolomite. Alunite could give such a peak, but no alunite is visible in thin sections of these rocks.

Neither the "cherty" jasperoid samples nor the two samples of true chert showed any marked endothermic inflections in the range 80°–300°C. This casts considerable doubt on the theory that opal or well-crystallized cristobalite is present in any appreciable amount. The DTA curves of cristobalite, reported by Eitel (1957, p. 148), all show strong single endothermic peaks between 230° and 260°C.

This small sampling indicates that many jasperoids and some cherts do give pronounced inflections on DTA graphs, but that these two rock types cannot be distinguished from each other by this method.

COMPOSITION OF JASPEROID

The connotation of a rock composed principally of fine-grained or dense replacement silica has been either stated or implied in the various definitions of jasperoid since the term was first introduced by Spurr in 1898. However, jasperoid grades into partly silicified mudstone, dolomite, and limestone with increasing alumina and carbonate content and decreasing silica content; into siliceous iron and manganese ore with increase in the oxides of these metals; and into siliceous sulfide ore with increasing sulfide content. The boundaries are vague and ill defined. They commonly have been established arbitrarily at the discretion of individual investigators in individual districts. Jasperoid that is minable for one or more metals is designated by the mining industry as siliceous ore. I consider that a rock matrix must consist of at least 50 percent replacement silica to be called a jasperoid.

MAJOR CONSTITUENTS

The few available complete analyses of jasperoids show considerable range in the concentration of major constituents, and do not differ notably from analyses of other similar rocks of different origin, with the exception of iron-formation jaspilites (tables 4, 5).

Any attempt to draw general conclusions as to characteristic differences in composition between jasperoids and the other silica rock types, with the possible exception of jaspilite, from the limited amount of data given in tables 4 and 5 is unwarranted. Some apparent differences in the sample data suggest the possibility of corresponding tendencies in the rock types, but, until considerably more analytical data become available for comparison, these differences must be regarded as suggestive only. Jaspilite samples contain about half as much silica and several times as much ferric oxide as the jasperoid samples, and somewhat less water. These

TABLE 4.—*Analyses of jasperoid and other similar rocks*

[I.L., ignition loss; ...., no analyses]

	Jasperoid											Chert, flint, and novaculite				Silcrete			Siliceous sinter	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SiO_2	96.79	95.75	93.28	81.70	96.27	79.11	95.26	95.77	97.33	97.07	97.32	98.17	95.50	98.19	99.47	95.10	97.05	94.92	72.25	92.67
Al_2O_3	.52	1.12	1.01	3.24	.26	3.82	.57	......	......	1.05	.52	.83	.10	.00	.17	2.03	.95	2.32	10.96	.80
Fe_2O_3	1.02	.36	1.29	5.41	.26	.44	.00	1.84	1.89	.53	.30		1.95	.02	.12	.53	.14	.31	.76	
FeO	.17	.19	.37	.28	.19	.69	.69	......	......	......	.02	......	.15	......	......	......	......	......	.31	......
MgO	.16	.01	.04	.16	.19	1.19	.05	.24	.09	Trace	.02	.01	Trace	.21	.05	.20	.0	......	.10	.05
CaO	.14	.00	.14	.44	1.16	.62	.25	.54	.11	.51	.52	.05	......	.30	.09	.16	.0	......	.74	.14
Na_2O	.01	.00	.03	.12	.05	.31	......	......	......	.99	.02	......	Trace	.08	.15	......	......	......	3.55	.75
K_2O	.09	.09	.07	1.10	.11	.54	......	......	......		.03	......	......	.03	.07	......	......	......	1.66	.18
H_2O+	.35	.75	.31	2.16	.42	2.68	......	1.17	.77	......	.49	.78	1.43	1.11	.12	.46	.47	1.38	9.02	5.45
H_2O-	.05	.05	.06	.29	.03	.81	......			......	.16	I.L.	I.L.	.33	I.L.	I.L	I.L	I.L	I.L	I.L.
TiO_2	.04	.03	.03	.20	......	.81	......	......	......	.04	.02	......	......	......	......	1.58	1.43	1.14	......	......
P_2O_5	.01	.06	.08	.05	......	.42	......	......	......	......	.02	......	......	.03	......	......	......	......	......	......
MnO	.03	.03	.03	......	......	......	......	......	......	Trace	.02	......	......	......	......	......	......	......	......	......
CO_2	.09	.16	.05	......	.96	......	......	......	......	......	.38	......	......	.24	......	......	......	......	......	......
S	.00	.08	1.05	[1] 2.97	.05	[2] 3.01	......	......	......	......	.00	......	......	.00	......	......	......	......	[1].45	......
BaO	.00	.00	.00	.43	.06	......	......	......	......	......	.00	......	......	......	......	......	......	......	......	......
Subtotal	99.47	98.68	97.84	98.55	100.01	94.45	96.82	99.56	100.19	100.19	99.84	99.84	99.13	100.54	100.24	100.06	100.04	100.07	99.80	100.04
Other	......	[3]–.04	[3]–.53	[4] 1.42	[2].11	[5] 5.19		......		[6].04									[7].36	
Total	99.47	98.64	97.31	99.97	100.12	99.64	96.82	99.56	100.19	100.23	99.84	99.84	99.13	100.54	100.24	100.06	100.04	100.07	100.16	100.04

[1] As SO_3. [2] Au+Ag+Te. [3] Oxygen correction. [4] $Sb_2O_5+As_2O_5$. [5] Cu+Fe as sulfides. [6] Cu+Zn+Ni+Co. [7] NaCl.

No.	Description	Locality	Source of data
1	Oxidized jasperoid	Minturn quadrangle, Colorado	Present study (E. L. Munson, analyst).
2	do	Tintic district, Utah	Do.
3	Unoxidized jasperoid	Tri-State district, Oklahoma	Do.
4	Oxidized jasperoid	Mercur district, Utah	Gilluly (1932, p. 114).
5	Unoxidized jasperoid	Black Hills, S. Dak	Irving (1911, p. 647).
6	Composite jasperoid sample	Ely district, Nevada	Spencer (1917, p. 117).
7	Jasperoid	Joplin, Mo	Bain (1901, p. 121).
8	do	Joplin district, Missouri	Cox, Dean, and Gottschalk (1916, p. 16).
9	do	Galena, Kans	Do.
10	do	Bull Frog mine, Chitwood, Mo	Do.
11	Chert	Custer County, S. Dak	Present study (E. L. Munson, analyst).
12	do	Belleville, Mo	Clarke (1924, p. 551).
13	Irish chert	Ireland	Do.
14	English flint	England	Weymouth and Williamson (1951, p. 580).
15	Arkansas novaculite	Arkansas	Clarke (1924, p. 551).
16	Silcrete	Albertina, Cape Province, South Africa	Frankel (1952, p. 179).
17	do	do	Do.
18	do	do	Do.
19	Siliceous sinter	Yellowstone Park, Wyo	Clarke (1924, p. 207).
20	do	Steamboat Springs, Nev	Do.

TABLE 5.—*The observed range and average concentrations, in percent, of the 13 commonly reported oxides plus sulfur for 10 representative jasperoid samples compared with those of certain other rock types*

[Leaders (......) indicate no information]

	Jasperoid		Chert		Silcrete		Siliceous sinter		Jaspilite	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
SiO_2	80 –97	92.8	95.5 –99.5	97.7	95 –97	95.7	72 –93	82.5	34.3 –61.4	47.3
Al_2O_3	.3 – 4	1.4	0 – .5	.2	1 – 2.3	1.8	.8 –12	6.2	0 – 4.6	1.2
Fe_2O_3	0 – 5	1.3	0 – 2	.6	.1 – .5	.3	......	......	30.6 –53.1	45.2
FeO	.15– .7	.4	0 – .15	.08	......	......	......	......	.4 – 5.7	2
MgO	0 – 1	.2	0 – .2	.06	0 – .2	.1	.05– .1	.07	0 – 2.7	.5
CaO	0 – 1	.4	.05– .5	.25	0 – .16	.08	.15 – .75	.4	0 – 4.2	1.3
Na_2O	0 – .3	.1	0 – .15	.06	......	......	.8 – 3.5	2.1	0 – 1.7	.6
K_2O	.1 – 1	.3	0 – .07	.04	......	......	.2 – 1.7	.9		
H_2O (total)	.4 – 3.2	1.2	.1 – 1.5	.8	.45– 1.4	.6	5.5 – 9	7.2	.07– 1.9	.7
TiO_2	.03– .8	.2	......	......	1.1 – 1.6	1.4	......	......	0 – .3	.1
P_2O_5	.01– .4	.1	......	......	......	......	......	......	.05– .6	.3
CO_2	0 – 1	.3	0 – .4	.3	......	......	......	......	.06– 2.9	1.3
S	0 – 3	1.2	0	0	......	......	......	......	0 – .2	.09
BaO	0 – .4	.1	0	0	......	......	......	......	......	......

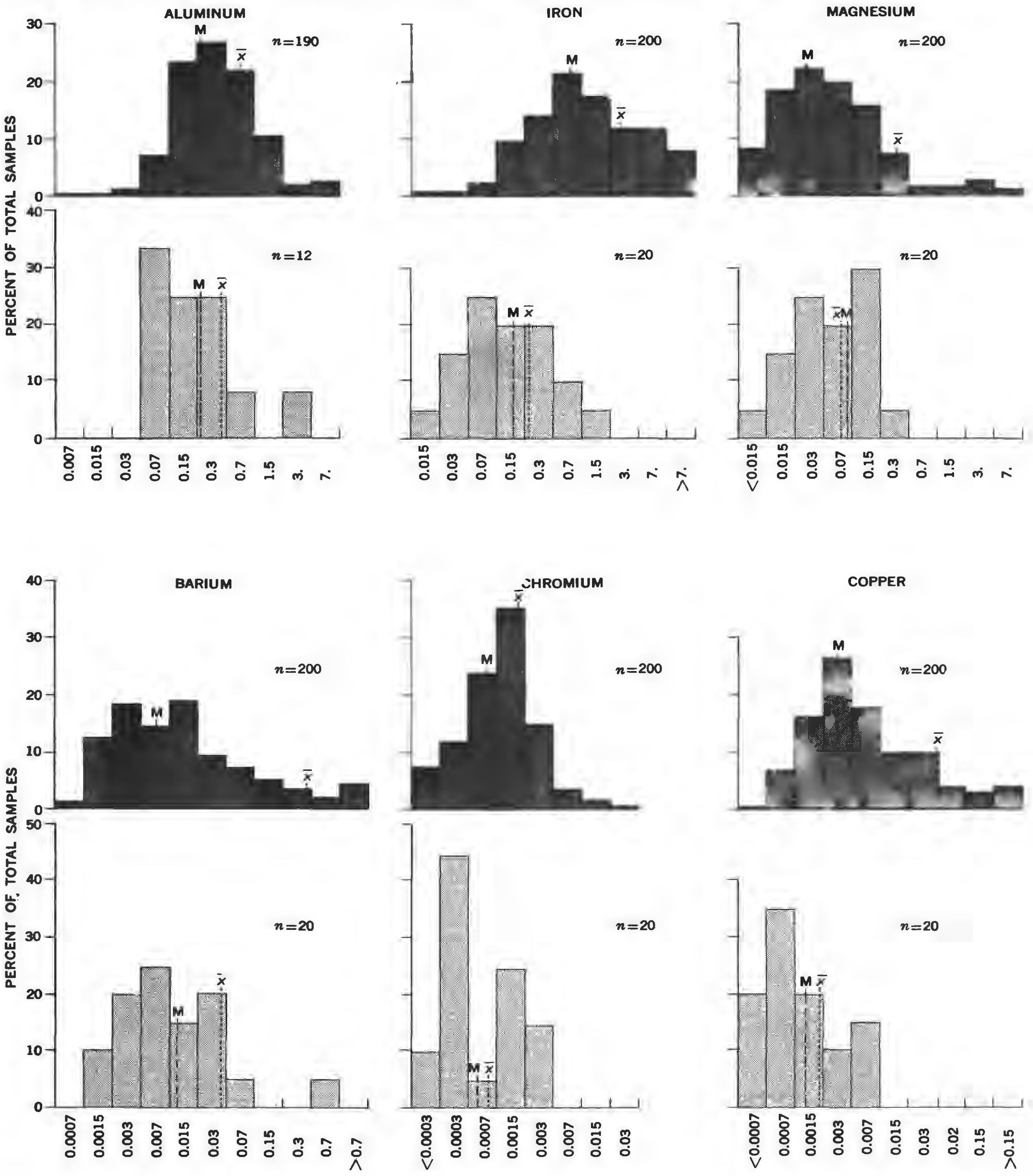
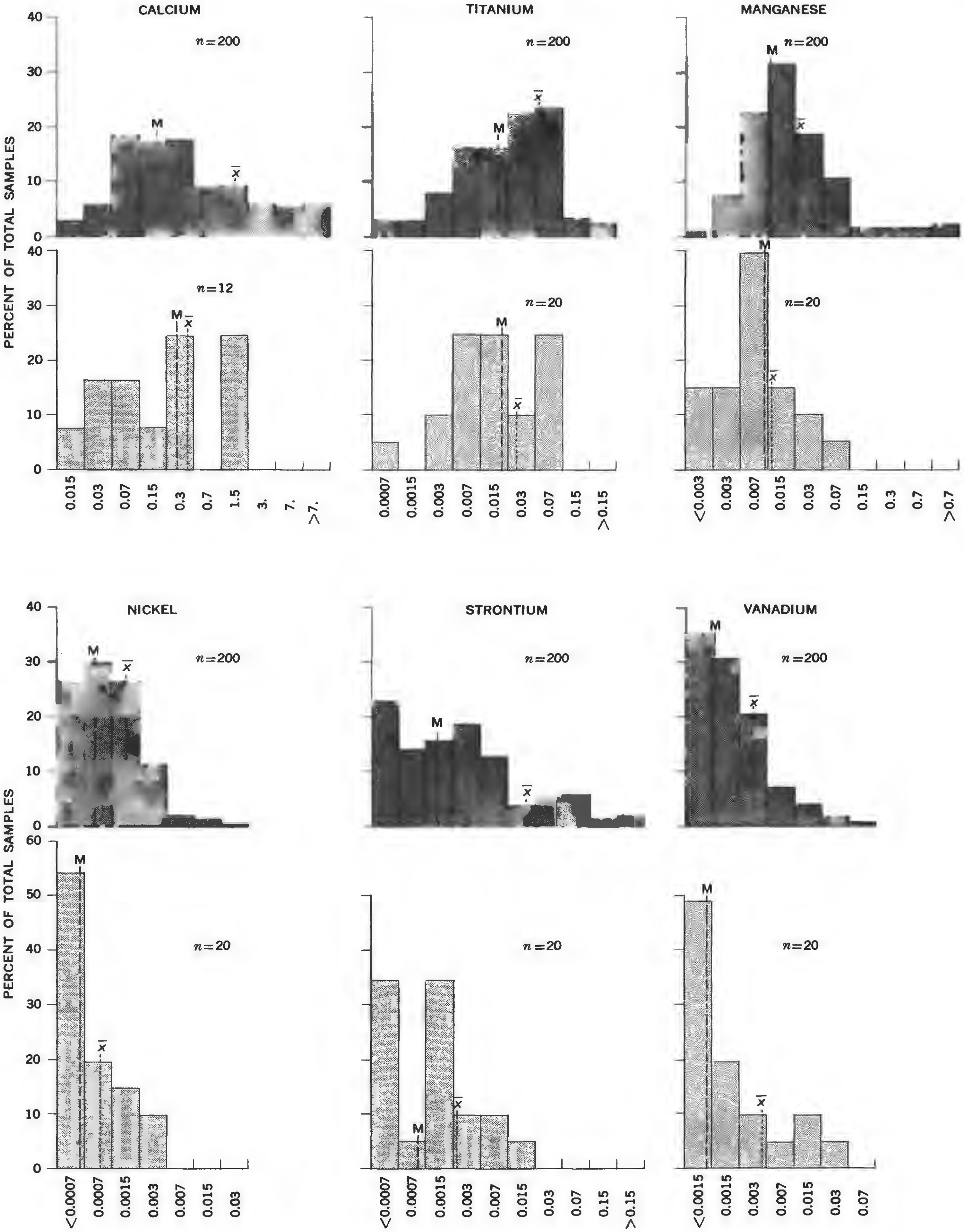


Figure 33.—Distributions of elements detected by semiquantitative spectrographic analysis in most of the jasperoid (black) and chert (stippled) samples. M, median, $\bar{x}$ arithmetic mean. Distribution in parts per million. n, number of samples analyzed.


CALCIUM
TITANIUM
MANGANESE
n=200
n=12
n=20
M
$\bar{x}$
PERCENT OF TOTAL SAMPLES
0
10
20
30
40
0.015
0.03
0.07
0.15
0.3
0.7
1.5
3.
7.
>7.
0.0007
0.0015
0.003
0.007
0.015
0.03
0.07
0.15
>0.15
<0.003
0.003
0.007
0.015
0.03
0.07
0.15
0.3
0.7
>0.7
NICKEL
STRONTIUM
VANADIUM
50
60
<0.0007
0.0007
0.0015
0.003
0.007
0.015
0.03
<0.0015
0.0015
0.003
0.007
0.015
0.03
0.07

differences reflect the fact that jaspilite consists of alternating layers of hematite and jasper.

The silica content of the jasperoid samples is slightly lower than that of the cherts and silcretes; Fe_2O_3 and Al_2O_3 are higher in the jasperoids than in the cherts, but lower than in the siliceous sinters. Differences in MgO and CaO contents between the rock types are minor; K_2O is higher than Na_2O in jasperoid samples, but the reverse is true in chert and siliceous sinter samples. Data for combined water versus free water are available only for the jasperoids, so no direct comparison can be made of these components; ignition loss in the chert and silcrete samples is comparable to the sum of H_2O_+ and H_2O_- in the jasperoid samples, but it is considerably higher in the siliceous sinter samples. TiO_2 is nearly an order of magnitude higher in samples of silcrete than in those of jasperoid, but the silcretes all came from the same area, and therefore, they may not be truly representative of this type of rock. It would be interesting to ascertain whether other representatives of ground-water-precipitated silica, such as the duricrusts in Australia and the silica-cemented gravels elsewhere, show the same tendency toward high titanium content.

MINOR CONSTITUENTS

Semiquantitative spectrographic analyses for 64 elements were made on about 200 samples of jasperoid and 20 samples of chert and novaculite by J. C. Hamilton of the U.S. Geological Survey, using a method described by Myers, Havens, and Dunton (1961). Only 43 elements were detected in one or more of the samples, and only 13 are present in detectable concentrations in most of the samples. These 13 are Si, Al, Fe, Mg, Ca, Ti, Mn, Ba, Cr, Cu, Ni, Sr, and V; Si, of course, is a major constituent of all the samples. Frequency distributions of the other 12 elements in the jasperoid and chart samples are shown in figure 33.

STATISTICAL SUMMARY

The class intervals of the histograms are those in which the analyses were reported. Some replicate samples were submitted to check the precision of the analyses. About 60 percent of the reported concentrations of the elements in these check samples duplicated the original determinations; about 90 percent came within one reporting interval of the original value.

All the jasperoid sample distributions are positively skewed, with an arithmetic mean higher than the median, and all but Ba, Ca, and Sr are unimodal. Ba and Ca display a single intermodal class which is only slightly lower than the adjacent modal classes; thus, the bimodality of the sample distributions may reflect a slight analytical or sampling bias in samples from populations with platykurtic distributions. Cumulative frequency-distribution plots on logarithmic probability paper reveal four different types of sample distributions of these 12 elements in jasperoid. Al, Fe, Mg, and Ni display straight-line plots closely approximating single log normal distributions; Ca, Mn, Ba, Cu, and V all display plots in which the low values fall close to one straight line and the high values close to another straight line with lower slope, with a pronounced breakpoint where the two lines intersect. This suggests that for these five elements the samples represent a mixture of two populations—one of low values with relatively small dispersion and one of high values with greater dispersion, both populations being approximately log normal. Cr and Ti also display plots characterized by two straight lines with a breakpoint, but the high values have a greater slope than the low, suggesting a smaller dispersion in the high values. Sr displays a very irregular cumulative frequency-distribution curve with three breaks in slope. The medians of the cumulative distributions for all the elements in which these distributions show a break in slope fall below or nearly on this break; thus, the sample median values are probably the best representative measures of central tendency for the concentration of these elements in jasperoid. The arithmetic-mean concentrations of many of these elements are strongly influenced by the presence of a few samples in which the elements are present in abnormally high concentration, and it is doubtful that the proportion of such samples in the suite of 200 samples analyzed is adequately representative of the proportion of jasperoids containing this high a concentration of these elements. Thus, for the elements Ca, Mg, Ba, and Cu in which the arithmetic mean is an order of magnitude or more higher than the median, the mean does not furnish a good representative value for the normal concentration of these elements in jasperoid.

The number of chert samples for which comparable analyses are available is so small (12 for Al and Ca; 20 for the other elements) that any general conclusions drawn from a comparison of these sample frequency distributions with the corresponding ones for jasperoid are of dubious validity. In all but three of the elements the mean and median values for chert either are bracketed by those for jasperoid or correspond closely to them. These three exceptions are Fe, Cu, and Sr; for Fe and Cu, both the mean and median values for chert are below the median for jasperoid. The sample data suggest, therefore, that iron and copper concentrations are characteristically higher in jasperoid than in chert, but a considerably larger number of representative chert sample analyses would be needed to establish this hypothesis. The median value for strontium in chert is slightly lower than in jasperoid, and the arithmetic mean in chert is slightly higher than the jasperoid median; however, in view of the highly irregular frequency distributions of this element in the samples of both rock types and the small number of samples involved, it is doubtful that any general significance can be ascribed to this fact.

Frequency distributions and estimated median values for the remaining 30 elements detected in one or more of the jasperoid samples are given in table 6. The median values of all 42 elements in the 200 jasperoid samples are given in table 7. The average abundance of these elements in igneous rocks is also shown for comparison (Rankama and Sahama, 1950, p. 39–40). Most of the elements seem to be deficient in jasperoid as compared with igneous rocks. Only Ag, As, Bi, In, and Sb are significantly enriched in jasperoid, and all five of these are chalcophile elements. This apparent tendency toward enrichment of chalcophile elements in jasperoid is reasonable, because most jasperoid is a product of hydrothermal alteration and chalcophile elements are likely to have been most concentrated in such solutions.

Concentrations of chalcophile elements in jasperoid may provide diagnostic criteria for distinguishing jasperoids from syngenetic and diagenetic chert. As shown in table 6, however, there is a wide variation in content of the chalcophile elements in jasperoid. Thus, their presence in abnormally high concentration may indeed be indicative of jasperoid rather than chert, but low concentrations are not indicative of chert.

GENESIS OF JASPEROID

The existence of a body of silicified rock (jasperoid) implies the existence of the following: (1) An adequate source of silica; (2) fluids capable of dissolving and transporting the silica to the site of deposition; (3) conditions at the site of deposition that caused silica to replace the host rock, and (4) reaction rates at this site such that host rock dissolved at the same rate or a little faster than silica precipitated. Any theory that seeks to explain the genesis of jasperoid must, therefore, account for each of these conditions.

SOURCE OF SILICA

The silica emplaced in jasperoid bodies may have

TABLE 6.—*Distribution of minor elements in 200 selected jasperoid samples*

[J. C. Hamilton, analyst. Numbers in parentheses ( ) indicate number of samples in which element is present in trace amounts. Leaders in figure columns (......) indicate no data (no samples in group). Query (?) indicates estimate for elements detected in 5 percent or less of the samples]

Element	Number of samples in which element detected in parts per million shown in first entry in figure columns													Number of samples in which element not detected	Estimated median [1] (ppm)	Abundance in igneous rocks [2] (ppm)
	>0.07	0.7	0.3	0.15	0.07	0.03	0.015	0.007	0.003	0.0015	0.0007	0.0003	0.00015			
Na	3	......	2	5	17	(12)	......	......	......	......	......	......	......	161	0.003	2.8
K	3	7	......	......	......	......	......	......	......	......	......	......	......	190	.02 ?	2.7
P	2	4	......	......	......	......	......	......	......	......	......	......	......	194	.005 ?	.12
Ag	......	......	1	......	4	5	10	6	22	14	11	13	12	102	.0001	.00001
As	13	......	9	6	2	......	......	......	......	......	......	......	......	170	.001	.0005
B	......	......	1	......	......	......	......	3	28	6	......	......	......	162	.0005	.0003
Be	......	......	......	......	......	......	......	......	......	3	5	13	25	154	.00002	.0006
Bi	......	2	......	1	......	5	5	4	10	13	(3)	......	......	157	.00005	.00002
Cd	......	......	......	......	......	3	1	3	......	......	......	......	......	193	.00001 ?	.00001
Ce	......	......	......	......	......	5	(1)	......	......	......	......	......	......	194	<.00001	.005
Co	......	......	......	......	......	......	1	1	1	4	(11)	......	......	182	.00005 ?	.002
Ga	......	......	......	......	......	......	......	1	1	3	12	(15)	......	168	.00003	.0015
Ge	......	......	......	......	......	......	......	2	2	2	......	......	......	194	.000001 ?	.0007
In	......	......	......	......	......	1	......	3	3	(17)	......	......	......	176	.0001	.00001
La	......	......	......	......	......	......	......	5	(10)	......	......	......	......	185	.0001 ?	.002
Li	......	......	......	......	......	1	......	......	......	......	......	......	......	199	<.00001 ?	.0065
Mo	......	1	......	1	......	......	......	7	17	28	21	......	......	125	.0002	.0005±
Nb	......	......	......	......	......	......	......	......	......	(6)	......	......	......	194	<.000001 ?	.002
Nd	......	......	......	......	......	......	1	......	......	......	......	......	......	199	<.000001 ?	.002
Pb	10	4	7	7	11	12	14	22	19	(14)	......	......	......	80	.002	.0016
Sb	1	1	1	4	4	10	10	......	......	......	......	......	......	169	.0006	.0001
Sc	......	......	......	......	......	......	......	......	......	3	6	......	......	191	.00005 ?	.0005
Sn	......	......	......	2	......	1	2	5	5	(15)	......	......	......	170	.00005	.004
Ti	......	......	......	......	......	......	1	......	......	......	......	......	......	199	<.000001 ?	.0001
U	......	......	......	1	......	......	......	......	......	......	......	......	......	199	<.00001 ?	.0004
W	......	......	......	......	......	......	2	1	......	......	......	......	......	197	.000001 ?	.002
Y	......	......	......	......	......	......	1	......	12	37	(3)	......	......	147	.0004	.003
Yb	......	......	......	......	......	......	......	......	......	1	......	10	39	150	.00004	.0003
Zn	4	4	7	11	23	21	2	(23)	......	......	......	......	......	105	.002	.013
Zr	......	......	......	......	1	8	10	27	39	48	......	......	......	67	.001	.02

[1] Median estimated by extrapolation of truncated cumulative frequency distribution.

[2] Data from Rankama and Sahama (1950, p. 39–40).

TABLE 7.—*Median concentrations of elements detected in the 200 jasperoid samples studied during the present investigation compared with average concentrations in igneous rocks as given by Rankama and Sahama (1950, p. 39–40)*

Element[1]	Element concentrations (in percent) in—	
	200 jasperoid samples (median)[2] (present study)	Igneous rocks (average) (from Rankama and Sahama, 1950, p. 39–40)
Fe	0.7	5
Al	.25	8.1
Ca	.18	3.6
Mg	.03	2.1
K	(.02)?	2.7
Ti	.016	.4
Mn	.011	.1
Ba	.008	.025
P	(.005)?	.12
Cu	.003	.007
Na	(.003)	2.8
Pb	(.002)	.0016
Zn	(.002)	.013
As	(.001)	.0005
Sr	.001	.03
V	.001	.015
Zr	(.001)	.02
Cr	.0008	.02
Ni	.0006	.008
Sb	(.0006)	.0001
B	(.0005)	.0003
Y	(.0004)	.003
Mo	(.0002)	.0005±
Ag	(.0001)	.00001
In	(.0001)	.00001
La	(.0001)?	.002
Bi	(.00005)	.00002
Co	(.00005)	.002
Sc	(.00005)?	.0005
Sn	(.00005)	.004
Yb	(.00004)	.0003
Ga	(.00003)	.0015
Be	(.00002)	.0006
Cd	(.00001)?	.00001
Ce	(<.00001)?	.005
Li	(<.00001)	.0065
Ge	(<.00001)	.0007
Nb	(<.00001)	.002
Nd	(<.00001)	.002
Tl	(<.00001)	.0001
U	(<.00001)	.0004
W	(<.00001)	.002

[1] Elements are given in order of decreasing abundance in jasperoid.

[2] Medians that are estimated by extrapolation from censored distributions are in parentheses; those for rarely detected elements, reported in 5 percent or less of the samples, are in parentheses followed by a question mark.

been derived from one or more of four major sources: (1) the silica-rich residual fluids emanating from a cooling magma; (2) silica released by reaction of a hypogene mineralizing solution with wall-rock minerals en route to the site of silicification; (3) silica in the form of chert, siliceous organisms such as diatoms and sponge spicules, or siliceous shale beds and argillaceous and siliceous fractions already present in the host rock, and (4) silica released by weathering of overlying or adjacent rocks. Silica, in minor amounts, may also be released during the alteration of silicate minerals, such as the conversion of montmorillonite to kaolinite by diagenetic or hydrothermal alteration or by weathering. Only the four principal sources just listed, however, seem adequate to supply the hundreds of thousands of cubic feet of silica commonly contained in the larger jasperoid bodies.

There is some question as to whether masses of siliceous rock composed of silica derived from ground water and furnished by sources 3 and 4 should be included under jasperoid, or whether the term "jasperoid" should be restricted to bodies composed of silica derived only from hydrothermal solutions. Examples of bodies that originated from silica in ground water include (1) silicified erosion surfaces in the Apache Group in north-central Arizona (Leith 1925, p. 515–516; A. F. Shride, oral commun., 1961), (2) the silcretes of South Africa (Frankel, 1952, p. 181–182), the duricrusts of Australia (Woolnough, 1928, p. 32), and certain silicified rocks from Tanganyika (Bassett, 1954), (3) some epigenetic "chert" bodies and the "case-hardened" limestone which are common in many arid and semiarid regions, and (4) highly silicified gossans replacing sulfides and host rock at and near the surface. Undoubtedly, a great many siliceous replacement bodies that have been designated as chert or hydrothermal jasperoid really belong in the category of bodies that originated from silica in ground water; however, there is at present no inclusive genetic term by which to designate the category. Furthermore, many "hydrothermal jasperoids" may have formed from juvenile solutions mixed with heated ground waters. Because of the practical difficulty in distinguishing between siliceous replacements derived from hot water and those derived from cold water, it seems best, for the present, to retain the term "jasperoid" as originally used by Spurr (1898, p. 219–220) to include all epigenetic siliceous replacement bodies, of whatever origin.

The primary source or sources of silica for most jasperoids cannot be conclusively established. In many mining districts there is strong field evidence that silicifying solutions rose from depth along faults and fractures, but whether this silica emanated directly from a cooling magma or was leached from siliceous rocks by upward-moving solutions is indeterminate. In a few places, such as the Gilman district of central Colorado and the Upper Mississippi Valley district, there is evidence that silica has been leached in quantity from rocks beneath the host rocks for the jasperoid.

SOLUTION AND TRANSPORTATION OF SILICA

The solvent properties of aqueous fluids for silica depend on the form in which silica is available, the temperature and pressure of the system, and the nature and concentration of other chemical components in the solution. Once silica is taken into the fluid and begins to move, it tends toward a dynamic equilibrium between ionic (monomeric) silica, and polymeric silica in true solution, and colloidally dispersed silica in the form of a peptized sol if the solution is supersaturated with respect to ionic and polymeric silica. Changes in any of the factors that influence release of silica to the solution also influence this equilibrum. Under controlled laboratory conditions, where all factors are held constant, days or even months may be required to establish such an equilibrium; thus, it probably is very rarely attained in moving hydrothermal solutions.

Considerable experimental data have accumulated on the solubility of silica under various conditions. These data may be divided roughly into four main categories: (1) solubility of various forms of silica in pure water at low temperature and pressure; (2) solubility of silica in pure water at higher temperature and pressure; (3) solubility of silica in various aqueous solutions at low temperature and pressure; and (4) solubility of silica in various aqueous solutions at higher temperature and pressure. Each of these categories may be further divided into (1) thermodynamic investigations of equilibrium solubility and (2) investigations of rates of solution and of equilibration.

SOLUBILITY OF VARIOUS FORMS OF SILICA IN PURE WATER AT LOW TEMPERATURE AND PRESSURE

Data on the solubility of quartz, powdered silica gel, and opal in water at 25°C and 1 atm (atmosphere) are given by Siever (1962, p. 129–133). He found that quartz particles on the order of 5 microns in diameter showed no measurable solubility in 3 years, but by extrapolating quartz solubility at higher temperatures downward, he calculated an equilibrium solubility of quartz at 25°C of about 10 ppm. Solubility of opal under these conditions is reported as about 120 ppm; that of powdered silica gel, about 140 ppm. On the other hand, quartz grains sized to −100, +200 mesh put under pressure of a steel rod in water at 25°C and 1 atm gave a solubility close to that of amorphous silica. Quartz grains kept in motion in a rotating polyethylene vessel at 1 atm and room temperature gave values that increased gradually to a maximum of 80 ppm at 386 days, then dropped abruptly to 6 ppm due to precipitation of quartz (Morey and others, 1962, p. 1036–1037). Krauskopf (1956, p. 5) gave the solubility of quartz in pure water at low temperature and pressure as 6 ppm; Iler (1955, p. 9) stated that solubility of quartz increases with diminishing particle size below 100 microns from about 7 ppm at 100 microns diameter to about 930 ppm at 3 microns diameter.

Experimental data on the equilibrium concentration of dissolved (monomeric) silica in pure water at 25°C and 1 atm in solutions supersaturated with total silica are not in complete agreement, possibly because silica can also form polymeric ion complexes. Iler (1955, p. 11–12) reported 100 ppm; Siever (1962, p. 129–130), 120–140 ppm; Alexander, Heston, and Iler (1954), 120 ppm; and Correns (1951, p. 51), about 250 ppm. In an experiment that I conducted (Lovering and Patten, 1962, p. 790), the monomeric silica content of a solution that contained 1,000 ppm total silica in pure water at room temperature and pressure dropped from an initial value of 270 ppm to 90 ppm within a week. The silica in solution remained at 90 ppm for 2 months, but when the experiment was discontinued at the end of 5 months, it had risen to 100 ppm.

SOLUBILITY OF VARIOUS FORMS OF SILICA IN PURE WATER AT HIGHER TEMPERATURE AND PRESSURE

Many problems are associated with the study of silica solubility in aqueous fluid at higher temperature and pressure.

1. Solubility varies as a function of the form of silica available; in general, it is lower for quartz at any given temperature and pressure than for the various forms of amorphous silica.
2. Equilibrium solubility at moderate temperature and pressure is established very slowly; Gruner (1930, p. 702) obtained a solubility for quartz at 200°C and 15 atm of 30 ppm after 24 hours, whereas Kennedy (1950, p. 636) reported its solubility under these conditions as 240 ppm after 230 hours.
3. Solubility does not vary directly with pressure at constant temperature nor with temperature at constant pressure; instead, it is a function of solution density at high temperature and pressure.
4. The reported "solubility" of amorphous forms of silica, such as silica glass, commonly is not a true equilibrium solubility; a change in conditions of the system that results in solution of silica may not, if reversed, cause precipitation of silica because of the tendency of solutions to remain supersaturated (Morey and Hesselgesser, 1951, p. 830).
5. Early investigators reported solubility of amorphous forms of silica equal to the total silica content of the aqueous phase, whereas more

recent investigators report only the ionic solubility, recognizing that much of the silica is present in the form of dispersed submicroscopic colloidal particles in a sol, a colloidal solution.

The solubility of quartz in H_2O has been investigated over a wider range of temperature and pressure than that of any other form of silica, and the data obtained by various investigators are more nearly in agreement. A large part of the solubility field of quartz was systematically studied by Kennedy (1950), and his work has since been supplemented by that of Morey and Hesselgesser (1951), Ellis and Fyfe (1957), Morey, Fournier, and Rowe (1962), and Siever (1962). Kennedy covered the region around the critical point of water, from 200° to 500°C at 200–1,000 atm pressure; Ellis and Fyfe obtained some solubility data for temperatures of 500° and 600°C at 1,000–3,000 atm pressure. Morey and Hesselgesser partly duplicated the field covered by Kennedy, obtaining nearly the same values, but they also obtained some critical information on solubility at high temperature and relatively low pressure. Morey, Fournier, and Rowe investigated quartz solubility in H_2O at 1,000 atm pressure in the temperature range of 45°–300°C; Siever investigated quartz solubility in the range of 100°–200°C at low pressure (the vapor pressure of the system). Data from these various sources have been combined in figures 34*A* and 34*B* showing the isobaric solubility of quartz as a function of temperature at 300 atm pressure and the isothermal solubility of quartz at 400°C as a function of pressure.

The marked inflection point on the isobaric solubility curve (fig. 34*A*) in the vicinity of the critical point, with decreasing solubility at higher temperatures, is a characteristic feature of these curves up to a pressure of about 700 atm; at pressures higher than this, solubility increases directly with temperature. If solubility is plotted at a constant specific volume of H_2O rather than at constant pressure, it increases steadily with temperature in the two-phase fields (quartz plus liquid and quartz plus gas), with no inflection at the boundary between these fields (Kennedy, 1950, p. 639, 642). The attenuated S-shaped isothermal solubility curve (fig. 34*B*) shows the marked effect of moderate pressure changes on quartz solubility at relatively high temperature in the range of 100–500 atm; a threefold increase in pressure (100–300 atm) results in a hundredfold increase in solubility of quartz at

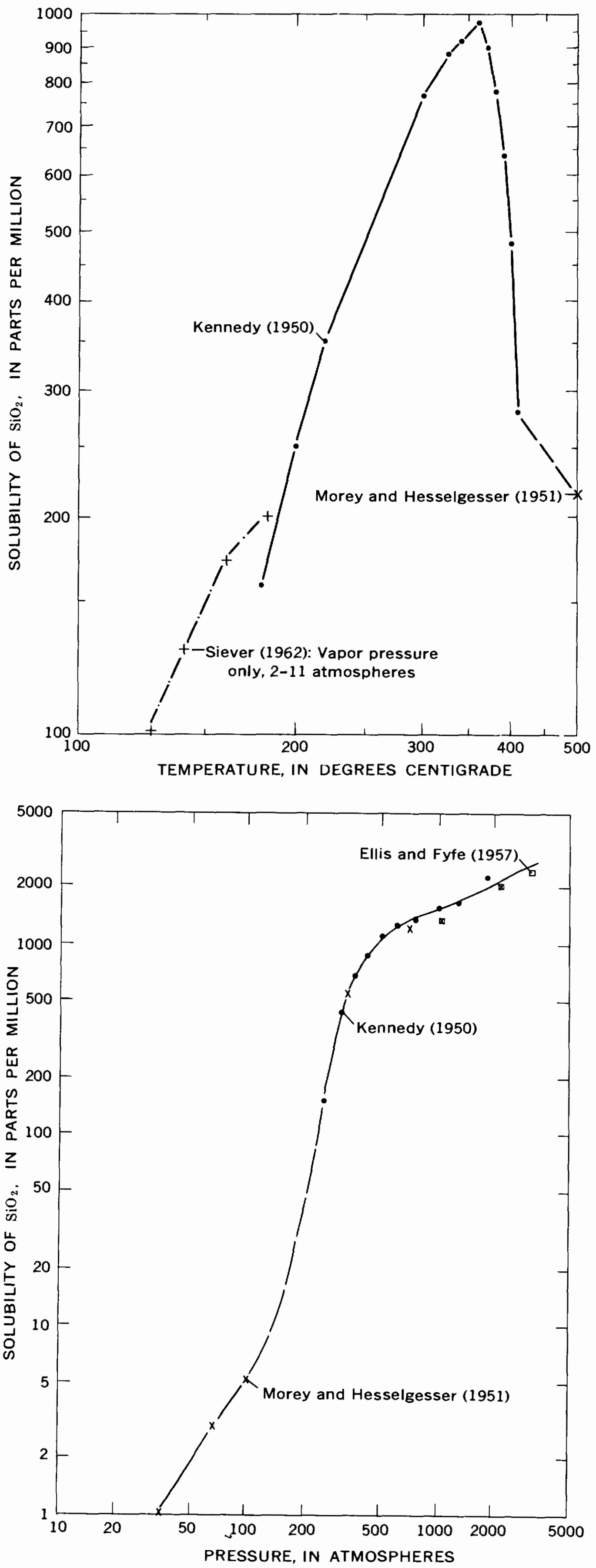


FIGURE 34.—Solubility of quartz in H_2O. *A*, At 300 atm pressure. *B*, At 400°C.

400°C. Thus, even a moderate throttling of a hydrothermal conduit could result in undersaturation below the constriction with solution of quartz and in a high degree of supersaturation with SiO_2 in the hydrothermal fluid above the constriction.

Published data on solubility of other forms of silica in aqueous fluid at various temperatures and pressures are difficult to compare, because many of them represent unique metastable equilibrium conditions. Some investigators report total silica, and others report ionic silica. In much of the early work it is questionable whether the stated conditions of the experiment were maintained long enough for equilibrium to be established. Kennedy's paper (1944), in which he summarized earlier work by Lenher and Merrill (1917) and Gruner (1930), is one of the most systematic studies of this difficult experimental field. His data suggest that the solubilities of various noncrystalline forms of SiO_2 conform to much the same solubility curves as quartz at intermediate conditions of temperature and pressure, but are commonly somewhat higher than those of quartz under the same conditions. Siever (1962, p. 133) stated that the solubility versus temperature curves for quartz and amorphous silica converge toward higher temperature.

The rate of solution of quartz is extremely slow in water at low to moderate temperature and pressure. Kennedy reported that 230 hours was required to achieve saturation at 200°C and 15 atm pressure. Carr and Fyfe (1958, p. 913–914) determined that quartz dissolves at the rate of 1 mg per hr (milligrams per hour) at 270°C and 1,000 atm, which increases to 18 mg per hr at 500°C under the same pressure; at 400°C, an increase in pressure from 345 to 1,725 atm increased the solution rate from 2 to 12 mg per hr.

SOLUBILITY OF VARIOUS FORMS OF SILICA IN AQUEOUS SOLUTIONS AT LOW TEMPERATURE AND PRESSURE

ACID SOLUTIONS

The amount of monomeric silica in equilibrium with colloidal silica in slightly acid solutions does not differ appreciably from that in pure water, but it declines in strongly acid solutions. Iler (1955, p. 11–12) reported 140 ppm SiO_2 at a pH of 1, rising to a maximum of 150 ppm at about a pH of 3 and then declining to 110 ppm at a pH of 5.7. Elmer and Nordberg (1958, p. 518–519) found 160 ppm SiO_2 in solution in $0.001N$ HNO_3 as opposed to 115 ppm in $0.8N$ HNO_3. Lenher and Merrill (1917, p. 2636) reported that SiO_2 content of sulfuric acid solutions containing less than 5 percent H_2SO_4 is virtually the same as that in pure water; also, that concentrated HCl will dissolve only 8 ppm of SiO_2, but that 3 percent HCl solution will dissolve 140 ppm. Lovering and Patten (1962, p. 789) obtained 320 ppm of monomeric silica in H_2SO_4 solution at a pH of 2.3, and 220 ppm at a pH of 3.6 after 1 month. In dilute carbonic acid solution with a pH of 5.2 they found 110 ppm of ionic silica in equilibrium with colloidal silica, virtually the same as that in pure water. Siever (1962, p. 132) reported that humic acid solutions repress the solubility of silica gel to about 15 ppm of monomeric silica.

Moore and Maynard (1929, p. 277) recognized that much of the silica transported by natural acid water is in the form of a dispersed hydrosol. The decline in true solubility of silica in highly acid solutions is counteracted by the stabilizing effect of such solutions on dispersed silica sols. This stabilizing effect will prevent the precipitation of silica from highly supersaturated solutions, even in the presence of strong electrolytes; a solution containing 2,000 ppm of total silica in the form of sodium silicate remained perfectly clear for a month at a pH of 2.3, although the monomeric silica content of the solution after that time was only 320 ppm (Lovering and Patten, 1962, p. 789). On the other hand, solutions highly supersaturated with silica become unstable in weakly acid solutions and tend to precipitate excess silica. This precipitation is accelerated by the presence of strong electrolytes, but it will occur even in their absence. Frondel (1938, p. 10) noted that the addition of HCl to a colloidal silica sol reverses the negative charge on the sol. The reversal of charge probably accounts for the buffering effect of strong acids against precipitation by electrolytes.

The solubility of silica derived from common silicate rocks and minerals in acid solutions has not been systematically investigated.

Gruner (1922, p. 435) reported that the solubility of silica from silicate minerals in acid solutions is inversely proportional to the silica content of the silicate. According to T. S. Lovering (1950, p. 237, 240), the attack of acid solutions on silicates results in solution of their bases, causing decomposition, although actual solution of silica is minor. He listed the common rock silicates in order of decreasing susceptibility to attack by acid solutions as follows: Zeolites, feldspathoids, calcic plagioclase, augite, hornblende, biotite, oligoclase, orthoclase, albite, muscovite, and quartz.

ALKALINE SOLUTIONS

The ionic solubility of silica, in equilibrium with colloidally dispersed silica, rises slowly in alkaline solutions from a minimum of about 100 ppm at a pH of 7 to about 200 ppm at a pH of 9.8, and then rapidly to about 500 ppm at a pH of 10.3, 1,100 ppm at a pH of 10.6, and 5,000 ppm at a pH of 11 (Iler, 1955, p. 11–12; Alexander and others, 1954). This rapid increase in solubility at a high pH is due to an increase in the concentration of polymeric silica—$Si(OH)_4 + (OH)^- \rightarrow (HO)_3SiO^- + H_2O$. Near the neutral point, supersaturated silica solutions become unstable in the presence of electrolytes, and excess silica readily precipitates. Above a pH of about 8, however, highly supersaturated solutions may remain stable for a considerable length of time, even in the presence of a moderate concentration of electrolytes. A solution containing 2,000 ppm total silica, 120 ppm ionic silica, and 1,650 ppm sodium remained clear for a month at a pH of 9 (Lovering and Patten, 1962, p. 789). Iler (1955, p. 48) reported that the stability of colloidal silica sols in the pH range 7–10 depends on the $SiO_2:Na_2O$ ratio; an increase in this ratio increases the sizes of particles in the sol, which favors nucleation and precipitation. He (p. 14) also stated that the presence of sodium chloride and alkaline carbonates accelerates the solution of colloidal silica in alkaline solutions.

The solubility of quartz, opal, chalcedony, actinolite, and glauconite in NaOH, Na_2CO_3, $CaH_2(CO_3)_2$, and $MgH_2(CO_3)_2$ solutions was investigated by T. S. Lovering (1923, p. 528–531). He found that opal and chalcedony are strongly attacked by dilute NaOH solutions and that Na_2CO_3 is an even stronger solvent for opal; $MgH_2(CO_3)_2$ is a moderately effective solvent with nearly uniform effect on all the silicates including quartz; the effect of $CaH_2(CO_3)_2$ is similar to, but much weaker than, that of magnesium bicarbonate. Later, Lovering (1950, p. 240) reported that mildly alkaline solutions are relatively ineffectual in causing decomposition of rock silicate minerals, although the cation present in highest concentration in such solution tends to be exchanged for any different soluble cation in the mineral; however, SiO_2 may be leached if the solution is undersaturated with silica. Van Lier, De Bruyn, and Overbeek (1960) established that dilute NaCl greatly accelerates the equilibration of SiO_2 in solution, resulting in precipitation of silica from supersaturated solutions and accelerated solution of quartz in contact with undersaturated solutions. Sodium chloride does not appreciably affect the solubility of silica unless present in concentrations greater than 0.1*N*. Such concentrated brines increase the solubility of silica (Van Lier and others, 1960, p. 1675, 1681–1682).

SOLUBILITY OF VARIOUS FORMS OF SILICA IN AQUEOUS SOLUTIONS AT HIGHER TEMPERATURE AND PRESSURE

ACID SOLUTIONS

Systematic studies of the monomeric silica content of acid solutions supersaturated with colloidal silica thus far have been limited to 1 atm pressure and temperatures below 100°C. Within this restricted range, silica in solution increases with temperature for any given composition of solution. For any given acid, solubility declines with increasing acid concentration above 0.1*N* at higher temperatures. Approximate equilibrium solubilities in parts per million at 90°C for common acids of comparable concentrations are as follows:

Solvent	HCl[1]	HNO_3[2]	H_2SO_4[1]
Concentration 0.1 *N*	420	415	425
5 percent	320	350	410
20 per cent	60	140	190

[1] Lenher and Merrill (1917, p. 2636).
[2] Elmer and Nordberg (1958, p. 518).

The solubility of silica in pure water at 90°C is about 430 ppm (Okamoto and others, 1957, p. 124).

Equilibrium solubility is attained more rapidly, at constant temperature, in strongly acid solutions than in weakly acid solutions. Elmer and Nordberg (1958, p. 518–519) found that at 90°C, 96 hours is required to reach equilibrium in 0.1*N* • HNO_3, but only about 48 hours in 0.8*N* • HNO_3.

A few studies have been made of the leaching of silica from rock silicates in acid solutions at elevated temperature and pressure. Lenher and Merrill (1917, p. 2636) reported that about 320 ppm of silica was leached from weathered chert and 200 ppm from fresh chert in a 4.6 percent HCl solution held at 90°C for 2 days. Blanck, Passarge, Rieser, and Heide (1925, p. 75) leached about 4.6 percent of the SiO_2 out of fresh Egyptian granite in boiling concentrated hydrochloric acid in 1 hour. White, Brannock, and Murata (1956, p. 52) proposed that hot waters highly charged with CO_2 will attack silicate minerals and will dissolve silica in the monomeric form. Ingerson (1947, p. 560) stated, however, that the presence of CO_2 in aqueous fluid at high temperature and pressure decreases the solubility of SiO_2, and his statement has been confirmed in the laboratory by Robert Fournier (written commun., 1962). These statements are not necessarily incompatible, because equilibrium solubility is achieved more rapidly in highly acid solutions than in dilute solutions, even though the saturation concentration is lower. The solubility of silica in boiling concentrated HCl is less than 100 ppm, yet such a solution leached more than 4 percent of the silica out of fresh granite in only 1 hour.

ALKALINE SOLUTIONS

Equilibrium solubility of monomeric silica in supersaturated alkaline solutions, of a pH of at least 10 and a temperature of 200°C, has been studied by Okamoto, Okura, and Goto (1957). They found that solubility increases in linear fashion independent of pH up to 100°C in the range of pH 7–pH 9 (from about 100 ppm at 0° to about 500 ppm at 100°C). From 100° to 200°C solubility increases with increasing alkalinity as well as increasing temperature in this range; at 200°C, solubility increases from about 920 ppm at pH 7, 980 ppm at pH 8, to 1,150 ppm at pH 9. At a pH of 10, the solubility is considerably higher at all temperatures from 0° to 200°C than it is at a pH of 9, but the solubility versus temperature curve is nearly parallel to that for a pH of 9 (about 800 ppm at 100°C, about 1,400 ppm at 200°C). The pressure was not specified by Okamoto, Okura, and Goto, but presumably it was equal to the vapor pressure of the system. T. S. Lovering (1950, p. 234) reported that the solubility of colloidal silica in Na_2CO_3 solution at 100°C increases from about 3,500 ppm in 0.25*N* solution to about 8,000 ppm in 1*N* solution. Its solubility in 0.1*N* NaOH at this temperature is about 12,500 ppm. Gruner (1930, p. 702) ran some experiments on the solubility of quartz and gabbro in sodium bicarbonate solutions maintained at 300°C in sealed metal bombs for 24 hours. He obtained 742 ppm of SiO_2 from the quartz and 64 ppm from the gabbro, which is less for both quartz and gabbro than the solubility in pure H_2O under the same conditions. Carr and Fyfe (1958, p. 916) maintain, however, that alkalies in aqueous solutions at high temperature and pressure accelerate the solution of silica; and Iler (1955, p. 161) stated that in alkaline solutions under these conditions a high concentration of Na^+ in the system causes the precipitation of excess colloidal silica. Thus, the main effect of alkalinity on silica solubility with increasing temperature and pressure probably is to maintain equilibrium solubility. Solutions undersaturated with SiO_2 should rapidly dissolve silica until they become saturated, and solutions that were supersaturated should precipitate the excess silica.

SUMMARY

The solubility of amorphous silica at low temperatures and pressures is highly dependent on pH; the solubility is greatest in strongly alkaline solutions and moderately high in weakly acid to neutral solutions. Solutions supersaturated with silica are metastable in highly acid and moderately acid solutions; unstable in weakly acid, neutral, and weakly alkaline solutions; and metastable in moderately alkaline solutions. Increasing pressure at low temperature increases solubility at any pH, but no data are available on the effect of pressure versus pH on stability of supersaturated solutions at low temperature. With increasing temperature at low pressure, solubility increases to the boiling point, then drops sharply in the vapor phase. Just below boiling, the solubility rises gradually from about 350 ppm at a pH of 0.1 to about 500 ppm at a pH of 9.2; then it increases rapidly in more highly alkaline solutions. At high temperature and pressure, solubility is highest in nearly neutral solutions; it drops off in both alkaline and acid solutions. Under these conditions, supersaturated solutions are unstable in alkaline systems, but no data are available on their stability in acid and neutral systems. Solubility is very low at low pressure in neutral solutions at supercritical temperatures, and it does not surpass room-temperature solubility until the pressure reaches about 300 atm. At still higher pressures, solubility increases rapidly with pressure. Solubility of silica in high pressure-temperature neutral aqueous systems varies directly with fluid density, or inversely with specific volume of the fluid phase.

COMPOSITION OF NATURAL SILICA-BEARING SOLUTIONS

Silica content of natural water is lowest in the oceans, < 10 ppm; in river water, it ranges from a trace to about 60 ppm and averages about 10 ppm; and in nonvolcanic lake water it ranges from a trace to about 150 ppm, although, like river water, it averages about 10 ppm. Hot springs of nonvolcanic origin can carry as much as 250 ppm silica; however, the most siliceous of the naturally occurring waters are found in hot springs, pools, and geysers emanating from regions of recent volcanism. Most of these contain more than 300 ppm silica, and a few contain nearly 1,000 ppm. White, Brannock, and Murata (1956, p. 29–30) reported that total silica content of supersaturated hot spring water from Yellowstone Park and Iceland ranged from 500 to 700 ppm. They found that at 100°C about 400 ppm of this is dissolved (monomeric) silica, and that the remainder is in dispersed colloidal form. They (p. 51) also found that the silica content of calcium bicarbonate hot springs that deposit travertine is very low (about 50 ppm); this fact, they suggest, may be due to the exchange of silica for calcium carbonate at depth. Thus, such springs at the surface may indicate formation of jasperoid replacement bodies below.

Clarke (1924) reported many analyses of various types of natural water. Table 8 gives a few of the

TABLE 8.—*Composition, in parts per million, of some samples of natural silica-bearing waters*

	Cold waters								Hot waters											
	Rivers				Lakes				Nonvolcanic hot springs			Volcanic hot springs and geysers								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	19a
CO_3	89	58	145	124	25	112	180	1,529	30	2,963	......	......	......	3	122	115	......	......	145	312
SO_4	67	24	53	164	8	190	9	85	18	43,579	5,781	4,572	5,330	34	18	102	75	136	131	129
Cl	7	7	30	304	9	9	3	115	11	356	2	......	34,549	670	439	153	550	1,030	998	949
Ca	48	29	69	82	9	44	42	249	3	4,759	577	22	132	7	2	......	8	71	7	12
Mg	11	5	14	26	<1	48	25	215	<1	8,220	76	313	612	1	<1	<1	2	5	<1	<1
Na	24	16	57	251	16	37	62	589	56	1,865	102	32	12,455	394	367	223	700	665	865	707
K	7	2		24	5	5	......	......	5	218	19	5	1,819	81	27	21	21	10	108	75
$Al_2O_3+Fe_2O_3$	<1	5	3	---	4	2	<1	33	......	12	1,158	161	3,950	......	......	......	---	---	<1	<1
Other	......	......	......	......	......	......	......	......	......	[1] 137	[2] 157	......	[3] 438	......	......	......	......	......	[4] 253	[4] 192
SiO_2	48	66	48	48	42	107	57	150	95	262	131	362	738	580	383	510	700	820	325	317
Total dissolved solids	302	212	422	1,023	118	554	379	2,966	218	62,371	8,150	5,467	60,023	1,830	1,388	1,131	2,064	2,735	2,850	2,508

[1] NH_4. [2] H_3AsO_4. [3] PO_4. [4] B_2O_3.

Source of samples:
1. Platte River at Fremont, Nebr.
2. Laramie River 20 miles north of Laramie, Wyo.
3. Republican River at Junction, Kans.
4. Gila River at head of Florence Canal, Ariz.
5. Yellowstone Lake, Wyo.
6. Bigstone Lake, Minn.
7. Silver Lake, Oreg.
8. Moses Lake, Wash.
9. Pyrenees Mountains, France
10. Bitter Spring, Laa, Austria
11. Roncegno, Southern Tyrol, Italy
12. Acid Spring, California Geysers, Sonoma County, Calif.
13. Green Lake, Taal Volcano, Luzon, Philippine Islands
14. Coral Spring Norris Basin, Yellowstone Park, Wyo.
15. Old Faithful Geyser, Yellowstone Park, Wyo.
16. Great Geyser, Iceland
17. Te Tarata, Rotorua, New Zealand
18. Otukapurang, Rotorua, New Zealand

19–19a. Steamboat Springs, Nev.

Source of Data:
Samples 1–19, Clarke (1924, p. 80–87, 164, 189–190, 196–197, 200–201); 19a, Brannock (1948).

most siliceous representatives of these waters and the content of their major components, converted from percent of total salinity to parts per million to facilitate comparison. Sample 19a, a thermal spring water, is from the same area as sample 19, whose analysis was quoted by Clarke. The general agreement between the two analyses is remarkably good, considering that they were made more than 50 years apart and by different methods, and that they probably do not represent the same spring.

The data given in table 8 seem to indicate that silica content of natural water is largely independent of the nature of the principal anion complex and also of the relative abundance of the alkalies (Na and K) versus the alkaline earths (Ca and Mg). The volcanic hot springs and geysers form a possible exception to the rule, inasmuch as all but one of them contain Na^{+1} and Cl^{-1} as the most abundant constituents other than silica. However, sample 12, from the California geysers, is a high sulfate water with no chlorine and a Ca + Mg to Na + K ratio of almost 10:1. Another generalization suggested by the data in table 8 is that, for any given type of water, the silica content is largely independent of the total dissolved solids. The Platte River sample (1) has 48 ppm SiO_2 out of a total of 302, as compared with one from the Gila River (4), which has 48 ppm SiO_2 out of a total of 1,023. One volcanic thermal water (17) has 700 ppm SiO_2 out of 2,064, another (13) has 738 ppm SiO_2 out of 60,023. Iron and alumina are negligible in, or absent from, most of these waters, but in two of the thermal water samples (11, 13) Fe_2O_3 + Al_2O_3 exceeds 1 gram per liter, which is considerably more than the silica content of any of the samples. The presence of appreciable quantities of ammonia, phosphate, arsenic, and boron as accessory constituents in some thermal waters is also noteworthy. Each of these constituents is normally not detectable, yet each may, under unusual circumstances, be transported along with silica in considerable quantities by hot aqueous solutions.

The total composition of a natural water seems to have relatively little effect on its ability to transport silica. A relatively pure water in which silica is a major constituent may carry about the same amount of silica as a highly saline one in which silica is a minor constituent. Clarke (1924, p. 96–97) mentioned the high proportion of silica to dissolved salts (46–56 percent) carried by some South American rivers, yet the total amount of silica in these waters is less than 40 ppm.

The aqueous fluid in primary fluid inclusions in quartz is another type of natural solution; its composition may be close to that of the solution from which the quartz was deposited. Fluid from a quartz crystal in a vein cutting rhyolite contained 0.047 percent Na, 0.011 percent K, 0.006 percent Ca, 0.063 percent Cl, and 0.063 percent SO_4 (Roeder and others, 1963, p. 368). Fluid inclusions in quartz from the Cave-in-Rock fluorite district of Illinois, which was deposited just before the ore sulfides, may bear an even closer resemblance to those from which ore-related jasperoids are deposited. This fluid contained 1.73 percent Na, 0.43 percent K, 0.84 percent Ca, 0.28 percent Mg, 4.7 percent Cl and 1.29 percent SO_4 (Hall and Friedman, 1963, p. 898).

Laz'ko (1965, p. 384–386) summarized some information on the composition of fluid inclusions from quartz veins in Russia. He found that Na>K>Ca in these inclusions and further stated (p. 384) that "The calculated dissolved Si, as SiO_3^{-2} (assuming its quantitative preponderance in the solution) indicates its total concentrations as high as 6–12 percent."

Laz'ko also reported that CO_2 is present in appreciable amounts in some inclusions, and he concluded that the mineralizing solutions, from which quartz is deposited, are primarily aqueous alkali chlorides.

DEPOSITION OF SILICA

The ability of natural waters and hot aqueous fluids to transport vast quantities of silica, in both monomeric and colloidal form, has been well established. We now consider the factors that induce precipitation of silica, the form in which silica is precipitated, and the causes of the conversion of a precipitated silica gel into the more stable forms of silica found in nature.

DEPOSITION AT LOW TEMPERATURE

Cold-water solutions that are supersaturated with respect to colloidal silica may, for a variety of reasons, precipitate some or most of this excess as hydrated amorphous silica; however, solutions that are just saturated or unsaturated with respect to colloidal silica, though highly supersaturated with silica relative to quartz, tend to maintain their metastable equilibrium and do not precipitate quartz under normal conditions. Geologic field evidence, on the other hand, strongly supports the conclusion that quartz can be precipitated directly from solution at relatively low temperatures. The evidence is in quartz crystals in geodes in unmetamorphosed limestone and shale, quartz-cemented surface gravels, and coarse quartz veining and lining cavities in limonite gossans. Murray and Grovenor (1953) reported that X-ray spectrometer and powder-photograph analyses of oceanic muds and the fine fractions of the insoluble residues of limestone and shale reveal abundant quartz particles less than a micron in diameter. They suggested that these particles may have been precipitated directly from solution.

The works of Siever (1962) and Morey, Fournier, and Rowe (1962) show that quartz subjected to abrasion or differential pressure in cold water will eventually supersaturate the solution as much as tenfold relative to its theoretical solubility, and that after a long time quartz will spontaneously precipitate from such a solution to reestablish equilibrium. The same process might occur more rapidly in dilute sodium chloride solutions, according to the evidence presented by Van Lier, De Bruyn, and Overbeek (1960).

According to Boydell (1927, p. 51), the precipitation of colloidal silica from supersaturated solutions can result from (1) mixing with solutions that contain a high concentration of electrolytes; (2) the mixing and reaction with a dispersed sol of opposite charge, such as a metal hydroxide sol; (3) the chemical removal of a protecting (peptizing) agent, such as fluorine in acid solutions; and (4) decrease in pressure or temperature of the system.

Evaporation.—One other way in which silica-bearing solutions may be induced to precipitate silica is by evaporation of such solutions under arid conditions. Clarke (1924, p. 366) stated that evaporation of acid siliceous waters forms opal. Rankama and Sahama (1950, p. 553–554) reported that the silica in alkaline solutions concentrated by evaporation precipitates as an amorphous silica gel. The siliceous duracrust of the Australian desert is thought by Woolnough (1928, p. 32) to have formed by the evaporation of siliceous ground water drawn to the surface by capillary action during dry cycles.

Neutralization.—Another factor that might contribute to the precipitation of dispersed colloidal silica is a change in pH; peptized sols that are stable under either strongly acid or strongly alkaline conditions become unstable as they are neutralized. Iler (1955, p. 45) wrote that gelation or precipitation of colloidal silica takes place most readily in the pH range 5–6. Lovering and Patten (1962, p. 789) found that supersaturated sodium silicate solutions that contain 1,000 ppm SiO_2 become unstable and precipitate colloidal silica in the pH range 4–8. These solutions remained clear and free of precipitate for a period of 2 months both in acid solutions with a pH lower than 4 and in alkaline solutions with a pH higher than 8. Solutions with the same silica content, from which sodium had been removed, remained clear at a pH of 7 for 3 months. Thus, the neutralization of a strongly acid or alkaline solution highly supersaturated with silica may not cause silica to precipitate unless some other agent that favors precipitation is also present.

Contact with solid phase.—Contact with a solid silica phase may also induce precipitation of colloidal silica. Nutting (1943, p. 220) observed that particles of solid silica will cause the precipitation of excess colloidal silica from supersaturated solutions in a few days and that "certain clays" will do the same thing in a few hours. The efficacy of opaline sinter, quartz, and chalcedony in causing the precipitation of amorphous silica from siliceous hot spring waters was noted by White, Brannock, and Murata (1956, p. 49). The effectiveness of various forms of solid silica in causing such precipitation must depend in part on the nature of the surface area that is in contact with the solutions, inasmuch as it is possible to keep supersaturated silica solutions in silica glass bottles for years without any precipitation.

Soluble salts.—Many investigators have commented on the precipitation of colloidal silica caused by the introduction of various soluble compounds, both electrolytes and nonelectrolytes, into supersaturated silica solutions or dispersed silica sols. Iler (1955, p. 14, 41–45, 93) reported that the addition of soluble salts causes gelation or flocculation of supersaturated silica solutions; sodium salts increase the viscosity of dispersed sols and, if present in high concentration, cause silica to precipitate. Boydell (1924, p. 89) stated that the addition of an electrolyte also increases the rate of diffusion of dispersed sol particles, and Gruner (1922, p. 445) believed that colloidal silica in acid solutions is precipitated on contact with alkaline chloride or alkaline carbonate solutions. Boydell (1924, p. 7) and Cox, Dean, and Gottschalk (1916, p. 6) agreed that calcium bicarbonate is one of the most effective natural electrolytes in causing precipitation of colloidal silica. Lovering and Patten (1962, p. 791–795) showed that relatively dilute carbonic acid solutions will precipitate colloidal silica from highly supersaturated solutions, even in the absence of cation electrolytes. Bassett (1954) mentioned the precipitation of silica from ground water in African freshwater lake marls as disseminated grains of amorphous silica, deposited with calcite and dolomite.

According to Iler (1955, p. 14), aluminum in solution inhibits the solubility of silica, and some experiments conducted by Okamoto, Okura, and Goto (1957, p. 129) indicate that soluble aluminum added to dispersed silica sols in concentrations as low as 10 ppm will precipitate as much as 90 percent of the excess colloidal silica from acid solutions with a pH of 4–5, provided the ratio of colloidal silica to Al^{+3} in solution is not greater than 50:1. At a pH lower than 4 or higher than 5, soluble aluminum has little effect on these sols. Okamoto, Okura, and Goto (1957) also found that aluminum in solution, if present in excess of 200 ppm, will precipitate dissolved (monomeric) silica from solution most effectively in the pH range 8–10. Harder (1965) has also shown experimentally that aluminum will precipitate silica from natural waters, and that the excess silica in the precipitated colloid will crystallize as quartz. The silcretes of South Africa are thought to have formed by replacement of selected clay layers by ground-water silica derived from adjacent shale or tillite (Frankel, 1952, p. 180–182); such an origin would substantiate the effectiveness of Al^{+3} as a silica precipitant. Okamoto, Okura, and Goto (p. 131) also stated that the action of Fe^{+3} ion is similar to that of Al^{+3}. Harder (1919, p. 73) wrote that ferrous sulfate solutions will react with alkaline silicate solutions in a reducing environment to precipitate ferrous silicate and colloidal silica, but that such solutions will also precipitate ferric hydroxide in an oxidizing environment.

Mixing of sols.—Neither ferric iron nor aluminum can exist in ionic form in high concentration except in moderately acid waters, because both tend to hydrolyze in near-neutral and alkaline solutions—Fe^{+3} at a pH of 3 and Al^{+3} at a pH of 5, according to Rankama and Sahama (1950, p. 228). Dispersed hydrosols of these metals in neutral or alkaline solutions may, however, on mixing with dispersed silica hydrosols, react to precipitate both silica and the metal hydroxide in colloidal form. The mutual precipitation of silica and metal hydroxide on mixing of dispersed hydrosols is caused by neutralization of the charges on the sols, silica being negative and metal hydroxide positive; such mutual precipitation begins at a slightly lower pH than that at which the metal hydroxide would precipitate alone. The completeness of flocculation and precipitation, as well as the relative proportions of the two colloids in the precipitate, depends upon the concentrations of the two sols that are mixed, and the pH, Eh, and temperature at which mixing takes place. When alkaline silicate is present in excess, it tends to form a protective layer of colloidal silica on the metal hydroxide particles, inhibiting precipitation (Rankama and Sahama, 1950, p. 235; Iler, 1955, p. 182–183). Moore and Maynard (1929, p. 284) found that mixing of ferric hydroxide and silica hydrosols precipitates most of the iron but only a little silica unless the Si:Fe ratio is greater than 3:1.

DEPOSITION AT HIGH TEMPERATURE

Because the solubility of silica at low pressure increases only slightly with temperature as high as the boiling point of water, the chief effect of increasing temperature in this range on supersaturated silica solutions is that it allows the various factors summarized in the preceding section to act more rapidly in causing precipitation of the excess silica. Iler (1955, p. 161) reported that precipitation of silica from supersaturated hot alkaline solutions is promoted by the presence of Na^{+1}, Ba^{+2}, and F^{-1} ions in the solution. Thus, it is probably no accident that barite and fluorite are relatively common accessory minerals in jasperoids.

Colloidal silica can be converted readily to quartz, particularly in alkaline solutions, at supercritical temperatures and moderate to high confining pressures. Siever (1962, p. 133) reported that above 200°C quartz precipitates readily as amorphous silica dissolves, and Boydell (1924, p. 15–16) reported that quartz crystals have been obtained by heating silica sol or gel in closed tubes at a temperature of 250°C. In alkaline solutions near the critical point, fused silica rods dissolve and quartz crystals precipitate. The maximum growth rate of these crystals was obtained in 0.3*N* $NaHCO_3$ solution, in a period of 6 hours. Then the growth declined, and after 20 hours it ceased owing to the growth of a layer of porous quartz needles on the nutrient glass rods (Walker, 1953, p. 250–251).

The mechanism of the conversion of silica gel to quartz at high temperature and pressure was investigated by Ellis and Fyfe (1957, p. 270) and by Carr and Fyfe (1958, p. 909). They found that this transformation proceeds through two intermediate metastable phases; thus, silica gel → crystobalite → silica K (keatite) → quartz. Quartz will not form in the presence of crystobalite, but once keatite is formed it inverts rapidly to quartz. The reaction rate increases with both temperature and pressure, but it is more sensitive to pressure than to temperature; the presence of alkaline solutions also speeds the reaction. These conclusions corroborate the findings of Wyart (1943, p. 483), who converted silica glass to crystobalite at 374°C and 220 atm in pure H_2O, but in similar experiments with 0.05*M* KOH solutions he obtained quartz instead. On short runs with aqueous fluid, Wyart got a mixture of silica gel and crystobalite, but in none of his experiments did he obtain crystobalite-quartz mixtures. The conversion of colloidal silica to jasperoid in nature would thus be facilitated by alkaline solutions in an environment of increasing temperature and pressure.

The temperature at which the fine-grained quartz of jasperoid has formed may be susceptible to geothermometric measurement, because quartz that is known to have formed at low temperatures is richer in O^{18} than quartz that formed at high temperatures (Keith and others, 1952). Fluid inclusions might also provide information on the formation temperature of jasperoid quartz, were it possible to find any in such a rock that has an average grain diameter of less than a tenth of a millimeter.

GENESIS OF VARIOUS FORMS OF SILICA IN JASPEROID

Relatively little is known of the natural conditions under which the various common types of silica found in jasperoid are formed. Silica deposited in colloidal form is metastable and commonly converts in time to some other form, normally quartz or chalcedony, yet the presence of opaline silica in some jasperoid shows that, under some conditions, it can remain amorphous for a long time.

Quartz.—The natural conditions under which quartz precipitates directly from solution at low temperature are still largely unknown, although at high temperature the deposition of silica in this stable anhydrous form proceeds readily. Quartz is probably deposited from solutions undersaturated with silica relative to colloidal silica but supersaturated with silica relative to quartz itself at the temperature of deposition (White and others, 1956, p. 55; Morey and others, 1962, p. 1036–1037). Its deposition at low temperature must require a long span of time under stable conditions. According to Adams (1920, p. 640), variety of form and heterogeneity of grain size are characteristic of quartz that originated at shallow depth. The conversion of various forms of amorphous silica, including silica gel, into quartz has been accomplished in the laboratory by simply raising the temperature in a closed system to about 250°C. Presumably, the same thing happens in nature at a lower temperature over a longer period of time. Folk and Weaver (1950) found that ordinary chert consists of a mixture of quartz and chalcedony, with no opal or other noncrystalline forms of silica, yet the extremely fine texture and prevalence of colloform banding in chert and in many jasperoids are evidence that these rocks were originally colloidal silica. Indeed, such textures in jasperoid give indirect evidence of its deposition at relatively low temperature, because at high temperature silica tends to deposit directly as quartz. Boydell (1924, p. 57–58) expressed the opinion that crystalline aggregates may be produced from a gel either by strain (which implies pressure) or by increasing temperature. White, Brannock, and Murata (1956, p. 55) found evidence at Steamboat Springs, Nev., of the replacement of opaline sinter by quartz and chalcedony at relatively shallow depth (50^+ ft); they also found complete gradations from fine-grained mosaic-textured quartz to chalcedony, a feature that has also been observed in jasperoid samples.

Chalcedony.—Folk and Weaver (1950) have shown that chalcedony is a fibrous, spongy variety of quartz that contains abundant submicroscopic bubbles filled with trapped water. These bubbles impart to chalcedony its distinctive optical properties. The nature of chalcedony also explains its gradation into ordinary quartz. Adams (1920, p. 626) reported that chalcedony forms only in near-surface deposits, whereas White, Brannock, and Murata (1956, p. 54) found that at Steamboat Springs, Nev., chalcedony formed only at depth as a replacement of opaline sinter or as bands lining the walls of cavities in this sinter. These bands are thicker on the bottom than on the sides of such cavities, and the bottom layers are horizontal. Such textures suggest precipitation of silica under the influence of gravity, even though the available evidence does not indicate whether chalcedony deposited directly or whether colloidal silica precipitated and was later converted to chalcedony. The difference in the opinions expressed by Adams (1920) and by White, Brannock, and Murata (1956) as to the environment in which chalcedony forms is more apparent than real, because Adams was discussing forms of silica characteristic of deep-seated high-temperature vein deposits as contrasted with those found in veins formed at shallower depths, whereas White, Brannock, and Murata were dealing with forms of silica deposited from hot springs at, or about 200 feet below, the surface. Chalcedony apparently forms in a rather restricted environment, characterized by low to intermediate conditions of temperature and pressure.

White and Corwin (1959) reported the successful synthesis of chalcedony by replacement of silica glass in alkaline solutions at 400°C and 340 atm pressure. They believed that natural chalcedony forms not by precipitation from solution but by replacement of amorphous silica in an alkaline environment.

Opal.—According to Clarke (1924, p. 366), opal is formed by the evaporation of acid siliceous water, and White, Brannock, and Murata (1956, p. 53–54) expressed the opinion that opal generally forms by direct precipitation of monomeric silica, or small polymeric molecules of silica, from the rapid evaporation of near-boiling water. They also reported that opal may form as an end product of the near-surface leaching of silicate minerals by hot acid solutions. Opal apparently is stable in the presence of H_2O only at low pressure and at a temperature not much above the boiling point. A sample of opal in a drill core taken from a depth of 220 feet, temperature 140°C, in the Norris Basin of Yellowstone National Park, showed incipient conversion to chalcedony.

REPLACEMENT OF HOST ROCK BY SILICA

The term "jasperoid" implies replacement of host rock by silica, and in many localities jasperoid bodies faithfully preserve the original textural features, the delicate fossils, and even the color of the rocks they replace (fig. 2*B*). This type of replacement requires (1) that solution of host rock and precipitation of silica must have taken place simultaneously in a thin layer at the contact; (2) that the silica, in whatever form deposited, must have been sufficiently competent to withstand the existing pressure without deformation and yet be sufficiently permeable to allow diffusion of solutions through it, carrying silica toward the replacement interface and host rock in solution away from it; (3) that the composition of these solutions must have been such that the host rock was soluble and that silica at the contact was less soluble; and finally (4), that these conditions must have persisted long enough to allow replacement of many thousands of cubic feet of rock. Considering the stringency of these requirements, it is not surprising that the mechanism of volume-for-volume siliceous replacement is a riddle that has baffled geologists for years, and that no one has yet succeeded in duplicating this phenomenon in the laboratory.

Another common type of siliceous replacement that results in courser grained jasperoid, commonly with reticulated texture, destroys the primary textural features and fossils of the host rock. Formation of this type of jasperoid does not require strictly simultaneous removal of host rock and deposition of silica. Neither does it require diffusion of solutions through an advancing silica layer; the silica can be deposited directly as quartz disseminated in the host rock.

PHYSICAL FACTORS

Although the silicification of host rocks by silica-bearing water was known to many early investigators, it was not until after 1900 that the physicochemical environment or the manner in which this process takes place was discussed. Church (1862, p. 109) described an experiment that resulted in the substitution of $CaCO_3$ for SiO_2 in solution at room temperature, and Spurr (1898, p. 217–220) recognized the epigenetic replacement origin of jasperoid at Aspen, Colo., and described the macroscopic and microscopic features of this rock.

Lindgren (1901), one of the first geologists to speculate seriously on the mechanism of siliceous replacement, stated (p. 602) that "waters containing carbon dioxide and silica deposit the latter, while simultaneously dissolving a corresponding proportion of calcite." Lindgren (1925, p. 258) later recognized that such replacement can produce either crystalline quartz disseminated through the host or amorphous silica that replaces the limestone completely and advances as a wave through the host rock. Irving (1904, p. 173; 1911, p. 630–631) described the replacement of carbonate rocks by jasperoid in the Black Hills, preserving original textures and colors and having sharp contacts with the unreplaced host rock. Later, Lindgren (1933, p. 91) wrote the famous equal-volume law of replacement:

> Replacement is the process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate * * *. The most fundamental changes in rocks take place with practical constancy of volume.

Lindgren (1933, p. 173, 176–177) also discussed the mechanism by which the reacting solution reaches the replacement interface. Penetrating solutions under heavy pressure permeate the rocks; such rocks then act as semipermeable membranes through which electrolytes and gases diffuse rapidly but colloids and slightly ionized compounds diffuse very slowly. Diffusion takes place in response to concentration gradients, but it is a slow process, does not act over long distances, and ceases after a certain time. Thus, in the formation of large replacement deposits the mechanism of diffusion must be supplemented by solution movement along openings.

The maximum distance from such channels at which replacement by diffusion can be effective is not known. Irving (1911, p. 538) stated that, in exceptional cases, replacement may extend outward as much as 100 feet from feeding channels; however, he was probably referring to large trunk channels rather than small fractures that could act as subsidiary feeding channels. According to Holser (1947, p. 395), transport of material in solution occurs mainly by bodily flow in any openings of larger-than-capillary size, but in capillary and subcapillary openings such transport is largely by diffusion. Such diffusion transport at the replacement interface is a necessary prerequisite to completing fine-grained replacement. These conclusions of Lindgren and Holser that large-scale complete replacement is dependent on transport by moving solutions supplemented by local diffusion over short distances were corroborated by Garrels and Dreyer (1952, p. 374–375). They calculated that a minimum of 3,000 years would be required for the replacement of the most permeable limestone beds in the Tri-State district by a layer of galena 1 cm thick deposited by dilute lead-bearing solutions in which the lead moved only by simple diffusion in response to concentration gradients. Thus, the ideal conditions for replacement occur in shatter zones characterized by numerous small closely spaced fractures.

The replacement product, as well as the host rock, must be permeable to the solutions; otherwise, replacement would cease as soon as a thin layer of this product had formed, for it would seal off and protect the host rock from further attack. Garrels and Dreyer (1952, p. 352) concluded that such a situation would occur if the volume of the guest mineral precipitated were greater than the volume of host mineral dissolved, and that the total amount of rock replaced depends only on this volume ratio of guest to host, not on solution concentration or rate of reaction. Solutions moving in response to a high pressure gradient might force their way through a somewhat thicker layer of reaction product, however, before the host rock became completely sealed by precipitation. Such a conclusion is logical regarding the advancing-wave type of massive replacement, but it would not necessarily apply with equal force to the disseminated type, in which replacement proceeds outward from a number of isolated nuclei scattered through the host. Even in this type, however, replacement by a larger volume guest mineral should eventually stop when the individual replacement fronts near the main supply channel coalesce. Ames (1961d, p. 1443–1444) also recognized the importance of the host-guest volume ratio in a continuing replacement process, though he pointed out that

> Volume relationships are a result of a given replacement reaction, but do not initially cause or prevent the reaction * * *. Starting with equivalent experimental conditions such as surface area, the initial significant correlation is between ion fraction reacted and activity product ratios. As the reactions proceed, the significant correlation tends to be between ion fraction reacted and molar volume change.

He concluded that replacement reactions resulting in a negative theoretical volume change may show little actual volume change due to changes in bulk density, whereas reactions involving a positive theoretical volume change decrease the permeability of the host, forcing replacement to become diffusion dependent and hence very slow, but the larger volume replacing mineral tends to occupy the same actual volume as the mineral replaced.

If the volume ratio theory of replacement is strictly valid, then it would seem to follow that large-scale volume-for-volume replacement with preservation of original texture could proceed only if the guest mineral has a density equal to, or greater than, that of the host. This would preclude the replacement of limestone by any form of silica lighter than quartz, and it would preclude the replacement of dolomite by any form of silica at all! Such a conclusion is at variance with the field evidence in many districts that dolomite as well as limestone has been silicified, and furthermore, that the silica was originally deposited in the form of silica gel, which would have a specific volume nearly twice that of the carbonate it replaces (Nolan, 1935, p. 94; Gilluly, 1932, p. 100; Cox and others, 1916, p. 11; Lindgren, 1925, p. 258; and many others). The replacement of large volumes of carbonate rock by silica probably proceeds both by diffusion of the reaction products through the gel layer and by movement of silica-bearing solutions along fractures.

Chemical reactions involving the movement of ions through a silica gel from an aqueous solution have been carried out successfully in the laboratory for more than half a century (Hatschek and Simon, 1912, p. 452); hence, there is experimental support for the theory that replacement can be accomplished in this manner. Furthermore, as pointed out by Garrels and Dreyer (1952, p. 347–348), the rate of diffusion increases with temperature.

CHEMICAL FACTORS

Ames (1961b, p. 528; 1961c, p. 737; 1961a, p. 1022, 1024) conducted many experiments on the replacement of limestone by minerals containing a common ion (either Ca^{+2} or CO_3^{-2}). In all of these he concluded that the dominant prerequisite to replacement was that the guest mineral is less soluble in the system than the host. In complex systems in which several possible alteration products are less soluble than the host, only the least soluble of these will form.

If, as stated by Ames, replacement can take place only in a system in which the guest compound is less soluble than the host, then siliceous replacement of limestone requires greater solubility of $CaCO_3$ than of SiO_2 in the solution at the replacement interface. The same requirement also applies to the siliceous replacement of other rock types, but consideration of the chemical processes involved is much simplified by limiting discussion to the replacement of calcite by silica.

$CaCO_3$ is less soluble than SiO_2 in pure H_2O at all temperatures above the freezing point, and the discrepancy between the relative solubilities of these compounds becomes greater as the temperature increases. Although the solubility of calcite does increase slightly with increasing pressure (a threefold increase in solubility for an increase in pressure from 1 to 1,000 atm, according to Garrels and Dreyer, 1952, p. 339–341), that of silica increases much more rapidly with pressure at constant temperature (fig. 34*B*). Thus, the replacement of limestone by silica derived from an aqueous fluid containing no other components should be impossible. The same thing is true of hot alkaline solutions, in which calcium carbonate is even less soluble than it is in pure water. However, as the pH of a solution decreases below the neutral point, the solubility of calcite rises rapidly; 100 times for each pH unit, according to Garrels and Dreyer (1952, p. 339–341). The ionic solubility of silica is relatively low in acid solutions, but such solutions are capable of carrying many times their saturation concentration of silica in the form of a dispersed sol.

Another factor that increases the solubility of calcite is increasing salinity of the solution (Siever, 1962, p. 145). Miller (1952, p. 173–175) ran a series of experiments on the solubility of calcite in water and in 0.5*M* NaCl solutions at various temperatures as high as 100°C and under various partial pressures of CO_2 from 1 to 100 atm. He found that $CaCO_3$ solubility increased steadily with increasing CO_2 pressure at constant temperature and decreased steadily with increasing temperature at constant CO_2 pressure; furthermore its solubility in the NaCl solution was 50–100 percent greater than in water at any given temperature and CO_2 pressure within the range of his experiment. The effect of salinity on silica solutions is to greatly accelerate the equilibration of these solutions without appreciably affecting the silica solubility (Van Lier and others, 1960, p. 1675). Thus, a warm siliceous brine should be saturated, or nearly saturated, with ionic silica under the prevailing conditions of pressure, temperature, and pH, and any change in these conditions that would decrease its solubility should cause the excess silica to precipitate, rather than to supersaturate, the solution.

The importance of CO_2 in promoting the simultaneous solution of calcite and deposition of silica has long been recognized. The increase in carbonate solubility with increasing CO_2 content of the solution is due to the increasing acidity caused by the formation of carbonic acid. Garrels and Dreyer (1952, p. 341) found that the solubility of calcite actually decreases with increasing CO_2 content of the solution if the pH is held constant. The pH of solutions saturated with volatile acid-forming gases such as CO_2 or H_2S is strongly pressure dependent. CO_2 under pressure corresponding to the hydrostatic pressure at a depth of 2,000 feet would cause the pH of water to drop to a value of 3.2 (Garrels and Dreyer, 1952, p. 371–372).

Solubility versus temperature curves for calcite and silica trend strongly in opposite directions, and at any given temperature the pH of the system, in the acid range, has a great effect on carbonate solubility but has relatively slight effect on silica solubility. Thus, at 1 atm CO_2 pressure, calcite is more soluble in H_2O than is silica up to a temperature of about 65°C; in 0.5*M* NaCl solution up to a temperature of about 90°C; at 100 atm CO_2 pressure the extrapolated solubility curves would cross at about 125°C for pure H_2O and at 150°C for 0.5*M* NaCl solution. These data, taken in conjunction with Ames' observation that replacement cannot occur unless the replacing substance is less soluble in the system than the material it replaces, suggest that the silicification of limestone must be a relatively low-temperature phenomenon. Such a conclusion is further substantiated by the field evidence, in many districts, that silica was originally deposited as a gel. As stated previously, silica will precipitate in the anhydrous form at temperatures above 200°C.

If a carbonated, silica-saturated brine attacked and dissolved calcium carbonate, this would tend to neutralize the solution at the reaction interface and thus promote the precipitation of silica, because the ionic solubility of silica is lower in a neutral solution than in an acid solution, and the presence of NaCl would prevent the excess silica from supersaturating.

THEORY OF REPLACEMENT PROCESS

We can now speculate on a hypothetical mechanism by which silica may replace limestone, which is consistent with the various observations previously discussed. Let us assume that hot emanations saturated, or nearly saturated, with silica, and also containing appreciable quantities of dissolved CO_2, H_2S, and possibly HCl are rising along a deep conduit, such as a major fault, into a thick sedimentary series containing abundant limestone beds, and that this conduit penetrates the zone of ground water but does not, initially, extend directly to the earth's surface. At great depth, where the rocks are tight, solution movement will largely be confined to the main conduit, the wallrocks will be hot, and changes in temperature and pressure within the solution will be slight. Such a solution will, in all probability, be out of chemical equilibrium with the wallrock of the conduit, and we can expect initial alteration of these rocks adjacent to the channel, such as silication of carbonate rocks and argillic alteration of other rock types. This will result in the formation of an alteration envelope around the conduit insulating the rock beyond it from further attack by the upward-moving solutions.

As the system approaches to within a few thousand feet of the earth's surface, the juvenile solutions will begin to mingle with connate brines and ground water, and numerous subsidiary fractures, minor faults, and other secondary channels will begin to tap the main line of the plumbing system. This will cause a relatively rapid drop in both temperature and pressure of the system as well as a change in its chemical composition, so that in place of a superheated aqueous fluid moving along a major channel, hot, acid, silica-bearing water with added alkaline chlorides is seeping upward through a broad fracture zone. Such a change will result in supersaturating the system with silica; however, so long as the pH remains low, this silica will not necessarily precipitate but will be carried as a dispersed colloidal sol. As soon as the solution enters a brecciated bed of limestone, the limestone will begin to dissolve, and this reaction will tend to neutralize the solution. The presence of dissolved alkaline chlorides will increase the solubility of the limestone, and at the same time cause the colloidal silica to become unstable as the pH of the solution rises. Thus, silica will precipitate as limestone dissolves. As the acid solutions penetrate and permeate the limestone, the initial solution of this rock must proceed slightly faster than the precipitation of silica from the more nearly neutral solutions resulting from the reaction. This may be the explanation for the commonly observed selvage of sanded limestone or dolomite intervening between jasperoid bodies and fresh host rock.

If the precipitated silica is in the form of colloidal particles or a gel, it coats the walls and fills the fractures; the rising pH of the solution tends to reduce the host-rock solubility on the outlet side of the fractured limestone. Both processes tend to inhibit further replacement. However, solutions can still diffuse through the aqueous gel, and this diffusion can be speeded by the development of a gas phase as CO_2 and H_2S come out of solution in response to decreasing pressure. Furthermore, the decline in carbonate solubility resulting from a rising solution pH is offset, at least in part, by an increase in carbonate solubility, as calcium bicarbonate, caused by the temperature drop resulting from exsolution of the acid gases.

As the gel layer thickens close to the point of entry of solutions into the limestone, the hot rising solutions increase the temperature of this gel and thus tend to promote its conversion to quartz. Such a conversion results in a considerable decrease in volume of the silica, accompanied by a corresponding increase in porosity and permeability, thus allowing continued movement through it of silica-bearing solutions toward the replacement interface, in response to both pressure and concentration gradients.

If silica precipitates directly in the anhydrous form as either quartz or cristobalite, rather than as a hydrous gel, the result will be either a layer of fine-grained crystals along the openings resulting from solution of calcite or a number of isolated quartz or cristobalite nuclei disseminated through the host, growing slowly by accretion. In either case, reacting solutions can continue to move through the replacement product along intergrain boundaries toward the replacement front.

Replacement eventually ceases as a result of one or more of the following conditions:

1. The pH of the solution at the replacement interface rises to the point where limestone is less soluble than silica under the prevailing temperature and pressure.
2. The whole rock body becomes too hot for the reaction to continue.
3. The silica layer becomes too thick or too impermeable to permit further diffusion of the reacting substances through it.
4. The supply of silica becomes depleted.
5. The main conduit breaks through to the surface along a different route.

If silica is initially deposited as a gel, this gel will rupture as it shrinks and inverts to quartz. Solutions circulating through the fractures thus formed will cause local solution and reprecipitation of silica, thus forming the veinlets and vug linings of late coarse quartz that are common in jasperoid bodies.

Low-temperature replacement of limestone by silica-bearing ground water and connate brines below the water table must largely be a pressure-dependent process. Such waters at depth are probably alkaline chloride solutions containing sufficient carbonic acid in solution to prevent the precipitation of excess silica. Movement of such solutions under pressure gradients into fracture zones in limestone decreases their ability to retain silica, both by decreasing silica solubility because of decreasing pressure and by neutralization caused by reaction of carbonic acid with limestone. Thus, silica precipitates as limestone is dissolved.

The replacement theory just outlined still does not account for replacement of rocks other than carbonate rocks by jasperoid. Neither does it entirely account for the replacement of limestone by supergene jasperoid during the oxidation and weathering of silica-bearing sulfide ore bodies nor the formation of younger jasperoid matrix, cementing fragments of older jasperoid. The chemical nature of the solutions involved in these processes is so complex that more research is required before they can be fully explained.

JASPEROID AS A GUIDE TO ORE

In many mining districts, bodies of jasperoid are both genetically and spatially related to replacement ore deposits. In other districts, jasperoid shows no such relationships, and is not useful as a guide to ore. Not uncommonly, both types of jasperoids are found in the same district, and methods of distinguishing between them are important for effective exploration.

DEFINITION OF FAVORABLE AND UNFAVORABLE JASPEROID

In this study, jasperoids are divided into two categories: (1) jasperoid related to, and associated with, ore (favorable jasperoid); (2) jasperoid unrelated to ore (unfavorable jasperoid). As in most rock classification systems, some borderline rock types are difficult to classify. The jasperoid may have been deposited from mineralizing solutions that later brought in ore metals, but, if the jasperoid bodies formed as an outer alteration zone at a considerable distance from the later ore deposits, a genetic relationship would be difficult to establish. Such jasperoids, even though genetically related to ore, could not be classed as favorable, inasmuch as they are not helpful in locating ore. This kind of jasperoid occurs in the Gilman mining district of central Colorado. Here, the major sulfide-replacement ore bodies show little or no silicification of carbonate host rock adjacent to the ore. Yet these rocks have been converted to dense aphanitic jasperoid, commonly preserving original textures, that extends along major fractures from half a mile to several miles updip from the ore bodies on the outlet side of the hydrothermal plumbing system. Conversely, silicification may be younger than the ore stage of mineralization and genetically unrelated to it. Where such late silicifying solutions pass through ore bodies they may become contaminated by the ore metals, and the resulting jasperoid bodies may be favorable for effective exploration. Possible examples of this type of jasperoid are present in the Clifton-Morenci district of Arizona.

The criteria for distinguishing favorable jasperoid from unfavorable jasperoid were developed from the comparison of samples taken from, or adjacent to, mine workings with samples taken more than a quarter of a mile from any mine workings. For this study, the first group was designated as favorable, the second, as unfavorable. Such a classification, based entirely on the presence or absence of spatial association with developed ore deposits, inevitably results in the misclassification of some samples in both categories. A further assumption, implicit in any attempt to reach general conclusions on the basis of sample investigation, is that the samples chosen for study are reasonably representative of the bodies from which they were taken. The samples included in this study were not selected according to a statistically randomized sampling plan; instead, an effort was made to obtain "typical" samples at each locality. Some samples of unfavorable jasperoid bodies that happened to be near, or penetrated by, mines are classified as favorable; some samples of favorable jasperoid related to undeveloped ore bodies are classified as unfavorable. The assumption was made that the number of such erroneously classified samples would be so small in proportion to the total that they would not obscure any significant differences that could be used as criteria for distinguishing between the two groups. After diagnostic criteria evolved from the initial study they were applied to each sample in both original groups to locate and reclassify samples that had been misclassified on the basis of field association alone; they were also applied to samples not included in the original study groups because their field relations to ore either were unknown or were not diagnostic.

METHODS OF DATA ANALYSIS

The characteristics of jasperoid specimens chosen for study were initially divided into two groups: (1) discontinuously distributed properties—those that may be either present or absent, such as a specific color, texture, or accessory mineral; and (2) continuously distributed properties—those that may be measured on a continuous scale, such as porosity, density, or concentration of a specific element. These two groups of properties require different statistical tests to appraise the significance of differences between the two categories of jasperoid samples.

For discontinuously distributed properties, the number of samples in each category that exhibits a specified property is recorded; also recorded is the number of samples that do not exhibit the property. This generates a 2×2 contingency table of the form with entries in each of the cells, *A*, *B*, *C*, and *D*. The data in these cells are then substituted in the formula for chi square given by Siegel (1956, p. 107–109).

	Favorable	Unfavorable
Positive (+)	A	B
Negative (−)	C	D

$$\chi^2=\frac{N\left(|AD-BC|\frac{N}{2}\right)^2}{(A+B)\ (C+D)\ (A+C)\ (B+D)}$$

where $N=A+B+C+D$.

The value of chi square thus obtained is then checked against a table of critical values of chi square with 1 degree of freedom, such as table C in Siegel (1956, p. 249). Values of chi square less than the tabulated value for a probability of 0.10 ($\chi^2=2.71$) are considered to indicate no significant difference in the frequency of occurrence of the property between the favorable and unfavorable sample groups.

As an example of the calculations, let us consider the distribution of vuggy texture between the favorable and unfavorable sample groups. Of 95 favorable samples, 55 were vuggy, and of 53 unfavorable samples, 18 were vuggy. This gives the following 2×2 contingency table distribution:

	Favorable	Unfavorable	
Positive (+)	A_{55}	B_{18}	
Negative (−)	C_{40}	D_{35}	N = 148

$$\chi^2=\frac{148(|(55\times35)-(40\times18)|-74)^2}{(55+18)\ (40+35)\ (55+40)\ (18+35)}$$

$$=\frac{148\ (1925-720-74)^2}{73\times75\times95\times53}$$

$$=\frac{189{,}315{,}828}{27{,}566{,}625}=6.87.$$

Reference to a table of critical values for χ^2 with 1 degree of freedom shows that the probability level associated with this value of χ^2 is slightly less than 0.01 ($\chi^2 0.01=6.64$). This means that there is only about one chance in a hundred of obtaining such a great discrepancy between the favorable and unfavorable sample distributions if, in fact, the property of vugginess were equally common in both types of jasperoid. Thus, we may conclude that favorable jasperoids are more likely to be vuggy than unfavorable ones; consequently, vugginess becomes one of our significant criteria for favorable jasperoid.

For continuously distributed properties, the Kolmogorov-Smirnov two-sample test (Siegel, 1956, p. 127) may be used. This tests the null hypothesis that there is no significant difference between the parent populations (favorable and unfavorable jasperoids) with respect to the measured property under consideration. The test compares the cumulative frequency distributions of the property in the two groups. If the greatest discrepancy between these distributions is sufficiently large to be significant at the chosen probability level, the null hypothesis of no significant difference is rejected. As with the chi-square test, we may use a probability level of 0.10; that is, if a maximum discrepancy between the cumulative distributions as great as, or greater than, the one observed may be expected to occur by chance as frequently as one time out of 10, in samples drawn from the same population, then we will assume that there is no significant difference.

The data for both sets of samples are tabulated in frequency distributions, using the same class intervals. It is convenient to use the same intervals in which the data are reported for grouped data such as semiquantitative spectrographic analyses (Myers and others, 1961). Ungrouped raw data such as density measurements, may be grouped in any convenient classes that will adequately define the frequency distributions.

The number of samples in each class is first tabulated for both groups, with the class representing the highest magnitude of the variable at the top of the table, and the class representing the lowest magnitude at the bottom. The number of samples in each class (frequency) is then converted to a proportion of the total samples in the group in a second parallel column (P), and the cumulative proportion is recorded in a third column (ΣP). The difference between the cumulative proportion values for the two groups is then recorded, class by class, in another column headed "Difference," and the maximum difference in this column, together with the class to which it belongs, is recorded at the bottom of the table as *D*. The value of *D* thus obtained may then be tested for significance (Siegel, 1956, p. 127–135, 279). The formula used is

$$D_8 = K\sqrt{\frac{n_1+n_2}{n_1 \times n_2}}$$

where *K* is a constant dependent on the level of significance desired, and n_1 and n_2 are the total numbers of samples in each of the two categories.

As an example, let us test the significance of iron concentration in the two categories of jasperoid. The data and calculations are as follows:

Class midpoint	Favorable			Unfavorable			Difference
Percent Fe	F	$P=\frac{F}{\Sigma F}$	ΣP_F	F	$P=\frac{F}{\Sigma F}$	ΣP_U	$\Sigma P_F - \Sigma P_U$
>10	8	0.084	0.084	1	0.019	0.019	0.065
7	16	.168	.252	0	.000	.019	.233
3	14	.147	.399	3	.057	.076	.323
1.5	13	.137	.536	14	.264	.340	.196
.7	17	.179	.715	13	.245	.585	.130
.3	12	.126	.841	13	.245	.830	.011
.15	11	.116	.957	7	.132	.962	.005
.07	4	.043	1.000	2	.038	1.000	....
Total	95	....	....	53	....	....	....

D=0.323 at 3 percent Fe.

$$D_s = K\sqrt{\frac{95+53}{95\times 53}} = K\sqrt{0.0294} = 0.17K$$

$K\ 0.10=1.22$ $\quad D\ 0.10=0.027$
$K\ .05=1.36$ $\quad D\ .05=.231$
$K\ .01=1.63$ $\quad D\ .01=.277$

The numbers in the "Class midpoint" column are the figures reported in grouped (three-step) spectrographic analysis (Myers and others, 1960) and represent the midpoints of three class intervals for each order of magnitude. The intervals are approximately equal on a logarithmic scale.

The *D* value of 0.323 at the iron concentration of 3 percent is significant at the 0.01 probability level, which can be interpreted as indicating that iron concentrations of 3 percent or more occur with significantly greater frequency in favorable jasperoids than in unfavorable jasperoids.

Although each of the properties vugginess and high iron content (given as examples in the preceding discussion) shows a statistically significant association with jasperoids of the favorable type, neither one by itself furnishes a diagnostic criterion for distinguishing between the two types. Of the favorable samples, 58 percent were vuggy and 42 percent were not, whereas of the unfavorable samples, 34 percent were also vuggy. Iron content was significantly high in about 40 percent of the favorable samples and also in about 8 percent of the unfavorable samples.

The application of these statistical tests to all the observed properties in both categories of samples revealed a number of properties significantly associated in varying degree with either favorable or unfavorable types of jasperoid. Each of these properties was then listed as a criterion and given a rank depending on its level of significance; 1 for the 0.1–0.01 level, 2 for the 0.01–0.001 level and 3 for the > 0.001 level; plus (+) if associated with favorable samples and minus (−) if associated with unfavorable samples. Many of the chemical elements show significant differences at relatively low concentrations; for these elements an additional scoring point was added arbitrarily for each order of magnitude of concentration above the one at which the significant value occurred. Thus, lead showed a *D* value that is significant at the 0.001 level, corresponding to a concentration of 0.0015 percent lead; so a sample containing 0.015 percent lead would have a score of +4 for this property instead of +3.

All the criteria were applied to each of the samples in the collection, and final classification of the sample was made on the basis of its total score. This last operation, although empirical rather than statistical, resulted in the separation of a large majority of the samples in the collection into those with distinctly favorable characteristics and those with distinctly unfavorable characteristics. It changed the classification for some samples in the original study groups, and it suggested a classification for many samples not included in these groups because their field relations to ore either were unknown or were not diagnostic.

COMPARISON OF MEGASCOPIC CHARACTERISTICS

The megascopic characteristics that were recorded for comparison between the favorable and unfavorable groups of jasperoid samples were color, based on the National Research Council "Rock-Color Chart" (Goddard and others, 1948), and macrotexture, including phaneritic, brecciated, and vuggy. Table 9 shows the frequency of occurrence and nonoccurrence of these characteristics in both sample groups, the computed value of χ^2, and the level of significance associated with this value.

From table 9, it seems that light- to moderate-red colors are more characteristic of unfavorable jasperoid, and a dark-brown color, of favorable jasperoid. The latter association was also noted by Locke (1926) and by Blanchard and Boswell (1928)

TABLE 9.—*Distribution of megascopic characteristics in favorable and unfavorable oxidized jasperoid samples*

[Rock-color designations are from Goddard and others (1948)]

Characteristic	Favorable [1]		Unfavorable [1]		χ^2	
	+	−	+	−	Computed value	Significance level [2]
Color						
Pink and light red ($5R\frac{6\text{–}8}{2\text{–}6}$)	0	94	10	97	7.35	0.001–0.01
Medium red and grayish red ($5R\frac{4\text{–}5}{2\text{–}6}$)	1	93	17	90	11.70	<.001
Dark red ($5R\frac{2\text{–}3}{2\text{–}6}$)	6	88	5	102	.05	N.S.
Orange pink ($10R\frac{6\text{–}8}{2\text{–}6}$)	2	92	5	102	.35	N.S.
Reddish brown ($10R\frac{4\text{–}5}{2\text{–}6}$)	4	90	8	99	.43	N.S.
Dark reddish brown ($10R\frac{2\text{–}3}{2\text{–}6}$)	10	84	5	102	1.78	N.S.
Grayish pink ($5YR\frac{6\text{–}8}{2\text{–}4}$)	5	89	5	102	.01	N.S.
Light brown and medium brown ($5YR\frac{4\text{–}5}{2\text{–}6}$)	24	70	5	102	15.96	<.001
Dark brown ($5YR\frac{2\text{–}3}{2\text{–}6}$)	7	87	2	105	2.42	.05–.1
Light brownish gray ($5YR\frac{8\text{–}6}{1}$)	6	88	5	102	.05	N.S.
Grayish orange ($10YR\frac{7\text{–}8}{2\text{–}6}$)	14	90	12	95	.09	N.S.
Yellowish brown ($10YR\frac{5\text{–}6}{2\text{–}6}$)	19	75	16	91	.63	N.S.
Dark yellowish brown ($10YR\frac{2\text{–}4}{2}$)	4	90	3	104	.03	N.S.
Olive gray ($5Y\frac{8\text{–}6}{1}$)	10	84	17	90	.77	N.S.
White and light gray ($N7$–9)	30	64	34	73	.02	N.S.
Medium gray ($N4$–6)	25	69	32	75	.23	N.S.
Dark gray and black ($N3$–1)	11	83	15	92	.08	N.S.
Macrotexture						
Phaneritic	66	29	22	31	9.91	0.001–0.01
Brecciated	33	62	23	30	.74	N.S.
Vuggy	55	40	18	35	6.87	.001– .01

[1] Plus (+) indicates frequency of occurrence; minus (−) indicates frequency of nonoccurrence.

[2] N.S. indicates not significant.

in connection with leached outcrops overlying sulfide ore bodies. Coarse grain and vuggy texture also seem to be considerably more common in productive jasperoid than in barren jasperoid. Brecciated texture is common in all jasperoids, but it is not significantly more abundant in either type.

COMPARISON OF MICROSCOPIC CHARACTERISTICS

The microscopic characteristics chosen for comparison between favorable and unfavorable categories of jasperoid samples were microtexture and the presence of various accessory minerals (table 10). The sulfide ore minerals, such as galena, sphalerite, and chalcopyrite, and their oxidation products have been excluded from the lists in table 10 because these minerals are present only in favorable jasperoid, and no statistical test of their significance is needed.

A heterogeneous texture, characterized by a wide range in grain size of quartz, and a reticulated texture seem to be significantly associated with favorable jasperoid, whereas jigsaw-puzzle texture shows a significantly greater association with unfavorable jasperoid. Pyrite is the only older mineral given that is more characteristic of favorable than of unfavorable jasperoid, but older sericite and montmorillonite clay are more common in the unfavorable variety. Among the younger minerals, goethite and jarosite are suggestive of favorable jasperoid; calcite and yellow-orange limonite are suggestive of unfavorable jasperoid in the oxidized zone.

TABLE 10.—*Distribution of microscopic characteristics in 95 favorable and 53 unfavorable jasperoid samples*

Characteristic	Favorable [1]		Unfavorable [1]		χ^2	
	+	−	+	−	Computed value	Significance level [2]
Microtexture [3]						
Size range of quartz grains >10X [4]	57	38	17	36	9.52	0.001–0.01
Xenomorphic	63	32	35	18	.02	N.S.
Jigsaw puzzle	48	47	40	13	7.78	.001– .01
Granular	15	80	5	48	.69	N.S.
Reticulated	31	64	5	48	8.73	.001– .01
Accessory minerals that are generally older than, or contemporaneous with, jasperoid silica						
Barite	15	80	3	50	2.39	N.S.
Calcite	12	83	8	45	.03	N.S.
Carbonate dust	26	69	16	37	.03	N.S.
Chalcedony	9	86	7	46	.18	N.S.
Chlorite or biotite	3	92	2	51	.08	N.S.
Clay (kaolinite group)	33	62	12	41	1.82	N.S.
Clay (montmorillonite group)	0	95	3	50	3.01	0.05 –0.10
Dolomite	5	90	1	52	.32	N.S.
Hematite	11	84	8	45	.13	N.S.
Pyrite	29	66	6	47	5.93	.02 – .05
Sericite or hydromica	25	70	22	31	2.96	.05 – .10
Tourmaline	4	91	0	53	.97	N.S.
Zircon	2	93	0	53	.10	N.S.
Accessory minerals that are generally younger than jasperoid silica						
Calcite	15	80	17	36	4.41	0.02 –0.05
Chalcedony	7	88	3	50	<.01	N.S.
Clay (kaolinite group)	4	91	0	53	.97	N.S.
Clay (montmorillonite group)	1	94	1	52	.10	N.S.
Fluorite	5	90	0	53	1.50	N.S.
Goethite	45	50	12	41	7.77	.001– .01
Hematite	20	75	14	39	.29	N.S.
Jarosite	23	72	3	50	6.85	.001– .01
Brown limonite	22	73	12	41	.02	N.S.
Yellow-orange limonite	1	94	5	48	4.18	.02 – .05
Opal	3	92	0	53	.49	N.S.

[1] Plus (+) indicates frequency of occurrence; minus (−) indicates frequency of nonoccurrence.

[2] N.S. indicates not significant.

[3] See pages 11–15 for definitions of textural designations.

[4] The ratio of the diameter of the largest common quartz grains in the groundmass to the diameter of the smallest common quartz grains is >10.

COMPARISON OF OTHER PHYSICAL PROPERTIES

The only physical properties other than color and texture determined for representative groups of favorable and unfavorable jasperoid samples were density and porosity; the porosity was computed from the ratio of bulk density to powder density. These properties were tested on the theory that favorable jasperoid samples might tend toward greater density because of incorporated ore element compounds, or that higher porosity might increase permeability of jasperoid for mineralizing solutions. The results of the Kolmogorov-Smirnov two-sample test on 72 favorable samples and 41 unfavorable samples are given in table 11.

The marked similarity in distributions of both powder density and porosity in the two groups of jasperoid samples suggests that these properties are of no use as criteria for distinguishing favorable jasperoid from unfavorable jasperoid. Furthermore,

TABLE 11.—*Distribution of density and porosity in 72 favorable and 41 unfavorable jasperoid samples*

[Density determinations by R. F. Gantnier]

	Frequency		Proportion		Cumulative proportion		Difference
	Favorable	Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable	
Density distribution (percent) [D=0.080 at 2.65–<2.70; $Ds(0.10)=0.237$; $D<Ds(0.10)$, is not significant[1]]							
Density:							
<2.60	17	9	0.236	0.219	0.236	0.219	0.017
2.60–<2.65	19	14	.263	.342	.499	.561	.062
2.65–<2.70	4	3	.055	.073	.554	.634	.080
2.70–<2.75	11	4	.153	.098	.707	.732	.025
2.75–<2.80	5	4	.070	.098	.777	.830	.053
2.80–<2.85	2	1	.028	.024	.805	.854	.049
>2.85	14	6	.195	.146	1.000	1.000	
Porosity distribution (percent) [D=0.127 at 3–<5 percent; $Ds(0.10)=0.237$; $D<Ds(0.10)$, is not significant[1]]							
Porosity:							
<1	9	7	0.125	0.171	0.125	0.171	0.046
1–<3	22	10	.306	.244	.431	.415	.016
3–<5	15	4	.208	.097	.639	.512	.127
5–<7	9	7	.125	.171	.764	.683	.081
7–<9	6	8	.083	.195	.847	.878	.031
9–<11	4	2	.056	.049	.903	.927	.024
>11	7	3	.097	.073	1.000	1.000	

[1] D=greatest difference in cumulative proportions; $Ds(0.10)$=difference required for statistical significance at 10 percent level.

a series of check determinations on replicate subsamples from the same original specimen showed variations of as much as 0.2 in both powder-density and bulk-density determinations. This heterogeneity of density distributions within a sample, coupled with the narrow range of density values for both groups of samples, suggests that density and porosity measurements on jasperoid serve no useful purpose beyond indicating the general range of these properties in this type of rock.

A few selected samples of favorable and unfavorable jasperoid were subjected to differential thermal analysis. The resulting curves showed no distinctive patterns that would be useful for distinguishing between the two types except for one highly favorable unoxidized sample that contained much visible pyrite and sphalerite.

Although none of the three physical properties investigated proved useful in distinguishing between the two types of jasperoid, it is possible that other such properties, which were not determined, might do so.

COMPARISON OF CHEMICAL COMPOSITION

Semiquantitative spectrographic analyses for 69 elements were made on 95 favorable jasperoid samples and 53 unfavorable jasperoid samples (most of them from the oxide zone). Only 42 of these elements (other than silicon) were present in detectable concentrations in any of the samples analyzed, and only 28 were present in detectable concentrations in more than 10 percent of the samples analyzed. The sensitivity of the analytical method varies considerably for different elements.

These elements may be classified, according to the proportion of samples in which they occur in detectable concentrations, as follows:

Elements	Classification of elements	Percent of samples in which elements occur in detectable concentrations
Al, Fe, Mg, Ca, Mn, Ti, Ba, Cr, Cu	Characteristic	>90
Ni, Pb, Sr, V, Zr	Common	50–90
Na, Ag, As, B, Be, Bi, Ga, In, Mo, Sb, Sn, Y, Yb, Zn	Minor	10–50
K, P, Cd, Ce, Co, Ge, La, Nb, Sc	Sparse	2–10
Li, Nd, Ta, U, W	Very sparse	<2

Significant differences in the distributions of characteristic and common elements between favorable and unfavorable jasperoid samples were also tested statistically by the Kolmogorov-Smirnov two-sample test, as summarized in table 12. Among the elements of this group, concentrations of >0.003 percent copper, >0.0015 percent lead, and >1.5 percent iron are characteristic of favorable jasperoid. Magnesium in concentrations >0.015 percent shows a barely significant association with unfavorable jasperoid.

TABLE 12.—*Maximum difference in cumulative proportions of characteristic and common elements between favorable and unfavorable samples, and significance of this difference*

[Data from semiquantitative spectrographic analyses by J. C. Hamilton]

Element	Concentration C at which D occurs (percent)	ΣP at concentration C: Favorable	ΣP at concentration C: Unfavorable	Difference D $\lvert \Sigma P_F - \Sigma P_U \rvert$	Significance level[1]
Al	0.3	0.725	0.515	0.210	N.S.
Fe	1.5	.605	.905	.300	0.01–.0001
Mg	.015	.375	.130	.245	.05–.02
Ca	.15	.560	.450	.110	N.S.
Mn	.007	.370	.275	.095	N.S.
Ti	.015	.450	.540	.090	N.S.
Ba	.007	.535	.440	.095	N.S.
Cr	.0007	.395	.535	.140	N.S.
Cu	.003	.355	.830	.475	.001
Ni	.0003	.420	.350	.070	N.S.
Pb	.0015	.210	.760	.550	.001
Sr	.0015	.505	.595	.090	N.S.
V	.0007	.460	.280	.180	N.S.
Zr	.0015	.235	.350	.115	N.S.

[1] N.S. indicates not significant.

The minor elements, which were detected in less than half the samples analyzed, require a somewhat less conservative statistical test to evaluate significant differences between the two groups of samples, because the Kolmogorov-Smirnov test requires a difference of 0.23 between the cumulative proportions for the two groups in order to attain the threshold significance level of 0.10. Thus, an element that was detected in 20 percent of the favorable samples and in none of the unfavorable samples

TABLE 13.—*Distribution of minor elements in 95 favorable and 53 unfavorable jasperoid samples*

[Data from semiquantitative spectrographic analyses by J. C. Hamilton]

Element	Detection limit (percent)	Favorable[1] +	Favorable[1] −	Unfavorable[1] +	Unfavorable[1] −	χ^2 Computed value	χ^2 Significance level[2]
Na	0.03	17	78	9	44	0.007	N.S.
Ag	.00015	65	30	6	47	42.183	0.001
As	.15	21	74	1	52	9.450	.01
B	.003	15	80	10	43	.063	N.S.
Be	.00015	19	76	15	38	.897	N.S.
Bi	.0007	32	63	0	53	20.833	.001
Ga	.00007	21	74	4	49	4.151	.05
In	.0007	20	75	0	53	11.163	.001
Mo	.0007	49	46	7	46	19.696	.001
Sb	.015	18	77	5	48	1.677	N.S.
Sn	.0015	23	72	0	53	13.404	.001
Y	.0007	21	74	13	40	.017	N.S.
Yb	.00007	25	70	15	38	.005	N.S.
Zn	.015	62	33	10	43	27.485	.001

[1] Plus (+) indicates frequency of occurrence; minus (−) indicates frequency of nonoccurrence.

[2] N.S. indicates not significant.

would fail of significance by this test, although, logically, such an element would certainly be considered as characteristic of favorable jasperoid.

Differences between minor-element distributions for the two groups can be tested for significance by returning to the chi-square test which was used for the evaluation of color, texture, and accessory minerals. For this test the two sample groups are dichotomized into those samples in which the element was detected and those in which it was not, as shown in table 13. The minor elements whose presence in detectable concentrations shows significant differences in frequency between the two groups are: Ag, As, Bi, Ga, In, Mo, Sn, and Zn. All these elements are more commonly detected in favorable jasperoid than in unfavorable jasperoid.

No statistical test can evaluate the significance of the sparse and very sparse elements in jasperoid. Some of these (Cd, Co, Ge) appear only in analyses of samples showing high concentrations of zinc, lead, silver, or copper, such that the sample would clearly fall in the favorable category on the basis of its content of these more common metals. Others (W, U) suggest areas of abnormally high concentration of these metals, which could be of economic interest. The detection of a sparse element in a jasperoid sample is highly significant if deposits containing that element are of commercial interest.

SUMMARY OF CRITERIA FOR EVALUATION OF JASPEROID SAMPLES

The criteria for distinguishing favorable jasperoid from unfavorable jasperoid, together with the scoring points for each criterion, are summarized in table 14, in which the criteria are divided into three categories—megascopic characteristics, microscopic characteristics, and chemical composition. The theoretical range for megascopic characteristics is from +8 to −5; for microscopic and megascopic characteristics it is from +17 to −11; and for chemical composition it is from +52 to −3. Thus, the highest possible combined score is +77, and the lowest is −19. The observed range in the two groups of samples was from +5 to −3 for megascopic

TABLE 14.—*Evaluation of criteria for distinguishing between favorable and unfavorable jasperoid samples*

[Rock-color designations are from Goddard and others (1948). ≥, greater than or equal to]

Megascopic characteristics

Criterion	Significance level		Score
Color			
Pink and light red ($5R\frac{6-8}{2-6}$)	Unfavorable	0.01	−2
Medium red and grayish red ($5R\frac{4-5}{2-6}$).	do	.01	−3
Light brown and medium brown ($5YR\frac{4-5}{2-6}$).	Favorable	.001	+3
Dark brown ($5YR\frac{2-3}{2-4}$)	do	.1	+1
Texture			
Phaneritic	Favorable	.01	+2
Vuggy	do	.01	+2

Microscopic characteristics

Criterion	Significance level		Score
Texture			
Size range of quartz grains >10×	Favorable	0.01	+2
Reticulated	do	.01	+2
Jigsaw puzzle	Unfavorable	.01	−2
Older minerals			
Clay, montmorillonite group	Unfavorable	.10	−1
Pyrite	Favorable	.05	+1
Sericite or hydromica	Unfavorable	.10	−1
Younger minerals			
Calcite	Unfavorable	.05	−1
Goethite	Favorable	.01	+2
Jarosite	do	.01	+2
Yellow-orange limonite	Unfavorable	.05	−1

Chemical composition

Element	Significant concentration (percent)	Significance		Score	Higher concentration scores					
					Concentration (percent)	Score	Concentration (percent)	Score	Concentration (percent)	Score
Fe	≥1.5	Favorable	0.01	+2						
Mg	≥ .015	Unfavorable	.05	−1	≥0.15	−2	≥1.5	−3		
Cu	≥ .003	Favorable	.001	+3	≥ .03	+4	≥ .3	+5	≥3	+6
Pb	≥ .0015	do	.001	+3	≥ .015	+4	≥ .15	+5	≥1.5	+6
Ag	≥ .00015	do	.001	+3	≥ .0015	+4	≥ .015	+5	≥ .15	+6
As	≥ .15	do	.01	+2	≥1.5	+3				
Bi	≥ .0007	do	.001	+3	≥ .007	+4	≥ .07	+5		
Ga	≥ .00007	do	.05	+1	≥ .0007	+2	≥ .007	+3		
In	≥ .0007	do	.001	+3	≥ .007	+4	≥ .07	+5		
Mo	≥ .0005	do	.001	+3	≥ .007	+4	≥ .07	+5	≥ .7	+6
Sn	≥ .0015	do	.001	+3	≥ .015	+4	≥ .15	+5		
Zn	≥ .015	do	.001	+3	≥ .15	+4	≥1.5	+5		

characteristics, from +13 to −7 for microscopic and megascopic characteristics, and from +36 to −2 for chemical characteristics; the combined scores ranged from a high +44 to a low of −8.

By comparing the frequency distributions associated with total scores for samples in the two groups, it is possible to decide the total score at which to draw the line between favorable and unfavorable samples in the various categories so as to minimize the number of samples that are misclassified. The sample frequency distributions for megascopic characteristics are as follows:

Score	Frequency		Proportion		Cumulative proportion		Difference
	Favorable	Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable	
<0	1	2	0.011	0.038	0.011	0.038	0.027
0	13	27	.137	.510	.148	.548	.400
+1	4	2	.042	.038	.190	.586	.396
+2	40	19	.421	.357	.611	.943	.332
+3	12	1	.126	.019	.737	.962	.225
+4	18	2	.189	.038	.926	1.000	.074
+5	7	0	.074	....	1.000	....	....

Evidently the lower the score at which the line is drawn between presumably favorable and presumably unfavorable samples the larger will be the proportion of actually unfavorable samples that will be misclassified as favorable. In a field reconnaissance investigation of jasperoid bodies, however, one would normally be more concerned about overlooking favorable bodies than about needlessly sampling unfavorable ones, and so the line might reasonably be drawn between a score of 0 and a score of +1, the point of maximum difference between the two distributions. If the samples included in this study had been classified on this basis, according to megascopic criteria alone, only about one favorable sample out of seven would have been misclassified as unfavorable, but nearly half (45 percent) of the unfavorable samples would have been thrown into the potentially favorable category. If all samples are classified on the basis of the combined megascopic and microscopic criteria, the maximum difference between the two sample distributions comes at a score of +2; if this is taken as the cutoff between unfavorable and favorable, about one sample out of five will be misclassified either way. By lowering the cutoff to +1, the number of favorable samples misclassified as unfavorable will be cut to about one in 10, and the number of unfavorable samples called favorable will increase to about one in three. The changes in the proportions of misclassified samples using various combinations of classification at the appropriate cutoff scores are summarized in table 15.

TABLE 15.—*Summary of percentages of misclassified samples scored according to various combinations of classifications*

Classification	Cutoff score	Favorable misclassified (percent)	Unfavorable misclassified (percent)
Megascopic alone	>0	14.8	45.2
Megascopic plus microscopic	>+1	10.6	37.7
Chemical alone	>+5	10.5	13.2
Chemical plus megascopic	>+5	7.3	13.2
Complete classification	>+5	5.3	7.6

Table 15 illustrates how the discrimination between favorable and unfavorable jasperoid samples improves as the number of criteria increases. It also shows that a classification based on chemical criteria alone is considerably better than one based on a combination of megascopic and microscopic criteria; and one based on a combination of megascopic and chemical criteria is very nearly as good as one based on a combination of all three categories. Figure 35 illustrates the relationship between scores for megascopic plus microscopic criteria and scores for chemical criteria on 148 samples. This classification system may be further refined by grouping samples on the basis of their combined scores as follows: 0 and <0=unfavorable, +1 to <+5=probably unfavorable, +5 to <+10=probably favorable, +10 to <+15=favorable, and >+15=highly favorable.

The practical evaluation of jasperoid bodies as ore guides in an exploration program could be done in three stages: (1) field sampling of jasperoid outcrops that revealed at least one favorable megascopic criterion, (2) analysis of these samples for the 12 elements given in table 14, and (3) scoring of these samples on their combined megascopic and chemical criteria. In drill core and mines, a distinction between oxidized and unoxidized jasperoids should first be made and then the evaluation continued as above.

If thin sections of jasperoid samples can be procured more quickly and cheaply than chemical analyses, microscopic criteria can also be used with some gain in discrimination; however, in most cases this gain would be offset by the cost of procuring and studying the samples.

CHARACTERISTICS OF JASPEROID IN MAJOR MINING DISTRICTS OF THE UNITED STATES

This chapter contains brief résumés of the available information on the characteristics of jasperoid in each of the major mining districts where it is prevalent. Much of the information has been ab-

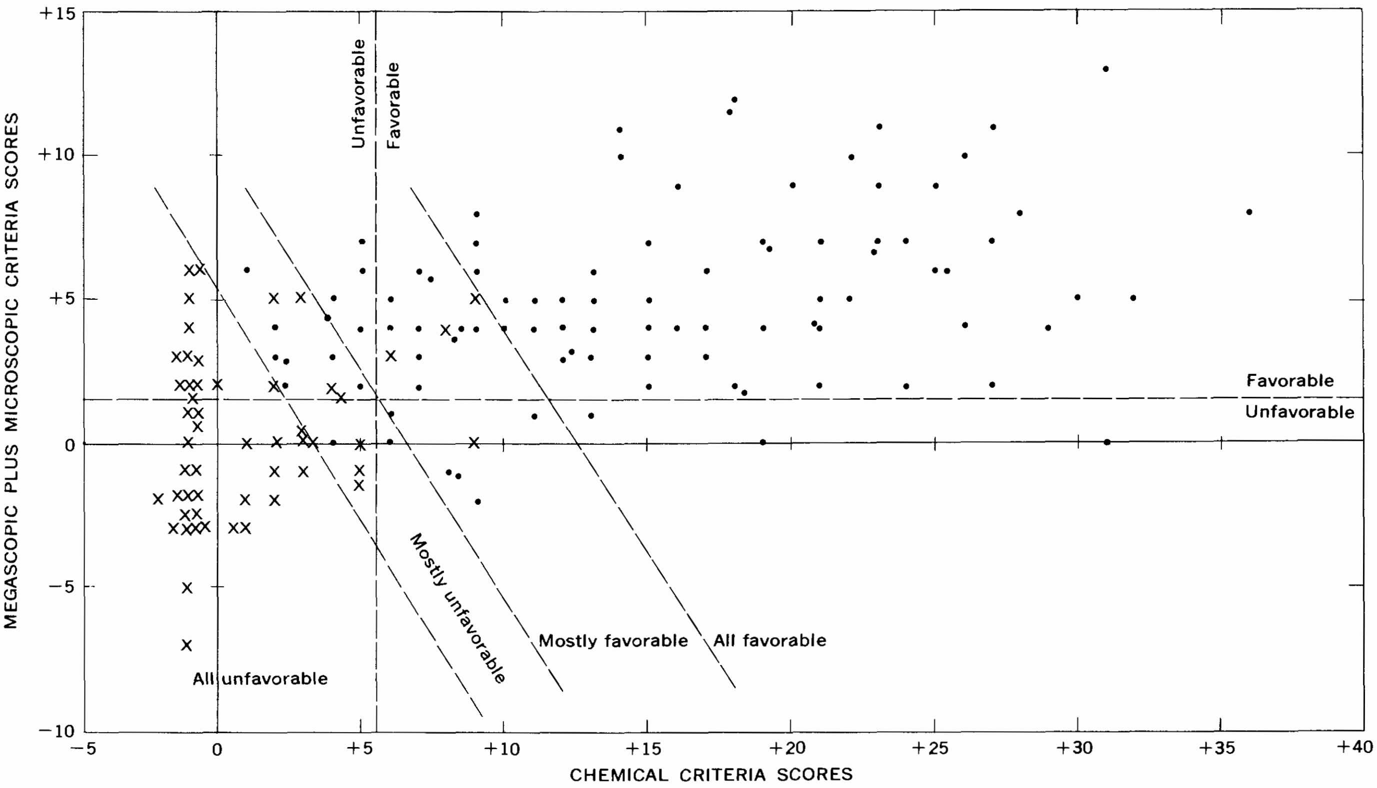


FIGURE 35.—Comparison of scores for megascopic plus microscopic criteria with scores for chemical criteria on all samples. Field classification: ×, unfavorable; ●, favorable.

stracted from the literature; it is supplemented by data on jasperoid samples studied by the author.

Ideally, a district résumé includes information on the distribution, genesis, relationship to ore bodies, physical appearance, microtexture, mineralogy, and composition of jasperoid within the district. Unfortunately, such complete information is not available on all the major districts, but whatever information is available is given in the aforementioned order for each district.

Major districts are here defined as those whose total production is in excess of $100 million. The nine such districts that are characterized by the presence of conspicuous jasperoid bodies are discussed in order of total production as follows:

Loc. no. (fig. 1)	District	State (s)	Production in excess of—
1	Tri-State	Oklahoma, Kansas, Missouri	$2,000,000,000
2	Clifton-Morenci	Arizona	$1,400,000,000
3	Bisbee	do	$1,200,000,000
4	Ely (Robinson)	Nevada	$800,000,000
5	Leadville	Colorado	$500,000,000
6	Tintic-East Tintic	Utah	$400,000,000
7	Gilman (Red Cliff)	Colorado	$150,000,000
8	Aspen	do	$100,000,000
9	Eureka	Nevada	$100,000,000

Bodies of jasperoid are present in some other major districts, such as the Bingham district, Utah, the Santa Rita district, New Mexico, and the Upper Mississippi Valley district of Wisconsin and Iowa, but they either are not a major feature of the alteration or have not been described in the literature; consequently, these districts are not included in this list. The number in parentheses below district names that head the following discussions indicates the district number on the index map (fig. 1) and on the maps for the individual States or areas (figs. 36–50).

TRI-STATE DISTRICT, OKLAHOMA, KANSAS, AND MISSOURI

(1, fig. 1; 2, fig. 36)

The Tri-State district covers a large region surrounding the common corner of Oklahoma, Kansas, and Missouri (fig. 36). In the first half of the 20th century it was the largest producer of lead and zinc ore in the United States. Most of the ore has been produced from two subdistricts or fields, Miami-Picher in Oklahoma and Joplin in Missouri, but the mineralized region also extends well into southeastern Kansas and into many smaller areas of western Missouri. Marine sedimentary rocks ranging in age from Ordovician to Pennsylvanian have a gentle northwesterly regional dip, which is modified

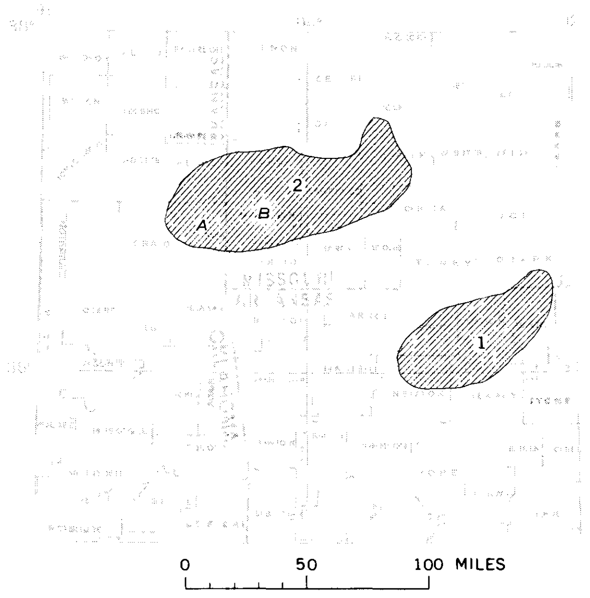


FIGURE 36.—Map showing the location of large jasperoid-bearing mining districts in Missouri, Oklahoma, Kansas, and Arkansas. 1, Northern Arkansas. 2, Tri-State; *A*, Miami-Picher field; *B*, Joplin field.

by numerous warps and open folds. A few persistent northeast-trending faults occur in some parts of the district. Lead and zinc sulfide deposits are largely confined to the Boone Formation, a marine limestone of Mississippian age that contains many chert beds. Replacement ore bodies occur in long narrow "runs" along breccia zones in the chert beds, where sulfide ore forms a matrix cementing breccia fragments of chert, and in wide thin irregular mantos, locally termed "sheet ground," that replace limestone between two chert beds (Smith and Siebenthal, 1907).

DISTRIBUTION

The Tri-State region is characterized by many different types and ages of siliceous bodies in the Mississippian limestone. The oldest of these bodies is nodular chert, which is widely distributed in certain beds and is thought by most investigators to be of syngenetic or diagenetic origin. The youngest replacement silica is dark gray to black and cryptocrystalline; it commonly occupies an intermediate position between sulfide ore and dolomitized limestone. This variety is generally conceded to be jasperoid that is genetically related to sulfide mineralization.

Two more distinctive forms of replacement silica, widely distributed in the area, are intermediate in age between the early chert and the late jasperoid. One of these types is light gray, white, or buff, has a porous appearance, and commonly contains inclusions of older chert. It has been called younger chert by Fowler, Lyden, Gregory, and Agar (1935, p. 108) and forms irregular replacement bodies in the Boone Formation which are most abundant around the fringes of ore bodies (A. V. Heyl, written commun., 1967). The second type is yellow to brown, massive, and cryptocrystalline. It is typically represented by the Grand Falls Chert Member of the Boone. This variety forms distinctive stratigraphic marker zones near faults and ore bodies; however, in many unmineralized and unfaulted areas these same stratigraphic units consist only of limestone with chert nodules. Siebenthal (1915, p. 27) regarded the Grand Falls Chert Member as a jasperoid replacement of cherty limestone, but many other geologists who are familiar with the district consider it to be a true massive chert bed. Both the younger chert and the Grand Falls Chert Member may be early unfavorable varieties of jasperoid, as the terms are used here. However, their age, genesis, and relationship to mineralization, if any, are in dispute.

The late black jasperoid in the Tri-State district shows a general distribution that is closely related to that of the sulfide ore bodies, of which it is the principal gangue. It cements older chert breccia in the "runs," and replaces limestone or dolomite between chert beds in the underlying "sheet ground." Lyden (1950, p. 1256–1257) stated that the jasperoid shows a zonal distribution with respect to the "sheet ground" deposits in the Picher field, where it surrounds a core of barren hydrothermal dolomite and grades outward through unmineralized jasperoid into unreplaced limestone.

GENESIS

Most investigators agree that the late black Tri-State jasperoid was formed by metasomatic replacement of the carbonate host rock, that it was deposited penecontemporaneously with sphalerite, galena, and dolomite, and also, that most of the silica was transported in dispersed colloidal form; however, there is a considerable difference of opinion as to the origin and composition of the transporting solutions, the temperature and depth at which deposition of silica took place, and the form in which it was deposited. Smith and Siebenthal (1907, p. 14) concluded that meteoric waters highly charged with silica and with ore metals in the form of soluble sulfates moved downward along the flanks of the Ozark uplift and deposited both silica and ore in permeable zones in the limestones, whose high organic content reduced the metal sulfates to sulfides, causing them to precipitate. Siebenthal (1915, p. 42, 179, 183) presented the theory that ore and jasperoid were both deposited from ascending alkaline saline waters and that the silica was deposited in colloidal form. Laney (1917, p. 108) also concluded that most of the silica was deposited as a colloid, but he did not speculate on the nature of the transporting solutions.

Weidman (1932, p. 82–84) and Tarr (1933, p. 475–478) believed that jasperoid silica was derived from ascending hydrothermal solutions of magmatic origin and that it was deposited in the temperature range of 100°–300°C. Tarr ascribed the origin of jasperoid to precipitation of silica directly as quartz from highly supersaturated solutions in preexisting solution channels and caverns in the limestone beneath the overlying impermeable Pennsylvania shale. He believed that precipitation was due largely to the escape of volatiles (CO_2 and H_2S) from the transporting solutions, resulting from the sudden release of pressure when these solutions penetrated the open solution channels. He conceded that replacement of limestone by silica occurred, but in his opinion this replacement was subordinate to cavity filling by precipitation. Bastin (1939, p. 108–110, 136, 142) concluded that the late black jasperoid was deposited as quartz rather than colloidal silica just before deposition of the sulfide minerals and that the sulfides were deposited from hydrothermal solutions of magmatic origin at temperatures of about 130°C. McKnight (in Behre and others, 1950, p. 58) stated "The ores are believed to have been deposited by hydrothermal solutions of magmatic origin."

RELATIONSHIP TO ORE

The jasperoid bodies are closely related to sulfide ore both spatially and genetically, forming the common host rock for these sulfides, with which they are penecontemporaneous. However, the Tri-State district is also characterized by the presence of widely distributed "chert" bodies. Fowler, Lyden, Gregory, and Agar (1935, p. 108) recognized two different ages of "chert," both younger than the Boone but older than the overlying Upper Mississippian (Chester) rocks. The older chert appears to be a true diagenetic bedded nodular chert, but the younger "chert" was formed by structurally controlled replacement of limestone (A. V. Heyl, written commun., 1967). The older chert is more limited in distribution and occurs as breccia fragments in the younger "chert," which is abundant in the Boone Formation throughout a vast region of northern Arkansas, southwestern Missouri, and eastern Kansas and Oklahoma. If these conclusions concerning the age and origin of the younger "chert" are correct, then I would consider it to be early unfavorable jasperoid. However, both the age and mode of origin of this chert have been disputed (Fowler and others, 1935, p. 151–163) ; there is general agreement only that it is older than the jasperoid and unrelated to the ore deposits.

APPEARANCE OF JASPEROID AND CHERT

The jasperoid is typically dark gray, dark brown, or black, dense, and finely saccharoidal textured. Locally, it exhibits rhythmic parallel banding in various shades of gray. It weathers to a light gray on the outcrop. In the transition zone between jasperoid and unreplaced carbonate host rock, where the carbonate matrix has been leached, the rest of the jasperoid silica is porous and spongy and crumbles readily into quartz sand.

The older chert is dark brown, light gray or white, and aphanitic with local concentric banding. It commonly contains abundant spherulitic inclusions of chalcedony that impart an oolitic appearance to the rock.

The younger "chert" (Fowler and others, 1934) is similar in appearance to the older, though it is generally lighter in color and contains less chalcedony. It fills fractures in the older chert and replaces the limestone, commonly preserving the original bedding structure, and in many places it contains abundant partly silicified fossils. It grades outward into limestone through a zone of soft chalky white material, locally called cotton rock (Fowler and others, 1934).

MICROTEXTURE AND MINERALOGY OF JASPEROID AND CHERT

The jasperoid matrix quartz consists of irregularly interlocking grains (jigsaw-puzzle texture) which range in diameter from about 0.03 mm to <0.001 mm and which locally contain abundant larger quartz laths elongated parallel to the *c* axis. These grains are randomly oriented, have a length-to-width ratio of about 3:1, and some show pyramidal terminations; locally, they impart a reticulated texture to the rock. Smith and Siebenthal (1907, p. 14) noted that incipient jasperoidization of the host rock is marked by the presence of scattered quartz crystals in the carbonate matrix. The Tri-State jasperoids locally contain, in addition to quartz, penecontemporaneous inclusions of dolomite, sphalerite, and pyrite, and remnants of unreplaced calcite, as well as interstitial films of carbonaceous material and clay. The sulfide inclusions are largely anhedral, but most of the dolomite is in well-developed rhombs, some of which contain poikilitic quartz-grain inclusions.

The older chert exhibits abundant small oval masses of light-brown fibrous chalcedony, and sponge spicules in a matrix of aphanitic irregularly interlocking quartz grains less than 0.02 mm in diameter. It locally contains inclusions of pyrite, marcasite, and tourmaline (Fowler and others, 1934, p. 35, 45). According to Laney (1917, p. 101), many of the quartz grains in the older chert show undulatory extinction that was probably induced by internal stress during crystallization from a colloidal gel.

The younger "chert" (Fowler and others, 1934) is similar in texture to the older, but chalcedony and sponge spicules are less abundant, and the chalcedony lacks the oval form which characterizes its appearance in the older chert. Furthermore, the younger "chert" contains numerous partly silicified calcareous fossils that are absent in the older chert.

COMPOSITION OF JASPEROID AND CHERT

Numerous standard rock analyses of both chert and jasperoid samples from the Tri-State district have been published (Cox and others, 1916, p. 14; Laney, 1917, p. 102; Fowler and others, 1934, p. 35–36), and a few of these are reproduced in table 7 of this report. Laney (1917, p. 103) noted that the average jasperoid sample contains a little less silica and a little more iron and aluminum than the average chert sample; also, that the jasperoid samples showed greater ignition losses and contained appreciable amounts of carbonaceous matter, which is absent in the chert samples. F. E. Gregory (in Fowler and others, 1934, p. 36) stated that samples of older chert show more Al_2O_3, less $CaCO_3$, and less loss on ignition than do samples of younger "chert"; also, he noted that samples of younger "chert" are considerably more variable in composition than samples of older chert.

A semiquantitative spectrographic analysis of a specimen of ore-bearing jasperoid from the Miami shear trough in the Picher Field of Ottawa County in northeastern Oklahoma showed surprisingly low concentrations of indicator elements for a favorable jasperoid; only copper and zinc were detected in significant amounts.

CONCLUDING REMARKS

In spite of all the work that has been done in the Tri-State district, the genesis and significance of the younger "chert" remain in dispute. The chert may be of late diagenetic origin, it may represent barren silicification along old structures in pre-Pennsylvanian time, or it may represent a very early barren stage of alteration related to the jasperoid and sulfide mineralization, and thus be early unfavorable jasperoid.

The undisputed jasperoids in the Tri-State district are unusual in their relative uniformity and simplicity. They exhibit only one major generation, contemporaneous with, or just preceding, the early stage of sulfide deposition, in contrast to the jasperoid bodies of other major districts, such as Tintic and Ely, which are marked by great diversity in color, texture, mineralogy, composition, and age of formation. Tri-State jasperoids also differ from most other favorable jasperoids in their fine-grained texture, scarcity of vugs, and in their lack of high concentrations of most of the "indicator" elements.

The fact that incipient jasperoidization is represented by disseminated quartz crystals in the carbonate host rock suggests that the first phase of jasperoid formation was marked by the deposition of silica from solution directly in the form of quartz, although the deposition of colloidal silica as a hydrogel from solutions more highly charged with silica must have followed shortly thereafter.

CLIFTON-MORENCI DISTRICT, ARIZONA

(2, fig. 1; 5, fig. 38)

The Clifton-Morenci district of southeastern Arizona (Lindgren, 1905) is in an area in which Precambrian schist and granite are overlain by about 800 feet of lower and middle Paleozoic limestone and shale with quartzite at the base. A few hundred feet of Cretaceous shale and sandstone rests unconformably on the Paleozoic sedimentary rocks. Porphyritic igneous rocks ranging in composition from granite to diorite were intruded along northeast-trending fissures during the Laramide orogeny to form a stock with associated dikes, sills, and laccoliths. Strong younger faults of northeasterly trend broke the intrusives and enclosing sedimentary rocks and served as conduits for hydrothermal solutions that deposited sulfide minerals. After a period of erosion that denuded the intrusive bodies and exposed the sulfide deposits to oxidation, the area was covered by a thick series of volcanic flows, breccias, and tuffs ranging in composition from rhyolite to basalt.

The sedimentary rocks were pyrometasomatically altered by the Laramide igneous intrusions, and both intrusives and sediments were later hydrothermally altered along the northeast-trending faults and fractures. In the area of most intense mineralization this hydrothermal alteration took the form of propylitization and sericitization of the host rock, but jasperoid replaced carbonate rock farther out in peripheral zones.

DISTRIBUTION

The jasperoid bodies of the Clifton-Morenci district are not mentioned in either of the two reports that discuss the wallrock alteration of the district in detail (Lindgren, 1905; Reber, 1916). This discussion probably was omitted because the ore deposits are largely within the igneous rocks and contact metamorphosed sediments, where the later hydrothermal alteration resulted in propylitization and sericitization rather than silicification of the host rock. Jasperoid does, however, form replacement bodies in the Cambrian and Ordovician Longfellow Limestone south and southeast of the main mineralized area. Lindgren (1905, p. 62–63) recognized the replacement origin of these bodies, for in his description of the Longfellow Limestone he mentioned the presence of a bed of buff to brownish-gray cherty limestone, 110–200 feet thick, near the top of the formation. His petrographic description of this rock contains the following statement.

> The chert occurs in irregular bands of nodules, which under the microscope appear as an aggregate of greatly varying grain. Some of it consists of irregular quartz grains, while other parts contain much cryptocrystalline and fibrous chalcedonic material. Ragged calcite grains lie embedded in this mass, giving distinct evidence of the metasomatic origin of the chert by replacement of calcite by siliceous waters.

Perhaps Lindgren did not consider this as true jasperoid because most of the rock he described does not exhibit the reticulated texture characteristic of the rock in the Aspen district of Colorado, for which Spurr (1898) had coined the name "jasperoid." The broader definition of the term "jasperoid" as used today was not commonly accepted until long after the report of Lindgren (1905).

The six jasperoid samples from this district that were examined during the present study all came from brecciated zones along faults in the Longfellow Limestone in the town of Morenci south and southeast of the open pit.

GENESIS

Petrographic study of the jasperoid samples suggests that the host limestone was recrystallized and permeated by iron-bearing solutions in a reducing environment, before the introduction of silica. Some of the iron combined with carbonate to form siderite, and some was precipitated as disseminated pyrite. The earliest silica-bearing solutions were apparently rather dilute, and locally permeated the recrystallized host rock and precipitated silica in the form of disseminated quartz crystals. This stage was closely followed by a wave of solutions which were supersaturated with both silica and iron and which also contained potassium. These constituents replaced the host rock, probably as colloidal gels, in an oxidizing environment. Desiccation of the gels was accompanied by minor movement along fractures and by introduction of later silica, which formed dense cherty jasperoid in some places and coarse vein quartz in others. The youngest silica-bearing solutions formed chalcedony as coatings on open cavities.

The available evidence suggests that much of the jasperoid in the Clifton-Morenci district was formed by replacement of favorable beds in the Longfellow Limestone close to fractures that served as conduits for the silicifying solutions, at relatively low temperature and sufficiently close to the surface to be within the zone of oxidation; also, that most of it formed subsequent to the main period of sulfide mineralization in the district. Only a more detailed study of these rocks can resolve the question as to whether silicification was induced by spent hydrothermal solution mingling with ground water or by much younger ground water that had leached its constituents from the siliceous and ferruginous rocks closer to the main center of mineralization.

APPEARANCE

The jasperoid is predominantly shades of red, yellow, and brown; it is commonly brecciated, with large angular breccia fragments of older jasperoid in a matrix of younger jasperoid heavily stained by oxides of iron and manganese. Locally, the rock contains numerous open vugs lined with quartz crystals, and in some places it is cut by veinlets of coarse calcite or vein quartz. The texture, however, is predominantly aphanitic.

MICROTEXTURE AND MINERALOGY

Four different textural varieties of quartz, in addition to the late chalcedony, can be distinguished. From oldest to youngest these are as follows:

1. Dense, relatively homogeneous quartz that has an average grain size of <0.005 mm, jigsaw-puzzle texture, and anomalously low birefringence. Locally, it contains quartz pseudomorphs after original dolomite rhomb inclusions. This quartz forms small scattered breccia fragments and is probably diagenetic or syngenetic chert.
2. Dense to locally vuggy, heterogeneous quartz whose grain size ranges from 0.01 to 0.3 mm and averages about 0.03 mm. This quartz ranges in texture from xenomorphic to reticulated, and it commonly contains clouds of car-

bonate particles which indicate its origin by replacement of the carbonate host rock. This variety forms the matrix in some localities and occurs as breccia fragments in others.

3. A generation of fine-grained heterogeneous jigsaw-puzzle-textured quartz whose grain size ranges from 0.003 to 0.05 mm and averages about 0.005 mm. It is characteristically dense, but vugs occur locally. This variety forms the matrix in which breccia fragments of older jasperoid and chert are locally incorporated.
4. A relatively homogeneous and coarse-grained quartz that has a mean grain diameter of about 0.08 mm, a range of 0.04–0.3 mm, and a xenomorphic texture; it is notably clean and free of inclusions. This youngest quartz fills veinlets and lines vugs in the older jasperoid.

Veinlets and vug fillings of late fibrous chalcedony are locally abundant. In one sample a vug lined with late quartz was filled with chalcedony, which thus seems to be the latest form of silica deposited and is probably of supergene origin.

Other minerals that are associated with all the varieties of jasperoid quartz, in the samples examined, are dolomite, siderite, calcite, sericite, pyrite, hematite, goethite, limonite, and manganese oxides. Dolomite was present as disseminated rhombs in the chert (variety 1), but in the sample studied the rhombs have been replaced by quartz. Siderite and calcite form ragged unreplaced remnant inclusions in the jasperoid quartz (varieties 2 and 3), and a younger generation of coarse calcite also fills fractures that cut the jasperoid. Clouds of carbonate particles in some of the first-generation jasperoid (variety 2) probably are calcite, but these particles are too small for positive identification. Sericite appears to be contemporaneous with the first generation of jasperoid silica (variety 2); it forms small flakes locally disseminated through the groundmass. Original pyrite has been converted to limonite or hematite pseudomorphs in the early jasperoid (variety 2). From its petrographic relations, the pyrite must be either older than, or contemporaneous with, the enclosing silica; the quartz surrounding the pyrite pseudomorphs is heavily impregnated with contemporaneous iron oxides (hematite, goethite, and brown limonite), and for this reason it seems probable that pyrite was introduced before the silicification of the enclosing limestone. The oxides of iron and manganese form abundant penecontemporaneous inclusions in both older and younger jasperoid (varieties 2 and 3). These oxides also constitute the matrix cement for jasperoid breccia fragments or fill veinlets that cut the jasperoid in some places; elsewhere, masses of iron and manganese oxides are cut by veinlets of late quartz (variety 4) or calcite. In general, hematite seems to be older than brown limonite, which is older than goethite and manganese oxide; but local departures from this sequence are common.

COMPOSITION

Information available on the chemical composition of the jasperoid of the Clifton-Morenci district is limited to the results of semiquantitative spectrographic analysis of the six samples in my collection. All these samples contain abnormally large concentrations of lead and zinc; most are rich in iron, beryllium, gallium, molybdenum, and silver; about half are rich in magnesium, manganese, copper, indium, vanadium, and nickel; and one or two samples contain abundant barium, bismuth, cobalt, and germanium. The abundance of ore metals and indicator elements in these jasperoids that are not closely associated with ore bodies is unusual. It seems reasonable that the silica-bearing solutions passed through previously formed sulfide ore bodies, leaching some of these elements from the ore. When the silica later precipitated as a colloidal gel, many of these elements probably were adsorbed on the surface of the gel particles and thus became fixed in the rock when the gel desiccated and crystallized.

CONCLUDING REMARKS

The jasperoid bodies in the Clifton-Morenci district and the surrounding area have not been studied in detail. The results of this preliminary investigation, together with the information available in the stratigraphic section of Lindgren's report (1905, p. 62–63) on the district, suggest that these bodies are concentrated in the upper part of the Longfellow Limestone, that they are younger than the ore deposits, and that they were efficient accumulators of ore metals leached from these deposits by solutions moving through them along faults and fracture zones. Thus, the study of jasperoids in the Longfellow Limestone in the area surrounding this district might furnish clues to the occurrence of undetected blind ore bodies in the vicinity.

BISBEE (WARREN) DISTRICT, ARIZONA

(3, fig. 1; 3, fig. 38)

The Bisbee district is in the south-central Mule Mountains near the southeast corner of Arizona. Here, Precambrian schist and granite are overlain by about 5,200 feet of rocks which range in age from Cambrian to Pennsylvanian and which consist largely of limestone above a basal quartzite. These rocks are truncated by an erosional unconformity and are overlain by about 5,000 feet of Cretaceous sedimentary rocks which consist largely of conglomerate, sandstone, and shale and which contain a thick limestone bed near the top. The Paleozoic rocks were complexly faulted and intruded by siliceous porphyritic rocks, which resulted in the formation of numerous dikes, sills, and, at Sacramento Hill, a small granite porphyry stock. This stock, which lies on the east-trending Dividend fault, intrudes Precambrian schist on the north and Paleozoic limestone on the south. It is a focal point for much of the faulting, alteration, and mineralization in the district. Tectonic movement, subsequent to the igneous intrusions and major period of mineralization, produced thrust faults and related high-angle faults that cut the Cretaceous rocks. Copper ore is disseminated in the altered porphyry of the Sacramento stock, and sulfide replacement ore bodies are localized along faults in the limestone south of the Dividend fault.

DISTRIBUTION

Jasperoid breccia forms a nearly continuous belt in the limestone adjacent to the Sacramento stock eastward from the vicinity of the Gardner shaft. This belt, which is irregular both vertically and horizontally, grades outward into recrystallized limestone 200–1,000 feet from the porphyry contact (Ransome, 1904, p. 83–131, pls. I, III; Bonillas and others, 1917, p. 319). Irregular pods and lenses of jasperoid breccia are also widely distributed throughout the district, especially along faults and fractures, where these cut favorable beds in the Paleozoic limestone. Some major centers of jasperoidization mentioned in the literature are (1) the area of the lower workings of the Lowell mine (Ransome, 1904, p. 131; Bonillas and others, 1917, p. 319); (2) the vicinity of the Czar fault where it crosses Hendricks Gulch; (3) in Uncle Sam Gulch above the mine and adjacent to a granite porphyry contact (Ransome, 1904, p. 83; and (4) just above the contact between the Martin and Escabrosa Limestones in Abrigo Canyon (Ransome, 1904, p. 97, pls. I, III). One type of jasperoid is commonly found in the vicinity of sulfide replacement deposits, and tends to occur at various distances above them along the plane of the controlling fault or fracture, particularly in cherty zones in the limestone (Trischka, 1938, p. 36). Bonillas, Tenney, and Feuchère (1917, p. 320) stated that jasperoid bodies related to porphyry intrusions are more abundant in the Abrigo and Martin Limestones than in the Escabrosa Limestone. However, Trischka wrote that the fault- and fracture-controlled jasperoid breccias are most abundant in the Escabrosa. Bodies of jasperoid breccia are found in all the Paleozoic formations in the district.

A distinctly younger type of jasperoid, which Trischka (1928, p. 1048–1050) described and termed "boxworks silica," is concentrated along post-Cretaceous faults and fractures. It is most abundant in the coarse Cretaceous conglomerates resting on the pre-Cretaceous erosion surface, although it also occurs a short distance below this surface in the Paleozoic limestone and a short distance above it in the Cretaceous shale and sandstone.

GENESIS

Both types of jasperoid in the district are considered by Trischka (1928, p. 1045–1049) to be of hypogene hydrothermal origin. According to Bonillas, Tenney, and Feuchère (1917, p. 319–320), the source of the hydrothermal solutions that silicified and otherwise altered the porphyry stock and the Paleozoic limestone along its southern margin was within or beneath the stock and genetically related to it. The various authors who have studied the district generally agree that a close genetic connection exists between this hydrothermal alteration and the primary ore mineralization which closely followed it, both within and adjacent to the stock, and outward from it along faults and fractures related to the intrusion. The general sequence of events appears to have been (1) faulting before igneous intrusion; (2) forceful intrusion of the stock and related dikes and sills, accompanied by further faulting and minor contact metasomatic silication of limestone adjacent to the stock; (3) crystallization and solidification of intrusive rocks; (4) further fracturing of intrusives and host rocks; and (5) hydrothermal alteration by fluids moving through these fractures, beginning with sericitic and chloritic alteration, progressing through hematitic alteration and silicification, and culminating with sulfide deposition.

The early "silica breccia" type of jasperoid resulting from this process was thought by Trischka (1928, p. 1047–1048) to have formed in the following manner. Brittle limestone beds were dragged apart, fractured, brecciated, and ground during faulting, producing a highly permeable breccia of angular limestone fragments in a matrix of powdered limestone. This powdery matrix was first recrystallized to coarse calcite and impregnated with red hematite by the mineralizing solutions. Both the matrix and the breccia fragment inclusions were then completely replaced by silicia, forming a dark-red aphanitic iron-silica matrix cementing creamy-white silicified limestone breccia fragments and, locally, gray breccia fragments of unreplaced primary chert. The completeness of the replacement, the angularity of the breccia fragments, the preservation of original textures and fossils in these fragments, and the general absence of vugs in the matrix led Trischka (1928, p. 1049) to conclude that silicification was a slow volume-for-volume replacement process without prior solution of calcium carbonate.

The late "boxworks silica" type of jasperoid originated also from hydrothermal silica-bearing solutions, according to Trischka (1928, p. 1048–1050). He expressed the opinion that it was formed by rapidly moving hydrothermal solutions, ascending along open fractures; these solutions partly dissolved and partly replaced the calcareous matrix and rock fragments they encountered. Later weathering and leaching away of the unsilicified remnants contributed to the rough vuggy texture that is characteristic of this rock. The ultimate source of these late siliceous emanations was not discussed, beyond the statement that they are later than, and unrelated to, the mineralizing solutions that produced the primary ore deposits.

RELATIONSHIP TO ORE

The early "silica breccia" type of jasperoid of Trischka (1928, p. 1047–1048) is thought by him to be related both genetically and spatially to sulfide replacement deposits in the Paleozoic limestones, and thus is of the favorable type. In contrast, the late "boxworks silica" type appears to be unrelated to ore, and is consequently unfavorable. Bodies of favorable jasperoid generally lie above the sulfide replacement deposits. In some places the sulfides are within the jasperoid, or immediately adjacent to it, and locally they penetrate it along small veinlets (Hogue and Wilson, 1950, p. 26; Mitchell, 1921, p. 248). Elsewhere, the ore bodies are at some distance from the jasperoid down the feeding fissure. The jasperoid then serves only as an indicator of sulfide deposits in the general vicinity, rather than in immediate proximity (Trischka, 1928, p. 1048).

In many places within the zone of oxidation the primary sulfides of iron, copper, and zinc have been leached from jasperoid, leaving porous soft and yielding masses of silica, or, where the leached jasperoid has been crushed under the weight of the overlying rocks, pockets of coarse sand containing cerussite. One such mass of leached jasperoid in the Lowell mine was described by Ransome (1904, p. 131). Layers of chalcocite and crystals of cerussite locally partly fill voids in the oxidized jasperoid (Mitchell, 1921, p. 248). Trischka (1938, p. 37) described a locality in Hendricks Gulch in which gold was sufficiently concentrated in a pocket of jasperoid sand to produce a minable ore body.

APPEARANCE

Bodies of jasperoid in the district form rough and irregular outcrops. Ransome (1904, p. 83) described them as "a rusty, cavernous siliceous rock, looking superficially not unlike a weathered amygdaloidal lava." According to Trischka (1928, p. 1045; 1938, p. 34), these outcrops form continuous veinlike bodies as much as 40 feet wide and 30 feet high in some places; elsewhere, they are smaller irregular pods strung out discontinuously along faults and fractures. The silica breccia type of jasperoid is generally a dark-red aphanitic rock containing conspicuous angular inclusions of white or cream-colored silicified limestone and, locally, of gray chert. In many places this rock has been repeatedly fractured and recemented with later silica, forming a network of quartz veinlets.

The late jasperoid (boxworks silica) was described by Trischka (1928, p. 1045, 1049) as a pale-yellow or pink rock with abundant open cavities, which are commonly coated with small quartz crystals. This siliceous matrix cements rounded, corroded, and partly replaced pebbles and breccia fragments of limestone and other rocks. It forms smaller bodies than the older jasperoid, but they are distributed over a larger area.

Four jasperoid samples from the Bisbee district are included in my collection. Three of these samples are of the older jasperoid, and one is of the younger jasperoid.

Two of the older jasperoid specimens are definitely favorable, having been collected from surface exposures above known ore bodies. One of these specimens is derived from Martin Limestone of Devonian age near the Dividend fault a short distance east of its junction with the Czar fault; the other is derived from Naco Limestone of Pennsylvanian age in a breccia zone along the Junction fault. Both samples are similar in appearance, consisting of shattered and brecciated dense white and gray silicified limestone cemented by veinlets and interstitial masses of dark-red hematite and silica, with local small patches of green malachite.

The third sample of older jasperoid is from a replacement of Mississippian Escabrosa Limestone along a roadcut about a mile east of Don Luis. This body is not related to any known ore deposits. The sample differs from the other two in that it is massive, pinkish gray, is cut by veinlets of coarse-grained calcite, and contains little hematite. It resembles the two favorable jasperoid samples in its aphanitic texture.

The sample of late unfavorable jasperoid came from Cambrian Abrigo Limestone along the Black Gap fault a short distance south of the contact between the Paleozoic rocks and the unconformably overlying Cretaceous rocks. It consists of partly rounded breccia fragments 1–3 inches in diameter of pale-brown slightly vuggy fine-grained silicified limestone in a matrix of fine-grained white quartz containing irregular open vugs as much as a quarter of an inch in diameter.

MICROTEXTURE AND MINERALOGY

The groundmass in all three samples of older jasperoid consists of dense, relatively homogeneous aphanitic quartz that has a jigsaw-puzzle texture and an average grain size of about 0.01 mm.

The two samples of favorable jasperoid have a groundmass locally impregnated with red hematite dust particles. This matrix is cut by veinlets and irregular masses of late homogeneous xenomorphic quartz that has an average grain diameter of 0.05 mm. Locally, masses of this late quartz, which line the walls of original cavities between breccia fragments of the fine-grained matrix jasperoid, have cores of flamboyant fibrous chalcedony. In one sample the walls of fractures that cut the matrix are locally coated with small fibrous masses of brochantite, which are enveloped by late xenomorphic quartz that fills the fracture. These quartz stringers are cut by later fractures partly filled with porous red hematite, and these, in turn, are cut by thin veinlets of malachite. Thus, a rather complex history of supergene mineralization is revealed.

The aphanitic groundmass in the third sample of older jasperoid contains irregular remnant grains of calcite and also a few grains of specular hematite that appear to be either contemporaneous with, or slightly younger than, the quartz. The matrix is cut by veinlets of coarse calcite as much as a centimeter wide and by narrower younger veinlets in which calcite is mixed with opaque brown limonite. This sample does not contain any of the late xenomorphic quartz that is prevalent in the other two, older, jasperoid samples.

The sample of late unfavorable jasperoid from the Black Gap fault, east of Bisbee, differs strikingly in its microtexture and mineralogy from the samples of older jasperoid. The breccia fragments are composed of heterogeneous xenomorphic quartz grains whose diameter ranges from 0.005 to 0.1 mm and averages about 0.02 mm. Inclusions of carbonate particles are common, and sparsely scattered through the groundmass are sericite flakes and larger masses of coarse-grained relict carbonate with high relief (probably ankerite or siderite). Small vugs are abundant, and some of these are lined with xenomorphic quartz having a mean grain diameter of about 0.1 mm. The matrix quartz that cements the breccia fragments has a heterogeneous granular to xenomorphic texture and a grain diameter that ranges from 0.015 to 0.1 mm and averages about 0.03 mm. It contains sparse allophane particles, but no carbonate. Vugs in the matrix are larger than those in the breccia fragments, and are lined with heterogeneous jigsaw-puzzle-textured quartz, which has a grain diameter that ranges from 0.005 to 0.05 mm and averages 0.02 mm, and which contains carbonate particles.

The appearance of this sample under the microscope clearly reveals its true identity, in contrast to the older jasperoid samples which closely resemble brecciated chert.

COMPOSITION

Semiquantitative spectrographic analyses were made on splits from each of the four samples previously described. All four samples show abnormally high concentrations of nickel and lead. The two favorable samples contain abundant iron, copper, vanadium, and yttrium, and one of these two is also rich in silver, bismuth, and ytterbium; the other contains unusual quantities of lanthanum. Strontium is concentrated in one favorable sample and in the unfavorable sample of older jasperoid; the latter sample is the only one of the four to show an abnormal amount of manganese. Beryllium and molybdenum both show slightly larger-than-normal concentrations in one of the favorable samples and in the sample of late unfavorable jasperoid. Zirconium is the only element present in abnormal amounts in this sample of younger jasperoid but not in any of the older jasperoid samples.

The evidence furnished by these four samples is insufficient to warrant any conclusions as to diagnostic indicator elements associated with favorable jasperoids in this district. However, it does suggest the possibility that one or more elements of the group that includes copper, silver, bismuth, lanthanum, vanadium, yttrium, and ytterbium, which were abnormally concentrated only in the favorable samples, might be useful for this purpose. Zirconium might be a useful element to distinguish the late unfavorable jasperoid.

CONCLUDING REMARKS

The jasperoids of the Bisbee district are unusual in that the color and texture that are generally indicative of unfavorable jasperoid are here associated with the favorable type, whereas the color and texture that would normally lead one to suspect favorable jasperoid are characteristic of the late unfavorable type. Nevertheless, the two types are generally distinguishable by color, texture, and mode of occurrence, and the use of jasperoids as a tool in the search for new ore bodies seems to have considerable promise in this area.

ELY (ROBINSON) DISTRICT, NEVADA

(4, fig. 1; 19, fig. 44)

Near the town of Ely, in the Egan Range of eastern Nevada, Paleozoic sedimentary rocks, consisting largely of limestone and shale, have been arched into a broad east-trending anticline, transverse to the trend of the range (Spencer, 1917). The western part of the axial area of this anticline is cut by low-angle thrust faults; near the center it is broken into alternating horsts and grabens by north-trending normal faults, and farther east, by minor faults along its flanks and across its axis. Major faulting was followed by the intrusion of a series of dikes, stocks, and sills of Tertiary monzonite porphyry along the trend of the anticlinal axis. These intrusive rocks together with the enclosing host rocks, were complexly shattered by renewed fault movement, hydrothermally altered, and mineralized with the disseminated porphyry-type copper deposits for which the district is famous; at the same time, replacement, vein, and breccia-type deposits of copper, lead, zinc, silver, and gold were formed in the Mississippian, Pennsylvanian, and Permian shales and limestones in the vicinity of the intrusives. After a long erosion interval, rhyolite was both intruded and extruded in the area, the extrusive flows partly covering the mineralized monzonite porphyries.

DISTRIBUTION

Irregular bodies of jasperoid are abundant in the western and central parts of the district (Spencer, 1917, pls. 6, 10). They range in size from small bodies covering a few hundred square feet to huge masses that can be traced for several thousand feet along the outcrop and are as much as 1,500 feet wide in places. Many of them either are at the contact of the monzonite porphyry with the enclosing limestone and shale or they cap ridges within the porphyry, but some form replacements in limestone at a considerable distance from the contact; the latter tend to form elongated veinlike bodies or "reefs" along fault and fracture zones. Lawson (1906, p. 325) concluded that the jasperoid originally formed a discontinuous and irregular envelope along the sides and over the top of the monzonite porphyry stocks, separating them from the adjacent sediments. He also noted (p. 329) that many jasperoid bodies terminate abruptly "at no great depth."

GENESIS

The close spatial association between the monzonite porphyry intrusives and many of the larger jasperoid bodies in the district, noted by Lawson (1906) and also by Spencer (1917, p. 51), may indicate that much of the jasperoid in the Ely district is genetically related to these intrusives rather than to the subsequent hydrothermal alteration and mineralization. However, many of these large bodies locally contain chalcopyrite and pyrite; hence, they may also be favorable jasperoid of hydrothermal origin (A. V. Heyl, written commun., 1967), or they may also be older jasperoid that was locally mineralized by the ore-stage fluids. This silicification along the intrusive contacts must have occurred after the crystallization of the intrusives, because the porphyry as well as the host rock has locally been converted to jasperoid, and in some places jasperoid overlies remnants of contact metasomatic garnet rock.

Some of the jasperoid bodies are localized by faults and fracture zones rather than by proximity to intrusive contacts, and some contain disseminated sulfides of their oxidation products; this fact suggests that a considerable amount of late jasperoid silica was also introduced by hydrothermal solutions preceding or accompanying ore mineralization. Such a theory is further supported by the presence of two or more distinct generations of quartz in many samples from the district.

On the basis of studies of fluid inclusions in jasperoid quartz, Spencer (1917, p. 63) concluded that the Ely jasperoids formed at minimum temperatures between 160° and 270°C, and that the replacement of limestone by silica was accomplished by cooling solutions, since the replacement reaction is exothermic, evolving 2,600 calories for each gram of calcite replaced. He (p. 64–69) also expressed the opinion that the early siliceous emanations, containing H_2S, HCO_3, KOH, F, Fe, and Cu, were slightly acid, that they became alkaline through reaction with the host rock as silica and sulfides were deposited, and that they finally were neutralized as they cooled.

RELATIONSHIP TO ORE

The early jasperoid, related to the monzonite porphyry intrusives, is generally unfavorable, according to Lawson (1906, p. 329) and Spencer (1917), although locally it has been mineralized by later hydrothermal solutions. Lawson (p. 329) reported that numerous outcrops of "blout" (jasperoid) in the district have been explored, and that most of them do not contain ore, except for small pockets and coatings of secondary copper minerals and remnants of disseminated pyrite. Spencer (p. 74), on the other hand, distinguished between a porous brecciated rubbly type of jasperoid that was associated with sulfide mineralization and a dense massive resistant type of jasperoid that was unrelated to ore. Most of the unoxidized ore-related jasperoids contain disseminated pyrite and chalcopyrite, although chalcocite-bearing jasperoid is found in the Veteran and Boston-Ely mines. Some small fracture-controlled jasperoid bodies in unmetamorphosed limestone lie above pockets of chalcocite ore. Most of the favorable jasperoids are associated with copper ore bodies in the western and central parts of the district; however, outlying jasperoid bodies also occur in the vicinity of silver-lead-zinc-, and gold-bearing galena-sphalerite replacement deposits in limestone (Spencer, 1917, p. 51, 99, 122–123, 128).

My jasperoid samples from the Ely district display a great variety of colors and textures and also a wide range in scores for favorability. However, those at the low end of the favorability scale with scores of <5 and those at the high end with scores of >18 are distinctive. The unfavorable samples, which probably represent Spencer's dense massive resistant type, are light gray or yellowish gray and have an aphanitic texture. The highly favorable samples, which probably represent his porous brecciated rubbly type, are heavily impregnated with moderate-brown to dark-brown iron oxides on the outcrop, and they are porous, vuggy, and coarse grained.

APPEARANCE

Lawson (1906, p. 327–329) recognized four varieties of "blout" (jasperoid) in the Ely district, which he classified as compact and massive, cavernous weathering, brecciated, and cellular, and which he described as follows. The compact and massive variety, the most abundant, is glassy, white or pale yellow, and it locally resembles a massive quartzite. It commonly has a bedded appearance, and adjacent layers are different in both color and texture. This layering is inherited from the bedding of the host limestone. In most places the outcrops are heavily stained with iron oxide. This rock weathers into rounded knobs or breaks down into talus of irregular angular blocks. The cavernous-weathering variety weathers into very irregular forms "with rugged chambers and straggling channels," in the bottoms of which unaltered remnants of limestone occur locally. The brecciated variety consists of angular fragments ranging from minute particles to blocks 4 inches in diameter, cemented in a matrix of quartz or, less commonly, of calcite. The breccia fragments are predominantly light colored, whereas the matrix characteristically consists of red or dark-yellow jasper. The cellular variety is light colored and porous, and it weathers to a rubble of small fragments. It represents silicified porphyry rather than silicified limestone, and it locally preserves textures of the porphyry and grades into unsilicified porphyry.

Spencer (1917, p. 74) emphasized two major types of jasperoid in the district, a massive barren variety and a porous friable sulfide-bearing variety. The barren type weathers to form prominent outcrops, in contrast to the sulfide-bearing type which breaks down into a rubble of small angular fragments stained rusty brown from oxidation of the pyrite.

My collection from the Ely district consists of 26 samples of jasperoid, all of which were derived from limestone. Twenty-one of these samples are in the vicinity of ore deposits and were classified as favorable; five are not associated with any known ore deposits and were classified as unfavorable. Two of the unfavorable samples were collected at the site of the old town of Ruth, one came from Verzan Canyon half a mile north of the east end of the Ruth ore body, and the remaining two from the east-trending ridge northeast of Weary Flat about a mile north of the Liberty Pit. All five are aphanitic to fine grained and fractured; one has been brecciated and recemented with younger silica. Their color on weathered surfaces ranges from pale yellow to grayish brown and on fresh surfaces, from light yellowish gray through light gray to medium gray.

Four of the favorable samples came from the area of the Veteran and Boston-Ely mines at the west end of the district, and two from small mines 1–1½ miles northeast of Lane at the east end; the remainder were collected at various localities in the central part of the district (south of the Liberty Pit, in the vicinity of the Ruth ore body, and in the vicinity of the Jupiter mine). This group shows a much wider range in both color and texture than does the barren sample group. The weathered surfaces are predominantly brown, in various shades ranging from light yellowish brown through moderate brown and dark brown to very dark brownish gray, almost black; one sample is brick red, and two or three are predominantly light gray. On fresh fractures a few of the brown-weathering samples are light to moderate gray or variegated brown and gray, but most of them show the brown color on fresh exposures as well as on weathered surfaces. Most of these samples are aphanitic to fine grained, but otherwise they are not consistent in texture; some are dense and massive, some are brecciated, some are vuggy; some weather to relatively smooth surfaces and some to very rough uneven surfaces. The 10 samples from this suite that scored +19 or higher on the basis of concentration of indicator elements are more similar in appearance; all are vuggy, rough weathering, and heavily stained with moderate- to dark-brown limonite.

MICROTEXTURE AND MINERALOGY

Spencer (1917, p. 51, 100–101) reported that the typical jasperoid of the Ely district consists of fine-grained quartz aggregates that locally contain abundant tiny vacuoles, some of which are partly filled with fluid. A few of these fluid inclusions also contain very minute crystals of halite or sylvite. Chalcedony is locally abundant; it is younger than the first generation of matrix quartz, but older than some of the late quartz. Other common accessory minerals in the jasperoid are fluorite, apatite, calcite, mica, and, locally, pyrite and chalcopyrite. Spencer (1917, p. 117) also reported that a variety of ore-bearing jasperoid from the Veteran mine also contains rutile, magnetite, pyrrhotite, and chalcocite.

Most of my jasperoid samples from the Ely district range in grain size from 0.01 to 0.1 mm, although a few are as much as 1 mm in diameter. Fluid inclusions are present in some of the coarse-grained samples. All the common jasperoid fabric textures discussed on pages 11–15 of this report are represented in the suite of Ely samples. Xenomorphic and jigsaw-puzzle textures are most abundant, but granular, reticulated, and fibrous textures are also present. Most of the samples exhibit at least two distinct generations of jasperoid quartz, and some show as many as four generations. In general, the older generation is granular to xenomorphic in texture and somewhat coarser grained than the younger generation, which commonly exhibits a jigsaw-puzzle texture. These observations tend to support the theory of early high-temperature, diffuse, siliceous emanations, from which silica probably deposited directly in the form of quartz, followed by late denser and cooler hydrothermal silica-bearing solutions from which silica deposited as a colloidal gel, giving rise to an aphanitic jigsaw-puzzle texture in the resulting jasperoid. Local exceptions, in which the latter type is followed by coarser xenomorphic or reticulated jasperoid, may indicate that late-stage hydrothermal solutions with lower silica concentration were in contact with previously silicified and therefore nonreactive rocks, again resulting in relatively slow deposition of SiO_2 as quartz. These exceptions are economically important because a late stage of coarse vuggy xenomorphic to locally reticulated quartz is characteristic of the most highly favorable type of samples in the Ely suite.

In thin sections cut from 25 jasperoid samples from the Ely district, 21 minerals, in addition to quartz, were identified. In order of decreasing abundance these are (1) chalcedony, hematite, and limonite (10 samples); (2) allophane dust and goethite (eight samples); (3) jarosite and calcite (six samples); (4) carbonate dust (five samples); (5) sericite, kaolinite, apatite, fluorite, and pyrite (three samples); (6) hydromica, halloysite, opal, and sphene (two samples); and (7) lussatite, zircon, siderite, and cerussite (one sample). The age relations of these 21 minerals to the jasperoid quartz are broadly indicated in table 16.

The samples were divided, on the basis of their indicator-element content, into three groups as follows: Highly favorable (score $\geqslant +19$), intermediate (score $< +19$ but $> +5$), and unfavorable (score $< +5$). This classification resulted in 10 samples in the first group, 10 in the second, and five in the third. The seven most abundant minerals (those recognized in more than five samples) were then classi-

TABLE 16.—*Age relations of minerals in Ely district jasperoid to the jasperoid quartz*

Mineral	Older[1]	Contemporaneous[2]	Younger[3]
Apatite	+	....	....
Zircon	+	....	....
Siderite	+	....	....
Sericite	+	+	....
Pyrite	+	+	....
Hydromica	+	+ ?	+
Sphene	+	....	+
Calcite (carbonate dust)	+	+	+
Allophane	....	+	+
Hematite	+	+	+
Limonite	....	+	+
Goethite	....	+	+
Chalecdony	....	+	+
Kaolinite	....	....	+
Halloysite	....	....	+
Fluorite	....	....	+
Jarosite	....	....	+
Cerussite	....	....	+
Opal	....	....	+
Lussatite	....	....	+

[1] Older than the first generation of jasperoid quartz.

[2] Formed simultaneously with a major generation of quartz or between two major generations.

[3] Formed after the youngest major generation of jasperoid quartz, but not necessarily after the youngest quartz veinlets and vug linings.

fied as to the proportion of the total samples in each group in which they occur, as follows.

Mineral	Frequency (as percent of total group)		
	Highly favorable	Favorable	Unfavorable
Jarosite	50	10	0
Goethite	30	50	0
Limonite	60	30	20
Hematite	40	50	20
Chalcedony	30	50	40
Allophane	20	50	20
Calcite	30	20	20

This limited amount of data suggests that among the more abundant minerals only jarosite, goethite, and possibly limonite are significantly more common in the favorable variety of Ely district jasperoid than in the unfavorable variety.

COMPOSITION

Spencer (1917, p. 117) reported a quantitative chemical analysis of a composite sample of ore-bearing jasperoid from the Veteran mine. This jasperoid contained rutile, magnetite, pyrrhotite, and chalcocite, which are not present in most jasperoids of the district, and therefore does not represent ordinary Ely district jasperoid. The analysis is as follows:

Element	Percent	Element	Percent
SiO_2	79.11	H_2O-	0.81
Al_2O_3	3.82	H_2O+	2.68
Fe_2O_3	.44	TiO_2	.81
FeO	.69	P_2O_5	.42
MgO	1.19	S	[1] 3.01
CaO	.62	Cu	[1] 2.55
Na_2O	.31	Fe	[1] 2.64
K_2O	.54	Total	99.64

[1] In sulfide inclusions.

Semiquantitative spectrographic analyses were made of splits from the 25 samples studied in the present investigation, and in one or more of these samples 33 elements other than Si were detected, as shown in table 17.

TABLE 17.—*Minor-element distribution in 26 samples of jasperoid from the Ely district, Nevada*

[J. C. Hamilton, analyst. Leaders (......) indicate no information]

Element	Limit of detection (percent)	Number of samples in which detected	Minor-element distribution (in percent)			
			Range	Mean	Median	Mode
Ag	0.0001	12	<0.0001– .07	0.0048	<0.0001	<0.0001
Al	.001	26	.15 – .7	.27	.14	.15
As	.1	3	<.1 –1.5	....	....	....
B	.002	4	<.002 – .003	....	....	....
Ba	.0002	26	.0007– .07	.0087	.003	.003
Be	.0001	3	<.0001– .00015	....	....	....
Bi	.001	11	<.001 – .7	.036	<.001	<.001
Ca	.005	26	.07 –>10.0	1.2	.12	.15
Cr	.0001	26	.0003– .007	.0023	.0014	.003
Cu	.0001	26	.0007– .15	.027	.007	.03
Fe	.0008	26	.07 –>10.	3.9	1.0	3.
Ga	.0002	6	<.0002– .003	....	....	....
Ge	.001	1	<.001 – .007	....	....	....
In	.001	5	<.001 – .0015	....	....	....
La	.002	2	<.002 – .003	....	....	....
Mg	.0005	26	.007 – .3	.061	.021	.03
Na	.05	1	<.05 – .07	....	....	....
Mn	.0002	26	.0015– .7	.044	.0095	.015
Mo	.0005	17	<.0005– .007	.0015	.0007	<.0005
Nb	.001	1	<.001 – .0015	....	....	....
Ni	.0003	8	<.0003– .0015	.00023	....	....
P	.2	1	<.2 – .7	....	....	....
Pb	.001	17	<.001 –7.	.39	.003	<.001
Sb	.01	1	<.01 – .015	....	....	....
Sn	.001	15	<.001 – .15	.0081	<.001	<.001
Sr	.0002	24	<.0002– .03	.003	.0008	.0007
Ti	.0002	26	.007 – .3	.052	.023	.07
V	.001	14	<.001 – .015	.0027	.001	<.001
W	.01	2	<.01 – .015	....	....	....
Y	.001	6	<.001 – .0015	....	....	....
Yb	.0001	8	<.0001– .00015	.00003	....	....
Zn	.01	16	<.01 – .3	.051	.015	<.01
Zr	.001	22	<.001 – .07	.0084	.003	.007

The actual relative abundance of these elements is difficult to evaluate, because many of them have highly irregular frequency distributions and because the limit of sensitivity of the analytical method varies widely from element to element. This evaluation difficulty is illustrated by table 18, in which the 15 most abundant elements are listed in order of decreasing concentration according to arithmetic mean, median, and maximum reported concentration. In spite of the uncertainties regarding the true abundance of the various elements, which are inherent in the nature of the samples, of the analytical data, and of the analytical method, it is apparent that bismuth, tin, and zinc are abnormally concentrated in this group of samples. However, a much larger number of samples would be required to ascertain whether these elements are characteristically high in jasperoid bodies of the district as a whole.

Comparison of the median concentrations of the various elements in the group of 10 highly favorable samples and the group of five unfavorable samples

TABLE 18.—*Relative abundance, in percent, of 15 most abundant elements in 26 samples of jasperoid from the Ely district, Nevada*

Arithmetic mean concentration		Median concentration		Maximum reported concentration	
Fe	3.9	Fe	1	Fe	>10
Ca	1.2	Ca	.15	Ca	>10
Pb	.39	Al	.14	Pb	7
Al	.27	Ti	.023	As	1.5
Mg	.061	Mg	.021	Al	.7
Ti	.052	Zn	.015	Bi	.7
Zn	.051	Mn	.0095	Mn	.7
Mn	.044	Cu	.007	P	.7
Bi	.036	Pb	.003	Mg	.3
Cu	.027	Ba	.003	Ti	.3
Ba	.0087	Zr	.003	Zn	.3
Zr	.0084	Cr	.0014	Cu	.15
Sn	.0081	V	.001	Sn	.15
Ag	.0048	Sr	.0008	Ag	.07
Sr	.0030	Mo	.0007	Ba	.07

showed that among the common elements only iron exhibits a difference of an order of magnitude or more between the two median values (4 percent in the favorable group, 0.13 percent in the unfavorable group); similar differences were also noted in the ore metals, silver, bismuth, copper, lead, tin, and zinc, but these can be ascribed largely to the criteria used to establish the two groups.

CONCLUDING REMARKS

The available data suggest two major generations of jasperoid in the Ely district: (1) an early unfavorable generation, genetically related to the monzonitic intrusive rocks, that is dense and massive and has a fine-grained granular to xenomorphic texture; and (2) a late, locally favorable generation genetically related to hydrothermal solutions younger than the intrusives. This late jasperoid again may be subdivided into two types: an aphanitic variety that has a jigsaw-puzzle texture, which is generally unfavorable, and a coarser grained vuggy xenomorphic to reticulated variety associated with abundant iron oxide, which is commonly favorable. A more detailed study of the district would be needed to establish the distribution patterns, structural controls, and age relations of the various types of jasperoid.

LEADVILLE DISTRICT, COLORADO

(5, fig. 1; 9, fig. 40)

The Leadville district of central Colorado is on the western slope of the Mosquito Range near the head of the Arkansas River (Emmons and others, 1927). It has produced large quantities of silver, lead, and zinc and some gold, manganese, and copper.

Here, Precambrian granite, schist, and gneiss are covered by about 150 feet of Cambrian quartzite and shale, which, in turn is overlain by about 350 feet of Ordovician, Devonian, and Mississippian rocks that consist dominantly of limestone and dolomite. The Mississippian and Devonian rocks are overlain by about 2,500 feet of Pennsylvanian continental and marginal marine sedimentary rocks, which are largely shale, siltstone, and arkose with a few interbedded limestones.

During Cretaceous time the sedimentary rocks were intruded by dikes and sills of monzonite and granodiorite. After these intrusions were emplaced, strong compressive forces folded the rocks and produced large northwest-trending thrust faults. This was followed by the intrusion of a small quartz-monzonite stock at Breece Hill, together with related dikes. Subsequent to the emplacement of this stock the area was again broken by numerous normal and reverse faults. These faults served as conduits for hydrothermal solutions which emanated from within or beneath the stock and which altered and mineralized the rocks adjacent to the faults. Still later, northeast-trending normal faults broke and offset many of the ore bodies, and plugs and dikes of rhyolite were locally intruded, probably in Pliocene time. This complex orogenic history has complicated the regional distribution pattern of ore deposits and related types of alteration, including jasperoid.

DISTRIBUTION

The Leadville district is close to the center of a jasperoid province (fig. 1) that extends outward from the district for many miles to the northeast, east, and southeast. Thus, it is difficult to establish boundaries between jasperoid bodies of the Leadville district (9, fig. 40) and those of the Kokomo district (7, fig. 40) and Pando area (14, fig. 40) to the north, and the Horseshoe-Sacramento district (6, fig. 40) to the southeast. Within this region replacement bodies of jasperoid are most abundant in the upper part of the Mississippian Leadville Limestone, particularly in areas where this formation is capped by porphyry sills and has been cut by faults and fractures that provided access for mineralizing solutions. Jasperoid bodies are also found locally in the Devonian Dyer Dolomite Member of the Chaffee Formation and in the Ordovician Manitou Limestone beneath the Leadville Limestone; they are also found in some limestone beds in the lower part of the Pennsylvanian Minturn Formation above the Leadville Limestone. Igneous intrusive rocks close to centers of intense alteration are also strongly silicified locally.

Emmons, Irving, and Loughlin (1927, p. 172, pl. 13) referred to many jasperoid replacement bodies in the Leadville Limestone on Fryer Hill and in the Downtown area. Additional areas that contain abundant jasperoid (Loughlin and Behre, 1934, p. 226, 229, 234, 240) are Iron Hill, the southeastern part of Carbonate Hill, the head of Evans Gulch, and a small area west of the Mike fault opposite Empire Hill. Many of the most extensive jasperoid bodies are also associated with the Tucson Maid fault west of Breece Hill in the central part of the district.

The six Leadville district samples in my collection are all dump samples from the northwestern and western parts of the district. Two are from Canterbury Hill, one about 1 mile and the other 1½ miles northeast of the center of Leadville. The remaining four samples are from mines on Fryer Hill and Stray Horse Ridge, ½–1 mile east of Leadville.

GENESIS

Much of the jasperoid in the district apparently was formed by hydrothermal silica-bearing solutions emanating from within or beneath the Breece Hill stock. Emmons, Irving, and Loughlin (1927, p. 218) concluded that the main period of jasperoidization in the district occurred during and after the ore stage of mineralization. Quartz was deposited in veins before the deposition of the sulfides, which partly replaced the vein quartz, displacing the silica outward to form jasperoid. However, Loughlin and Behre (1934, p. 226) pointed out that many of the jasperoid bodies are impregnated with sulfides and are cut by sulfide veins, and therefore, that some of the jasperoid must have formed before the ore-sulfide stage of mineralization.

Loughlin and Behre (1934, p. 221) classified the deposits of the district, on the basis of mineral assemblages representing successively lower temperatures of formation, into pyrometasomatic, hypothermal, high mesothermal, intermediate mesothermal, low mesothermal, and epithermal or telethermal. They regarded (p. 225) the jasperoids as most characteristic of the intermediate mesothermal deposits, which were formed outward from, and at lower temperatures than, the manganosiderite deposits that characterize the high mesothermal class; but they also mentioned the association of jasperoid with some deposits of the low mesothermal and epithermal classes.

Emmons, Irving, and Loughlin (1927, p. 218) mentioned the fact that much of the Leadville jasperoid is heavily impregnated with "products of oxidation." Indeed, most of the Leadville jasperoid samples in my collection are of this type, in which the jasperoid silica is intimately mixed with limonite and manganese oxides, suggesting a possible supergene origin.

RELATIONSHIP TO ORE

The favorable jasperoids of the district tend to form a floor beneath, or a casing around, massive sulfide deposits. Jasperoid impregnated with sulfide ore is relatively sparse. Many extensive jasperoid bodies, particularly those in the northwestern part of the district, are unfavorable (Loughlin and Behre, 1934, p. 228). At the Continental Chief mine, near the head of Evans Gulch, favorable jasperoid, which retains the color and texture of the carbonate host rock, forms a casing adjacent to the mineralized fissures, but prominent ledges of unfavorable jasperoid also crop out in the same vicinity (Loughlin and Behre, 1934, p. 234). Favorable jasperoid is most commonly associated with lead-silver ore and is less abundant around the zinc and copper ore bodies (Ogden Tweto, oral commun., 1965). Many of the dense dark-colored jasperoids impregnated with iron and manganese oxides have the composition of favorable jasperoid; however, their spatial relations to ore bodies are not yet known.

APPEARANCE

All the jasperoid samples from the Leadville district, in my collection, are dark gray to black, aphanitic on the outer surface, with local brown patches. Most of the samples are homogeneous in texture, but one sample, from the dump of the Annie 5 mine on Fryer Hill about half a mile east of Leadville, has a shell or rind of dense black manganiferous jasperoid coating a core of porous vuggy friable light-gray and light-brown saccharoidal jasperoid. The contact between shell and core of this sample is knife-edge sharp, suggesting leaching and thorough oxidation of the core before formation of the rind. The only sample of clearly hypogene jasperoid in the collection came from the dump of the Forepaugh mine, also on Fryer Hill. This sample is dark to medium gray and aphanitic, and it contains abundant fine-grained disseminated pyrite and a few tiny vugs that appear to have been formed by local leaching of the original pyrite.

MICROTEXTURE AND MINERALOGY

The hypogene jasperoid in the sample from the dump of the Forepaugh mine is fine to medium grained (0.005–0.1 mm) and heterogeneous, and has a jigsaw-puzzle texture. The extremely fine grained quartz is locally segregated in bands, and thin veinlets of coarser xenomorphic quartz cut the matrix. Abundant inclusions of pyrite and younger sphalerite are present. Some, if not all, of the quartz is older than the sulfides as shown by the presence of quartz-grain inclusions in some of the pyrite. The same heterogeneous jigsaw-puzzle texture is also characteristic of the quartz in the core of the sample from the dump of the Annie 5 mine and of rounded inclusions of older jasperoid in a matrix of younger iron and manganese oxides found in a sample from a dump on the North Fork of Little Evans Gulch.

Jasperoid of possible supergene origin forms the outer rim of the specimen from the dump of the Annie 5 mine and constitutes nearly all the remaining specimens, exclusive of the one from the Forepaugh mine dump previously described. This rock is characterized by small scattered inclusions of quartz and dolomite, in a matrix of earthy, vuggy, and porous iron and manganese oxides, which are locally crystallized into pyrolusite, goethite, and hematite. In some places the pores are filled with late quartz; in others, bands of xenomorphic medium-grained quartz alternate with bands of manganese oxide; and in nearly all samples veinlets of medium-grained homogeneous xenomorphic quartz cut the matrix oxides. Thus, if these oxides are supergene, the late silica associated with them must also be supergene. However, this rock may not be a true replacement jasperoid but rather a variety of case-hardened gossan. Because the samples were not taken in place, the field relationships of this rock to its host could not be ascertained; however, the abundant quartz and dolomite grains suggest that these minerals may have been original inclusions in limestone, of which the calcite has been replaced by supergene iron and manganese oxides and silica.

COMPOSITION

Semiquantitative spectrographic analyses available on four of the supergene(?) samples and the single definitely hypogene sample showed that all five have a composition characteristic of favorable jasperoid. Of the five, the hypogene sample has the smallest suite of minor elements present in abnormally high concentrations. After the associated sulfide minerals had been largely removed from this sample by heavy liquid separation, the remaining jasperoid quartz showed only Ag, Ba, Mo, Pb, and Zn present in concentrations more than one order of magnitude higher than the median concentration for all jasperoid samples in the collection. The quartz of the remaining four samples was not separated before analysis, and the resulting data show that in them silica is subordinate to iron and manganese. The high concentrations of a number of minor elements in these samples, therefore, probably represents association with iron and manganese oxide rather than with quartz. These samples are consistently rich in Fe, Mn, Ag, Ba, Pb, Ni, and Zn; three of the four are also high in Cu and Sr; and two are high in In and Mo. High In is associated with high Cu, but high Mo is not.

CONCLUDING REMARKS

Although both favorable and unfavorable jasperoid samples have been reported from this district, only favorable samples are represented in my collection. Thus, no direct comparison between favorable and unfavorable jasperoid in the Leadville district is possible here. According to Ogden Tweto (oral commun., 1965), there is a marked similarity in appearance between the two types, such that they are not readily distinguishable in the field. The known presence of both varieties in the area, however, and the abnormally high concentrations of the indicator elements Ag, Pb, and Zn in all the available favorable samples suggest that a detailed study of the Leadville jasperoids, coupled with adequate sampling and analysis for these elements, might be a fruitful adjunct of any comprehensive exploration program in the district.

TINTIC AND EAST TINTIC DISTRICTS, UTAH

(6, fig. 1; 21, fig. 49)

The Tintic and East Tintic mining districts in Utah are about 70 miles south of Great Salt Lake in a mineralized belt that crosses the East Tintic Mountains, whose crest forms part of the boundary between Juab County on the west and Utah County on the east (Lindgren and Loughlin, 1919).

A thick sequence of Paleozoic limestone, dolomite, and shale with a Cambrian quartzite at the base in this area is largely covered by Tertiary extrusive quartz latite, latite, and associated pyroclastics, all of which were later intruded by monzonite stocks and dikes. Before the extrusion of the Tertiary volcanic rocks, the sedimentary strata were folded into a series of north-trending asymmetrical anticlines and synclines, and were cut by high-angle transcurrent faults that were accompanied by overthrust faulting, particularly in the eastern part of the area. The major high-angle faults have predominating northeasterly and northwesterly trends; their major displacement predates the volcanics, although there has been some renewed postvolcanic movement on some of them. The intrusion of monzonite and quartz monzonite was accompanied and followed by hydrothermal alteration of both the volcanics and the underlying sedimentary rocks, culminating in ore deposition. The primary ore bodies consist of sulfide-bearing veins and replacement deposits in the sedimentary rocks. Most of the production of the districts has come from the lead-zinc-silver replacement deposits in limestone and dolomite; but copper and gold, which commonly occur in fissure vein deposits and pipes cutting Cambrian quartzite, are also economically important locally.

DISTRIBUTION

The distribution of jasperoid bodies in the East Tintic district is shown by Lovering (1949, pl. 4) and by Lovering and others (1960), and in the main Tintic district, by Morris (1964a, pl. 1; 1964b, pl. 1).

Bodies of silicified rock occur in all of the Paleozoic sedimentary formations in the two districts and in the Tertiary volcanic rocks as well. In the East Tintic district, however, jasperoid bodies are most abundant in the carbonate rocks that have been altered to hydrothermal dolomite along faults (Lovering, 1949, p. 29). This structural control is very pronounced; the jasperoid bodies form envelopes around the faults and fissures that served as conduits for the hydrothermal solutions. The jasperoids of the Tintic and East Tintic districts show no direct relationship to the monzonitic intrusive rocks; they are found in areas where these intrusives are lacking, although they are somewhat more abundant in areas marked by centers of intrusion.

GENESIS

The formation of jasperoid largely represents a late stage in a long and complex history of hydrothermal alteration in the districts, which culminated with the emplacement of sulfide ore bodies. Lovering (1949, p. 16–17) recognized five distinct stages of alteration, each with its own characteristic mineral assemblage; these, in chronological order, he called the early barren stage, the middle barren stage, the late barren stage, the early productive stage, and the productive stage. Silicification resulting in the formation of favorable jasperoid was largely confined to the late barren stage (Lovering, 1949, p. 28). Locally, argillic alteration of the middle barren stage was accompanied by minor silicification (Lovering, 1949, p. 38).

Lindgren and Loughlin (1919, p. 156–157) concluded that the favorable variety of jasperoid formed as a result of the replacement of carbonate rock by colloidal silica. The characteristically abrupt contacts between jasperoid and host rock led them to express the opinion that the silicifying solutions moved outward in a wave from the feeding channels, converting all the rock behind the advancing wave front into silica gel. As this gel later desiccated and crystallized into jasperoid quartz and chalcedony it also shrank, causing the formation of vugs and fractures. These openings were later filled or coated with younger jasperoid, quartz crystals, barite, and sulfides. Local banding in the jasperoid is ascribed to penetration of the original gel by electrolyte-bearing solutions, resulting in Liesegang diffusion banding.

Lovering (1949, p. 56–58) expressed the opinion that the jasperoidizing solutions were highly charged with silica, iron, barium, carbonic acid, and sulfate; they were hot neutral or slightly alkaline solutions, partly of magmatic origin, rising along major fractures through the quartzite, from which they may have leached silica and iron. As these solutions rose into the carbonate rocks, they cooled, and the carbonates became more soluble and silica less soluble. The calcium and magnesium that were replaced during the silicification moved upward into the overlying volcanic rocks, resulting in calcitic and chloritic alteration of these rocks.

An unfavorable type of jasperoid occurs in carbonate rocks just below the base of the Tertiary rhyolite flows. This type is controlled by proximity to the unconformity rather than by faults and fractures. It appears to have formed as a result of the leaching of silica from these flows by water seeping downward through them, and subsequent precipitation of the silica when this water was neutralized by reaction with the underlying carbonate rock. Much of this jasperoid probably formed during the period when the flows were still cooling, as a result of alteration by hot-spring and fumerole emanations; some of it may be due to leaching of silica by acid waters generated by the oxidation of pyrite disseminated through the flows, and thus may be of comparatively recent origin (T. S. Lovering, oral commun., 1964). This type of jasperoid is, in either case, unrelated to the hydrothermal alteration that culminated in sulfide mineralization.

Bodies of possibly supergene jasperoid have been found in and near large oxidized ore bodies in some of the mines on the north slopes of Eureka Peak and Godiva Mountain near the town of Eureka (A. V. Heyl, written commun., 1967). These jasperoid bodies presumably formed by reaction of silica-bearing ground waters with carbonate host rock during the oxidation of sulfide ore bodies.

RELATIONSHIP TO ORE

Howd (1957, p. 125–132) presented an excellent historical summary of the views of various investigators concerning the relationship between jasperoid and sulfide ore in the Tintic and East Tintic mining districts. The close association between jasperoid and many of the sulfide replacement deposits in carbonate rocks was recognized by the miners early in the development of the districts. This association was reported by Lindgren and Loughlin (1919, p. 155), who concluded that the jasperoid, although older than the ore, was closely related to it and that it formed envelopes around the ore bodies. Lovering (1949, p. 28) recognized that jasperoid forms a broad envelope around the major circulation channels that were open during the late preore stage of alteration, of which it is the most characteristic product. Many of these same channels later served as conduits for ore solutions, giving rise to the association noted by Lindgren and Loughlin (1919, p. 155–157). However, some channels were completely sealed off by the early silica so that no sulfides could form in them; in other places, ore solutions followed new channels and thus resulted in ore bodies not intimately associated with jasperoid. Thus, late barren-stage jasperoid in the carbonate rocks of the district is not, by itself, a wholly reliable indicator of proximity to ore, nor does its absence preclude the possibility of ore in an area. Furthermore, not all the jasperoid bodies in the districts were formed during the late barren stage of alteration.

Favorable jasperoid, of possibly supergene origin, locally forms bodies on the lower carbonate wallrock side of oxidized zinc ore pipes and mantos (A. V. Heyl, written commun., 1967). The jasperoid that is localized at the contact between the volcanic and sedimentary rocks appears to be completely unrelated to ore, and this unfavorable type is widely distributed, particularly in the area north of Eureka (H. T. Morris, written commun., 1957). The known presence of both favorable and unfavorable jasperoids in the Tintic and East Tintic districts prompted personnel of the Bear Creek Mining Co. to make a detailed study and comparison of suites of samples of the two types in an effort to establish criteria for the recognition of the favorable type. The results of this study are summarized by Howd (1957), Duke (1959), and Bush, Cook, Lovering, and Morris (1960b, p. 1516–1517).

APPEARANCE

The jasperoid bodies in the Tintic and East Tintic districts are characterized by sharp contacts between completely silicified rock and completely unsilicified host rock. Many bodies form elongated narrow "reefs" along fractures, but some are highly irregular in shape. They tend to be smaller, but more widely distributed, than those at Ely. The largest attain a maximum dimension in excess of 1,000 feet, but most have an outcrop area of only a few hundred to a few thousand square feet.

Lindgren and Loughlin (1919, p. 154) described the typical Tintic jasperoid as a fine-grained, dark-gray to bluish-gray rock, locally resembling a fine-grained quartzite. According to H. T. Morris (written commun., 1957), some of the favorable hypogene jasperoids are locally coarse grained, many show textural as well as color banding with textures and structures suggestive of colloidal deposition, all are distinctly vuggy, and some show several periods of brecciation and recementation by later silica. One variety has a saccharoidal texture, and most of the favorable jasperoids contain megascopically visible platy crystals of barite. Although the favorable jasperoids range widely in color, most of them are lighter hued and more translucent on thin edges than the unfavorable jasperoids.

The unfavorable jasperoids, as a group, are dense and have a flinty appearance. They are predominantly black to brown or gray and are characterized by uniform texture and scarcity of vugs.

According to A. V. Heyl (written commun., 1967), the possibly supergene favorable jasperoid forms vuggy banded colloform casings adjacent to oxidized sulfide ore bodies. It contains abundant limonite and hemimorphite and sparse chrysocolla and malachite. This jasperoid is distinguishable from oxidized hypogene jasperoid by its lack of relict sulfides or of pits and pseudomorphs revealing their former presence.

My collection from the Tintic and East Tintic districts consists of 25 samples from 14 localities of which eight samples from four localities represent oxidized unfavorable jasperoid bodies, and the rest represent hypogene favorable jasperoid bodies. Six of the sample localities are in the vicinity of Eureka, four are in the southern part of the district on Mammoth Peak, one is near the center of the East Tintic district, one is on Pinyon Peak, one in Fremont Canyon, and one on Old Baldy Peak.

In this suite, all favorable jasperoid samples that are unoxidized and most that are oxidized are various shades of gray; several oxidized samples are white or moderate brown to dark brown, and a few show green copper stains or yellow iron sulfate stains. Many of the samples are mottled, banded, or streaked. Nearly all the favorable samples are brecciated and conspicuously vuggy, and some are porous and friable as well. Although a saccharoidal texture is evident in one or two of these samples, most are aphanitic; a few contain abundant randomly oriented blades of barite.

The few samples of unfavorable jasperoid in my collection are dark red, dark gray, bright yellow, or lavender gray, commonly variegated. All are dense, and one has a glassy texture and conchoidal fracture.

MICROTEXTURE AND MINERALOGY

Lindgren and Loughlin (1919, p. 155–156) described "typical" Tintic jasperoid as composed of quartz grains less than 0.25 mm in diameter with wavy extinction and commonly abrupt variations in grain size. They mentioned a local variety from the Gemeni mine which is strongly microbanded with alternating dark bands of cryptocrystalline quartz and light bands of spherulitic light-brown chalcedony, with minute grains of sulfides disseminated through both types of bands (fig. 30).

Lovering (1966) reported the presence of asymmetrically zoned quartz in much of the late barren stage jasperoid and made a petrofabric study of the preferred orientation of the asymmetry of the zonal overgrowths. Plots of the direction of displacement of the *c* axis showed consistent relations that were interpreted as indicating the dominant direction of movement of the jasperoidizing solutions. These directions seem to coincide with the rake of the associated but later ore. The jasperoid quartz contains abundant minute low-index inclusions, which may be allophane; some of it also contains nearly isotropic particles, with an index of about 1.65, which may be barite. Chalcedony is most abundant in jasperoids replacing dolomite and shale away from the main channels of mineralization; opal is sparsely distributed and is supergene; barite is present in several generations, some older than jasperoid quartz and some younger; chlorite is younger than jasperoid quartz, in which it is locally abundant near mineralizing conduits; in the zone of oxidation, chlorite is largely altered to kaolinite; and disseminated pyritohedral pyrite is abundant in the jasperoid and is of about the same age as the chlorite.

The most comprehensive study yet made of the microtexture and mineralogy of Tintic jasperoids was done under the auspices of the Bear Creek Mining Co. The results of this work are summarized in reports by Howd (1957), Duke and Howd (1959), and Bush, Cook, Lovering, and Morris (1960a, b), and are discussed in detail by Duke (1959). A suite of "barren" jasperoid samples from an area north of Eureka was compared petrographically with a suite of "productive" jasperoid samples from various mines in the Tintic and East Tintic districts.

Seven textures were distinguished by Duke (1959) as follows: (1) Anhedral quartz mosaic—consisting of relatively homogeneous aggregates of anhedral quartz grains ranging from 0.1 to 0.2 mm in diameter; (2) colloform texture; (3) cryptocrystalline texture—aggregates in which all quartz grains have diameters less than 0.02 mm; (4) microbrecciated texture–angular fragments of jasperoid in a matrix of coarser quartz; (5) variable grain size—heterogeneous mixture of minute particles and coarse grains; (6) veinlets; and (7) vuggy texture. The minerals identified are barite, calcite, chalcedony, clay, dolomite, galena, hematite, jarosite, limonite, magnetite, manganese oxides, pyrite, quartz, sericite, and sphalerite. Duke (1959) compared the frequency of occurrence of these textures and minerals in the two groups of samples and concluded that cryptocrystalline and anhedral quartz mosaic textures in the same sample, variable grain size, microbrecciation, and vugginess were significantly more common in the "productive" group, as were the minerals barite, galena, hematite, and sphalerite. He considered chalcedony, clay, and jarosite to be more abundant in the "barren" samples.

In a petrographic study of 17 favorable jasperoid samples and eight unfavorable jasperoid samples, I distinguished 10 different textures and 21 accessory minerals in the combined suite of 25 samples. These textures I designated as (1) multiple generations (approximately equivalent to microbrecciated texture of Duke, 1959), (2) homogeneous coarse-grained (approximately equivalent to Duke's anhedral quartz mosaic), (3) homogeneous fine-grained (cryptocrystalline of Duke), (4) heterogeneous (variable grain size of Duke), (5) colloform banding, (6) vuggy, (7) reticulated, (8) xenomorphic, (9) granular, and (10) jigsaw puzzle. The last four of my textural classifications, referring to the shape of the quartz grains, have no counterpart in Duke's classification. The accessory minerals recognized, in order of decreasing abundance, are (1) hematite; (2) goethite; (3) allophane; (4) sericite; (5) limonite; (6) jarosite and barite; (7) pyrite; (8) chalcedony; (9) galena and sphalerite; (10) dolomite, siderite, malachite and wurtzite; (11) kaolinite, biotite, opal, smithsonite, and cerussite.

The frequency of occurrence of these textures and minerals was tabulated in each of the two groups. Although statistical tests of significance are difficult to apply to such small sample groups, a qualitative impression of the significance of certain textures and minerals, suggestive of favorable or unfavorable jasperoids, can be gained from the following tabular summaries, which show the differences in frequency

Common textures and minerals (observed in 20 percent or more of all samples) suggestive of favorable and unfavorable jasperoid in the Tintic and East Tintic districts

	Percent Difference
Favorable jasperoid	
Texture	$(F_F - F_U)$
Heterogeneous	52
Homogeneous, coarse grained	41
Vuggy	35
Xenomorphic	30
Multiple generations	28
Reticulated	24
Mineral	
Jarosite	41
Barite	41
Allophane	40
Pyrite	35
Goethite	28
Unfavorable jasperoid	
Texture	$(F_U - F_F)$
Homogeneous, fine grained	70
Jigsaw puzzle	47
Granular	26
Mineral	
Sericite	58
Hematite	40
Limonite	38
Chalcedony	35

of occurrence, expressed as percent of the group, between favorable and unfavorable jasperoid for the common textures and minerals.

The agreement between Duke's criteria (1959) and mine is much closer for jasperoid-quartz microtextures than for associated minerals. This is reasonable because oxidation would have relatively little effect on jasperoid microtexture, but it would have a profound effect on the associated mineral assemblage. All of my unfavorable samples and most of my favorable samples were oxidized. Although the relative proportions of oxidized and unoxidized samples in the two groups studied by Duke were not specifically stated, it is improbable that the proportions of oxidized and unoxidized samples in his "productive" group were the same as in his "barren" group, or the same as in my favorable and unfavorable groups.

COMPOSITION

An outcrop sample of favorable jasperoid from near the Eureka Hill mine submitted by the author was analyzed by E. L. Munson. An analysis of "productive" jasperoid from the Tintic Standard mine was published by Lovering (1949, p. 54). Analyses of the two samples, in percent, are as follows:

	Mine	
	Eureka Hill	*Tintic Standard*
SiO_2	95.75	90.12
Al_2O_3	1.12	4.38
Fe_2O_3	.36	.20
FeO	.19	.36
MgO	.01	.55
CaO	.00	.02
Na_2O	.01	0
K_2O	.09	.87
H_2O+	.75	2
H_2O-	.05	.45
TiO_2	.03	.31
P_2O_5	.06	.02
MnO	.03	Trace
CO_2	.16	.08
S	.08	......
BaO	.00	......
Total	98.68	99.36

The agreement between these two analyses is surprisingly close, considering that they represent jasperoid replacement of different formations from different localities and that one sample is oxidized, the other, unoxidized. However, the variation in composition of favorable jasperoids in the district probably is considerably greater than is reflected by this pair of analyses. No quantitative chemical analyses of unfavorable jasperoid from the Tintic or East Tintic districts are available.

TABLE 19.—*Minor-element distribution in 25 samples of jasperoid from the Tintic and East Tintic districts, Utah*

[J. C. Hamilton, analyst. Leaders (......) indicate no information. Amounts in parentheses are extrapolated values]

Element	Limit of detection (percent)	Number of samples in which detected	Minor-element distribution (percent)			
			Range	Mean	Median	Mode
Al	0.001	25	0.07 –3	0.33	0.12	0.15
Fe	.0008	25	.15 –>10	2.6	.43	.7
Mg	.0005	25	.007 – .3	.039	.014	.015
Ca	.005	25	.015 – .7	.098	.041	.07
Na	.05	4	<.03 – .07	......	......	<.03
K	.7	1	<.7 – .7	......	......	<.7
Ti	.0002	23	<.0015 – .15	.024	.009	.007
Mn	.0002	25	.003 –1.5	.077	.0075	.007
Ag	.0001	18	<.00015– .3	.022	.001	<.00015
As	.15	9	<.15 –3	......	......	<.15
B	.002	1	<.0015 – .003	......	......	<.0015
Ba	.001	25	.0015 –>10	2.45	.013	.003
Be	.0001	14	<.00015– .0015	.0002	(.0001)	<.00015
Bi	.001	9	<.0015 – .7	......	......	<.0015
Cd	.005	4	<.007 – .03	......	......	<.007
Co	.0005	3	<.0007 – .0007	......	......	<.0007
Cr	.0001	25	.00015– .003	.0006	.0002	.00015
Cu	.0001	25	.0007 –1.5	.135	.005	.003
Ga	.0002	5	<.00015– .007	......	......	<.00015
In	.002	6	<.003 – .007	......	......	<.003
La	.002	2	<.003 – .003	......	......	<.003
Mo	.0005	8	<.0007 – .003	......	......	<.0007
Ni	.0005	10	<.0007 – .007	......	......	<.0007
Pb	.005	19	<.007 –7	.491	.04	<.007
Sb	.01	8	<.015 – .7	......	......	<.015
Sc	.0005	1	<.0007 – .0007	......	......	<.0007
Sn	.002	4	<.0015 – .15	......	......	<.0015
Sr	.0002	19	<.0007 – .7	.073	.002	<.0007
V	.002	12	<.0015 – .007	......	......	<.0015
Y	.002	4	<.0015 – .015	......	......	<.0015
Yb	.0002	5	<.00015– .0015	......	......	<.00015
Zn	.005	16	<.007 –3	.182	(.005)	<.007
Zr	.002	12	<.0015 – .007	......	......	<.0015

Semiquantitative spectrographic analyses were made of splits from the 17 favorable samples and eight unfavorable samples in my collection. Thirty-three elements other than silicon were detected in one or more of these samples. These analytical data are summarized in table 19, in the same way as the spectrographic data on the samples of jasperoid from the Ely district were summarized in table 17.

The relative abundance of the 13 elements that were detected in more than half of the samples, as expressed by the mean, median, and maximum concentrations, is given in table 20. These data suggest that barium, lead, and silver are highly concentrated in this group of samples.

Semiquantitative spectrographic analyses of suites

TABLE 20.—*Relative abundance, in percent, of 13 most abundant elements in 25 samples of jasperoid from the Tintic and East Tintic districts, Utah*

Arithmetic mean concentration		Median concentration		Maximum reported concentration	
Fe	2.6	Fe	0.43	Fe	>10
Ba	2.45	Al	.12	Ba	>10
Pb	.49	Ca	.041	Pb	7
Al	.33	Pb	.04	Al	3
Zn	.18	Mg	.014	As	3
Cu	.14	Ba	.013	Zn	3
Ca	.10	Ti	.009	Mn	1.5
Mn	.077	Mn	.007	Cu	1.5
Sr	.073	Cu	.005	Ca	.7
Mg	.039	Zn	.005	K	.7
Ti	.024	Sr	.002	Bi	.7
Ag	.022	Ag	.001	Sb	.7
Cr	.0006	Cr	.0002	Sr	.7

of "barren" and "productive" jasperoids were made by the Bear Creek Mining Co. to ascertain which elements were characteristically concentrated in either type. The results of this investigation were summarized by Duke and Howd (1959) and Bush, Cook, Lovering, and Morris (1960b). Duke and Howd stated that Sb, Bi, Cd, Cu, Pb, Ag, Na, Th, and Zn are more abundant in "productive" jasperoids, whereas Ca and Mg are more abundant in "barren" jasperoids. Bush, Cook, Lovering, and Morris (1960b) listed Sb, Bi, Cu, Pb, Zn, Ag, Na, and Th as elements characteristically concentrated in "productive" jasperoid, and Ca and Mn, in "barren" jasperoids. They supported this conclusion with a table giving the average concentration of each of these elements in each sample group in parts per million. These averages, converted into percent for comparison with my data, are as follows:

	Ag	Bi	Ca	Cu	Mn	Na	Pb	Sb	Th	Zn
Productive	0.0046	0.0093	0.41	0.073	0.039	0.21	0.42	0.0055	0.0020	0.23
Barren	.00016	.0040	.68	.027	.13	.14	.02	.0045	(1)	.13

[1] Not detected.

The median values of the distributions of the commonly detected elements in my suites of favorable and unfavorable jasperoid samples were compared. Medians were used in preference to means, because most of the distributions are erratic and cover a large concentration range and therefore the mean values are strongly influenced by one or two high values. The elements that showed an appreciable difference in median concentrations between the two groups are given in the following table, in which median values are given only for those elements that showed a greater-than-twofold difference between the two groups; smaller differences were considered unlikely to be significant.

Median values, in percent, of selected elements in 12 favorable and eight unfavorable jasperoid samples from the Tintic and East Tintic districts, Utah

[Values in parentheses are extrapolated]

	Ag	As	Ba	Be	Bi	Cu	Pb	Sr	Ti	Zn
Favorable	0.003	(0.07)	0.03	(0.00003)	(0.0008)	0.025	0.07	0.0013	0.007	0.02
Unfavorable	(.00005)	(0.001)	.007	.0001	(.0001)	.001	(.001)	.0005	.03	(.001)

Some of the elements listed by Duke and Howd and by Bush and Cook were detected in few or none of my samples, and some elements in my list were not mentioned by these authors. Such differences are to be expected where different sample groups are analyzed independently with different analytical equipment.

In summary, it seems that Ba, Na, Th, and possibly Sr, in addition to the ore metals, tend to concentrate in the favorable jasperoids of the late barren alteration stage. Be, Mn, and Ti seem to be higher in the unfavorable jasperoid related to the unconformity at the base of the volcanic rocks.

CONCLUDING REMARKS

At Tintic, apparently two distinct major types of hypogene jasperoid are present. One is genetically related to the hydrothermal alteration that culminated in ore mineralization, and is commonly, though not universally, associated with ore bodies. The other type is not related to this alteration and is consequently unfavorable. The available evidence suggests that this is also true of the Ely district, Nevada. A more detailed study of the late barren-stage jasperoids of the Tintic district is needed to establish the relative favorability of various jasperoid types within this group, as well as the geographic patterns of distribution of the various minor elements in it.

GILMAN (RED CLIFF) DISTRICT, COLORADO

(7, fig. 1; 5, fig. 40)

The Gilman (Red Cliff) district is in central Colorado on the east side of the Eagle River in Eagle County, about 25 miles north of Leadville (Crawford and Gibson, 1925). It is on the gently dipping southwestern limb of a northwest-plunging asymmetrical syncline formed in Paleozoic sedimentary rocks that lie between the Precambrian rocks exposed in the Sawatch Range just west of the district and the Precambrian rocks of the Gore Range about 7 miles to the northeast. The Precambrian granitic rocks, schists, and gneisses of the district are overlain by about 250 feet of quartzite, shale, and minor dolomite ranging in age from Cambrian to Ordovician. These rocks, in turn, are overlain by an approximately equal thickness of predominantly carbonate rocks consisting of the Devonian Dyer Dolomite Member of the Chaffee Formation and the dolomitized Mississippian Leadville Limestone. The Leadville Limestone in this area is capped by a thin, persistent, and highly altered sill of quartz latite porphyry, which separates it from the nearly 5,000 feet of Pennsylvanian shale, siltstone, arkose, and minor limestone that constitutes the rest of the Paleozoic section.

The ore deposits of the Gilman (Red Cliff) district consist of gold-silver veins in the Precambrian rocks and the Cambrian quartzite, auriferous manganosiderite mantos in the quartzite, large pyritic copper-silver chimney deposits in the carbonate rocks that underlie the upper part of the Leadville Limestone, and extensive lead-zinc manto deposits extending updip from the chimney deposits in the upper part of the Leadville Limestone. Most of the district's production has come from the deposits in the carbonate rocks. Faults in the main district tend to be small and traceable only for short distances. Sulfide distribution in the Leadville Limestone appears to have been largely controlled by open channels, many of which follow older joints and fractures. Some of these channels are of pre-Pennsylvanian age; others were formed or enlarged by early hydrothermal solutions related to mineralization.

DISTRIBUTION

There is no close spatial association between jasperoid and the major sulfide ore bodies in the Gilman (Red Cliff) district. Crawford and Gibson (1925, p. 57, 59) reported jasperoid outcrops in the Leadville Limestone near the junction of Turkey Creek and the Eagle River at the south end of the district, and in a large body about three-quarters of a mile north of Gilman, beyond the north end of the district. They also mentioned the occurrence of small blocks of jasperoid on the dumps of some of the old mines on Battle Mountain south of Gilman, although jasperoid does not crop out at the surface in this area. Large masses of jasperoid replace the Dyer Dolomite Member northwest of the district on the flanks of the Sawatch Range north of Cross Creek, and the overlying Leadville Limestone is locally jasperoidized, according to Lovering and Tweto (1944, p. 77). Very little jasperoid is present in the Pennsylvanian rocks east of Gilman, although there is local minor silicification on some of the faults. Similar bodies of jasperoid are also abundant in the Leadville Limestone and Dyer Dolomite Member of the Chaffee Formation south of Red Cliff all the way to the East Fork of the Eagle River near the south boundary of Camp Hale, but this jasperoid is too far away to be considered in the Gilman (Red Cliff) district and is discussed separately under the heading "Pando Area" on page 99 of this report.

GENESIS

The jasperoid bodies in the vicinity of Gilman are considered by Crawford and Gibson (1925, p. 56–57, 59) to be the result of replacement of dolomite by silica gel, the silicifying solutions moving outward in a wave from major circulation channels along faults and fractures. They advocate the same origin for this rock as that suggested by Lindgren and Loughlin (1919, p. 156–157) for the Tintic jasperoids of the late barren stage. The source of the silica-bearing solutions is tentatively postulated as a cupola on a buried monzonitic stock or batholith. Crawford and Gibson (1925, p. 65) further stated: "It is evident that both jasperoid and dolomite were deposited after—though in part perhaps contemporaneously with—the ore minerals, and it is probable that solutions that brought in both metallic and nonmetallic minerals had a common source." Lovering and Tweto (1944), on the other hand, found strong evidence that hydrothermal dolomitization preceded sulfide mineralization in the Gilman (Red Cliff) district. They found "zebra rock" texture preserved in jasperoid replacing the Dyer Dolomite Member and concluded that jasperoidization took place after this phase of dolomitic alteration; however, they made no statement as to the relative ages of jasperoidization and sulfide mineralization. Some of the silica that formed the jasperoid may have been leached from the Cambrian quartzite by hydrothermal solutions, but this source alone is regarded as insufficient to account for the large volume of silica now present as jasperoid in the area northwest of Gilman (Lovering and Tweto, 1944, p. 77–78).

The jasperoids of the Gilman (Red Cliff) district seem to be relatively simple and homogeneous in composition. This fact suggests that there was only one major period of jasperoid formation, and that the silica-depositing solutions were different in composition from those that deposited the sulfide ore.

RELATIONSHIP TO ORE

Crawford and Gibson (1925) and Lovering and Tweto (1944) generally agree that jasperoids in the vicinity of Gilman are a product of the hydrothermal alteration that, at some stage, produced the sulfide mineralization. Crawford and Gibson (1925) regarded jasperoid as a favorable guide to ore in the vicinity. They pointed out that ore occurs near jasperoid in the Leadville Limestone in several small mines in the southern part of this district, on Battle Mountain, and around Red Cliff, and suggested that "good prospecting ground" should lie east or northeast of jasperoid bodies that occur along faults. Lovering and Tweto (1944) regarded jasperoid as a fringe effect of the mineralization at Gilman because silicification is generally absent in the altered host rocks adjacent to the major ore bodies. These rocks have been converted to jasperoid along faults and fractures updip from the ore deposits to the west and northwest at distances ranging from a quarter of a mile to several miles from the major ore bodies. The information now available indicates that most of the Gilman jasperoid bodies should be classed as unfavorable because they show no close spatial association with ore bodies.

APPEARANCE

Crawford and Gibson (1925, p. 56–57) described the jasperoid of the Gilman area as being dark gray to medium gray and locally yellowish gray or brownish gray, varying in texture from flinty to "gritty," and having uneven fracture locally resembling a fine-grained quartzite. Both varieties are characterized by abundant cavities and open fractures, and the dense variety commonly exhibits alternating light and dark streaks or bands. Some of the cavities in the jasperoid are lined with small quartz crystals. Jasperoid breccias, containing angular masses of material that is coarser grained and lighter colored than the matrix, are locally abundant along faults. These breccias probably resulted from the silicification of previously brecciated carbonate rock, rather than from brecciation and recementation of massive jasperoid.

The large masses of jasperoid northwest of Gilman consist largely of yellowish-brown, brown, and locally grayish, aphanitic to microcrystalline silicified Dyer Dolomite Member, which is commonly brecciated and vuggy with quartz crystals lining the vugs. Textures inherited from the dolomite are locally preserved in this jasperoid, including brecciation and "zebra texture," which indicates that jasperoidization of these rocks was younger than the early hydrothermal dolomitization.

My collection includes seven jasperoid samples from the vicinity of the Gilman (Red Cliff) district. Five of these are of jasperoid in the Dyer Dolomite Member 1–3 miles northwest of Gilman, one is from near the base of the Leadville Limestone in the same area, and one is a float sample from the Minturn Formation on Battle Mountain that presumably is residual from a locally silicified zone along a fault where it cut a limestone bed.

The samples from the Dyer Dolomite Member are predominantly light brown on weathered surfaces and light yellowish brown on fresh surfaces; one is medium gray, and one is moderate red with yellowish-brown patches. All are fine grained to aphanitic. The sample from the Leadville is light gray and aphanitic. The float sample from the Minturn Formation is light gray and fine grained, and it contains abundant small irregular vugs lined with tiny crystals of quartz and calcite.

MICROTEXTURE AND MINERALOGY

Typical jasperoid, according to Crawford and Gibson (1925, p. 56–57), consists of anhedral aggregates segregated in some places into coarser and finer grained bands or masses, with locally abundant tiny inclusions of carbonaceous matter or limonite; these impurities tend to concentrate in the finer grained material, whereas rounded detrital quartz grains are more abundant in the coarser material. Sparsely scattered shreds of sericite are present in both types. Carbonate inclusions are sparse, except locally near the contact with the host rock; in one thin section transverse to such a contact, these authors reported that aphanitic streaky jasperoid ends abruptly in a wavy line against unsilicified dolomite.

Lovering and Tweto (1944, p. 78) described the jasperoids in the Dyer Dolomite Member of the Chaffee as a mixture of cryptocrystalline quartz, brown limonite, and carbonaceous dust, with local vague wavy bands of high limonite content. Vugs locally contain carbonate minerals, sericite, chlorite, and barite.

Three of my samples of jasperoid from the Dyer have a xenomorphic to jigsaw-puzzle texture in the matrix, which is relatively homogeneous, and an average grain size of 0.02 mm. Rounded detrital quartz grains, some of which show irregular overgrowths, are sparsely scattered through this matrix; one sample shows a veinlet of late coarse xenomorphic quartz. Goethite and limonite are abundant in all samples, both as dusty inclusions in the matrix and as coatings on fractures cutting the matrix. The matrix of some samples contains, in addition to limonite, dust particles of allophane and carbonate.

One sample from altered Dyer along an east-trending fault zone is strikingly different from the others. It consists of relatively coarse ferroan dolomite (0.1–2 mm) about half replaced by disseminated coarse quartz (0.05–1 mm). The ferroan dolomite shows deformation of cleavage traces and microbrecciation along grain boundaries. Fine-grained orange goethite fills fractures in it. The goethite is also disseminated through the quartz, suggesting hydrothermal recrystallization of dolomite, followed by fracturing and oxidation along the fractures, followed by silicification.

A similar history is revealed by a sample of incipient jasperoid from the base of the dolomitized

Leadville Limestone. In this sample, fine-grained brown ferroan dolomite, containing abundant inclusions of orange goethite, has been brecciated and cemented by veinlets lined with coarse quartz and filled with coarse crystalline calcite. The dolomite fragments have been silicified in a zone about 1 mm wide bordering these veinlets, and the grain size of the replacing quartz changes progressively from about 0.15 mm adjacent to the vein down to about 0.02 mm adjacent to the unreplaced dolomite core, where it contains abundant inclusions of orange goethite.

The sample of completely jasperoidized Leadville Limestone consists of clean aphanitic homogeneous quartz that has a jigsaw-puzzle texture and an average grain size of about 0.01 mm; this matrix is cut by sparse thin veinlets of calcite.

The sample of jasperoid float from the Minturn Formation has a matrix of fine-grained quartz that has a jigsaw-puzzle texture and a size range of 0.01–0.04 mm. Within this matrix are wavy concentric bands and small rounded masses as "ghost" textures that are visible with reflected light but invisible under crossed polars, suggesting original deposition of silica as a gel. The matrix is cut by many irregular masses of coarser xenomorphic quartz, which is most abundant around vugs and along fractures. Local concentrations of tiny equant red hematite grains, about 0.05 mm in diameter, and sparse flakes of sericite are present in the younger xenomorphic quartz but not in the matrix, which suggests that these two minerals may have formed from the same solutions that brought in the second-stage quartz.

COMPOSITION

A quantitative standard rock analysis of a typical sample of jasperoidized Dyer Dolomite Member of the Chaffee Formation (field No. 183A–T–41) by E. L. Munson gave the following results:

Element	Percent	Element	Percent
SiO_2	96.79	H_2O-	0.05
Al_2O_3	.52	TiO_2	.04
Fe_2O_3	1.02	P_2O_5	.01
FeO	.17	MnO	.03
MgO	.16	CO_2	.09
CaO	.14	S	.00
Na_2O	.01	BaO	.00
K_2O	.09		
H_2O+	.35	Total	99.47

This sample contains somewhat more ferric iron than normal, as was anticipated because of abundant limonite in the specimen; otherwise, there appears to be nothing unusual in its composition.

Semiquantitative spectrographic analyses were run by J. C. Hamilton on five of the previously described samples, including the one with the foregoing standard rock analysis. Only 16 elements other than silicon were detected in this group, and only 11 of these were detected in three or more of the five samples. These elements and their observed range in concentration follow:

Element	Range (percent)	Element	Range (percent)
Al	0.015 –0.15	Cr	0.0007 –0.0015
Fe	.7 – .3	Cu	.0015 – .007
Mg	.015 – .15	Mo	<.0007 – .0015
Ca	.07 – .3	Ni	.0007 – .003
Ti	.0015– .015	Pb	<.007 – .007
Mn	.007 – .07	V	<.0015 – .003
Ba	.0015– .03	Yb	<.00015–.00015
Co	<.0007– .0007	Zn	<.007 – .007

The concentration ranges exhibited by these few elements are no greater than could be expected from five replicate samples taken from a single outcrop; yet one of these samples is from the Minturn Formation, one from the Leadville Limestone, and three from the Dyer Member, all taken at widely separated localities. Thus, it seems that the jasperoid bodies peripheral to the ore deposits of the Gilman district are unusually uniform in composition and, except for iron, unusually low in minor elements.

CONCLUDING REMARKS

The age relations of the Gilman jasperoids to the sulfide ore bodies cannot be established from the information now available. They seem to have formed at various, but commonly considerable, distances above or updip from these ore bodies, and therefore, if they are genetically related to the mineralization they formed on the outlet side from solutions that were poor in the ore elements. Apparently, they formed in an oxidizing environment, probably under conditions of low temperature and pressure and probably from a common but unknown source. These jasperoids seem to be of little value as direct guides to ore.

ASPEN DISTRICT, COLORADO

(8, fig. 1; 1, fig. 40)

The Aspen district is in Pitkin County, Colo., on the west side of the Sawatch Range on the Roaring Fork River, about 75 miles west of Leadville (Spurr, 1898). The ore deposits of the district are confined to a relatively narrow, north- to northeast-trending belt of pre-Pennsylvanian Paleozoic sedimentary rocks between Precambrian schists and gneisses on the east and Pennsylvanian and Cretaceous sedimentary rocks on the west. A few miles south of Aspen this belt bifurcates around a narrow northplunging syncline, the trough of which is filled with predominantly clastic Pennsylvanian sedimentary rocks. The western fork of the belt is bounded by the large Castle Creek normal fault and terminates northward at the edge of the town of Aspen. The eastern fork swings to a northeasterly trend where it crosses the river just east of Aspen and continues in that direction for many miles, beyond the limits of the district. This belt has a stratigraphic thickness of about 900 feet. The lower part of it is composed largely of quartzites and shales of Cambrian and Ordovician age; the middle and upper parts consist dominantly of carbonate rocks of Ordovician, Devonian, and Mississippian age. In addition to the Castle Creek fault, which bounds the district on the west and extends far beyond it to the south and to the northwest, the district is cut by numerous small faults that form two general groups, one of which trends northerly, the other westerly or northwesterly. The major ore deposits of the district consist of silver and lead vein and replacement deposits in the Mississippian Leadville Limestone, which were localized by the intersections of cross faults with bedding-plane faults or with favorable beds (Spurr, 1898; Vanderwilt, 1935). These known deposits were largely mined out by the end of World War I and there has been little mining activity in the district since that time.

DISTRIBUTION

The available geologic maps of the Aspen district do not show the distribution of the jasperoid bodies. According to Spurr (1898, p. 217, 220), these bodies formed along faults, fractures, and bedding planes in the limestone and dolomite, as did the ore bodies; however, jasperoid is more abundant and widely distributed than is the ore.

I have 12 jasperoid samples from nine localities in the Aspen district. These are all from the north-trending ridge formed by Aspen Mountain and Richmond Hill; the northernmost locality is on Pioneer Gulch about half a mile south of Aspen, and the southernmost locality is near the head of McFarlane Creek about 6 miles south of Aspen.

GENESIS

Spurr (1898, p. 217–218, 220, 229) concluded that the jasperoid at Aspen was introduced by hydrothermal solutions related to, but older than, those that deposited the primary sulfide ores of the district. These solutions probably were rich in iron, magnesium, and carbonate in addition to silica, because dolomite, siderite, and some pyrite are penecontemporaneous in origin with the jasperoid.

Petrographic study of my suite of oxidized jasperoid samples suggests that much of the coarse-grained reticulated type of jasperoid quartz is contemporaneous with, or younger than, the associated limonite, and may therefore be of supergene origin.

RELATIONSHIP TO ORE

The jasperoid bodies apparently were localized by the same structures and rock units that influenced the deposition of the sulfide ore bodies. Spurr (1898, p. 220) stated that silicification always accompanies the ore deposition and that jasperoid quartz is an important gangue of the ore, although jasperoid is more widespread and is also found in areas where there has been no ore mineralization. However, Vanderwilt (1935, p. 238) noted that the massive jasperoid bodies of the district commonly are not found in close proximity to the ore bodies, but that disseminated quartz crystals in the carbonate host rocks, which appear to represent incipient jasperoidization, are common on old stope walls and in mineralized fractures and breccia zones.

The favorable jasperoid that forms a gangue for the ore may have been completely removed from the old stopes, and, as a result, only incipient jasperoid now remains in the stope walls. Samples of jasperoid taken from old mine dumps contain abundant ore minerals.

APPEARANCE

Some of the jasperoid bodies in the Aspen district have sharply defined contacts with the host rock; others grade outward through a zone marked by disseminated quartz grains or euhedral quartz crystals in a carbonate matrix, or by narrow anastomosing quartz veinlets that become visible only on weathered surfaces. The massive jasperoid is commonly red or yellow, and conspicuously vuggy. Its texture ranges from aphanitic, resembling chert, to fine grained, resembling quartzite. The vugs in this rock are commonly lined with chalcedony or small quartz crystals. Local leaching of the coarser grained variety has produced a porous, spongy mat of quartz (Spurr, 1898, p. 217–219; Vanderwilt, 1935, p. 238).

All my jasperoid samples that were taken from outcrops are shades of brown, yellow, and orange. They range from light brown, yellowish brown, and yellowish orange through moderate brown to dark brown. Two specimens taken from mine dumps are gray, indicating that the outcrop colors probably are the result of near-surface weathering and oxidation.

MICROTEXTURE AND MINERALOGY

Spurr (1898) described and illustrated the gradual transition from carbonate rock containing scattered quartz crystals and disseminated grains, through jasperoid containing abundant interlocking quartz crystals and unreplaced remnant inclusions, to jasperoid in which the inclusions have disappeared and the interstices of the quartz crystal net have been completely filled with anhedral quartz, producing a reticulated texture.

This texture is well illustrated in many of the samples. Some of them show gradations from coarse reticulated jasperoid to masses of coarse-grained relict carbonate, or carbonate replaced by limonite, containing abundant doubly terminated quartz crystals as much as 3 mm in length. Most of the samples contain abundant limonite or goethite associated with medium- to coarse-grained xenomorphic or reticulated quartz. The larger quartz grains in many of these samples exhibit poikilitic inclusions of limonite, limonite particles in their cores, or thin septa of limonite outlining growth stages in individual quartz crystals. Thus, a considerable overlap probably existed in the formation of limonite and quartz, both of which replaced limestone, and must have done so under oxidizing conditions at relatively low temperature.

An older, and less abundant, generation of jasperoid is present in one of the unoxidized mine dump samples and as breccia fragments in some of the outcrop samples. It consists of aphanitic quartz with xenomorphic to jigsaw-puzzle texture and sericite inclusions. This quartz is older than the ore sulfides, and in one sample it preserves the original texture of the lithographic limestone it has replaced.

Accessory minerals observed in this suite of samples include hypogene pyrite, sphalerite, galena, barite, and sericite; probably supergene hematite, limonite, and manganese oxides; and supergene goethite, calcite, jarosite, cerussite, smithsonite lussatite, and an unknown apparently isotropic dark-brown mineral that forms very minute hairlike overgrowths on grains of hematite and limonite in a quartz matrix.

Spurr (1898, p. 218–220) referred to dolomite both as relict inclusions and zoned rhombohedral crystals; siderite and pyrite as contemporaneous inclusions in the jasperoid; and also to barite, hematite, and limonite as minerals that commonly accompany it.

COMPOSITION

My 12 samples of jasperoid from the Aspen district were analyzed spectrographically. All 12 are anomalously rich in lead and zinc, and most of them contain anomalous concentrations of copper and barium. About half of the samples contain high values for Fe, Mn, Ag, Be, Co, and Mo, and one or two contain the rarely detected elements As, Cd, Ce, Ga, Ge, La, Nd, and Sb. Samples collected near the center of the sampled area, between Bell Mountain on the north and the head of Queens Gulch on the south, all show the presence of Mo, which does not occur in detectable concentrations in any of the other samples from the district.

A suite of three samples was taken from an elongated jasperoid outcrop along a small fracture about half a mile southwest of the nearest mines in Tourtellotte Park. One of these samples is oolitic Leadville Limestone host rock adjacent to the body, one is ferruginous jasperoid near the edge of the body, and one is highly ferruginous vuggy jasperoid from near the center of the body. The limestone sample shows a few small quartz grains and crystals, representing incipient jasperoidization, but otherwise appears fresh. It contains anomalous concentrations of Ba and slightly anomalous concentrations of Pb. The jasperoid sample from near the edge of the body is also high in Ba and contains considerably more Pb than the limestone; in addition, it contains anomalous Be, Co, Cu, Ga, Mo, and Zn. The sample from near the center of the body contains more of all these elements than the one from near the edge, and also contains anomalous Ag, As, B, Ge, V, Y, and Yb. This apparently systematic increase in both number and concentration of detectable minor elements toward the center of the body may be fortuitous because only one such suite of samples is available for study. The strong contrast between anomalous minor elements detected in the host rock and those in the jasperoid does indicate that all of them, except possibly Ba, were introduced and not inherited from the host rock.

The 12 jasperoid samples yield indicator-element scores in the range +5–+19. Seven samples, including the three samples from mine dumps, scored +15 or higher; three samples had scores in the range +10–+15 and the other two scored +5 and +6. Thus, all but the last two fall in the definitely favorable category, and these two are in the possibly favorable category.

CONCLUDING REMARKS

The presence of anomalously large amounts of lead and zinc in all jasperoid samples from the Aspen district and of copper and silver in most of them, together with the fact that all such samples taken from mine dumps yield high favorability scores, suggests that this area should be excellent for exploration based on field geochemical analysis of jasperoid samples. The apparent contradiction between

Spurr's conclusion (1898) that jasperoid is older than sulfide mineralization, and the petrographic evidence that much of it is younger than limonitic alteration of the host rock, can be resolved only by a detailed study with emphasis on jasperoid bodies below the zone of oxidation. Certainly a presulfide generation of jasperoid is present, but examination of surface samples of the coarse-grained reticulated jasperoid described by Spurr suggests that it is not only younger than the sulfides but also younger than the oxidation of the sulfides.

EUREKA DISTRICT, NEVADA

(9, fig. 1; 20, fig. 44)

The Eureka district lies south and west of the old town of Eureka in eastern Eureka County, Nev., about 60 miles west-northwest of Ely; Nolan (1962) has discussed it in detail. Eureka has been one of the principal silver-lead districts of the Western United States. Paleozoic and Cretaceous sedimentary rocks in this district have been broken by a complicated network of faults, which locally served as channelways for mineralizing solutions that formed both fissure vein deposits and replacement deposits in carbonate rocks. Jasperoid in this district is not confined to any one stratigraphic unit, for it occurs in carbonate rocks of Cambrian, Ordovician, Permian, and Cretaceous age.

DISTRIBUTION

In the heavily mineralized Adams Hill area in the northern part of the district, the Cambrian Hamburg Dolomite has been extensively replaced by jasperoid adjacent to the overlying Cambrian Dunderberg Shale, although relatively little silica is associated with sulfide replacements in the younger Cambrian Windfall Formation and Cambrian and Ordovician Pogonip Group in the same area (Nolan, 1962, p. 63). This silicification of the Hamburg Dolomite is attributed to the blanketing effect of the shale.

A. V. Heyl (written commun., 1967) described "the Burnouts," the original discovery area of the Eureka district, on the upper south slope of Adams Hill, as follows:

> At the surface, the area of "the Burnouts," the original discovery area of the district, consists of huge outcropping red and brown masses of oxidized jasperoid replacing limestone. Deep pits, small opencuts, many shafts, and several adits have mined the parts of the jasperoid masses containing rich yellow-brown veins and replacement masses of silver-bearing plumbojarosite, anglesite and cerussite that made up the original rich bonanza-bodies of silver lead ore. The jasperoid is dense and aphanitic, but slightly sugary with some jigsaw-puzzle texture. The jasperoid is veined with limonite; cavities in the jasperoid contain white radiating masses of hemimorphite and small yellow areas of plumbojarosite. The large outcrops of jasperoid that still remain total many thousands of tons.

Nolan (1962, p. 72) mentioned prominent masses of jasperoid in the Cambrian Eldorado Dolomite near the Burning Moscow mine south of Prospect Peak. In lower New York Canyon, dolomite beds in the Ordovician Hanson Creek Formation have locally been brecciated and replaced by jasperoid close to the contact with the underlying Ordovician Eureka Quartzite, along steep northwest-trending faults (Nolan, 1962, p. 71). The Permian Carbon Ridge Formation, which consists of thin-bedded impure limestones with local chert pebble zones, contains no economically important ore bodies; but locally, particularly near its fault contact with Eureka Quartzite on Hoosac Mountain, it is replaced by jasperoid. In this same general area, fresh-water limestone of the Cretaceous Newark Canyon Formation is also locally silicified (Nolan, 1962, p. 12, 71).

Many other small jasperoid bodies are shown on the geologic map of the Eureka district accompanying Nolan's report.

GENESIS AND RELATIONSHIP TO ORE

Although little specific published information is available on the genesis and economic significance of jasperoid in the Eureka district, the localization of massive jasperoid bodies in the upper part of the Hamburg Dolomite, beneath the relatively impermeable Dunderberg Shale on Adams Hill (Nolan, 1962, p. 63), suggests a hydrothermal origin for some of this rock. On the other hand, Nolan's observation (1962, p. 43) that oxidized ore minerals in this area locally contain considerable quantities of fine-grained quartz intermixed with them indicates that supergene jasperoid is also present.

Samples of jasperoid from the Eureka district in my collection provide evidence that both favorable and unfavorable varieties are present and can be distinguished by the criteria discussed on page 56 of the present report.

APPEARANCE, MICROTEXTURE, AND MINERALOGY

I have nine samples from the Eureka district; however, only three of these are wholly or predominantly jasperoid, four represent incipient jasperoidization of altered limestone or dolomite, and the remaining two are silicified limy siltstones. Four of the samples are from the heavily mineralized Adams Hill area west of Eureka; the other five represent widely separated outcrops along New York Canyon and Windfall Canyon south of Eureka (Nolan, 1962, pl. 1). The host rock for four of the samples is the Cambrian Hamburg Dolomite; two samples are from the Ordovician Hanson Creek Formation, and one sample each was taken from the Cambrian Windfall, the Permian Carbon Ridge, and the Cretaceous Newark Canyon Formations.

All four samples from the Hamburg Dolomite are from within 200 feet of mine workings; three are from the Adams Hill area, and one is from an outcrop near the Catlin shaft at the head of New York Canyon. Samples 1 and 2, from the vicinity of the Helen shaft on Adams Hill, are aphanitic medium-gray jasperoids that have a heterogeneous xenomorphic to jigsaw-puzzle texture and a grain diameter that averages 0.03 mm and ranges from 0.01 to 0.15 mm. Relict carbonate grains are locally abundant; the quartz contains abundant carbonate particles and is cut by late calcite veinlets. Both samples contain abnormally high concentrations of Ag, Pb, Zn, and Sr, and both yield scores that place them in the favorable category. Samples 3 and 4, one from near the Helen shaft and the other from near the Catlin shaft, consist largely of brecciated and recrystallized Hamburg Dolomite showing incipient jasperoidization. Both samples are aphanitic and weather brown with a rough surface. Sample 3 is medium gray with dark-gray inclusions; sample 4 is dark yellowish brown. Sample 3 is a finely comminuted microbreccia that contains tiny fragments of chert and vein quartz as well as dolomite. It also contains abundant irregular masses of an aphanitic opaque mineral, creamy white by reflected light, which was unidentifiable in thin section but which is probably a supergene lead-arsenic compound. Sample 4 contains only dolomite fragments and supergene orange goethite in addition to introduced silica. Two generations of introduced silica are distinguishable in both samples; the older of these is jasperoid similar in texture to that of the two jasperoid samples first described, but slightly coarser in average grain size. The quartz is disseminated as grains and small isolated aggregates in the dolomite. These aggregates become more numerous and coalesce through a narrow transition zone into a jasperoid matrix heavily contaminated with carbonate particles and containing numerous inclusions of the larger dolomite grains. Both dolomite and jasperoid are cut by veinlets of aphanitic quartz that has a jigsaw-puzzle texture and an average grain diameter of about 0.01 mm. Both samples 3 and 4 are rich in Ag, Ba, Cu, Pb, and Zn, and sample 3 also contains abundant As and Sb. They scored +21 and +12, respectively, on their indicator element content.

One sample of partly silicified dolomitic limestone of the Cambrian Windfall Formation was taken from an isolated outcrop surrounded by valley fill a quarter of a mile southwest of the Silver Lick group of mines on Adams Hill, the nearest mine workings. This sample is dense, fine grained, and pale yellowish gray, weathering yellowish brown, and has a rough pitted surface. In thin section the texture of the jasperoid and the manner in which it replaces the limestone are similar to those in the two dolomite samples described in the preceding paragraph; however, no late quartz veinlets or accessory minerals are visible. In addition to the Mg, Ca, and Ce of the host rock, this sample is slightly high in Na, Ag, Cu, Pb, Sr, and V. It yields a score of +6 on the basis of its indicator-element content.

Two samples of jasperoidized dolomite of the Ordovician Hanson Creek Formation were collected from outcrops in New York Canyon. One of these outcrops is near the mouth of the canyon about a mile from the nearest mines; the other is about halfway up the canyon and 200 yards south of the 76 mine shaft. The first consists largely of brecciated yellowish-gray and light-olive-gray dolomite cut and cemented by medium-gray jasperoid; the second is a dense dark-gray fine-grained jasperoid with inclusions of dolomite fragments. Incipient jasperoid in the first sample differs from that in the Cambrian rocks previously described in that it is both coarser grained and more homogeneous, having an average grain diameter of about 0.2 mm; this probably reflects the more coarsely crystalline nature of the host rock. The second sample consists of heterogenous xenomorphic quartz that has a grain diameter that averages 0.1 mm and ranges from 0.02 to 0.5 mm; it contains inclusions of coarse-grained dolomite. In both samples the quartz contains abundant carbonate dust, and the dolomite fragments are clouded with opaque dark-brown or black dust particles, which are largely concentrated near the rims of the grains. Both samples are slightly high in Na, Ag, Ba, Pb, and Sr in addition to Ca and Mg; the second sample (from near the 76 mine) is also higher than normal in Mn and Zn. Indicator-element scores are +3 for the first sample, and +7 for the second.

A sample of silicified limy siltstone of the Permian Carbon Ridge Formation was taken from Windfall Canyon near the junction of the Windfall Canyon road and the cutoff road to New York Canyon. This outcrop is in a brecciated zone along a strong fault that brings the Mississippian Chainman Shale in contact with the Carbon Ridge Formation; it is about a mile from the nearest mines. The rock is fine grained with local sparse vugs, dusky yellowish brown to dark gray, and weathers moderate yellowish brown. It has a matrix of aphanitic jasperoid quartz that has a jigsaw-puzzle texture and grain

TABLE 21.—*Characteristics of jasperoid*

District	Major generations or types	Field relations of jasperoid (characteristics of jasperoid bodies of the district as a whole)				Appearance of jasperoid (characteristics of particular jasperoid bodies considered to be typical)
		Host rocks	Structural control	Relationship to intrusives	Relationship to ore	Nature of contact
Tri State, Oklahoma-Kansas-Missouri.	1 generation	Mississippian limestone.	Related to fractures and bedding planes.	No known intrusives.	Late preore, commonly adjacent to sulfide ore bodies.	Commonly gradational into host rock on one side and ore on the other.
Clifton-Morenci, Ariz.	Probably 2 generations but not distinguished.	Cambrian and Ordovician limestone.	Related to faults and breccia zones.	May be genetically related to felsic Laramide intrusives, but spatially remote from intrusive centers.	Probably postore; spatially remote from major deposits; relationship not studied in detail.	Commonly abrupt
Bisbee, Ariz	Early	Paleozoic limestone.	Localized by strong faults and proximity to intrusive contacts.	Genetically and in part spatially related to siliceous porphyritic intrusives.	Late preore, genetically and commonly spatially related to ore.	do
	Late	Cretaceous basal conglomerate.	Localized by unconformity at base of Cretaceous and by faults and fractures cutting it.	None known	None	Commonly irregular, locally gradational.
Ely, Nev	Early	Paleozoic limestone and shale; Tertiary monzonite.	Localized by proximity to monzonite porphyry intrusives.	Genetically and spatially related to intrusives.	do	Commonly abrupt, locally gradational with intrusives.
	Late	do	Localized by faults and fractures.	None known	Genetically and locally spatially related to ore.	Commonly abrupt
Leadville, Colo	Not distinguished	Ordovician, Devonian, and Mississippian limestone and dolomite.	Localized by faults and fracture zones.	Genetically related to quartz monzonite stock, but spatially remote.	Largely contemporaneous to postore; some is spatially associated, some is not.	No information
Tintic, Utah	Early (?)	Paleozoic sedimentary rocks, largely dolomite.	Related to unconformity at base of Tertiary extrusive rocks.	None apparent	None apparent	Commonly abrupt
	Late	do	Related to faults and fractures.	Genetically related to monzonitic intrusive, but spatially remote.	Preore, genetically and commonly spatially related to ore.	do
Gilman, Colo	1 generation	Devonian and Mississippian dolomite.	Related to faults	None apparent	Possible genetic relationship; no close spatial relationship.	do
Aspen, Colo	Probably 2 generations, but not distinguished.	Mississippian carbonate rocks.	Related to faults and fractures.	do	Preore, genetically related and locally spatially related to ore.	Transitional in some places, abrupt in others.
Eureka, Nev	Not subdivided	Cambrian, Ordovician, Permian, and Cretaceous carbonate rocks.	do	do	Genetically related to mineralization; locally spatially related to ore.	do

in major districts of the United States

Appearance of jasperoid—Continued (characteristics of particular jasperoid bodies considered to be typical)—Continued			Microtexture and composition of particular jasperoid samples				Other information
Color	Macrotexture	Other information	Fabric texture	Grain type and size	Mineralogy	Elements concentrated	
Dark gray to black.	Dense, fine grained, locally banded.	Weathers light gray; porous and friable in transition zone to host rock.	Largely jigsaw-puzzle texture; locally reticulated.	Generally homogeneous; 0.001–0.03 mm.	Carbon, clay, dolomite, pyrite, sphalerite.	Fe, Al, C, Ni, Pb, Zn.	Locally associated with older chert, which may be of replacement origin.
Red, yellow, brown.	Largely aphanitic; locally brecciated and cemented by younger quartz.	None	Older host predominantly jigsaw-puzzle texture; younger is xenomorphic, locally reticulated.	Older, homogeneous, <0.005 mm; younger, heterogeneous, <0.005–0.3 mm.	Dolomite, siderite, calcite, sericite, pyrite, hematite, goethite, limonite, Mn oxides.	Pb, Zn, Fe, Be, Ga, Mo, Ag.	Many textural types distinguishable in thin section suggesting more than 1 major generation.
Dark red, gray	Aphanitic, locally vuggy.	Locally weathers to porous friable masses or to quartz sand.	Jigsaw-puzzle to locally xenomorphic texture.	Homogeneous; about 0.005 mm.	Hematite, chalcedony, calcite, brochantite, malachite, limonite.	Fe, Cu, Ni, Pb, V, Y, Yb, Ag, Bi.	Jasperoid is post-Pennsylvanian and pre-Late Cretaceous in age.
Pale yellow, pink.	Vuggy, fine grained; abundant inclusions of host rock.	None	Xenomorphic to granular texture.	Heterogeneous; 0.005–0.1 mm.	Siderite, calcite dust, sericite.	Ni, Pb, Mo, Be, Zr.	Jasperoid is probably Tertiary in age.
White, pale yellow.	Dense, massive, fine grained; locally brecciated.	Forms prominent outcrops.	Xenomorphic to jigsaw-puzzle texture, locally granular.	Relatively homogeneous; 0.01–0.1 mm.	Chalcedony, hematite, limonite, allophane, goethite, jarosite, calcite, sericite, kaolinite, apatite, fluorite, pyrite.	No information.	None.
Dark red, dark yellow, shades of brown.	Vuggy, locally porous, commonly brecciated.	Weathers to a rubble of small fragments.	Jigsaw-puzzle texture, locally xenomorphic or reticulated.	Heterogeneous; 0.005–1 mm.	do	Bi, Sn, Zn, Fe, Ag, Cu, Pb.	None.
Gray to black; locally brown.	Largely aphanitic	None	Jigsaw-puzzle to locally xenomorphic texture.	Heterogeneous; 0.005–0.1 mm.	Mn oxides, goethite, limonite, hematite, pyrite.	Ag, Ba, Mo, Pb, Zn, Fe, Mn.	Some jasperoid may be of supergene origin.
Black, dark gray, brownish red, yellow.	Aphanitic	Commonly opaque on thin edges.	Jigsaw-puzzle to granular texture.	Homogeneous; <0.01 mm.	Sericite, hematite, limonite, chalcedony.	Be, Mn, Ti, Ca, Mg.	Particularly abundant in north part of Tintic district.
Shades of gray and brown.	Vuggy, commonly banded and brecciated; aphanitic to fine grained.	Variable grain size, commonly translucent on thin edges.	Xenomorphic to reticulated texture, more than 1 generation, vuggy.	Heterogeneous, commonly coarse grained; >0.1 mm.	Barite, jarosite, goethite, allophane, pyrite.	Ba, Pb, Ag, Sb, Bi, Cu, Zn, As, Na, Th, Sr.	None.
do	Commonly vuggy and brecciated; aphanitic to fine grained.	Locally preserves primary and older alteration (zebra) textures.	Xenomorphic to jigsaw-puzzle texture.	Commonly homogeneous; <0.05 mm.	Limonite, goethite, carbonaceous matter, sericite, barite.	None in unusual abundance.	None.
Shades of yellow, brown, and gray.	Aphanitic to medium grained, vuggy.	Leached; coarser grained varieties are commonly porous and spongy.	Reticulated to jigsaw-puzzle texture.	Reticulated type, coarse and heterogeneous, >0.1 mm; jigsaw-puzzle type, homogeneous, <0.05 mm.	Dolomite, siderite, pyrite, barite, hematite, limonite, Mn oxides.	Fe, Mg, Mn, Ag, Ba, Co, Cu, Pb, Sr, Zn.	Ore bodies commonly associated with incipient jasperoid and locally with coarse reticulated jasperoid.
do	Largely aphanitic	Incipient jasperoid locally developed in dolomite.	Xenomorphic to jigsaw-puzzle texture.	Some varieties homogeneous, <0.05 mm; others heterogeneous, 0.02–0.5 mm.	Calcite, dolomite, limonite, goethite, chalcedony, sericite, zircon, tourmaline.	Ca, Mg, Na, Ag, Ba, Cu, Pb, Sr, Zn.	None.

diameter less than 0.01 mm; it contains sparse detrital zircon and tourmaline and abundant detrital quartz grains with overgrowths in optical continuity with the grains. The matrix is cut by veinlets of late orange goethite and chalcedony, and chalcedony also lines vugs. Analysis shows this sample to be slightly high in Al, Fe, Mg, Ag, B, Ba, Cu, Ni, Pb, Sr, Y, Yb, and Zn, and abnormally high in Sb and Zr. Its indicator-element score is +11.

A sample of similar material from the Cretaceous Newark Canyon Formation near the head of Windfall Canyon, about a mile from the nearest mines, consists of dense fine-grained pale-yellowish-brown silicified limy siltstone or silty limestone that weathers moderate brown. The matrix is homogeneous aphanitic quartz that has a jigsaw-puzzle texture as in the specimen described in the preceding paragraph. It also contains disseminated flakes of sericite and masses of chalcedony, as well as numerous detrital grains of zircon and tourmaline and abundant detrital quartz. However, there are no overgrowths on the quartz grains, and the sample also lacks disseminated limonite particles and late orange goethite. Analysis shows it to be slightly high in Ca, Mg, Na, B, Ba, Ni, V, Y, Yb, and Zr; it yields an indicator-element score of −2.

CONCLUDING REMARKS

With one exception the indicator-element scores of specimens from the Eureka district reflect their location relative to known ore deposits. The four samples taken close to mine workings yielded scores in the favorable range; two samples taken within a quarter of a mile of mines, but more than 100 yards from them, yielded scores in the probably favorable range; two of the three samples taken about a mile from the nearest mines scored in the unfavorable or probably unfavorable category. The third such sample (from the Carbon Ridge Formation) yielded a score in the probably favorable category. This sample, from a breccia zone along a strong fault, may reflect updip leakage from a buried center of mineralization.

SUMMARY OF JASPEROID IN THE MAJOR DISTRICTS

The main characteristics of jasperoids in each of the major districts are summarized in table 21. It should be noted that the characteristics given under "Field relations of jasperoid" in the left part of the table apply to jasperoid bodies of the district as a whole; those given under "Appearance of jasperoid" are more restrictive, in general applying to particular jasperoid bodies that were examined and considered to be "typical"; and those given under "Microtexture and composition of particular jasperoid samples" are still more restrictive, applying only to those samples that were collected, studied, and analyzed. As a result, the confidence that can be placed in the stated characteristics, as representative of the jasperoid bodies of the district, decreases toward the right in the table. Thus, interdistrict comparisons based on field relations are more reliable than those based on appearance, and these, in turn, are more reliable than comparisons based on microtexture and composition.

Certain generalizations are apparent from the field relations. In all the major districts Paleozoic carbonate rocks are the hosts for at least one major generation of jasperoid. In the districts characterized by a close spatial and genetic relationship between intrusive bodies and jasperoid, the intrusives are felsic, generally monzonitic in composition, and there is also a younger jasperoid localized by faults and fractures. In most of the districts in which a major generation of jasperoid is associated with ore, this jasperoid formed during a late stage of preore alteration.

Jasperoid samples that have coarse or highly variable texture, abundant vugs, or a porous friable texture commonly are related to ore; those characterized by an aphanitic texture are commonly unfavorable. Sulfides, or the oxidation products of sulfides, and unusually high concentrations of the ore metals as trace elements are characteristic of favorable jasperoid samples.

CHARACTERISTICS OF JASPEROID IN OTHER THAN THE MAJOR MINING DISTRICTS IN THE UNITED STATES

Jasperoid has been reported from nearly 200 mining districts or mineralized areas in the United States in addition to the nine major districts discussed in the preceding chapter (fig. 1). Some of these are large districts in which jasperoid is not sufficiently abundant to warrant inclusion in the preceding chapter; others are large districts in which the abundance of jasperoid is not clear and needs further study; most are smaller districts characterized by abundant jasperoid; a few are mineralized areas that have as yet produced no ore.

Information on these jasperoid localities has been derived in part from the literature and in part from examination and analyses of samples. This information ranges from detailed description with numerous analyses to only a brief mention of occurrence.

Summary discussions in this chapter are arranged alphabetically by State. The discussion of each locality includes a brief summary of available information on (1) the distribution and field relations of jasperoid bodies, (2) genesis and relationship of jasperoid to ore, (3) appearance and petrography of jasperoid, and (4) minor-element content of jasperoid samples.

ALABAMA

No descriptions of jasperoid in specific districts in Alabama have been found. However, in a résumé of cobalt-bearing manganese deposits of Alabama, Georgia, and Tennessee, Pierce (1944, p. 265) observed that "Cobalt-bearing manganese oxide is commonly associated with some variety of siliceous rock, such as sandstone, quartzite, or chert, or with a fine-grained crystalline quartz which Kesler has identified as jasperoid."

In an old report on the upper gold belt of northern Alabama, Brewer (1896, p. 12) mentioned deposits similar to those of Cartersville, Ga., in which ore is associated with "whitish flinty quartz, highly sulpheretted." Thus, it seems that Alabama is not devoid of jasperoid occurrences, though their prevalence, nature, and economic significance cannot be evaluated from the information available.

ALASKA

Siliceous replacements associated with sulfide ore bodies have been reported from two areas in Alaska (fig. 37). One of these is the southern Seward Peninsula area where copper, lead, and zinc deposits are commonly associated with jasperoid in Paleozoic limestone. The other is the Salmon River district, near the head of the Portland Canal in the southeastern part of the Alaskan panhandle. Here, Jurassic greenstones have been locally silicified near deposits of copper sulfide.

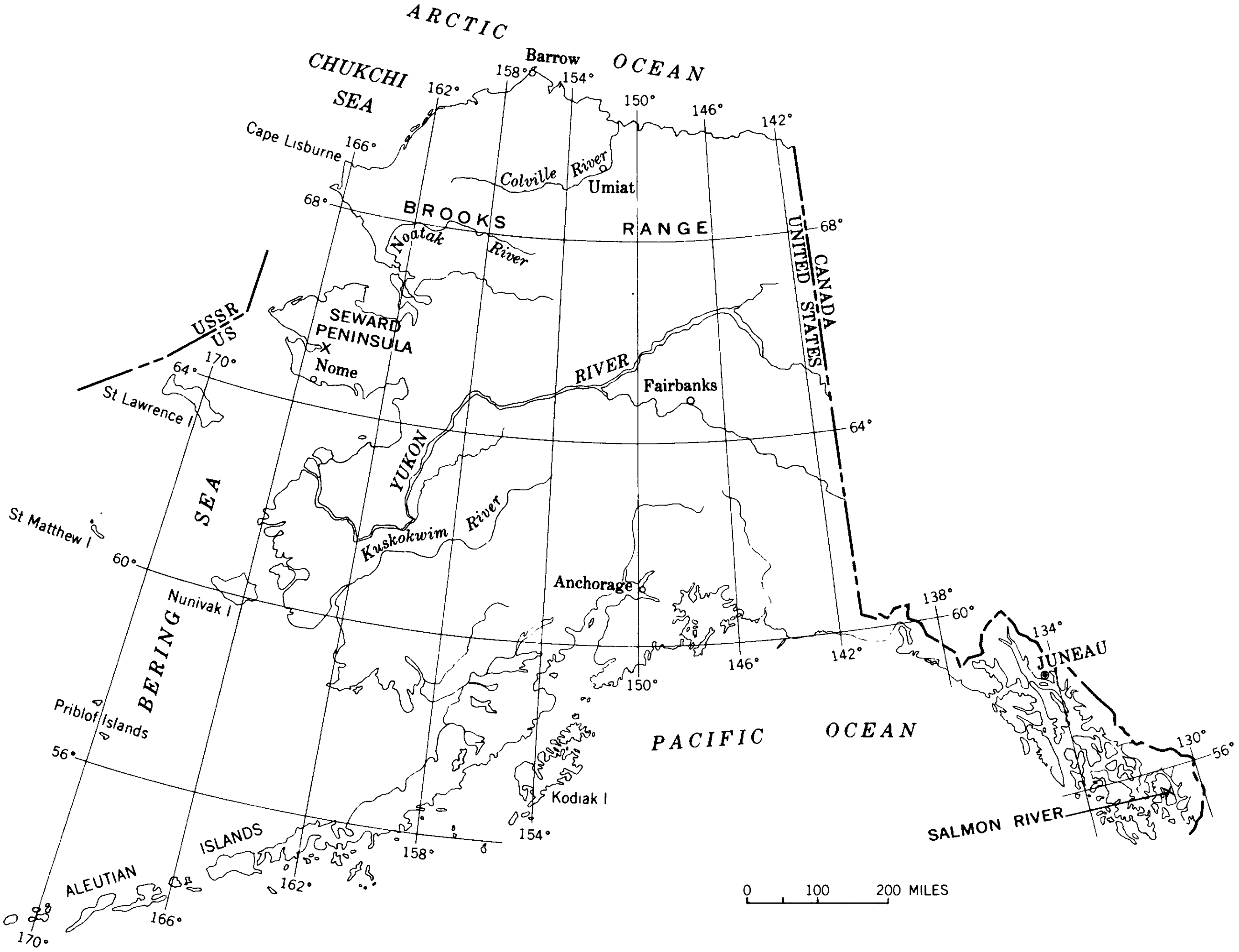


Figure 37.—Map showing the location of jasperoid-bearing areas in Alaska.

SOUTHERN SEWARD PENINSULA AREA

Cathcart (1922, p. 179, 181) mentioned bleached and silicified limestone with copper deposits at Casedepaga, on Penny River in the Solomon district, on Mount Dixon, on Slate Creek, on Manila Creek, and on Iron Creek at Copper Mountain. Cathcart said of these jasperoids: "The quartz bodies in which the copper minerals occur seem to conform with the bedding of the limestone. The quartz contains many shrinkage cavities and retains the original bedding planes of the replaced rock. The most noticeable feature of the rock is its banded structure." The jasperoids of the Iron Creek district he (p. 212–213) described as being adjacent to bleached limestone and consisting of shattered and strained quartz cut by veinlets of sericite and chlorite. Chalcopyrite is locally present in these bodies in layers roughly parallel to the original bedding.

SALMON RIVER DISTRICT

Bodies of greenstone, which resulted from the metamorphism of tuff and lava, have been intensely silicified in mineralized areas. This rock is bleached and locally resembles quartzite, both in macrotexture and composition. Sulfide minerals were introduced at about the same time as the silica. In some places the quartz replacement bodies contain abundant calcite or sericite, and at one locality (Summit claim) masses of nearly pure pyrrhotite are enclosed in silicified greenstone (Westgate, 1922, p. 123, 133, 137–138).

ARIZONA

Although no jasperoid provinces have been defined in Arizona that are comparable to those in the adjoining States of California, Nevada, Utah, Colorado, and New Mexico, jasperoid is present in at least 17 mineralized areas in the State, and some information is available on seven of these (fig. 38). Besides the major districts of Clifton-Morenci (5, fig. 38) and Bisbee (3), previously discussed, these are the Banner district (2), the Cameron area (4), the Court-

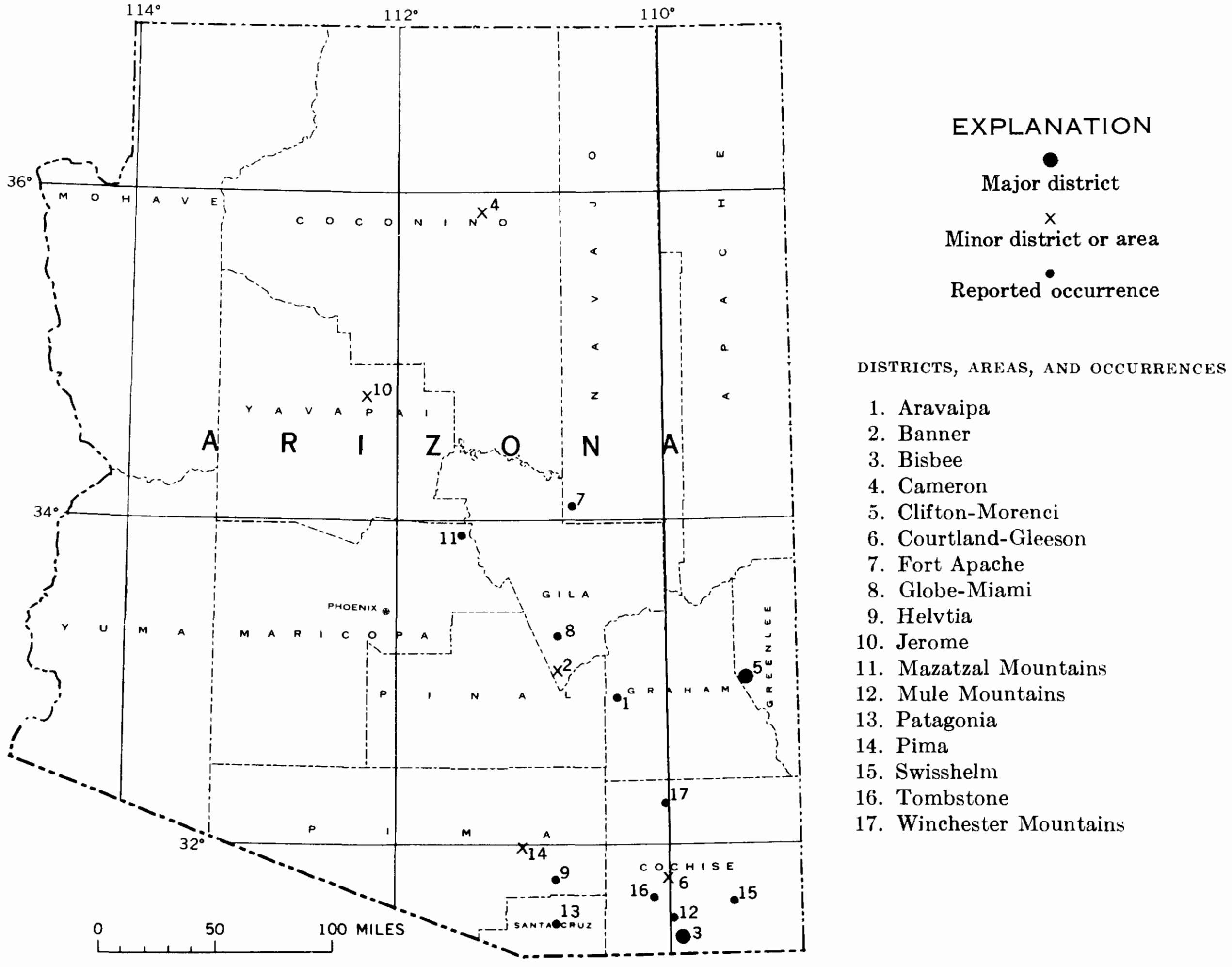


FIGURE 38.—Map showing the location of jasperoid-bearing areas in Arizona.

land-Gleeson district (6), the Jerome district (10), and the Pima district (14). Except for Cameron and Jerome, all of these are in the southeast quarter of the State. This geographic distribution may be largely attributable to the tendency of such siliceous replacements to occur in Paleozoic limestones and dolomites. Mineral deposits in these rocks are largely restricted to the southeastern part of the State. However, jasperoid bodies have also been reported in Triassic siltstone near Cameron (Abdel-Gawad and Kerr, 1963; Barrington and Kerr, 1963) and in Precambrian metamorphosed tuffaceous rocks near Jerome (Anderson and Creasey, 1958, p. 43–44, 109–111).

BANNER DISTRICT

(2, fig. 38)

The Banner district is in southern Gila County a few miles north of Hayden (Kiersch, 1951). At the Seventy Nine mine copper-lead-zinc-sulfide replacement deposits in faulted and fractured Pennsylvanian Naco Limestone are associated with massive jasperoid bodies. One of these forms a circular outcropping mass 15 feet high directly overlying a pyritic ore body; similar jasperoid bodies appear to be localized by the Keystone fault near the mine. Many of these form lenses parallel to the bedding of the Naco Limestone. Lenses and irregular masses of jasperoid have been penetrated by mine workings as deep as the seventh level.

According to Kiersch (1951, p. 78–79), the sulfide ore bodies are cut and replaced by stringers, veins, and masses of quartz, which is the youngest hypogene mineral. Although Kiersch did not directly stipulate the age of the jasperoid bodies relative to the sulfide ore, the preceding statement implies that he regarded them as a product of the late-stage hydrothermal silica-bearing solutions. Regardless of their genesis, many of them are closely associated spatially with ore bodies.

The three samples from the Seventy Nine mine in my collection show considerable variation in color, texture, and mineralogy. Two are outcrop samples, and these are aphanitic and dark red to reddish brown. Their texture is heterogeneous and largely xenomorphic, locally almost granular or reticulated. The quartz is cut by veinlets of red hematite. One outcrop sample contains numerous microvugs surrounded by clean xenomorphic quartz showing zonal overgrowths. The other outcrop sample shows no vugs; but the quartz contains numerous inclusions of chlorite, sericite, rutile, hematite pseudomorphs after pyrite, and a high-index carbonate which is probably cerussite. The third sample, from the mine dump, is coarse grained, vuggy, and white stained with various shades of brown. Its texture is heterogeneous and strongly reticulated. The larger quartz laths contain numerous two-phase fluid inclusions, as well as flakes of sericite and tiny needles of rutile. Vugs and late fractures contain cerussite and wulfenite in addition to the ubiquitous limonite and goethite.

All three samples scored high in the favorable category on their minor-element content. All were high in lead; two were high in Ag, Cu, Ga, In, and Zn; and one was high in Bi, Mo, and V.

CAMERON AREA

(4, fig. 38)

The town of Cameron seems to be near the center of a considerable area of scattered jasperoid bodies in the Triassic sedimentary rocks, and locally in the underlying Permian Kaibab Limestone (Barrington and Kerr, 1963, p. 1252–1253). A silicified zone 5–10 feet thick is present at the top of the Shinarump Member of the Chinle Formation in two areas in Coconino County—one on the west side of the Little Colorado River a few miles southeast of Cameron, and the other near Shadow Mountain, 11 miles north of Cameron (Abdel-Gawad and Kerr, 1963, p. 25–26). Near the junction of the Colorado and Little Colorado Rivers about 15 miles west of Cameron, a group of silicified breccia pipes, containing fragments of Shinarump and Kaibab Limestone, crops out in the shale and siltstone of the Moenkopi Formation (Barrington and Kerr, 1963, p. 1238). Both the silicified zone in the Shinarump and the silicified pipes in the Moenkopi are ascribed to alteration by siliceous hydrothermal solutions.

The jasperoid in the area southeast of Cameron forms anastomosing veins and lenses, locally as much as 7 feet thick, in sandstone and siltstone at the top of the Shinarump Member just below a thin gray shale of the Chinle. It is variegated and mottled in various shades of red, purple, and yellow and is commonly surrounded by a bleached kaolinized zone in the host rock. The surface is covered by an angular rubble of jasperoid surrounding the outcrops. Jasperoid here consists largely of dense aphanitic quartz and red chalcedony (Abdel-Gawad and Kerr, 1963, p. 25–26).

The silicified pipes west of Cameron present a very different appearance. They are nearly vertical pipes filled with a rubble of silica-cemented fragments of quartzite, limestone, siltstone, sandstone, and clay derived from the underlying Kaibab Limestone and Shinarump. The Moenkopi sandstone and siltstone surrounding these pipes have been bleached in irregular halos, which represent a combination of kaolinitic and sericitic alteration. These pipes form prominent conical, irregular, black-weathering outcrops. Some breccia fragments in the cores are silicified, others are not. The cryptocrystalline silica cement is vuggy and porous and has cavities lined with crystals of anhydrite. Locally, silicified breccia fragments are embedded in a matrix of yellow kaolinite clay. Silica is confined to the vents and does not replace the wallrock. All the pipes are anomalously radioactive. The siliceous matrix is stained with limonite in addition to manganese oxide, and it locally contains malachite and azurite. Disseminated pyrite is present at depth in the altered wallrock surrounding some of the pipes (Barrington and Kerr, 1963, p. 1242–1246).

The silicification that produced both the zone and the pipes probably occurred at temperatures of about 200°C and at moderate pressure. Silicification probably was accompanied, in the early stages, by kaolinization of the wallrock and, in the later stages, by the local introduction of oxides of uranium and manganese and sulfides of copper and iron, with excess sulfur resulting locally in the conversion of calcite to anhydrite (Abdel-Gawad and Kerr, 1963, p. 34, 44; Barrington and Kerr, 1963, p. 1246–1247). The ultimate source of the hydrothermal fluids is not known in this area. The jasperoid layers and lenses in the area southeast of Cameron are beneath, and near, small uranium deposits in sandstone beds of the Chinle Formation. No ore bodies have been developed in the area of the silica pipes, but the fact that the pipes show anomalous radioactivity and locally contain copper minerals as well as disseminated pyrite suggests that uranium and base-metal sulfide replacement ore bodies, if they are present in this area, probably are associated both spatially and genetically with jasperoid.

Jasperoid bodies in the Shinarump Member near Shadow Mountain are not described separately.

COURTLAND-GLEESON DISTRICT
(6, fig. 38)

The Courtland-Gleeson district occupies an area of about 8 square miles near the southeast margin of the Dragoon Mountains 15 miles east of Tombstone and 20 miles north of Bisbee in Cochise County. Ore deposits consist of pyritic copper and lead-zinc-silver replacement deposits in Carboniferous carbonate rocks. They are localized by west-dipping thrust faults and younger north- and east-trending normal faults and fractures (Wilson, 1951, p. 12, 14).

The jasperoid bodies of this district are not discussed in the literature, although Wilson (1951, p. 14–15) mentioned a prominent limonitic silicified breccia zone along a north-trending mineralized fault on the west slope of Gleeson Ridge.

Three samples from this district are included in my collection. One sample, from an outcrop near the Shannon shaft, near Gleeson, is of the favorable oxidized type; the other two are of unfavorable oxidized jasperoid—one from a pit south of the Marine shaft near Courtland, the other from a breccia zone outcrop about a mile south of Browns Peak. The favorable sample, from a silicified breccia zone along a fault, consists of angular pale-orange and medium-gray breccia fragments of aphanitic jasperoid in a slightly vuggy moderate-brown siliceous matrix. The fragments have a homogeneous aphanitic jigsaw-puzzle texture. The matrix, which is similar in texture, contains abundant brown limonite and is cut by veinlets of orange goethite and younger coarse xenomorphic quartz; it also contains sparse open vugs as much as 1 mm in diameter.

The unfavorable sample from the prospect pit near Courtland is fine grained, light gray, and dense and is cut by thin veinlets of calcite. It has a heterogeneous granular to jigsaw-puzzle texture and a grain size of 0.005–0.15 mm. The larger grains have sutured boundaries and poikilitic inclusions of smaller grains. Accessory inclusions consist of fibrous chalcedony, calcite, and abundant large masses of tremolite. It also exhibits sparse elongated open vugs.

The second unfavorable sample, from south of Browns Peak, is fine to medium grained, grayish orange pink, and contains scattered vuggy areas and square pits. The matrix consists of homogeneous aphanitic jigsaw-puzzle-textured quartz, which has been fractured and recemented by late coarse xenomorphic quartz. The late quartz contains abundant allophane dust, much of which shows zonal overgrowth patterns on original euhedral crystals, and scattered embedded hematite pseudomorphs after original pyrite, which suggests that this jasperoid body may be of the fringe-zone favorable type rather than the truly unfavorable type.

The favorable sample from the Gleeson district is higher than normal in Fe, Ag, Bi, Cu, Ga, Mo, Pb, Sn, and Zn. The unfavorable sample from the pit near Courtland is abnormally rich only in Ba, and the unfavorable sample from south of Browns Peak is slightly high in B and Pb.

Differences in appearance, texture, mineralogy, and minor-element content among the three available samples show that several distinct types of jasperoid exist in this district, but their relationships to the ore bodies and to each other have not yet been determined.

JEROME DISTRICT
(10, fig. 38)

Several occurrences of jasper and silicified bodies in Precambrian metavolcanic and metasedimentary rocks in the Jerome district, Yavapai County, were described by Anderson and Creasey (1958).

In the vicinity of the United Verde ore body, tuffaceous rocks of the Grapevine Gulch Formation were locally replaced by fine-grained quartz adjacent to an intrusive gabbro contact, before the further replacement of this rock and the underlying quartz porphyry by massive pyrite. The jasperoid bodies thus formed are lenticular to irregular in form; they are most abundant in the tuffaceous sediments although some isolated masses are completely enclosed within the pyrite, and small jasperoid nodules are present in the quartz porphyry on the footwall side of the pyritic pipe. The largest jasperoid bodies, as much as 500 feet long and 150 feet wide, are localized by structural terraces in the hanging-wall gabbro (Anderson and Creasey, 1958, p. 109–111). Both the silicification and the sulfide mineralization in this deposit are clearly Precambrian. These are the only bodies of favorable jasperoid of unquestionable Precambrian age known to the author, though it is probable that hard massive quartz containing small chalcocite bodies in the upper levels of the United Verde extension ore body (Anderson and Creasey, 1958, p. 143) and pods of jasperoid in andesitic tuffs of the Alder Group between the United Verde and Copper Chief mines (Anderson and Creasey, 1958, p. 43–44) are also Precambrian. Other such bodies, remote from mineralized areas, in the Deception Rhyolite along shear zones and along the contact with the Grapevine Gulch Formation were reported by Anderson and Creasey (1958, p. 44), who believed them to be of Precambrian age but younger than the regional deformation.

The jasperoid of the United Verde deposit is fine grained, almost flinty, and red, black, or white with gradational color variations (Anderson and Creasey, 1958, p. 111).

Jasper magnetite beds are also locally intercalated with dacite flows in the Grapevine Gulch Formation, but these beds probably represent metamorphosed chemical precipitates, rather than epigenetic siliceous replacements (Anderson and Creasey, 1958, p. 19).

PIMA DISTRICT
(14, fig. 38)

At the San Xavier mine in the northern part of the Pima district, Pima County, about 20 miles south of Tucson, a few small masses of favorable jasperoid are associated with base-metal sulfide replacement deposits in Permian limestone. Wilson (1950, p. 46–47) summarized the geology and ore deposits of this mine, but he did not mention jasperoid.

Two samples of favorable jasperoid from the San Xavier mine area are included in my collection. One is a dump sample; the other is from a small outcrop, which caps an ore body, in limestone near the service shaft. The distribution of the ore bodies, and apparently of the jasperoid, is largely controlled by the intersection of a strong northeast-trending fault zone with favorable limestone beds.

Both samples are porous, vuggy, and heavily stained with iron oxide. The quartz is coarse grained and heterogeneous, and it has a xenomorphic to locally reticulated texture. In both samples the quartz is clouded with carbonate particles, and in one of them, small fluid inclusions are present in some of the coarser grains. In one sample, abundant relict grains and masses of siderite form inclusions in the quartz; in the other sample, porous masses of brown limonite and orange goethite cement fragments of jasperoid quartz, and late fibrous chalcedony partly fills the voids.

Both samples are rich in Ag, Bi, Cu, Mo, Pb, and Zn. One sample also shows high V, and the other one, high Ni.

OTHER OCCURRENCES

In the Winchester silver district (17, fig. 38) in the northeast corner of the Dragoon quadrangle, Cochise County, limestone of Paleozoic age has locally been replaced by jasperoid bodies, some of which are as much as 100 feet wide and 1,000 feet long. These jasperoid bodies are host rocks for silver ore deposits, although the distribution of silver is erratic and only small parts of the bodies are minable (Cooper and Silver, 1964, p. 161).

In the Helvetia district (9, fig. 38), in the Santa Rita Mountains, the footwall of a copper ore body in the Copper World mine consists of highly silicified gray limestone, although the ore itself is not very siliceous (Schrader, 1915, p. 103). In the Patagonia district (13, fig. 38), at the Mowry mine, a silicified breccia zone as much as 250 feet wide occurs along a fault in limestone, according to Schrader (1915, p. 302), who wrote, in his general description of alteration in the district, that

> The quartz in limestone occurs mostly in irregular masses locally developed in association with the garnet along the contact zone and in the impure cherty zones or metamorphic bands in the sedimentary rocks. Here and there it replaces chert and the earlier metamorphic minerals, such as calcite and actinolite, whose crystalline forms are preserved in masses of relatively pure pseudomorphic silica.

Jasperoid bodies have been reported in the Pennsylvanian Naco Limestone in the Swisshelm district (15, fig. 38), Cochise County, about 30 miles north of Douglas (J. R. Cooper, oral commun., 1962), and in the Cretaceous Bisbee Group of the Mule Mountains (12, fig. 38), Cochise County, north of the Bisbee district (P. T. Hayes, oral commun., 1964). The "novaculite" in the Naco Limestone at Tombstone (16, fig. 38), Cochise County, which is associted with replacement ore deposits (Butler and Wilson, 1938, p. 108), also may be at least partly jasperoid.

At the Grand Reef mine in the Aravaipa district (1, fig. 38), Graham County, Ross (1925, p. 62) described lode deposits of lead and zinc sulfides in a silicified breccia of country rock, and also "irregular masses of white and pink glassy quartz."

In the Fort Apache iron district (7, fig. 38) in Navajo County, near Young, silicified chert breccias occur in the Precambrian Mescal Limestone. Silicification was controlled partly by proximity to an old erosion surface and partly by the intersection of joints and fractures with favorable beds. The alteration took place in Precambrian time and seems to have been characterized by repeated cycles of brecciation and silicification (A. F. Shride, oral commun., 1962). In some places these silicified zones are peripheral to, and grade into, bedded iron ore deposits. Silica of both the breccia fragments and the matrix tends to be aphanitic, and it has a jigsaw-puzzle texture. The rocks are variegated in color, commonly banded in shades of gray, red, pink, yellow, and brown, and locally display small vugs and open cavities. It is doubtful that these silicified breccias represent true jasperoids in the sense of bodies formed by heated upward-moving silica-bearing solutions; more probably their origin, like that of the silcretes of South Africa and the duricrusts of Australia, was due to cementation by silica-bearing ground and surface water at or near an erosion surface.

In the Mazatzal Mountains (11, fig. 38), Maricopa County, near some mercury deposits on Alder and Sycamore Creeks, conspicuous bands of red jasper in a pale-yellow Precambrian dolomitic limestone that is interbedded with schist and slate were reported by Lausen and Gardner (1927, p. 63, 65).

In the Globe-Miami district (8, fig. 38), Gila County, quartz monzonite and granite porphyry are completely replaced by quartz and pyrite along some major faults and breccia zones of the Copper Cities deposit, according to Peterson (1962, p. 92)

ARKANSAS

Jasperoid is associated with many of the small zinc and lead deposits scattered through the Ordovician and Mississippian carbonate rocks of northern Arkansas, in Washington, Boone, and Marion Counties on the west, and in Lawrence and Sharp Counties about 100 miles to the east. The deposits in the main northern Arkansas zinc district are most concentrated in Boone and Marion Counties in the north-central part of the region. The deposits, although numerous, are small, and the total value of all the zinc and lead produced from the entire region is less than $10 million.

NORTHERN ARKANSAS ZINC-LEAD DISTRICT

(fig. 36)

In this district, as in the Tri-State district to the northwest, many of the dolomite and limestone beds contain large masses of preore jasperoid that resembles chert, which locally replaces the enclosing rocks, although McKnight (1935, p. 19–23) stated that it is probably only slightly younger than these host rocks. The deposits are very similar to, but smaller than, those in the Tri-State district.

Gray or brown jasperoid is closely associated both spatially and genetically with many of the sulfide replacement ore bodies. It selectively replaces limestone rather than dolomite in mineralized areas where the two rock types are present. 'McKnight (1935, p. 119–120, 138–150) believed that the gray jasperoid was deposited from hydrothermal solutions that resulted from the mingling of far-traveling magmatic emanations with ground water. He regarded it as the first stage of mineralization, immediately preceding the stage of sulfide deposition, and believed that the silica of which it is composed precipitated directly in the form of quartz, rather than crystallizing from a silica gel.

Incipient jasperoidization is commonly marked by the presence of disseminated quartz prisms in the carbonate host, and the massive jasperoid characteristically contains numerous relict grains of carbonate. Unreplaced dolomite rhombs occur in some samples of completely jasperoidized limestone. The jasperoid is typically a fine-grained dense dark-gray to black rock that has a heterogeneous reticulated texture (McKnight, 1935, p. 111–112, pls. 10, 11).

CALIFORNIA

Four mining areas in California that are characterized by large bodies of jasperoid are discussed in the literature: the Darwin district (3, fig. 39), the Diadem lode in the Bidwell Bar district (1), the Mescal mine in the Ivanpah district (6), and the East Shasta district (4). The first is a base-metal sulfide and scheelite district in the northwestern Mojave

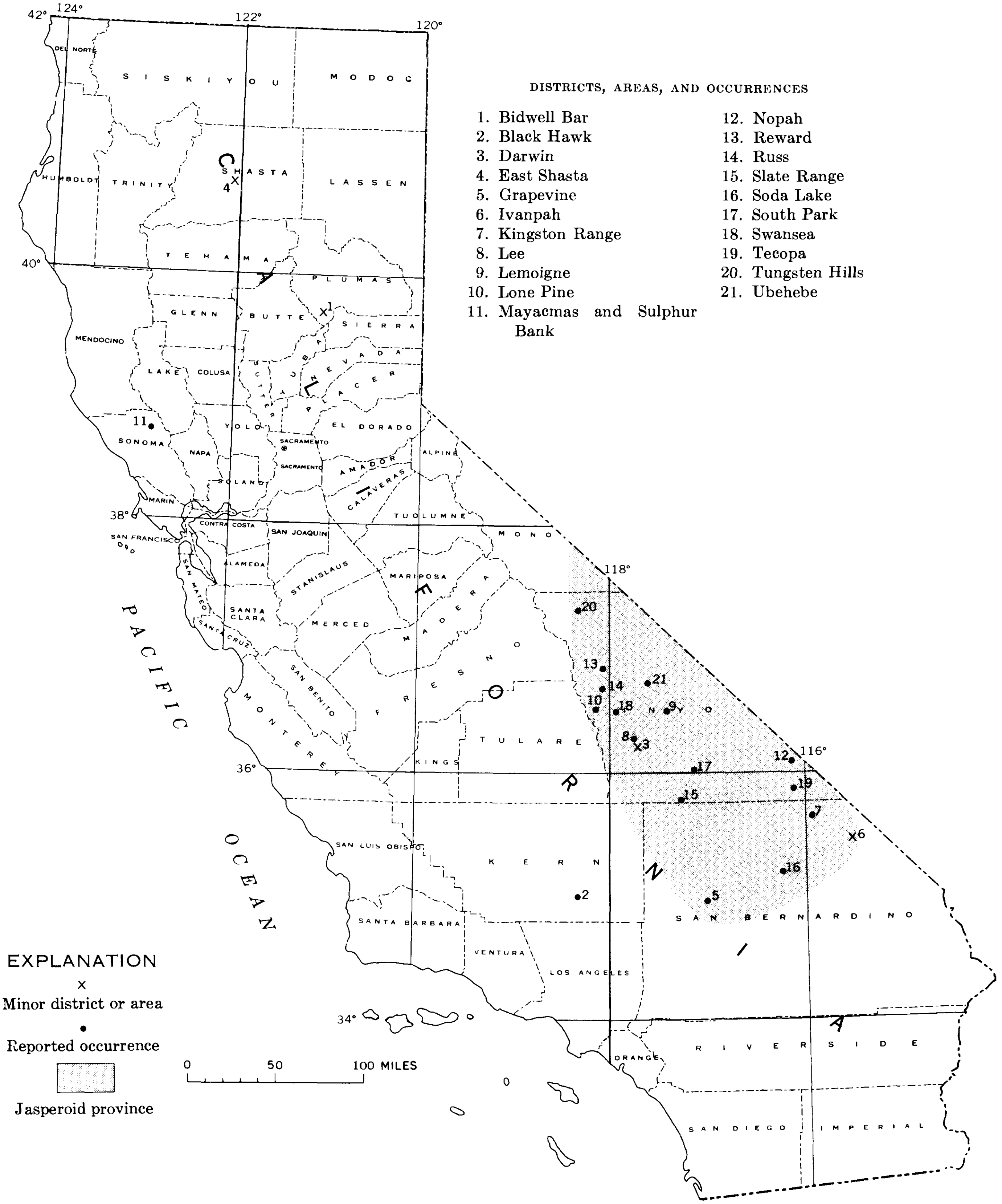


FIGURE 39.—Map showing the location of jasperoid-bearing areas in California.

Desert near Owens Lake; the second is a gold district near the north end of the Mother Lode gold belt; the third is an antimony-silver mine in the eastern Mojave Desert near the Nevada State line; and the fourth is a copper-zinc district in Shasta County. Jasperoid is known to be present in many other areas in California (fig. 39), but the literature on mining districts in the State contains little information about it.

DARWIN DISTRICT

(3, fig. 39)

The Darwin district is in hills that lie between the south end of the Inyo Mountains and the north end of the Argus Range, about 20 miles east of the south end of Owens Lake in Inyo County (Hall and MacKevett, 1962). The Panamint Springs, Zinc Hill, and Modoc mining districts a few miles west of Darwin in the Argus Range also contain abundant jasperoid (A. V. Heyl, written commun., 1967).

A series of upper Paleozoic carbonate rocks in the area has been metasomatically altered to calc-silicate rocks in broad zones surrounding Mesozoic felsic intrusive stocks and batholiths. Most of the ore bodies are in fissure veins and bedded replacements within this zone of contact metamorphism.

Knopf (1915, p. 16–18) noted the occurrence of "iron-bearing jasper" gangue at the Lane, Columbia, and Wonder mines in this district. Hall and MacKevett (1958, p. 17–18; 1962, p. 63, 68, 76) listed "jasper" as an important gangue for some of the ore bodies formed in major fault zones and stated that it is particularly abundant at the Santa Rosa mine. "Jasper" in this district apparently is confined to the fault zones and does not appreciably replace the host rock. However, this rock replaces breccia within the fault zones and thus is true jasperoid (A. V. Heyl, written commun., 1967).

BIDWELL BAR DISTRICT

(1, fig. 39)

Turner (1899, p. 389–390) described a replacement of Carboniferous limestone and dolomite on the Diadem lode in the Bidwell Bar district, Plumas County, Calif., near the north end of the Mother Lode gold belt. This body is localized by a strong fault zone, and attains a maximum width of 60 feet. Silicified foramanifera are present in this rock, which consists largely of iron- and manganese-stained quartz and chalcedony and, locally, of fine-grained silicified shale beds. The jasperoid contains selenides of Au, Ag, Pb, and Cu in addition to free gold. Ore mineralization is regarded as penecontemporaneous with silicification.

IVANPAH DISTRICT

(6, fig. 39)

The Mescal mine is in the Ivanpah district, on the northeast slope of the Mescal Range about a mile south of U.S. Highway 91 in eastern San Bernardino County, close to the Nevada State line. Hewett (1956, p. 132) has summarized the geology and ore deposit at this mine.

The host rock is lower Paleozoic Goodsprings Dolomite, which at this locality is a thin-bedded dark-gray dolomite intruded by a rhyolite sill. The ore zone is along a minor thrust fault in the dolomite, nearly parallel to the bedding. Stibnite, pyrite, and other sulfides are disseminated through a jasperoid body replacing the dolomite along this fault. According to Hewett, "these sulfides fill the pores of the spongelike mass of quartz that replaced the dolomite." A. V. Heyl (written commun., 1967) reported that jasperoid is abundant at many other silver and base-metal mines in this district.

EAST SHASTA DISTRICT

(4, fig. 39)

The East Shasta district is on Shasta Lake in central Shasta County, about 20 miles northeast of Redding. Massive base-metal sulfide deposits form lenses along shear zones and faults in Triassic rhyolite. The geology of the district is complex, and rocks ranging in age from Devonian to late Tertiary or early Quaternary are exposed within it. These are predominantly extrusive rocks and pyroclastics of many different ages, with subordinate interbedded shales and mudstones and a few limestone beds; a small stock of felsic plutonic rocks was emplaced in Late Jurassic or Early Cretaceous time.

Albers and Robertson (1961, p. 51, 52, 73, 97) mentioned silicification of rocks of many kinds, including Mississippian and Permian limestone, in the district; however, the rhyolitic host rock for the ore deposits is the most conspicuously silicified rock unit, and it is this silicification of the rhyolite that they discussed, as summarized in the following paragraph.

In its more intensely silicified phases both the groundmass and the feldspar phenocrysts of this rock have been replaced by anhedral microcrystalline quartz, and only the relict quartz phenocrysts remain. Silica, liberated during the replacement of rhyolite by sulfates and sulfides, probably moved outward to replace feldspar in the rhyolite at the Rising Star mine, where sulfide lenses are largely enclosed by intensely silicified rhyolite. A dense reddish-brown flintlike jasperoid containing disseminated sulfides in the Bully Hill mine appears to be a siliceous replacement of metadiabase, and Albers and Robertson (1961, p. 97) stated that "its presence near prominent ore shoots seems to be an important indicator of mineralization within the metadiabase."

Jasperoids of the favorable type are thus abundant in parts of the East Shasta district, though they are somewhat unusual in that they replace igneous rocks rather than sedimentary carbonate rocks.

OTHER OCCURRENCES

Serpentine in the vicinity of mercury deposits in the Mayacmas and Sulphur Bank districts (11, fig. 39), Sonoma County, was reported by Ross (1940, p. 333, 340) to have been hydrothermally altered to a fine-grained rock composed of quartz, chalcedony, opal, and carbonates. In the Tungsten Hills (20, fig. 39), Inyo County, 10 miles west of Bishop at the east base of the Sierra Nevada, roof pendants of metamorphosed sedimentary rocks are enclosed in granite and form the host rocks for scheelite deposits. Lemmon (1941, p. 502) wrote that "The calcareous rocks, limestone, shaly limestone, and calcareous shale show the most varied alteration. Some beds are silicified and on casual inspection resemble quartzite."

A. V. Heyl (written commun., 1967) reported that jasperoid is common or abundant in the following lead and zinc mining districts in Inyo, San Bernardino, and Kern Counties in eastern California: Tecopa (19, fig. 39), Black Hawk (2), Lemoigne (9), Grapevine (5), Kingston Range (7), Nopah (12), Reward (13), Slate Range (15), Russ (14), Ubehebe (21), and Panamint Springs (hypogene jasperoid); Zinc Hill, Modoc, and Swansea (18) (both hypogene and supergene jasperoid); Lee (8), Clark Mountain, Soda Lake (16), Lone Pine (10), and South Park (17) (supergene jasperoid). The host rock of the jasperoid in most of these districts is limestone or dolomite; however, jasperoid replaces andesite and tuff in the Grapevine district.

COLORADO

Most of the small jasperoid-bearing mining districts of Colorado are within the central Colorado jasperoid province (fig. 1), which covers parts of Eagle, Summit, Lake, Park, Pitkin, Chaffee, Saguache, and Gunnison Counties, and includes the major districts of Leadville (9, fig. 40), Gilman (5), and Aspen (1), previously described. These smaller districts within the province include the Horseshoe-Sacramento district (6) in the Mosquito Range southeast of Leadville, the Kokomo district (7) in the Gore Range a few miles north of Climax, the Pando area (14) in the upper Eagle River Valley between Tennessee Pass and Red Cliff, the Sedalia district (18) near Salida, the Monarch-Tomichi (12), Quartz Creek (15), Tincup (22), and Sugar Loaf and St. Kevin (21) districts in the Sawatch Range, the Lenado (10) and Snowmass Mountain (19) districts near Aspen, the Spring Creek district (20) north of Gunnison, and the Bonanza district (2) in the northeastern Saguache County. Isolated occurrences of jasperoid have also been reported from the Uncompahgre (23) and Red Mountain (16) districts near Ouray in the northern San Juan Mountains, in the Rico (17) and La Plata (8) districts in the southwestern San Juan Mountains, the Massadona-Youghall district (11) in Moffat County, and the Carbonate district (4) in eastern Garfield County outside the jasperoid province (fig. 40). The host rocks for nearly all these jasperoids are limestone and dolomites ranging in age from Devonian to Pennsylvania.

HORSESHOE-SACRAMENTO DISTRICT

(6, fig. 40)

The Horseshoe-Sacramento district is south of Alma and southeast of Leadville on the east slope of the Mosquito Range in Park County. The nature and genesis of its jasperoid bodies were discussed in detail by Butler and Singewald (1940), from which the following information is abstracted.

The ore deposits consist of lead-zinc-silver sulfide vein and replacement deposits in Devonian Dyer Dolomite Member of the Chaffee Formation and the overlying Mississippian Leadville Limestone on the steep west limb of a northwest-trending anticline, which is cut off by the major north-northwest-trending London fault on the west. This fault brings barren Pennsylvanian shale, arkose, and siltstone in contact with the ore-bearing carbonate rocks.

Silicification of the carbonate rocks was preceded by the formation of vein quartz that fills faults and small fractures. Several distinct types and ages of jasperoid were distinguished in the area, and they exhibit both abrupt and transitional contacts with their host rocks (Butler and Singewald, 1940, p. 820–828). The jasperoid forms lenticular bodies parallel to the bedding and silicified breccia zones along major faults, which locally act as "feeder dikes" to the lenticular bodies. Butler and Singewald recognized four types of jasperoid, which they designated as coarse euhedral, coarse granular, fine granular, and nodular. These types grade transitionally into each other and exhibit a crude regional zonation outward from a core of coarse euhedral jasperoid to a peripheral zone of nodular jasperoid. They (p. 828–831, 835–836) believed that this tex-

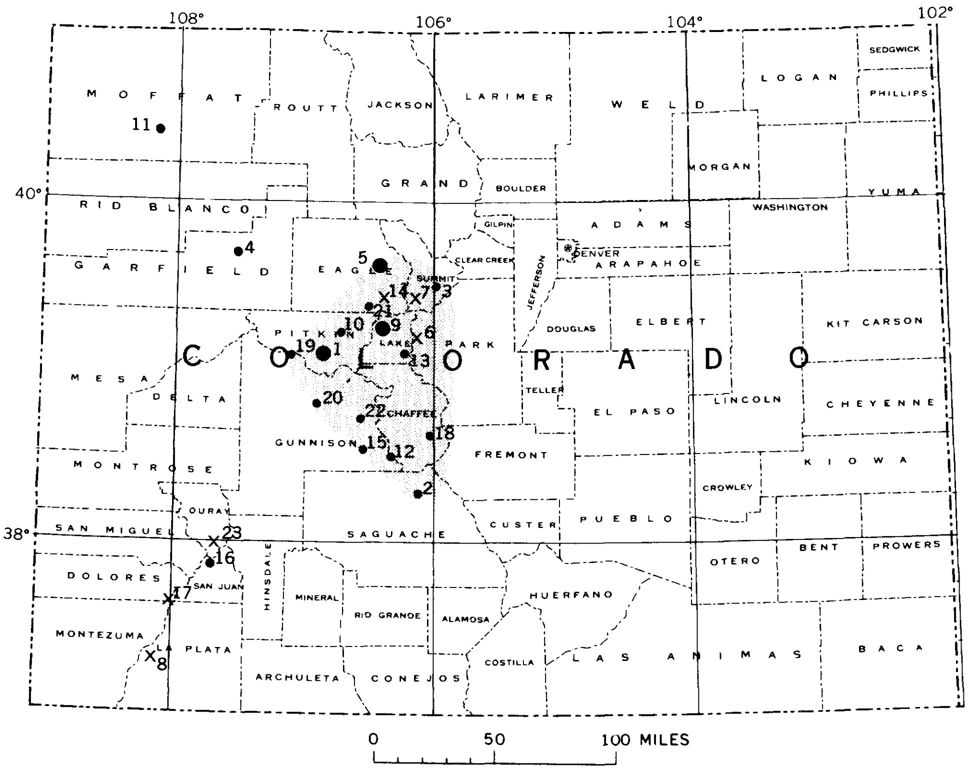


FIGURE 40.—Map showing the location of jasperoid-bearing areas in Colorado.

DISTRICTS, AREAS, AND OCCURRENCES

1. Aspen
2. Bonanza
3. Breckenridge
4. Carbonate
5. Gilman (Red Cliff)
6. Horseshoe-Sacramento
7. Kokomo
8. La Plata
9. Leadville
10. Lenado
11. Massadona-Youghall
12. Monarch-Tomichi
13. Mosquito Range
14. Pando
15. Quartz Creek
16. Red Mountain
17. Rico
18. Sedalia
19. Snowmass Mountain
20. Spring Creek
21. Sugar Loaf and St. Kevin
22. Tincup
23. Uncompahgre

tural gradation reflected a change from relatively dilute and relatively low temperature silica-bearing solutions precipitating quartz to form coarse euhedral jasperoid, through successively hotter and more concentrated silica solutions to a hot, highly supersaturated solution, which precipitated silica gel that later crystallized to form the aphanitic nodular type of jasperoid.

The coarse euhedral jasperoids are restricted to a small area at the southeast end of the larger jasperoid-bearing area. This rock resembles fine-grained quartzite and is transitional into the recrystallized dolomite host rock through a zone characterized by skeletal quartz crystals or disseminated quartz prisms in the dolomite gangue. In thin section it shows a coarse reticulated texture with carbonate particles in the laths, which are cemented by, and locally overgrown with, clear quartz. Late clear coarse quartz also forms veinlets and drusy coatings of cavities and vugs. Relict inclusions of dolomite and grains of barite partly replaced by jasperoid are common. Flakes of sericite are locally abundant, and late ferruginous carbonate replaces some of the jasperoid. This type of jasperoid is closely associated with, and grades into, baritic sulfide ore consisting largely of galena, sphalerite, and pyrite in a gangue of barite, dolomite, and jasperoid (Butler and Singewald, 1940, p. 808, 821–823).

Euhedral jasperoid grades into coarse granular jasperoid consisting of sparse, poorly terminated quartz laths embedded in a groundmass of relatively coarse anhedral quartz grains. This type also contains relict inclusions of carbonate host, but it lacks the carbonate particles that characterize the euhedral variety. The coarse granular jasperoid grades outward into fine granular jasperoid with the disappearance of quartz laths and gradual diminution in grain size. This type could have formed either by the crystallization of colloidal silica or by the rapid precipitation of quartz from solution at abundant centers of nucleation. Both barite and the early quartz laths show strain, brecciation, and corrosion by the granular matrix quartz (Butler and Singewald, 1940, p. 826–827, 831).

The fine granular jasperoid is transitional outward into nodular jasperoid that consists of nodules of fine-grained jasperoid quartz in a matrix of aphanitic cherty-looking quartz whose average grain size is a few thousandths of a millimeter. The nodules lack spherulitic or chalcedonic banding, but they commonly contain carbonate particles that are segregated in the cores of some nodules and concentrated in the rims of others. Both nodules and matrix are cut by veinlets of late coarse clear quartz. This nodular jasperoid, which is most abundant on the outer fringes of the jasperoid area, characteristically exhibits sharp contacts with the host rock and is thought to represent the recrystallization of a silica gel deposited by hot solutions highly supersaturated with silica (Butler and Singewald, 1940, p. 824–825). Ore bodies associated with this type of jasperoid apparently consist of pyrite, sphalerite, and galena and subordinate tennantite, argentite, and chalcopyrite, although this relationship is merely inferred and not directly stated by Butler and Singewald. They did state that this assemblage of ore minerals is characteristic of the nonbaritic ores and that barite is abundant in the euhedral jasperoid and not in the nodular jasperoid.

KOKOMO DISTRICT

(7, fig. 40)

The Kokomo district is a few miles north of Climax, near the south end of the Gore Range in Summit County. The White Quail Limestone Member, one of several limestones in a thick section of siltstone, shale, and arkose in the Pennsylvanian Minturn Formation, is the host rock for lead-zinc sulfide replacement deposits along northeast-trending faults and fractures. Masses of jasperoid are closely associated with some of these ore bodies, and, in places, jasperoid quartz forms the matrix for siliceous ore.

The ore zone was argillized before it was silicified, and silicification preceded deposition of the sulfides. Limestone beds above and below the ore zone show no visible alteration, suggesting that the mineralizing solutions moved updip from their feeding channels for some distance in the ore zone before reacting to form the ore bodies and their associated alteration (A. H. Koschmann, oral commun., 1959).

Kokomo jasperoid, where unoxidized, is typically medium to dark gray, coarse grained, vuggy, and heavily impregnated with pyrite, which ranges from tiny disseminated grains to masses an inch or more in diameter, and locally forms a network of veinlets cutting the quartz. Much of the pyrite is euhedral, with striated cube faces predominating, although these are locally modified by octahedral and pyritohedral faces. Breccia fragments of light-gray soft friable argillized wallrock are commonly incorporated in the jasperoid. Masses of coarse-grained calcite cement the jasperoid fragments in places, and most vugs in the jasperoid are encrusted with prismatic quartz crystals associated with pyrite and younger dark sphalerite.

In thin section the jasperoid quartz is coarse grained, and it has a heterogeneous texture that grades from reticulated to xenomorphic. Many quartz grains contain carbonate particles, and some of the larger quartz grains have zone inclusions of allophane. Flakes of sericite, penecontemporaneous with the matrix quartz, are abundant. Pyrite, galena, and sphalerite inclusions are all younger than jasperoid quartz and seem to have formed in approximately the order in which they are listed. Veinlets of calcite and of quartz cut both the sulfides and the jasperoid.

Spectrographic analyses of two jasperoid samples from Kokomo show abnormally high concentrations of Fe, Mn, Ag, Bi, Ge, Pb, and Zn, and thus confirm that it is a favorable jasperoid.

LA PLATA DISTRICT

(8, fig. 40)

The La Plata district is in western La Plata County, about 20 miles northwest of Durango. Complex gold and silver ore has been mined, largely from vein deposits in sedimentary rocks that range in age from Pennsylvanian to Cretaceous, in an area cut by many dikes and sills of Tertiary felsic igneous rocks. The sedimentary rocks, which consist largely of siltstone, shale, and sandstone, are commonly silicified adjacent to the veins in zones as much as 3 feet thick. This silicification ranges in intensity from cementation to nearly complete replacement (Eckel, 1949, p. 77).

The Jurassic Pony Express Limestone Member of the Wanakah Formation has been largely replaced by sugary quartz and pyrite on Jackson Ridge, particularly on the slope south of Rush Basin (Eckel, 1949, p. 111). Hydrothermal alteration and subsequent mineralization in the district closely followed intrusion of the Tertiary igneous rocks and are probably genetically related to the intrusives.

PANDO AREA

(14, fig. 40)

The Pando area of central Colorado is west of Kokomo, north of Tennessee Pass, and south of Red Cliff. It comprises about 50 square miles bounded approximately by the valleys of the Eagle River and Homestake Creek on the west, the east fork of the Eagle River on the south, the crest of the Gore Range on the east, and the divide south of Turkey Creek on the north. It is in Eagle County and includes the Camp Hale Military Reservation. A few small mines and prospects in pre-Pennsylvanian rocks in the western part of the area produced some oxidized lead, silver, and gold ore before 1900; but these mines and prospects are now idle, and there is no mining activity in the area at present.

The Devonian Dyer Dolomite Member of the Chaffee Formation and the hydrothermally dolomitized Mississippian Leadville Limestone overlying it have been extensively replaced by jasperoid at many places along the valley of the Eagle River from its confluence with the East Fork of the Eagle River northward to the north boundary of the Pando area. Scattered bodies of jasperoid are also found in carbonate beds in the thick pile of dominantly clastic sedimentary rocks of the Pennsylvanian Minturn Formation overlying the Leadville Limestone to the northeast.

The jasperoid bodies of this area, together with those of the adjoining Gilman district (5, fig. 40), were first described by Crawford and Gibson (1925, p. 56–59), and their observations have been summarized in my section on the Gilman district (p. 78). Tweto (1953), in a more recent study of these rocks, pointed out the association of jasperoid with previously hydrothermally dolomitized and brecciated rock, particularly in the permeable Gilman Sandstone Member of the Leadville Limestone and the adjacent dolomite beds of the Dyer below and the Leadville above. This zone and local channels in the old karst erosion surface at the top of the Leadville served as major conduits for the silicifying solutions.

Carbonate beds in the Pennsylvanian Minturn Formation are also strongly jasperoidized along faults near the heads of Cataract and Pearl Creeks and on North Sheep Mountain.

Silicification that resulted in the formation of jasperoid seems to represent a late barren stage in a long period of hydrothermal alteration that began with pervasive conversion of the Leadville Limestone into fine-grained dolomite, with subsequent recrystallization of the dolomite into "zebra rock," sanding of the dolomite along channels, and brecciation preceding silicification. Local fracturing and brecciation continued during silicification, which was followed by weak local sulfide mineralization. Tweto regarded this sequence as probable manifestations of fringe zone mineralization leaking updip from a major center of mineralization that lies buried beneath the thick section of Pennsylvanian rocks, to the northeast of Camp Hale. The scattered areas of alteration in the Pennsylvanian carbonate rocks may also represent leakage upward, along strong faults, from this same source.

Many varieties of jasperoid are present in the area, and some of the larger bodies exhibit several distinctive types and generations. Most of these varieties seem to be unfavorable; but small grains of pyrite, cerussite, and cerargyrite occur locally, and barite is common (Tweto, 1953).

My samples from the Pando area exhibit wide variations in appearance. Some are mottled, some show thin alternating color bands like varves, some are silicified breccias that contain angular fragments of chert and older jasperoid, and some are megascopically homogeneous. The samples are white mixed with various shades of gray, brown, brick red, yellow, or orange. Most samples have aphanitic textures, but some are vuggy and have a saccharoidal texture like fine-grained quartzite.

Many of the Pando samples have a homogeneous aphanitic jigsaw-puzzle texture, which in some samples characterizes an older generation that is cut by veinlets and masses of coarser xenomorphic quartz. Wavy colloform banding is characteristic of some samples. Heterogeneous textures with abrupt variations in grain size characterize a few samples, and one of these has a strongly reticulated texture suggestive of favorable jasperoid. Common accessory minerals include hematite, pyrite, barite, chalcedony, and late orange goethite; flakes of sericite are scattered through the matrix in a few samples, and much of the aphanitic jasperoid quartz is clouded with abundant dust-sized inclusions of allophane, carbonaceous particles, or carbonate.

Spectroscopic analyses were obtained on three samples from the Pando area. One of these samples is from Dyer Dolomite Member near a small adit in the Eagle River Canyon near the north boundary of the area; the second is from an unmineralized body in the lower dolomitized part of the Leadville Limestone in the Eagle River Canyon a little farther south; and the third is from a body replacing a dolomite bed in the Pennsylvanian Minturn Formation on a ridge south of Pearl Creek in the east-central part of the area. The first of these is high in Ba, Be, Na, Sr, and Ti; the second is high in Ba, Be, Sr, Yb, and Zr; and the third shows no abnormally high concentrations of minor elements but is deficient in Fe, Ti, and Cr. Although none of these samples contain high concentrations of the indicator elements for productive jasperoid, it is highly probable that some of the jasperoid bodies in the lower Paleozoic carbonate rocks along the Eagle River valley do contain them, and a detailed study of these bodies might outline favorable areas for exploration.

RICO DISTRICT

(17, fig. 40)

The Rico mining district is in eastern Dolores County, in the western part of the San Juan Mountains, about 35 miles north-northwest of Durango and 30 miles southwest of Ouray. It lies about 20 miles northward from the La Plata district (8, fig. 40) in the same part of the San Juan Mountains.

According to Cross and Ransome (1905, p. 14–15, 20), the major ore deposits of the district are blanket replacements of limestone and shale of the Pennsylvanian Hermosa Formation by silver-bearing galena associated with sphalerite and abundant pyrite. The sedimentary rocks in the district were intruded by sills of monzonite porphyry in late Tertiary time at the beginning of a domal uplift that culminated with profound faulting. Bedding-plane faults and northeast-trending normal faults, formed at this time, served as conduits for later mineralizing solutions that silicified the wallrocks and deposited the ores. Black shale, limestone, and monzonite porphyry sill rocks have locally been replaced by jasperoid.

Ransome (in Cross and Ransome, 1905, p. 14–15) stated:

> In the form of jasperoid (a cryptocrystalline aggregate commonly associated with replacement deposits) quartz occurs in the Blackhawk mine and in the blanket of the Sambo mine. In the former mine, also, are found spongy, cavernous masses of rusty quartz, apparently due to the removal of limestone, by solution, from a network of quartz stringers. Quartz is abundant in some of the blanket breccias as a replacement of breccia material.

In a further description of the Blackhawk mine, Ransome (p. 19) stated that massive sulfide ore bodies have selectively replaced a limestone bed and that the limestone next to the ore is commonly changed to jasperoid.

UNCOMPAHGRE DISTRICT

(23, fig. 40)

The Uncompahgre mining district is in the northern San Juan Mountains near Ouray, the county seat of Ouray County. This district, like the Leadville district (9, fig. 40), is characterized by fissure vein deposits of copper, lead, zinc, gold, and silver. The deposits show a zonal arrangement around a center of mineralization that developed at the intersection of major northeasterly and northwesterly structural trends. High-temperature pyritic gold ore was deposited in the core area, which is surrounded by an intermediate zone of base-metal sulfides; this, in turn, is surrounded by a silver belt that forms the outer zone of commercial mineralization. Jasperoid bodies are largely confined to this outer zone (Burbank, 1940).

Jasperoid formed during a preore stage of hydrothermal alteration that was preceded or accompanied by leaching of carbonate rocks, which opened up solution channels. This stage was followed by the formation of ankerite, sericite, pyrite, and barite immediately preceding the ore stage of mineralization. During the ore stage, pyrite, sphalerite, chalcopyrite, galena, tetrahedrite, pearceite, pyrargyrite, rhodochrosite, and manganocalcite were deposited. This was followed by the emplacement of late calcite, quartz, and barite (Burbank, 1940, p. 207).

At the Mineral Farm mine, about a mile south of Ouray, silicification and subsequent mineralization were localized by an unconformity between the Leadville Limestone and the overlying shales and siltstones of the Mississippian and Pennsylvanian Molas Formation. Small fractures in the top of the Leadville were opened up by hydrothermal leaching, and the overlying red shale of the Molas was silicified. The larger ore bodies formed in these open channels in the Leadville beneath the competent and impermeable caprock of silicified shale. The mineralized upper part of the Leadville is coarsely clastic and contains interbedded porous sandstone layers, indications that it was highly permeable during mineralization (Burbank, 1940, p. 209–210). I have three samples of partly oxidized jasperoid from the Mineral Farm mine, taken from the walls of a sulfide deposit that formed in one of these channels at the top of the Leadville Limestone. They range in color from light gray through light olive gray and from grayish orange to pale yellowish brown, have a distinctly saccharoidal texture, small sparse vugs, and visible disseminated grains of pyrite and galena. One sample contains angular breccia fragments of white, light-gray, and dark-gray aphanitic silica and coarse-grained white vein quartz with disseminated pyrite. This latter inclusion suggests that some pyrite must be older than the matrix jasperoid.

Thin sections reveal that the sample with the most abundant sulfides has a coarse heterogeneous reticulated texture, characteristic of favorable jasperoid; pyrite and galena in this sample show incipient alteration to limonite and cerussite, respectively, and the matrix quartz contains local concentrations of allophane and carbonate particles. The other two samples consist largely of rounded detrital-looking quartz grains cemented by aphanitic quartz that has a jigsaw-puzzle texture. These probably represent a silicified sandstone bed in the limestone.

The favorable jasperoid sample is rich in Ag, Cd, Co, Cu, Mo, Ni, Pb, Te, Zn, and Zr. The two samples of silicified sandstone contain abnormally high concentrations of Ti, Ag, Cu, Nb, Pb, Te, Zn, and Zr, but they do not yield as high a score on indicator elements as the favorable jasperoid sample.

OTHER OCCURRENCES

White sulfide-bearing jasperoid in the Pennsylvanian Hermosa Formation at the Black Queen mine, on the south slope of Sheep Mountain in northern Gunnison County, was reported by Vanderwilt (1937, p. 106, 116). He also mentioned a bed of barren white jasperoid in Pennsylvanian sedimentary rocks near the head of Yule Creek in the same area. Intensely silicified Cretaceous shale in the Wellington mine at Breckenridge (3, fig. 40), Summit County, was described by Lovering (1934, p. 56), who stated that "Much of the limy shale has been strongly silicified near the veins and is converted into black jasperoid, locally called jasper." In the Sugar Loaf and St. Kevin districts (21, fig. 40), Eagle County, in the northern part of the Sawatch Range, the widespread occurrence of "chert" dikes, zones, and veins cutting Precambrian igneous and metamorphic rocks was reported by Singewald (1955, p. 260). The larger "chert" zones are as much as 350 feet wide, and Singewald ascribed their origin to replacement of the country rock along strong faults.

Burbank (1932, p. 72) described the replacement of Tertiary volcanic rocks by silica adjacent to faults in the Bonanza district (2, fig. 40), Saguache County, and (1941, p. 203) similar silicification forming "casings" around ore channels in quartz latite of the Red Mountain district (16, fig. 40), San Juan County.

Replacement of limestone by silica, adjacent to sulfide replacement deposits in limestone, in the Quartz Creek (15, fig. 40), Tincup (22), and Monarch-Tomichi (12) districts, Gunnison and Chaffee Counties, was noted by Dings and Robinson (1957, p. 60, 63–64, 69). Behre (1953, p. 99, 100) mentioned jasperoid in densely packed anhedral grains replacing the groundmass of porphyry near some ore bodies and also replacing carbonate rocks, particularly the Leadville Limestone, on the west slope of the Mosquito Range (13, fig. 40), Lake County, east and southeast of the Leadville district.

Jasperoid is also mentioned by Heyl (1964, p. C25) as a gangue mineral in oxidized zinc veins of the Massadona-Youghall deposit (11, fig. 40) in central Moffat County near the Yampa River. Brecciated upper Paleozoic limestone is both replaced and cemented by large masses of jasperoid that form the principal gangue of an oxidized zinc-lead replacement ore body at the Doctor mine in the Spring Creek district (20, fig. 40) north of Gunnison in Gunnison County (Heyl, 1964, p. C25, C28, C29). Heyl (written commun., 1967) also reported the presence of abundant jasperoid associated with oxidized zinc and lead deposits in the Lenado district (10, fig. 40), Pitkin County, north of Aspen, the Sedalia district (18, fig. 40), Chaffee County, on the Arkansas River north of Salida, and the Carbonate district (4, fig. 40) on the White River Plateau in eastern Garfield County.

GEORGIA

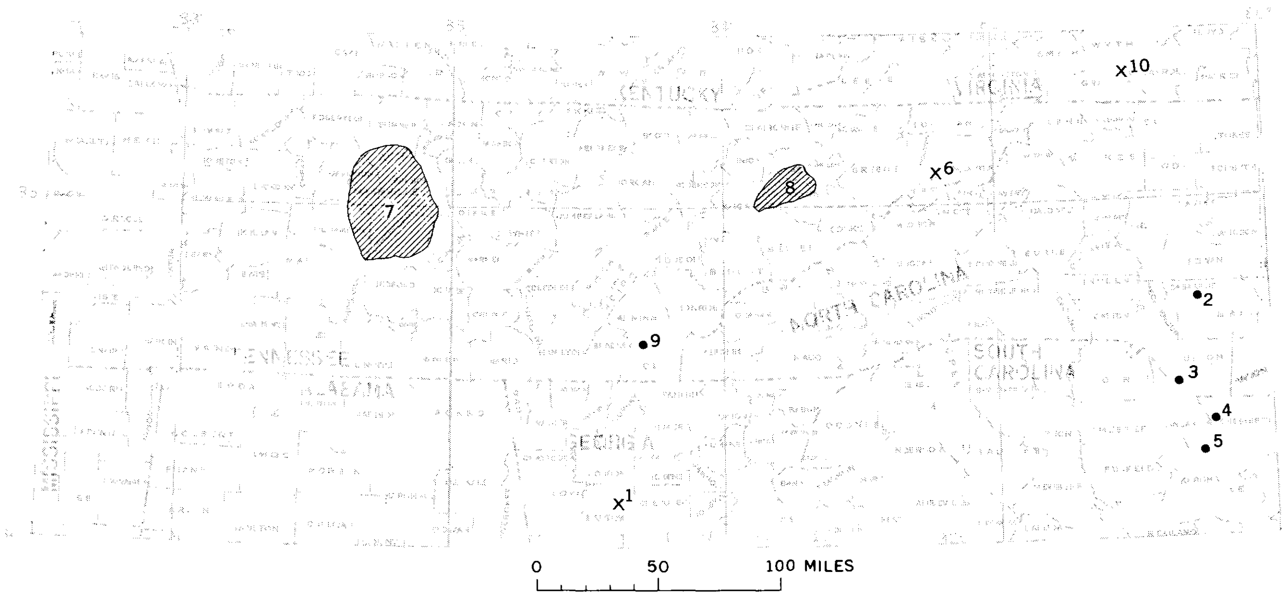
CARTERSVILLE DISTRICT

(1, fig. 41)

An economically important mining district in Georgia that contains large bodies of jasperoid is the Cartersville iron and manganese district about 40 miles northwest of Atlanta in Bartow County in the southern Appalachian Mountains. The Cartersville district is largely underlain by folded and slightly metamorphosed shale, limestone, and dolomite of Cambrian age. The rocks were apparently folded in Carboniferous time; folding was closely followed by high-angle faulting and fracturing. These faults and fractures later served as conduits for hydrothermal solutions that formed fissure vein and replacement deposits of jasperoid, hematite, barite, siderite, pyrite, and base-metal sulfides. Deep weathering accompanied by supergene alteration and enrichment, during the Tertiary Period, produced commercial deposits of manganese oxide and brown iron ore (Kesler, 1950, p. 1–2).

Jasperoid bodies are not restricted to any one stratigraphic zone, although they are confined to carbonate rocks or to residual clay underlain by carbonate rocks in the vicinity of faults and fractures. They decrease in size and abundance from east to west across the district. Residual clays derived from weathering of carbonate rock contain irregularly distributed bodies of jasperoid ranging from small nodules to masses 20 feet in diameter.

Jasperoidization is related to deposition of primary ore and gangue minerals. Local preservation of original carbonate bedding textures and fossils in jasperoid gives clear indication of its replacement origin. Angular inclusions of barite and sulfide-bearing vein quartz in jasperoid matrix show that some silicification took place subsequent to sulfide mineralization. However, similar inclusions of dense fine-grained jasperoid in a matrix of coarse-grained jasperoid also show that there was more than one period of silicification. Primary ore and gangue minerals consisting of sulfides, barite, vein quartz, and carbonate were introduced by hydrothermal solutions moving upward along faults and fractures. The deposition of these minerals preceded renewed faulting and brecciation, which was followed by silicification in the form of jasperoid of both vein



EXPLANATION

▨

Area of large mining district

x

Minor district or area

•

Reported occurrence

LIST OF DISTRICTS, AREAS, AND OCCURRENCES

1. Cartersville
2. Gold Hill
3. Howie and Whitney
4. Brewer
5. Haile
6. Bumpass Cove
7. Central Tennessee
8. Eastern Tennessee
9. Sweetwater
10. Austinville

FIGURE 41.—Map showing location of jasperoid-bearing areas in Georgia, North Carolina, South Carolina, Tennessee, and southwest Virginia.

carbonate and wallrock carbonate (Kesler, 1950, p. 49–50).

Some jasperoids of the Cartersville district are thinly bedded and aphanitic, but most are massive and have a saccharoidal texture. The fresh rock is light to dark gray; but in the zone of alteration, and particularly in the residual clay, it is commonly heavily stained and colored by oxides of iron and manganese. Much of this weathered jasperoid consists of porous friable masses of ocherous quartz, coated with minute euhedral supergene quartz crystals; unweathered jasperoid does not contain these crystals. Coarse-grained massive jasperoid commonly contains angular breccia fragments of aphanitic jasperoid, and locally it also contains disseminated grains of pyrite, chalcopyrite, and tennantite. Coarser textured jasperoid replaced coarse vein carbonate; aphanitic jasperoid replaced carbonate host rock. Near the close of jasperoid deposition a late generation of crystalline barite, pyrite, and hematite was locally deposited as crystals lining vugs in the jasperoid.

In thin section, jasperoid typically consists of minute anhedral interlocking grains of quartz, though locally the coarser textured variety faithfully preserves the form and even the cleavage of the coarse vein carbonate it replaced (Kesler, 1950, p. 48, pl. 13*D*).

OTHER OCCURRENCES

Pardee and Park (1948, p. 131–140) described some lode gold deposits in Precambrian schists and associated felsic intrusive rocks in Lumpkin County in northern Georgia, in which the gold occurs in irregular veins and lenticular masses in silicified wallrock. Both the schists and associated intrusives are locally replaced by, as well as impregnated with, silica; however, most of the quartz lodes appear to be fracture fillings rather than replacement bodies.

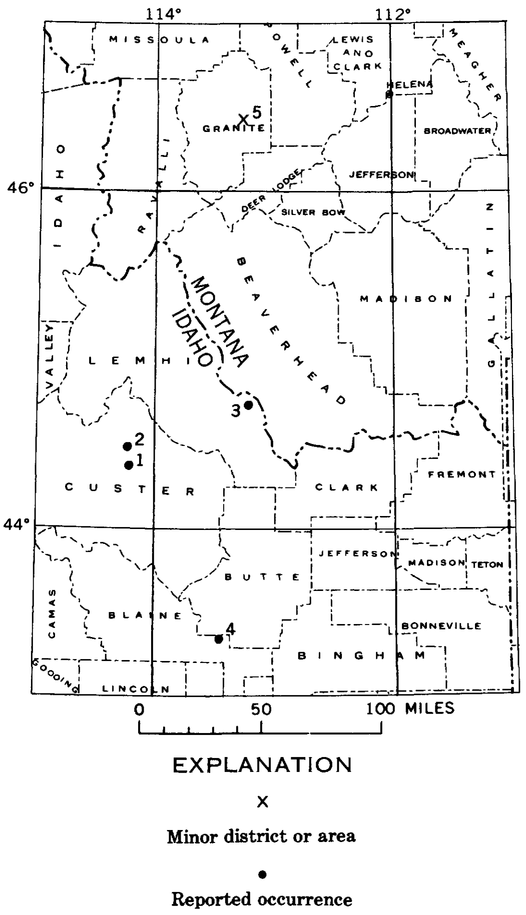


FIGURE 42.—Map showing location of jasperoid-bearing areas in Idaho and Montana. 1, Bayhorse; 2, Challis; 3, Lemhi; 4, Skull Canyon; 5, Phillipsburg.

IDAHO

A search of the literature has failed to reveal any description of replacement bodies of jasperoid in the mining districts of Idaho, although the existence of such bodies in Paleozoic carbonate rocks of Custer County may be inferred from references in various reports. Umpleby (1917, p. 80) stated that the copper veins in Skull Canyon (4, fig. 42) near Mackay, are composed of heavily iron stained jaspery material enclosing irregular lenses and slabs of limestone and large bunches of hematite. Ross (1937, p. 101) wrote of the lead-silver replacement deposits in Custer County in the Bayhorse Dolomite near the town of Bayhorse (1, fig. 42): "Commonly the rock in and near the ore is more or less completely silicified, silicification being evidently one of the earliest and volumetrically one of the greatest effects of the mineralizing solutions." In a report on fluorspar deposits in this same formation in Custer County near Challis (2, fig. 42), Anderson (1954, p. 11) mentioned, but did not describe, silicified ledges of dolomite.

It seems logical that jasperoid should also occur with the lead and zinc replacement deposits in Paleozoic carbonate rocks in Lemhi County; however, the only "jasperoid" mentioned in association with ore deposits in Lemhi County (3, fig. 42) is in Precambrian quartzite of the Belt Supergroup. Sharp and Cavender (1962, p. 21, 22, 25, 40) discussed copper-gold-thorium vein and replacement deposits in micaceous quartzite associated with "dense brown jasperoid" formed by the silicification of hydrous iron oxide gangue.

ILLINOIS, IOWA, KENTUCKY, AND WISCONSIN

Three districts in which base-metal sulfide ore deposits are locally associated with jasperoid have been reported in the region that comprises Illinois, Iowa, Kentucky, and Wisconsin. (1) The upper Mississippi Valley zinc-lead district (3, fig. 43) in southwestern Wisconsin and northwestern Iowa, where zones of thin veins, breccias, and replacement deposits of sphalerite, galena, pyrite, and barite are found in carbonate rocks of Ordovician age. (2) The Kentucky-Illinois district (2, fig. 43), in northwestern Kentucky and adjacent parts of southeastern Illinois, in which many fissure veins and a few replacement deposits of fluorite are associated with sphalerite, barite, galena, and jasperoid in Mississippian carbonate rocks. (3) The central Kentucky mineral district (1, fig. 43), where barite, fluorite, and base-metal sulfide veins cut Ordovician limestone, and where breccia fragments of limestone in some of these veins are locally replaced by jasperoid.

UPPER MISSISSIPPI VALLEY DISTRICT
(3, fig. 43)

Siliceous replacement of carbonate rocks in this district is confined to the sulfide ore bodies and the wallrock adjacent to them. Jasperoid is most abundant in dolomite of the Lower Ordovician Prairie du Chien Group. The overlying Ordovician St. Peter Sandstone has been locally silicified along major faults and fracture zones; the carbonate rocks of the Ordovician Platteville and Decorah Formations and the Galena Dolomite, above the St. Peter Sandstone, have been replaced by jasperoid to a much smaller degree than those of the Prairie du Chien Group, generally within, and adjacent to, the larger sphalerite ore bodies. Jasperoid is most prevalent along faults, shears, and shatter zones, extending outward from these channels along selected beds for short distances. In the Galena Dolomite, dark-gray pyritic jasperoid locally forms overgrowths on older

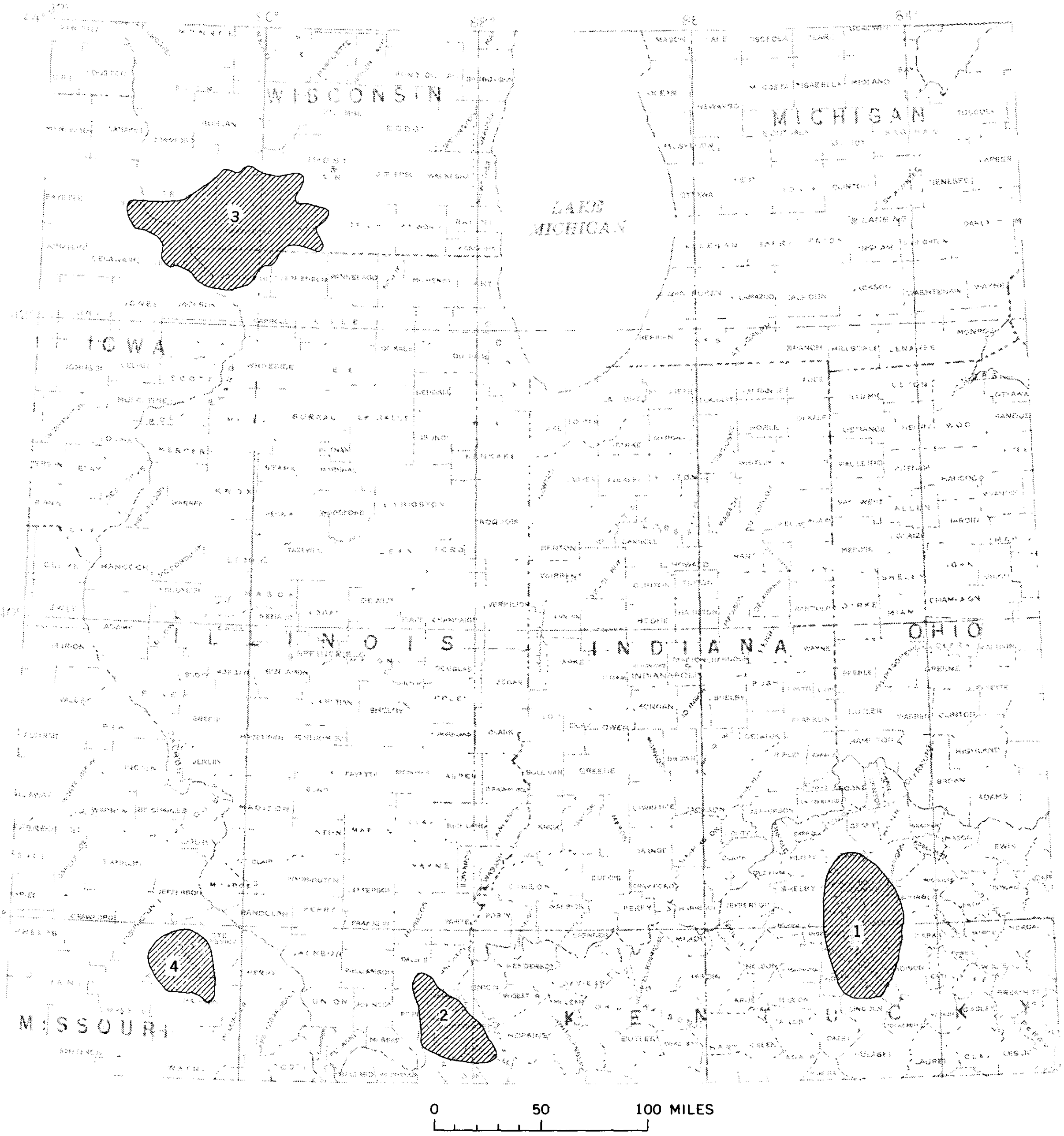


FIGURE 43.—Map showing location of large jasperoid-bearing mining districts in Illinois, Iowa, Kentucky, Wisconsin, and southeastern Missouri. 1, Central Kentucky; 2, Kentucky-Illinois; 3, Upper Mississippi Valley; 4, Southeastern Missouri.

sedimentary chert nodules in intensely mineralized areas. Silicified zones in the Platteville and Decorah Formations are notably more abundant in the southern part of the district than in the northern part. Where the larger reverse faults flatten along bedding planes, the wallrock is commonly replaced by jasperoid in ore bodies. In such areas, as in the Tri-State district, all the lithologic units that are cut by the faults are replaced by gray or brown jasperoid or by white "cotton rock," but, unlike the Tri-State district, jasperoid is very abundant in only a few deposits.

Jasperoid is massive, dense, locally banded, brown or gray, and, because it commonly preserves both the color and texture of the host rock so faithfully, it can be distinguished from unaltered rock only by its superior hardness. At one locality (the Hoskins mine), jasperoid preserves the original appearance not only of the carbonate rocks but of interbedded carbonaceous shale as well. Thin sections of jasperoid show a grain-for-grain equal volume replacement of the host rock (Heyl, and others, 1959, p. 101–105).

KENTUCKY-ILLINOIS DISTRICT

(2, fig. 43)

Jasperoid in western Kentucky was first reported by Smith (1905, p. 128, 139–140). He noted its replacement of limestone adjacent to fissure veins and of breccia fragments within the veins and concluded (p. 139): "This silicification of limestone by quartz is believed to be related to the process of fissure filling, and not to be a common characteristic of the limestones of the district."

According to Fohs (1910, p. 382, 384), fluorite, barite, zinc, and lead veins and a few replacement deposits in Mississippian limestone are irregularly distributed through an area about 80 miles long, east and west, by about 50 miles wide, north and south. Most of the production from this district has come from mines in Caldwell, Crittenden, and Livingston Counties in Kentucky and in Hardin, Pope, and Saline Counties in Illinois. Jasperoid and fluorspar are associated both genetically and spatially with many of these deposits. The jasperoid and fluorspar probably were deposited penecontemporaneously, at least in part. In some localities, laminated limestone is replaced by alternating bands of jasperoid (or quartz) and fluorspar.

Hardin (1955, p. 24) estimated that 5–20 percent of the limestone within 10 feet of many of the veins had been replaced by cryptocrystalline quartz. He believed that this silicification largely preceded the deposition of fluorite.

The paragenesis of ore and gangue minerals from this district and the composition of their primary fluid inclusions have been studied by Hall and Friedman (1963). They believed that several recognizable generations of fluorite preceded the deposition of vein quartz and sulfides, which was followed by deposition of late fluorite, calcite, barite, and witherite. They concluded (p. 902) that the fluids trapped in the early fluorite are mainly connate brines, that a water of different and possibly magmatic origin was introduced during the quartz-sulfide stage, and that the composition of the fluid returned to that of a normal brine during formation of the late gangue minerals.

Silicified breccia pipes and dikelike bodies are present near the center of Hicks dome, a broad structural dome in western Hardin County, Ill. The host rock of these breccia bodies is cherty Devonian limestone, and in drill-core samples below the zone of oxidation, the bodies consist largely of angular breccia fragments of chert and partly silicified host rock in a matrix of fine-grained iron-stained microcrystalline quartz, with accessory fluorite and apatite and minor sulfides. Locally, this breccia is slightly radioactive, although no uranium-minerals have been recognized in it. The breccias are considered to be explosion breccias formed by the explosive venting of steam and hot gases possibly related to deeply buried igneous intrusive rocks (Brown and others, 1954; Bradbury and others, 1955, p. 1–8).

CENTRAL KENTUCKY DISTRICT

(1, fig. 43)

This district covers an area of about 3,600 square miles extending from Owen and Henry Counties on the north to Lincoln County on the south and from Bourbon and Clark Counties on the east to Anderson and Mercer Counties on the west. This large area roughly follows the trend of the Cincinnati arch and is best developed near the Lexington dome.

Ore deposits within the district consist largely of fracture fillings in veins or of breccia-zone replacements along numerous faults and fractures. These deposits show a zonal arrangement outward from a central zone characterized by fluorite, calcite, and black sphalerite through a transition zone of fluorite, barite, calcite, and both light and dark sphalerite, to a broad peripheral zone of barite, galena, and light-colored sphalerite with little fluorite (Jolly and Heyl, 1964, p. 597, 605, 615). The host rocks for these deposits are of Ordovician age and consist largely of limestone.

Jasperoid is not abundant in the Central Kentucky district, but it does occur in a few of the breccia zones in the veins. Jolly and Heyl (1964) stated that gray jasperoid replaces breccia fragments of limestone and older ore and gangue minerals, and that this jasperoid is probably younger than most of the fluorite, barite, and sulfide minerals. They ascribed the origin of these deposits to hydrothermal solutions, mainly heated connate brines and a lesser magmatic solution fraction, ascending along faults from a deep-seated magmatic source centered beneath the Lexington dome.

MICHIGAN

The word "jasperoid" was originally coined by Spurr (1898) because of the resemblance of this rock to the Precambrian jasper of the iron formations in Michigan and Minnesota. Although the jasper beds of the iron formation are now considered by Huber (1959, p. 111–113) to be of syngenetic origin, some Precambrian dolomites in the Michigan iron ranges have been extensively silicified in places, subsequent to their lithification. Leith (1925, p. 515–516) described silicified chert breccias in the upper part of the Randville Dolomite on the Menominee Range and in the upper part of the Kona Dolomite in the Marquette district of Marquette County in the Upper Peninsula (fig. 1). These siliceous replacements he ascribed to the action of silica-bearing ground water on residual chert rubble accumulating on an old erosion surface. However, Gair, Thaden, and Jones (1961, p. C79–C80), after a detailed study of silicification in the Kona Dolomite, concluded that the silicification was more probably caused by silica-bearing solutions migrating laterally or upward along faults and fractures.

MISSOURI

Jasperoid is abundantly associated with bedded sulfide replacement deposits in the vicinity of Joplin, in southwestern Missouri. These deposits are within the big Tri-State district or province (2, fig. 36), which has been discussed previously in the present report. Copper, lead, and zinc sulfide deposits are also concentrated in southeastern Missouri, in St. Francois and Washington Counties; most of these are vein deposits in carbonate rocks of Cambrian and Ordovician age.

SOUTHEASTERN MISSOURI DISTRICT

(4, fig. 43)

The genesis of much of the silica in the carbonate host rocks for the sulfide deposits in this area is controversial. Buckley (1909, p. 51–52, 59–60) mentioned the association of lead deposits with pipelike, sheetlike, and lenticular chert bodies in dolomite beds of the Potosi, Bonneterre, and Gasconade Dolomites. These "chert" bodies in the Potosi he described as irregular crosscutting bodies of honeycombed chert with drusy quartz nodules. In describing the deposits of the Gasconade Dolomite, he (p. 60) wrote: "The horizons at which occur lens-like masses or pockets of chert have associated with them galena, blende, and barite." Buckley (p. 225–226) concluded that both silicification and later sulfide deposition in the Potosi resulted from ground-water circulation in Pennsylvanian or pre-Pennsylvanian time. However, he (p. 225–233) attributed similar deposits in the Bonneterre Dolomite to metasomatic replacement of dolomite (by downward percolating solutions) in post-Pennsylvanian time.

Spurr (1926, p. 974) stated that these deposits in general are characterized by the lack of major gangue minerals or wallrock alteration, and he attributed their origin to the injection of a fluid sulfide ore magma. However, he (p. 975) also stated that "silicification of wall rocks took place during the deposition of the original sulphides."

Ohle and Brown (1954, p. 219–221), in a paper on the lead deposits of the main Southeast Missouri district, ascribed the origin of the ore to aqueous fluids that rose from a deep source and migrated laterally along favorable structures. However, they did not mention silicification in their discussion of wallrock alteration. Brown (1958, p. 6–7) proposed that hot mineralizing fluids rose from an igneous basement along favorable structures and spread laterally; then, as these fluids cooled and mingled with ground water, they changed to downward-moving mineralizing solutions that deposited the ore. Heyl, Delevaux, Zartman, and Brock (1966, p. 952) mentioned a marked similarity in isotopic composition of lead derived from two galena samples in this area, one from an alkalic peridotite dike and the other from a bedded replacement ore body in dolomite.

The Cornwall copper mines, in Madison County near the east edge of this district, have been described by Rust (1935). They are mostly copper-iron-zinc sulfide deposits in pockets and lenses along favorable stratigraphic zones in massive Ordovician dolomites. Solution of the dolomite preceded ore deposition. The remaining pillars between these solution cavities locally collapsed forming "crush breccias"; the dolomite in these breccias was then replaced by silica to form a dense aphanitic rock containing abundant angular breccia fragments of primary chert. The sulfides were then deposited in the remaining open cavities as colloids by far-traveling hydrothermal solutions contaminated with ground water.

Although there is considerable argument as to the origin of the base-metal sulfide and barite deposits of southeastern Missouri, there seems to be general agreement that bodies of silica replacing carbonate rocks are associated, both spatially and genetically, with many of them.

MONTANA

I know of only one mining district in Montana that is characterized by the development of jasperoid; this is on the west flank of the Flint Creek Range near Philipsburg in Granite County, about 50 miles northwest of Butte. The Philipsburg (or Flint Creek) mining district and several smaller districts are in this area. There probably are other jasperoid-bearing areas in the State, but they are not described in the literature. Much of the following data on the

Philipsburg district is from W. C. Prinz (written commun., 1967; 1967, p. 2–10).

PHILIPSBURG DISTRICT

(5, fig. 42)

The Philipsburg district has yielded $70 million in base and precious metals from steeply dipping quartz veins in Tertiary granodiorite and intruded Precambrian rocks and Paleozoic limestone, shale, and quartzite and from quartz-rich bedding veins in Paleozoic limestone. In addition, the district has produced substantial amounts of manganese oxide ore that was derived from the weathering of primary manganese carbonate replacement deposits in Paleozoic limestone and marble.

Two types of favorable jasperoid are recognized in the district, but nowhere is jasperoid abundant. One type is associated with primary manganese and vein deposits and is most abundant in the manganese deposits, where it consists of light- to medium-gray or greenish-gray silicified limestone that is commonly brecciated and cemented by rhodochrosite and manganoan dolomite. In a few places jasperoid also occurs along the borders of steeply dipping quartz veins where they cut carbonate rocks. Some of this jasperoid is brown, probably owing to admixed very fine grained sphalerite.

The second type of jasperoid in the Philipsburg district is associated with the oxidized manganese deposits. Medium- to dark-gray silicified limestone occurs locally along the borders of these deposits and in remnants, veinlets, or cavity fillings within the deposits. That some jasperoid fills cavities in manganese oxides shows that it is, at least in part, supergene in origin.

Emmons and Calkins (1913, p. 68–69) also referred to the prevalence of abundant irregular masses of "chert" in the upper part of the Madison Limestone along Flint Creek 6 miles south of Philipsburg and to one large mass of this "chert" nearly 100 feet thick along a fault that forms the contact between Madison Limestone and Precambrian rocks, near the mouth of Boulder Creek 8 miles north of Philipsburg. The mass along Boulder Creek, they said, is probably the result of silicification along the fault zone. The irregular masses of "chert" in the upper part of the Madison they described as consisting chiefly of fine-grained cryptocrystalline quartz in allotriomorphic grains, mixed with some carbonate. From these descriptions it seems probable that much of the "chert" in the Madison is really unfavorable jasperoid.

NEVADA

Information is available on jasperoid bodies in at least 33 mining districts in Nevada besides the Ely (Robinson) (19, fig. 44) and Eureka (20) districts, which are previously described in this report. Silicified rocks that are probably jasperoid also have been noted, but not described, in another 20 districts (fig. 44). These districts are scattered throughout most of the State east of long 118° W. and north of lat 37°30′ N., but they seem to be most concentrated in two provinces. One province comprises most of Eureka and White Pine Counties as well as parts of Elko, Lander, and Lincoln Counties in eastern and north-central Nevada, and it extends eastward into Utah. A second province comprises Esmeralda County and the eastern part of Mineral County in southwestern Nevada, and it extends southward into California.

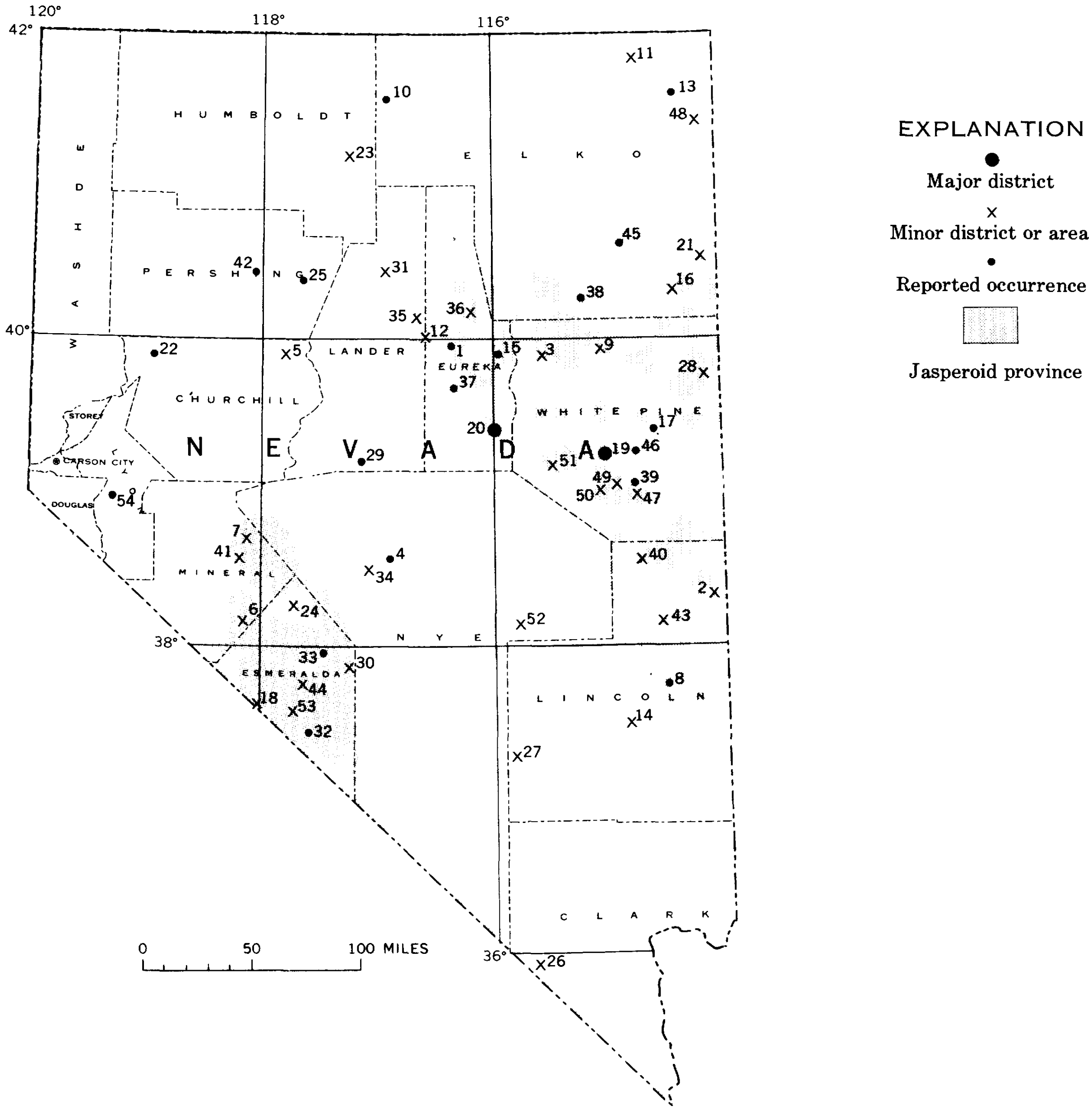
In most of these districts, jasperoid is associated with either silver-bearing or non-silver-bearing base-metal replacement deposits in Paleozoic carbonate rocks and in felsic volcanic rocks. The jasperoid in these districts generally is localized by faults or fracture zones that also served as conduits for the ore-stage mineralizing solutions, and in many districts it also seems to be related to intrusive siliceous dikes and stocks. The Atlanta (2, fig. 44), Delmar (14), and Getchell (23) districts are mainly gold producers; Boyer (5) is a nickel-cobalt district; in the Cortez district (12) antimony, silver, and gold are abundant; the Manhattan district (34) produced gold, arsenic, and antimony; and the Taylor district (47) produced antimony, lead, and silver.

ATLANTA DISTRICT

(2, fig. 44)

The Atlanta mining district lies close to the Utah border in northeastern Lincoln County about 40 miles northeast of Pioche. Silicified pipes, faults, and fracture zones in Ordovician limestone and dolomite were mined for gold and silver in the early part of the 20th century, and small silicified pods containing uranium were developed during the 1950's (Hill, 1916; Sharp and Myerson, 1956).

Hill (1916, p. 116–117) mentioned prominent bodies of jasperoid along a north-trending fault zone in the vicinity of the Atlanta mine, and argentiferous red jasper bodies in quartzite at the Bradshaw mine about a mile south of Atlanta. According to Sharp and Myerson (1956, p. 10), breccia pipes and fault zones in dolomite overlying the quartzite are extensively silicified into drusy quartz and jasperoid in the area of mineralization, and some of the silicified pipes contain gold, silver, and uranium minerals



LIST OF DISTRICTS, AREAS, AND OCCURRENCES

1. Antelope
2. Atlanta
3. Bald Mountain
4. Belmont
5. Boyer
6. Candelaria
7. Cedar Mountain
8. Chief (Caliente)
9. Cherry Creek
10. Columbia
11. Contact
12. Cortez
13. Delano
14. Delmar
15. Diamond
16. Dolly Varden
17. Duck Creek
18. Dyer
19. Ely (Robinson)
20. Eureka
21. Ferguson
22. Fireball
23. Getchell (Potosi)
24. Gilbert
25. Gold Banks
26. Goodsprings
27. Groom
28. Kern
29. Kingston
30. Klondike
31. Lewis
32. Lida
33. Lone Mountain
34. Manhattan
35. Mill Canyon
36. Mineral Hill
37. Mount Hope
38. Mud Springs
39. Nevada
40. Patterson
41. Santa Fe
42. Sheba-De Soto
43. Silverhorn
44. Silver Peak
45. Spruce Mountain
46. Success
47. Taylor
48. Tecoma
49. Ward
50. West Ward
51. White Pine (Hamilton)
52. Willow Creek
53. Wyndypah
54. Yerington

FIGURE 44.—Map showing location of jasperoid-bearing areas in Nevada.

disseminated in the jasperoid. At the Atlanta mine, breccia fragments of limestone, quartzite, rhyolite, and jasper are cemented by quartz containing gold and silver minerals, manganese oxides, limonite, and barite. Northeast-trending reefs of red jasperoid east of the Atlanta mine contain some low-grade gold ore (Hill, 1916, p. 117).

BALD MOUNTAIN DISTRICT

(3, fig. 44)

The Bald Mountain district is in the northwest corner of White Pine County, near the south end of the Ruby Range and about 60 miles northwest of Ely. Ordovician limestone is here intruded by a quartz monzonite stock. Sulfide deposits form replacement ore bodies in the limestone and vein ore bodies in the stock and its aureole of lime-silicate rock. Some of the ore bodies in the limestone consist of pockets of copper carbonate in jasperoid (Hill, 1916, p. 159–160).

Four jasperoid samples from this district are included in my collection; one of these is from a shaft dump, the other three are from outcrops a few hundred feet, a quarter of a mile, and half a mile from the nearest mine workings. The dump sample consists of medium-gray aphanitic jasperoid which is cut by veinlets of brown limonite and which contains sparse small vugs filled with white clay. The other three samples are jasperoid breccias in which both breccia fragments and matrix are dense and aphanitic. The fragments are shades of gray, and the matrix is yellowish brown, moderate brown, or reddish brown, locally banded and streaked.

In thin section the sample from the mine dump consists of heterogeneous xenomorphic quartz that has an average grain diameter of about 0.03 mm. It contains locally abundant carbonate particles and sparse scattered grains of pyrite and zircon. Two of the outcrop samples, taken from breccia zones, contain fragments of jasperoid similar to those in the dump sample, as well as aphanitic cherty fragments, and masses of feathery-textured jasperoid (apparently derived from chalcedony). The matrix has texture and grain size similar to those of the older jasperoid fragments. It is heavily loaded with dust-sized particles of brown limonite and carbonate, and also contains abundant inclusions of a pale-yellowish mineral with low anomalous birefringence, which is probably one of the chlorite group. The matrix is cut locally by jarosite veinlets. The remaining outcrop sample consists of dense cherty-looking quartz containing abundant tiny particles of brown limonite, goethite, and sericite. This matrix has been shattered, and the fractures have been filled with a mixture of limonite, goethite, cryptocrystalline apatite, and kaolinitic clay in various proportions.

All four samples are slightly richer than average in copper, nickel, and zirconium. One of the outcrop samples from a breccia zone contains detectable amounts of the rare-earth elements cerium, lanthanum, yytrium, and ytterbium as well as arsenic, molybdenum, and vanadium. The sample last described above, which is the farthest from mine workings, contains abundant phosphorus and strontium as well as detectable amounts of gallium, scandium, vanadium, yttrium, and ytterbium. None of the samples scored higher than +10 on their indicator elements, and the dump sample scored only +5.

BOYER DISTRICT

(5, fig. 44)

The Boyer district is in northeastern Churchill County, about 30 miles southeast of Lovelock. Nickel and cobalt ore occurs here in small veinlets cutting quartzite and silicified limestone near an intrusive body of diorite (Ferguson, 1939, p. 8, 12). Within the partly silicified limestone are conspicuous bodies of dense white silica that may be either bleached chert or jasperoid. Silicification of the limestone in and around the Nickel mine in Cottonwood Canyon was specifically mentioned by Ferguson (p. 17, 20), but, unfortunately, no description or analysis of this jasperoid was included in his report.

CANDELARIA DISTRICT

(6, fig. 44)

Candelaria is about 50 miles west of Tonopah in southeastern Mineral County. Deposits of gold, silver, lead, and zinc are present here in veins cutting highly altered Ordovician, Permian, and Triassic rocks, which originally consisted predominantly of shale and a few thin beds of carbonate rocks and sandstone. Within the mineralized area the shale has been intensely silicified, sericitized, argillized, carbonatized (Page, 1959, p. 21, 44–46), and stained gray and black by manganese. The most extensive alteration in the area is carbonatization, which has converted large volumes of argillite and associated fine-grained metadolorite intrusive rock to a dense fine-grained grayish-white hydrothermal dolomite. Bodies of jasperoid resembling fine-grained quartzite nearly everywhere form prominent outcrops associated with the hydrothermal dolomite. These jasperoid bodies are particularly conspicuous near the Lucky Hill mine.

CEDAR MOUNTAIN DISTRICT

(7, fig. 44)

Cedar Mountain is in eastern Mineral County about 20 miles northeast of Mina. Triassic limestones and interbedded quartz keratophyres have been intruded by granodiorite, which is cut by dikes of aplite, lamprophyre, alaskite porphyry, and diorite porphyry. Replacement deposits of argentiferous galena and sphalerite are encased in a dark-gray fine-grained jasperoid replacing limestone adjacent to dikes and fractures. These latter have been cut and offset in places by postmineral faults (Knopf, 1922, p. 370–373).

CHERRY CREEK DISTRICT

(9, fig. 44)

Cherry Creek is in northern White Pine County, about 30 miles east of the Bald Mountain district (3) and 40 miles north of Ely, at the south end of the Cherry Creek Range. The ore deposits of the district consist largely of fissure veins of lead, zinc, and silver in lower Paleozoic quartzite and shale and in small bodies of quartz monzonite that locally intrude these rocks. Contact-metamorphic bodies of scheelite were mined in the 1950's. A few manto-type replacement deposits of base and precious metals have also been developed in the northern part of the district in a massive lower Paleozoic limestone overlying the shale, and it is with these deposits that jasperoid is associated. The geology and ore deposits of the Cherry Creek district have been summarized by Hill (1916, p. 161–172); however, most of the ore deposits in limestone have been developed since that report was written. The only mine of this type described by Hill is the Biscuit mine, of which he (p. 166) stated that lenslike bodies of white quartz occur in limestone, and these lenses locally contain disseminated particles of a soft black metallic silver mineral.

I have five jasperoid samples from the Cherry Creek district, taken from localities in the limestone north and west of the mines described by Hill (1916). Three are from outcrops adjacent to mine workings, one is from the dump of a prospect pit, and one is from a breccia zone along a gently dipping fault near a small quartz monzonite dike, about half a mile from the nearest mine workings. All five jasperoid bodies sampled appear to have been localized by breccia zones along faults in the limestone.

Three distinct ages and types of quartz are distinguishable in jasperoids from this district. The oldest of these is dark gray and dense, and has a homogeneous xenomorphic texture, an average grain size of about 0.02 mm, and abundant tiny inclusions of sericite and hematite. This type is cut by, and locally forms inclusions in, a light- to medium-gray compact coarse-grained jasperoid that has a heterogeneous, strongly reticulated texture and a grain diameter that averages about 0.1 mm and ranges from 0.01 to 1 mm; it contains abundant carbonate particles locally concentrated in the cores of the larger grains. This type commonly contains relict inclusions of coarse crystalline calcite. The youngest generation of quartz has a coarse xenomorphic texture, an average grain diameter of about 0.2 mm, and sparse local concentrations of allophane dust. It fills veinlets cutting the older jasperoid and commonly lines sparse small vugs.

The two types of jasperoid were not analyzed separately, and therefore, no comparison of their chemical composition is possible. Analyses of the five whole-rock samples show that most are anomalously high in Ag, Pb, and Zn, as well as Ca, Mg, and Sr. The high concentration of Ca, Mg, and Sr reflects the abundance of calcite in the samples. Silver (lead, and zinc) may be useful indicator elements in jasperoids of the Cherry Creek district; all four samples taken in the vicinity of mine workings are anomalously high in silver, which was not detected in the sample taken half a mile from the nearest mine.

CONTACT DISTRICT

(11, fig. 44)

The Contact district is in northeastern Elko County about 15 miles south of the Idaho State line and 40 miles west of the Utah State line. The ore deposits consist of copper oxides and carbonates in replacement deposits and veins cutting Paleozoic limestone close to the contact with a small granodiorite stock. Limestone adjacent to the intrusive contact is metasomatized to a lime-silicate skarn, but beyond this contact zone, jasperoid is abundant. Schrader (1912, p. 118, 121, 130, 137) spoke of conspicuous bodies of silicified limestone in the Blue Bird, Brooklyn, Queen of the Hills, Ivy Wilson, and War Eagle mines. Some of this jasperoid he described as light colored and fine grained, resembling quartzite, and some as blue and chloritic. Both silicification and ore mineralization in the district seem to be genetically related to the intrusion of the stock.

CORTEZ AND MILL CANYON DISTRICTS

(12 and 35, fig. 44)

The old mining districts of Cortez (12) and Mill Canyon (35) straddle the county line between Eureka and Lander Counties, a few miles north of the

40th parallel and about 40 miles south-southeast of Battle Mountain. The Cortez district is just south of Mount Tenabo, a prominent peak at the south end of the Cortez Range; the Mill Canyon district is on the northern flanks of Mount Tenabo.

The geology and ore deposits of these two districts have been summarized by Emmons (1910, p. 100–108), and the general geology of the area is discussed in more detail by Gilluly and Masursky (1965). Emmons reported that the ore bodies of the Cortez district consist of irregular bedded replacement deposits in Paleozoic limestone. These deposits are localized by northeast-trending fractures, and consist of galena, sphalerite, stibnite, stromeyerite, tetrahedrite, and other arsenic antimony sulfosalts, associated with pyrite and calcite, in a siliceous (jasperoid) matrix. A number of small silver deposits in jasperoid were mentioned "on the trail between Cortez and Mill Canyon." In the Mill Canyon district argentiferous base-metal sulfide deposits in a siliceous gangue are localized by the intersection of fractures with favorable beds in limestone close to its contact with an intrusive granodiorite stock.

A few miles west of the Mill Canyon district, the Roberts Mountain thrust fault brings Ordovician siliceous shale and chert in the upper plate over Silurian shale and Devonian limestone in the lower plate. Both upper and lower plates are broken by high-angle normal faults and are intruded by small dikes and lenticular masses of Tertiary felsic plutonic rocks. Geochemical mapping of altered rocks close to these faults and intrusive masses in both upper and lower plate rocks has defined pronounced copper, lead-zinc-silver, arsenic, bismuth, and manganese anomalies in the siliceous rocks of the upper plate close to the trace of the thrust fault and gold, arsenic, antimony, and tungsten anomalies in the carbonate rocks of the lower plate adjacent to a strong northeast-trending normal fault (Erickson and others, 1961, 1964b).

Thirteen samples of jasperoid are included in the suite from the lower plate rocks collected and analyzed by Erickson and his colleagues (1964a). Most of these samples contain anomalously high concentrations of As, Ba, Sb, and Zr, and many of them are also high in B, Be, V, and W. Only five of the 13 samples score as possibly or probably favorable on the basis of their indicator-element concentrations. Only two of these samples were described as conspicuously vuggy, and these two yielded the highest scores, +12 and +9, respectively. Four of the five jasperoid samples scoring +5 or higher came from close to the strong northeast-trending fault in the area with the strongest geochemical anomaly (Erickson and others, 1964b, p. B93). Although no gold assays are reported on these samples, the recent discovery of a large low-grade gold ore body in the area suggests that gold is also present.

DELMAR DISTRICT

(14, fig. 44)

The Delmar district is in south-central Lincoln County about 40 miles southwest of Pioche. Most of the production from the district has been of gold ore from veins and breccia zones in the Lower Cambrian Prospect Mountain Quartzite; however, evidence of mineralization is also found in Middle Cambrian shale and limestone above this quartzite (Callaghan, 1937, p. 33, 40, 45–49).

The quartzite breccia fragments are commonly cemented and partly replaced by fine-grained vuggy ore-bearing silica, and some limestone beds in the thick shale units have been completely replaced by jasperoid in places. The thick Middle and Upper Cambrian Highland Peak Formation has locally been converted to aphanitic dark-gray jasperoid along faults and breccia zones in the southern part of the district, particularly near the wash northeast of Big Lime Mountain (Callaghan, 1937, p. 45). A small body of rhyolite on the Jumbo claim has been completely replaced by silica with preservation of the original quartz phenocrysts.

DOLLY VARDEN DISTRICT

(16, fig. 44)

The Dolly Varden district is in southeastern Elko County in a small group of mountains at the south end of Goshute Valley about 35 miles southwest of Wendover. The general geology and ore deposits of the area were summarized by Hill (1916, p. 76–88).

A small quartz monzonite stock in the northern part of the district is in intrusive contact with Carboniferous shale and limestone near the center of the district. These sedimentary rocks form the bedrock in the rest of the district, south and east of Dolly Varden Pass. Close to the edge of the intrusive these rocks have locally been contact metasomatized to skarn, hornfels, and white marble. In the southeastern part of the district, around Castle Peak, the unmetamorphosed sedimentary rocks consist of a thick section of medium-bedded limestone overlain by calcareous and cherty shale and argillite. Oxidized copper ore bodies are associated with lime-silicate rocks near the intrusive, and bedded replacement lead deposits occur in limestone in the southeastern part of the district.

Hill (1916) mentioned a prominent iron-stained siliceous outcrop containing copper carbonate on the

Hidden Treasure claim in limestone south of Watson Spring. He also mentioned a jasperoid body on the Victoria claim in Watson Canyon west of Watson Spring, of which he (p. 86) wrote: "The croppings, iron-stained cellular quartz and jasper, with some copper carbonates, stand about 10 feet above the surrounding country and cover an area about 100 feet long north and south by 75 feet wide." The ore on this property consists of secondary copper minerals in iron-stained silicified limestone containing abundant tremolite.

Three samples of jasperoid from the Dolly Varden district are included in my collection. One of these samples is from an outcrop close to the Victoria mine shaft, probably the same one described by Hill (1916); the other two are from outcrops adjacent to old mine workings in the lead-bearing southeastern part of the district on both sides of Spring Canyon north of Castle Peak.

The sample from the outcrop near the Victoria mine shaft looks barren in the hand specimen. It is aphanitic and dark red to reddish brown on fresh surfaces and weathers almost black. It consists of heterogeneous matrix quartz that has xenomorphic to jigsaw-puzzle texture and a grain diameter that ranges from 0.01 to 0.15 mm and averages 0.03 mm, and it contains abundant disseminated grains and interstitial masses of red hematite. The brown areas consist of irregular ragged quartz particles disseminated through a mixture of hematite and orange goethite. Spectrographic analysis of this sample, however, belies its unpromising appearance. It contains abundant copper (0.15 percent) and is also anomalously high in Fe, Bi, In, Mo, Ni, and V. The concentrations of indicator elements in the sample yield a score of +15, which places it in the highly favorable category.

One of the two remaining samples, from the dump of a prospect pit, appears to be a silicified siltstone; the other is from a jasperoid outcrop in limestone close to the collars of two adjacent inclined shafts. These samples are similar in appearance but are strikingly different from the sample previously described. They are light gray, yellowish gray, brownish gray, and aphanitic, and they contain local porous areas honeycombed with microvugs. Both are fractured though not brecciated, and the fractures are coated with brown limonite and, locally, with green copper stains.

The dump sample has a matrix of rounded quartz grains and sparse accessory tourmaline, zircon, sphene, and hematite. This matrix is cut by veinlets rimmed with fibrous chalcedony and commonly filled with coarse jigsaw-puzzle-textured quartz. Thin veinlets of orange goethite cut the chalcedony quartz veinlets, and goethite is also disseminated through the matrix in scattered equant grains that look to be pseudomorphous after pyrite.

The outcrop sample has a granular to xenomorphic heterogeneous matrix whose grain diameter ranges from <0.01 to 0.1 mm and averages 0.03 mm. Small barite crystals and an unidentified aphanitic yellow mineral with low birefringence and indices of refraction greater than quartz but less than those for barite form abundant inclusions in the matrix, which also contains sparse hematite and goethite pseudomorphs after original pyrite. Small irregular open vugs are moderately abundant in the finer grained matrix quartz.

The dump sample of silicified siltstone is high in B and moderately high in Fe, Na, Be, Cr, Mo, Pb, Sc, Sr, V, and Zr. The outcrop sample of jasperoid is high in Ag and moderately high in B, Bi, Pb, and Sr. Both samples yielded a score of +9 for their indicator elements.

The indicator elements present in these favorable jasperoid samples faithfully reflect the nature of the ores with which they are associated. The sample from the copper mine in the central part of the district is high in copper and its associated minor elements indium, molybdenum, and nickel but low in lead and silver; whereas the samples from the southeastern part of the district are high in lead and silver but low in copper, indium, molybdenum, and nickel. All samples are moderately high in bismuth.

DYER DISTRICT

(18, fig. 44)

The Dyer district is in western Esmeralda County close to the California State line and about 45 miles west of Goldfield. Little information has been published about the geology and ore deposits of this small district, which has long been abandoned. Spurr (1906b, p. 84–85) mentioned the occurrence here of replacement deposits of siliceous black argentiferous copper sulfide ore along bedding-plane faults in lower Paleozoic limestone; he also referred to small irregular pods of jasperoid scattered abundantly through this limestone.

FERGUSON DISTRICT

(21, fig. 44)

A group of small abandoned mines and prospects, just west of U.S. 50 Alternate Highway at Ferguson Springs, Elko County, Nev., about 25 miles south of Wendover, and 7 miles west of the Utah State line, constitutes the Ferguson district. In a brief summary of this district, Hill (1916, p. 97-98) stated that mineralization is concentrated in Paleozoic limestone along an east-trending fracture zone. The ore consists of irregular replacement deposits of barite and limonite, locally stained with copper carbonate. He mentioned the occurrence of large bodies of dark chert in the limestone but said nothing about silicification related to the mineralization.

Three samples collected from this district consist of aphanitic gray slightly vuggy jasperoid or jasperoid breccia fragments in a yellowish-brown siliceous matrix with similar texture; the rock weathers yellowish brown or dark brown. Both the older jasperoid quartz and the younger matrix quartz have a slightly heterogeneous xenomorphic texture and an average grain diameter of about 0.02 mm. The older jasperoid contains sparse detrital grains of tourmaline and sphene and local concentrations of carbonate particles. The matrix quartz is heavily clouded with yellow limonite dust, and it contains abundant shreds of sericite. Vugs in both older jasperoid and matrix are largely open, though a few are lined with calcite, which also fills late fractures cutting the matrix. These samples are all slightly high in Ba, Sr, and Zr, and one sample, taken at a prospect pit, also is slightly high in B, Ga, Ni, and V. All three samples yielded indicator-element scores of −1.

GETCHELL MINE AREA (POTOSI DISTRICT)

(23, fig. 44)

The Getchell mine is at the northeast end of the Potosi district on the northeast flank of the Osgood Mountains, in Humboldt County, about 30 miles northeast of Winnemucca. In this area Cambrian shale and argillite with some interbedded limestone have been intruded by a granodiorite stock of Cretaceous age. A strong steeply eastward-dipping fault zone strikes northerly along the east base of the range in the sedimentary rocks. Gold deposits of the Getchell mine are largely concentrated along sheeted zones in black shale within this fault zone. Much arsenic and some mercury are associated with the gold ore (Erickson, Marranzino, Oda, and Janes, 1964, p. A2–A4). Tungsten has been mined in the mountains west of the fault, in tactite zones adjacent to the granodiorite stock (Hobbs and Clabaugh, 1946).

Jasperoid bodies are exposed in Paleozoic rocks on the east side of the fault. One such occurrence is in limestone of Permian and Pennsylvanian age about a quarter of a mile east of the northern workings of the Getchell mine, and another is in interbedded argillite and limestone of Ordovician age about 2 miles south of the southern workings of the mine.

The jasperoid replaces the country rock along small shears and fractures. It is commonly brecciated and heavily stained on the outcrop in various shades of yellow, brown, and red. Analyses of four samples of jasperoid from the northern area and 11 from the southern area (by Erickson and others, 1964, tables 2, 4, 5) show that most of the jasperoid samples from the northern area are anomalously high in As, Ba, Pb, and Zn, and that most of the samples from the southern area are anomalously high in As, B, Ba, Sr, and W. All samples from the northern area yield favorable scores. Four from the southern area would be classified as favorable, four as possibly favorable, and three as barren.

GILBERT DISTRICT

(24, fig. 44)

The Gilbert district is in northern Esmeralda County, about 20 miles northwest of Tonopah, at the east end of the Monte Cristo Mountains. Tertiary volcanic rocks cover most of the district, but older rocks are exposed in the vicinity of the Carrie mine in the northwestern part of the district. These older rocks consist of massive crystalline limestone, of probable Ordovician age, interbedded with a little dark shale and tuff and intruded by dikes of quartz monzonite. The limestone has been silicified near the dikes to form prominent jasperoid "ledges" cut by abundant quartz veins (Ferguson, 1928, p. 130, 138).

At the Carrie mine silver-bearing base-metal sulfide deposits formed in these quartz veins. Ferguson (1928) noted that the jasperoid contains sericite and epidote, and that the ratio of epidote to quartz increases with distance from the dikes. In his description of the Carrie mine, Ferguson (p. 139) stated:

> The silicified wall rock is texturally the equivalent of the jasperoid ledges which occur in the district. The vein locally includes a considerable proportion of this jasperoid in relations that suggest a gradation between the replaced limestone cut by later veinlets of crystalline quartz and the massive quartz veins themselves.

The jasperoid and its associated quartz veins are older than the Tertiary volcanic rocks.

GOODSPRINGS DISTRICT

(26, fig. 44)

Jasperoid has been reported in the Goodsprings district by Albritton, Richards, Brokaw, and Reinemund (1954, p. 25–26), and was described under other names by Hewett (1931). This district is in southwestern Clark County, close to the California line and about 35 miles southwest of Las Vegas. Mississippian limestone in the district has been cut by numerous faults and fractures that controlled the mineralizing solutions that formed base-metal sulfide deposits as both replacements and veins. Jasperoid is not abundant in this district. Hill (1914) did not mention it, and, in fact, he (p. 246) stated that most of the limestone replacement deposits in the district are characterized by absence of gangue minerals. Hewett (1931, p. 57) noted that, although silicification is not a conspicuous feature of the district, "ferruginous chert" is abundant in some mines, and that Yellow Pine, Double Up, Boss, and John mines contain appreciable silica related to ore deposition. Although Hewett did not refer to either of these rocks as jasperoid, his description clearly indicates that the ferruginous chert corresponds to supergene jasperoid and that the silica related to ore deposition corresponds to hypogene favorable jasperoid.

Hewett (1931, p. 83) described a dense, opaque, yellowish-brown to dark-brown ferruginous chert, associated with limonite and jarosite, which is locally abundant at and near the surface and grades downward into cream-colored chert containing scattered quartz grains. This variety forms veinlike masses replacing shale or dolomite, and is absent at depths of 100–250 feet below the surface. The origin of this "chert" is ascribed to the action of circulating surface water.

Hewett also referred to masses of cavernous gray quartz, exposed in some copper and silver mines, that is composed of interlocking grains that are 0.05–0.2 mm in diameter and that contain minute inclusions of octahedrite and rutile, and of cavities filled with a white powder consisting of tiny doubly terminated quartz crystals. He described hypogene silicification of dolomitic wallrock at the Double Up and Pilgrim mines resulting in veinlets and poorly defined areas of quartz that in part replace and in part fill cavities in the dolomite. A broad fracture zone at the Double Up mine contains lenses of dark fine-grained quartz as much as 35 feet long, 20 feet wide, and 5 feet thick bordered by a porous limonitic zone. A similar mass forms a lenticular pipe which is the main ore body at the Boss mine. This pipe consists of dark coherent cellular masses composed of interlocking quartz grains that are 0.03–0.1 mm in diameter, interspersed with white crystalline quartz powder, surrounded by an envelope of limonite that grades outward into dolomite impregnated with copper carbonates. Assays of the dark cellular quartz in the core of this pipe yielded as much as 12 oz Au, 11 oz Ag, 7 oz Pt, and 4.5 oz Pd per ton (Hewett, 1931, p. 82, 109, 115–116).

Albritton and his colleagues (1954, p. 25–26) reported jasperoid near the Yellow Pine and Prairie Flower mines. These two mines are on the east slope of Shenandoah Peak in the Spring Mountains near the center of the district. In this area the limestone has been intruded by irregular dikes and sills of quartz monzonite porphyry and extensively altered by hydrothermal solutions. The limestone is dolomitized and silicified. Silicified zones are generally parallel to the bedding and range from a fraction of a foot to 25 feet in thickness. Within these zones the jasperoid in part preserves the original color and texture of the limestone, and in part consists of irregular gray, black, and brown cherty lentils and pods. Veins of brown "chert" follow many fractures and faults (Albritton and others, 1954, p. 25–26).

GROOM DISTRICT

(27, fig. 44)

The Groom district is in southwestern Lincoln County, about 75 miles west-southwest of Caliente and 35 miles west of Alamo. The district is in a downfaulted block of Cambrian shale and limestone; the internal structure of this block is complex. Replacement deposits, which consist largely on argentiferous galena, occur both along fractures and as mantos in the limestone (Humphrey, 1945, p. 9, 17, 32). This limestone is commonly silicified along faults and fractures in the vicinity of the ore bodies.

KERN DISTRICT

(28, fig. 44)

Hill (1916, p. 207) mentioned the occurrence of jasperoid in Water Canyon about 12 miles southeast of Tippett, near the south end of the Kern Mountains in northeastern White Pine County. Dark-blue Paleozoic limestone has been replaced by lenticular masses of quartz, parallel to the bedding near the contact of the limestone with an intrusive granitic stock. The jasperoid quartz locally contains hematite, and some of it is coated with yellow cerussite along fractures.

LEWIS DISTRICT

(31, fig. 44)

The Lewis district is near the north end of the Shoshone Range in northeastern Lander County, about 12 miles southeast of Battle Mountain. Paleozoic quartzite and limestone in this area have been intruded by granodiorite porphyry of Laramide age. The ore deposits consist of pyritic gold-quartz veins in the intrusive rocks and quartzite and of base-metal sulfide replacement bodies in the limestone. One of these replacement deposits, at the Starr Grove mine, contains disseminated sulfides in a siliceous baritic gangue. Emmons (1910, p. 126) stated that the main ore body is a large tabular-bedded replacement body in dark-gray limestone overlain by massive quartzite.

This body consists of barite and quartz with disseminated pyrite, galena, and sphalerite. The barite is older than both quartz and sulfides, as shown by the fact that breccia fragments of barite occur in a matrix of quartz with disseminated sulfides. From Emmons' brief description, it cannot be ascertained whether the quartz gangue in this deposit is a true replacement jasperoid or whether it consists only of vein quartz filling fractures and cavities in an older barite body.

MANHATTAN DISTRICT

(34, fig. 44)

The Manhattan district is in the southern part of the Toquima Range in northwestern Nye County, about 35 miles north of Tonopah. Fissure veins and replacement deposits in Cambrian limestone have been mined for gold, arsenic, and antimony. The following description is taken from Ferguson's report (1921) on the geology and ore deposits of this district.

The ore-bearing limestone beds are concentrated near the bottom and near the top of a thick section composed mostly of micaceous schist with some interbedded lenticular sandstones and quartzites. These Cambrian rocks are overlain by about 400 feet of Ordovician schists, and these schists, in turn, by a similar thickness of dark-gray thin-bedded barren limestone containing abundant black to dark-gray jasperoid. The main ore bed, known locally as the "White Caps limestone," is cut by a number of closely spaced preore normal faults, some of which show postore movement. These faults were the conduits for mineralizing solutions that formed replacement ore bodies in the limestone.

The earliest gangue mineral is coarse white calcite, which was followed by dark-gray fine-grained jasperoid that replaced both the early calcite and the limestone host rock in the immediate vicinity of the ore bodies. Muscovite and fine-grained auriferous pyrite and arsenopyrite formed penecontemporaneously with this jasperoid and are disseminated through it. Younger stibnite and realgar replace coarse calcite and, to a lesser extent, the jasperoid.

Numerous lenticular vugs, elongated parallel to the bedding of the host rock, are present in the jasperoid, and many of these are encrusted with one or more of the following minerals: quartz, calcite, dolomite, fluorite, stibnite, pyrite, orpiment, and realgar. The dark-gray to black color, characteristic of the jasperoid in this district, is caused by abundant carbonaceous particles disseminated through it. In some places, jasperoid has been brecciated by postore movement on the faults. The deposits of this district were considered by Ferguson (1921, p. 34) to be of probable Tertiary age and to have formed at shallow depth.

MINERAL HILL DISTRICT

(36, fig. 44)

The Mineral Hill district is on the west side of the Pinyon Range in east-central Eureka County, about 50 miles south-southwest of Elko. According to Emmons (1910, p. 95–99), argentiferous base-metal sulfides form replacement deposits in gray crystalline Paleozoic limestone along a north-trending silicified fracture zone. These deposits are all shallow, and were chiefly mined for silver. The ore bodies are irregular, highly silicified bodies that are localized by fractures transgressing the bedding of the host rock. In some places, quartz and sulfides have replaced the host rock; in others, they merely cement breccia fragments in a fracture zone. Iron-stained jasperoid forms prominent outcrops over many of the ore bodies. Near the surface the sulfides have oxidized to cerargyrite, malachite, azurite, pyromorphite, cerussite, limonite, and manganese oxides. Primary ore and gangue minerals of the deposits are sparse sulfides (pyrite, galena, sphalerite, tetrahedrite, and argentite) and quartz, barite, and calcite.

PATTERSON DISTRICT

(40, fig. 44)

The Patterson district is in northwestern Lincoln County, about 45 miles north-northwest of Pioche, and 50 miles south of Ely, near the south end of the Schell Creek Range. According to Schrader (1931a, p. 7, 11, 15), the country rock in the district is Cambrian shale, quartzite, and limestone. Ore deposits consist of siliceous copper-lead-silver minerals in quartz-carbonate replacement veins in limestone that is commonly silicified to a jasperoid. In his description of ore deposits on the Streater claims, Schrader (p. 15) wrote that

> The ores occur mostly as replacement deposits in silicified limestone in a gangue of quartz, barite, and altered rock. The chief ore mineral is argentiferous galena * * *. Some of the ore consists chiefly of silicified limestone, stained by yellowish-brown iron oxide and by lead and copper carbonates. It is crudely ribbed or banded with stringers of replacement quartz as much as two-tenths of an inch wide * * *.

SANTA FE DISTRICT

(41, fig. 44)

The Santa Fe district is in eastern Mineral County, near Luning, in the Pilot Mountains. White and gray crystalline limestone of probable Triassic age has been intruded by quartz monzonite and quartz diorite and metasomatized to garnet rock adjacent to the intrusive contacts (Hill, 1915, p. 159–160).

In addition to the typical contact skarns, which are host rocks for copper and lead sulfide ores, partly metasomatized limestone has been locally silicified to form jasperoid bodies with calc-silicate inclusions. Hill (1915, p. 168–170) described the Giroux Ledge as a dark-gray, brown-weathering jasperoid containing angular breccia fragments of white cellular quartz; at the Mayflower property the top of a hill is altered to greenish-white jasperoid containing garnet and epidote; and at the Wall Street mine supergene copper minerals form thin films and irregular masses in reddish-brown jasperoidal limestone.

SILVERHORN DISTRICT

(43, fig. 44)

The Silverhorn district, in northern Lincoln County, is about 20 miles northwest of Pioche and 4 miles north of Bristol Pass. Westgate and Knopf (1932, p. 51) described huge outcrops of jasperoid, as much as several hundred yards long and several hundred feet wide, in the Mississippian Bristol Pass Limestone in this district. It is apparent that this jasperoid is structurally controlled and that it locally formed the host rock for oxidized silver deposits. An adit in the district cuts an 80-foot-thick jasperoid body 200 feet below the outcrop. This body replaces limestone along its fault contact with shale and, according to Westgate and Knopf (1932, p. 51), "is the normal fine-grained siliceous rock that is formed as a result of the replacement of limestone by minutely crystalline quartz."

SILVER PEAK DISTRICT

(44, fig. 44)

The Silver Peak district is about 25 miles west of Goldfield in central Esmeralda County. Most of the production from this district has come from mines on Mineral Ridge, 4 miles northwest of the town of Silver Peak. The ore bodies are bedded replacements in Cambrian and Ordovician limestone and dolomite associated with intrusive dikes and sills of alaskite. The ore consists of a black copper-silver sulfide locally disseminated through white jasperoid, according to Spurr (1906b, p. 73–74). He described the jasperoid as a mesh of interlocking quartz crystals with the interstices filled by finer grained anhedral quartz (reticulated texture); the jasperoid is coarser grained in the vicinity of the sulfides than elsewhere. It is approximately contemporaneous with the sulfides, and it has gradational contacts with the enclosing carbonate rock.

I have one sample from this area, taken from the north end of Mineral Ridge, about 6 miles north of the town of Silver Peak and more than 1 mile from the mines. This sample is light gray and aphanitic with local porous areas, it has dark-yellowish-orange fracture coatings, and it weathers grayish brown. In thin section it does not exhibit the reticulated texture described by Spurr, but it has a heterogeneous xenomorphic texture and an average grain size of 0.04 mm. It contains abundant disseminated grains of microcline approximately contemporaneous with the quartz. It also contains numerous red hematite inclusions pseudomorphic after pyrite, shreds of sericite, and irregular masses of opaque dark-brown limonite. The matrix is cut by veinlets of coarse calcite.

Spectrographic analysis shows this sample to be slightly high in Fe, Na, K, Ti, Ba, Co, Cr, Ga, Sc, Sr, V, Y, Yb, Zn, and Zr. It yields a score of +4 on the indicator elements. The absence of reticulated texture and of high Cu and Ag suggests that this sample probably does not represent the ore-bearing jasperoid described by Spurr.

TAYLOR DISTRICT

(47, fig. 44)

The Taylor district is near the south end of the Schell Creek Range in White Pine County, about 15 miles southeast of Ely. The geology and ore deposits of this district have been briefly described by Hill (1916, p. 200–201) and, more recently, by Drewes (1962, 1967).

According to Hill, the ore deposits at the Argus mine are in a massive brownish-gray bed of limestone, 70 feet thick, which is cut by north-trending block faults. The limestone is brecciated near the faults, and it has been selectively silicified in two bands, one about 15 feet above the base and the other about 15 feet below the top of the bed. These silicified bands contain most of the ore. They are heavily stained with carbonates of lead and copper and contain a disseminated dark-gray metallic sulfosalt with Fe, Cu, and minor As, Ag, and Pb. Both mineralization and silicification extend outward irregularly into the limestone from these high-grade bands. The silicified rock is cut by veinlets of late calcite.

According to Drewes (1962), most of the ore in the district is concentrated in two stratigraphic units, the upper member of the Devonian Guilmette Formation and the upper part of the Mississippian Joana Limestone. Both of these units are thin-bedded limestones that are overlain by black shale. Most of the production from the district has come from mines in the Guilmette Formation, which was the unit described by Hill. Mineralization is largely restricted to silicified zones in limestone, and these zones, in turn, are controlled structurally by proximity to faults and stratigraphically by thick shale cappings over the limestone host rock. Many thick short rhyolitic dikes are present in the district, and these dikes may be related to mineralization (Drewes, 1962).

Although the ore in the district has been mined mostly for its silver content, it also contains gold, copper, lead, zinc, and antimony in various places. A number of grab samples of jasperoid taken by Drewes from abandoned mine workings in the central part of the district were analyzed spectrographically. Seven of these samples were abnormally high in Ag, Cu, Pb, and Zn and slightly high in B. Most of the samples were also high in Ba, Cd, Sb, and Zr. Their indicator-element scores range from +18 to +26, placing them high in the favorable category (Harald Drewes, written commun., 1965).

Seven samples from the Taylor district and its vicinity are included in my collection. Three of these samples were collected about 2 miles north of Taylor close to the road leading to Taylor Springs; the stratigraphic unit represented by these samples is probably Guilmette Formation. One sample of jasperoid from the Joana Limestone was collected from the dump of an adit along a strong fault on the North Star claim half a mile north of the main workings of the district. The remaining three samples are of jasperoid from the upper member of the Guilmette Formation near the center of the district and close to the old Monitor and Argus mines. These three samples are from a large brecciated zone not far from major faults; all the other samples are from silicified fault zones. The first three samples, from the ridgecrest above the Silver Queen shaft and the small saddle just west of it, close to the road, are all more than a mile from mine workings and hence, presumably are unfavorable; however, they vary considerably in both appearance and other characteristics.

One of these samples consists of light-gray breccia fragments in a dark-gray slightly vuggy matrix. In thin section two types of breccia fragments can be distinguished: aphanitic pale-brown cherty-looking fragments and fine-grained heterogeneous reticulated jasperoid fragments that have an average grain diameter of about 0.03 mm. These fragments are embedded in quartz that has a xenomorphic to reticulated texture and a grain diameter that averages 0.02 mm and ranges from <0.01 to 0.1 mm. Calcite is present as ragged relict grains in jasperoid breccia fragments, as carbonate particles in both breccia fragments and matrix, and as filling in late veinlets cutting the matrix. The sample showed anomalously high values for Na, As, B, Mo, Pb, Sb, Sr, Zn, and Zr, and it yielded an indicator-element score of +9 (probably favorable). Thus, this sample may indicate leakage along the fault from ore deposits at depth.

A second sample of this group appears to represent the same jasperoid that formed the breccia fragments in the first one. It has a similar appearance and microtexture, but it contains tiny red hematite grains and interstitial yellow limonite in addition to the carbonate particles. B, Ba, Pb, Sr, and Zn are slightly high, and the indicator-element score is +5.

The third sample of this group is dense, dark-red, streaked with light brown, xenomorphic jasperoid quartz whose grain diameter averages 0.03 mm and ranges from 0.01 to 0.2 mm. The quartz contains abundant carbonate particles, and it is cut by a mesh of red hematite veinlets, many of which are filled with a microbreccia of jasperoid particles. The trace-element suite associated with it consists of Fe, B, Ba, Ni, Sb, Sr, V, Y, Yb, and Zr. Its indicator-element score is −1; this jasperoid, therefore, is classified as unfavorable.

The single sample of jasperoid from the Joana Limestone, from the adit dump on the North Star claim, is unusual in that it contains antimony as a major constituent. It is light olive gray and dark yellowish brown, fine grained, and compact, and it is cut by veinlets of relatively coarse white quartz. The matrix jasperoid is xenomorphic, and its grain diameter averages 0.02 mm and ranges from 0.01 to 0.1 mm. The late white quartz is also xenomorphic, and its grain diameter averages 0.1 mm and ranges from 0.03 to 0.5 mm; it contains sparse irregular open vugs. The antimony mineral, which forms abundant irregular inclusions in the matrix, is aphanitic and yellowish brown, and it has a high index of refraction. It probably is a supergene alteration product of stibnite and may be the basic antimony sulfate klebelsbergite. In addition to Sb, this sample is highly enriched in Ag and slightly enriched in As, B, Ba, Pb, Ni, Sr, Y, Yb, and Zn. It yields a score of +14.

The three samples of jasperoid from the central part of the district are light gray to yellowish brown, fine grained, and locally vuggy with abundant limonite stains and fracture coatings. They exhibit a reticulated to xenomorphic texture, and their grain diameter averages about 0.05 mm and ranges from 0.01 to 0.1 mm. The samples are locally cut by veinlets of slightly coarser xenomorphic quartz. The matrix contains abundant carbonate particles; limonite, jarosite, and hematite are locally abundant as supergene inclusions and fracture fillings. Minor-element content varies considerably among the three samples, but there is general enrichment in Ag, B, Cu, Pb, Sb, Sr, Yb, Zn, and Zr. Presumably, these samples are similar to those collected by Drewes from the same locality, though they do not yield as high scores; the maximum score obtained from my group is +13.

Ore deposits of this district appear to be closely associated both spatially and genetically with jasperoid bodies, and jasperoid in the immediate vicinity of such deposits commonly exhibits favorable characteristics; thus, these jasperoids should provide a useful tool for any future exploration in the area.

TECOMA DISTRICT

(48, fig. 44)

The Tecoma district is in northeastern Elko County, about 4 miles west of the Utah State line and 35 miles south of the Idaho State line in the southwestern part of the Goose Creek Range. The ore deposits in the district are largely oxidized lead and zinc sulfide vein deposits in complexly faulted Paleozoic sedimentary rocks, consisting predominantly of limestone and dolomite.

Near the Jackson mine coarse-grained quartzite is in fault contact with Devonian blue-gray limestone and dolomite. These carbonate rocks are cut by several north-trending faults that locally have served as conduits for silicifying solutions producing large jasperoid bodies. One such body, about 500 feet long and 40 feet wide, is the host rock for the ore bodies in the mine. These bodies consist of silver-bearing cerussite, a little smithsonite, and a few residual pods of galena in a gangue of oxidized rusty jasperoid; limonite, calcite, clay, and barite occupy fracture zones in the jasperoid. A larger, but apparently unmineralized jasperoid body, crops out 1,000 feet northeast of the mine; it is about 200 feet wide and extends northward for several thousand feet. Contacts between jasperoid and host rock are commonly brecciated (Granger and others, 1957, p. 149–150).

WARD DISTRICT AND WEST WARD AREA

(49 and 50, fig. 44)

The Ward district (49) is in White Pine County about 10 miles south of Ely, on the east side of the Egan Range. A second mineralized area, centered about 2½ miles west of the Ward district on the opposite side of the Egan Range, is characterized by magnetic and geochemical anomalies and by locally abundant jasperoid (Brokaw and others, 1962). This area I refer to as the West Ward area (50).

The geology and ore deposits of the Ward district have been summarized by Hill (1916, p. 180–186). Paleozoic limestone beds, which make up a thick section and which have gentle easterly dips throughout most of the district, are locally intruded by north-trending quartz monzonite dikes. Both dikes and limestones are cut by younger faults and have been hydrothermally altered by mineralizing solutions. The ore deposits are closely associated with the dikes, and they generally occur close to the contacts as bedded replacements in the limestone and as veins in both the limestone and the dikes. Within the zone of oxidation the ore consists largely of argentiferous cerussite, hemimorphite, smithsonite, and copper oxidation products in a siliceous limonite gangue. Primary sulfides below the zone of the oxidation are galena, sphalerite, pyrite, and a little chalcopyrite. Limestone is locally silicified near the dikes, and in some places the ore bodies are in this silicified zone. The Defiance ore body, 500 feet below its outcrop, is a silicified zone 300 feet wide impregnated with pyrite and galena adjacent to a strong northeast-trending fault (Hill, 1916, p. 183–184). Silicified limestone adjacent to porphyry dikes is also present in the lower Paymaster tunnel and the Welcome Stranger Tunnel (Hill, 1916, p. 185–186).

I have three jasperoid samples from the Ward district. The host rock for all three samples is Mississippian, Pennsylvanian, and Permian Ely Limestone. One sample is from a silicified zone along a northeast-trending fault about a mile south of the district. Another sample is from a zone adjacent to a quartz monzonite dike a few hundred feet south of the strong east-west fault that marks the south boundary of the district and about a quarter of a mile southwest of the 280 Tunnel. The third sample is siliceous gossan from the outcrop of a vein in a fault zone adjacent to a large quartz monzonite dike; it was taken within a few feet of mine workings about half a mile west of the 280 Tunnel.

The first sample is grayish red and aphanitic, and it contains sparse irregular vugs, of which some are open and some are filled with coarse white calcite. Its microtexture is xenomorphic, and its grain diameter averages 0.02 mm and ranges from 0.01 to 0.1 mm. The larger grains have carbonate particles, and some show zonal overgrowths. Red hematite is abundant both as disseminated particles and as irregular inclusions. The sample is slightly high in Ag and Sr and yields a score of +2.

The second sample is dark gray and dense and is cut by sparse veinlets of white calcite. The matrix has a homogeneous granular texture, and an average grain diameter of 0.06 mm. It contains partly assimilated breccia fragments of feathery chalcedony mixed with jigsaw-puzzle textured quartz having an average grain diameter of 0.05 mm, and also of similar, but more heterogeneous, quartz without the chalcedony. Ragged relict grains of calcite are abundant in both matrix and inclusions. Small flecks of brown limonite are scattered through the matrix, and some of these surround tiny grains of pyrite. In addition to abundant Ca and Mg, the sample is slightly high in Al, Cr, Ni, Pb, Sr, Y, Yb, and Zr.

The third sample is moderate brown, brownish-black weathering, aphanitic, and porous. The matrix is vuggy orange goethite cementing isolated grains and small breccia fragments of coarse reticulated jasperoid quartz that has a grain diameter that averages 0.1 mm and ranges from 0.03 to 0.8 mm. Carbonate particles are moderately abundant in the quartz. This sample is unusually rich in minor elements; Fe, Ag, As, and Pb are enriched by more than two orders of magnitude above the norm, and Ca, Mg, Ti, Bi, Cr, Cu, In, Mo, Ni, Sn, Sr, V, Zn, and Zr are enriched by more than one order of magnitude. The indicator-element score is +31 (very favorable).

The geology of the West Ward area and the results of a geochemical exploration program in the area were summarized by Brokaw, Gott, Mabey, McCarthy, and Oda (1962, p. 7). On the geologic map accompanying their report, jasperoid in the Mississippian Joana Limestone is shown in a stippled pattern. The West Ward area is underlain by a thick section of middle Paleozoic marine sedimentary rocks consisting largely of limestone, dolomite, and shale. This section is broken by both low-angle thrust faults and high-angle normal faults.

Spectrographic analyses of 27 jasperoid samples from the Joana (Mississippian) and Arcturus (Permian) Limestones in the West Ward area, given to me by J. H. McCarthy, show that the modal concentrations of Ti, Ag, Ba, Cr, Ni, and V are appreciably higher than in my reference groups of 200 samples from various localities. Geochemical anomaly maps for various elements, based on analyses of both jasperoid and limonite samples, are illustrated by Brokaw, Gott, Mabey, McCarthy, and Oda (1962, p. 5–6).

Five additional samples of jasperoid from the Joana Limestone in the West Ward area are in my collection. These samples have been analyzed both petrographically and spectrographically. Three samples are from the vicinity of a small prospect about a quarter of a mile north of the abandoned Old Quake mine. The exact sample localities for the other two samples are not known, but they represent bodies not associated with any known ore.

One sample, from the group of three, consists of angular and irregular crudely stratified inclusions of aphanitic dark-reddish-brown and dark-brown jasperoid in a matrix of coarse white quartz. Three distinct generations of quartz are in the sample. The oldest generation consists of homogeneous xenomorphic quartz having an average grain diameter of 0.015 mm, sparse carbonate dust, and abundant interstitial yellow limonite. This generation forms inclusions in a cleaner and coarser heterogeneous xenomorphic matrix that has a grain diameter that averages 0.03 mm and ranges from 0.01 to 0.12 mm. The matrix is cut by the coarse vein quartz whose grains are as much as 3 mm in diameter. In spite of its complex nature, this sample has a very ordinary composition, exhibiting a minor anomaly only for Ba, and yielding an index element score of −1 (unfavorable).

The second sample from this group of three samples is dark gray and dense; it is cut by vuggy white quartz veinlets, and it weathers olive gray to pale yellowish brown. The matrix has a jigsaw-puzzle texture and a grain diameter that averages 0.01 mm and ranges from <0.01 to 0.06 mm. It contains sparse carbonate and hematite particles and is cut by veinlets of xenomorphic quartz that has a grain diameter that averages 0.07 mm and ranges from 0.01 to 0.2 mm. Most vugs in this late quartz are open, but a few are partly filled with jarosite. The sample contains anomalous concentrations of Ag and Ba and slightly anomalous concentrations of Cr, Cu, Sb, Sr, V, Y, Yb, and Zr, yielding an indicator-element score of +6 (probably favorable).

The last sample in this group is similar in appearance to the second, but it lacks the late quartz veinlets and weathers dark gray. It consists of homogeneous quartz particles that have an average grain diameter of 0.02 mm in a matrix of dark-brownish-gray to black amorphous opaque material, presumably organic, that contains abundant shreds of sericite and grains of goethite as well as sparse irregular masses of nontronite. The matrix is cut by sparse lenticular masses of younger quartz that has a jigsaw-puzzle texture and a grain diameter that averages 0.02 mm and ranges from <0.01 to 0.15 mm. Some of the larger grains of this younger quartz contain sparse carbonate particles and small fluid inclusions. This sample contains highly anomalous concentrations of Ag, Ba, Cr, Ni, Sr, and Zr, as well as slightly anomalous concentrations of Na, K, Ti, B, Cu, La, Pb, Sb, V, Y, Yb, and Zn; it gives an indicator-element score of +15 (favorable).

One of the two remaining samples in my collection is dark gray, dense, brecciated, and cemented by coarse white calcite. It has a homogeneous jigsaw-puzzle texture and an average grain diameter of <0.01 mm; it contains carbonate particles and is cut by veinlets of coarser xenomorphic quartz as well as coarse calcite; and it grades transitionally through a zone about 2 mm wide into lithographic limestone that contains scattered grains and irregular masses of coarse-grained epigenetic calcite. Tiny subhedral grains of hematite, which appear to be pseudomorphous after pyrite, are sparsely disseminated in both jasperoid and limestone. This jasperoid sample is slightly high in Na, Ag, Ce, Cu, and Ga, and it yields a score of +4. Comparison of spectrographic analyses of the jasperoid and the adjacent Joana Limestone host rock shows the jasperoid to be significantly enriched in Si, Fe, Ag, Cr, Cu, Ga, and Ni relative to the limestone.

The other remaining sample is a breccia composed of angular fragments of dark-gray aphanitic jasperoid in a matrix of fine-grained, locally vuggy, dark-yellowish-orange to moderate-brown jasperoid. In thin section several different types of breccia fragments can be distinguished. One type consists of clean coarse homogeneous xenomorphic quartz that has an average grain diameter of 0.4 mm. Another type has a xenomorphic to jigsaw-puzzle texture and average grain diameter of 0.2 mm; it is locally vuggy and it contains abundant carbonate particles. A third type has a jigsaw-puzzle texture gradational to fibrous chalcedony and an average grain diameter of 0.03 mm; it contains sparse carbonate particles. The last type of inclusion is similar to the matrix jasperoid in the specimen discussed in the preceding paragraph. The cementing matrix for all these fragments is a vuggy limonitic microbreccia of smaller jasperoid particles. This sample is very high in As, Sb, and Ti and slightly high in Al, Fe, Na, Ba, Cr, Cu, Ga, Mo, Ni, and Y, and it yields a score of +8 (probably favorable).

WHITE PINE (HAMILTON) DISTRICT

(51, fig. 44)

The White Pine district is in western White Pine County, about 30 miles west of Ely in the White Pine Mountains. The sedimentary section in the main mineralized area consists predominantly of Devonian and Mississippian limestone and shale, broken by strong north-trending faults and smaller subsidiary faults and fractures. About 5 miles west of this area the Paleozoic sedimentary rocks have been intruded and locally metasomatized by a small stock of quartz monzonite. The stock rock is strongly brecciated and silicified, but neither the stock nor the altered sediments surrounding it have thus far yielded any economically important ore deposits.

Bonanza silver deposits of cerargyrite and silver-manganese-bearing calcite were mined in the early days on Treasure Hill. In recent years most of the ore in the district has come from argentiferous base-metal sulfide replacement deposits, oxidized near the surface, in the Devonian Nevada Limestone west-southwest of Treasure Hill. This host rock is overlain, as in the Taylor district (47), successively by the Pilot Shale of Devonian and Mississippian age and by the Joana Limestone and the Chainman Shale, both of Mississippian age. Jasperoid bodies are largely confined to the upper part of the Joana Limestone near its contact with the Chainman Shale and close to faults and fracture zones. The Joana Limestone, however, is largely barren of ore (Humphrey, 1960, p. 32, 46–47, 88). Jasperoid in the Joana Limestone typically is brecciated, dark reddish brown, and fine grained, and it resembles quartzite. Jasperoid bodies similar in appearance to those in the Joana Limestone, except that they are not conspicuously brecciated, are present locally in limestone beds above the Chainman Shale (Humphrey, 1960, p. 35). I have 13 jasperoid samples from within or near the White Pine district. Most of them were taken from the Treasure Hill area of the main silver district; but two samples of supposedly barren jasperoid in the Joana Limestone were collected 1½ and 5 miles southwest of this area, and three more, from the same stratigraphic zone, were collected 5 miles north and about 10 miles northeast of it. Five of the eight samples from within the Treasure Hill area of the district are of jasperoid from the Joana Limestone; the other three are of silicified Pilot Shale in breccia zones along the contact with Nevada Limestone.

All five of these jasperoid samples from the Joana Limestone show two distinct generations of silica. The older is predominantly light gray to moderate gray and aphanitic. It has jigsaw-puzzle texture and contains abundant inclusions of chalcedony; locally, it contains microvugs, some of which have been filled with coarse xenomorphic quartz, and in places it is clouded with dusty particles of limonite or carbonate. The younger silica forms a matrix surrounding inclusions of the older silica. It is various shades of yellow, orange, brown, and red, and it has a heterogeneous jigsaw-puzzle texture and an average grain size markedly coarser than that of the older silica; it also contains larger and more abundant vugs. It commonly contains abundant particles of hematite, limonite, jarosite, or carbonate as well as larger masses of jarosite and barite. These minerals, together with coarse xenomorphic quartz, also fill fractures and vugs. All five of these samples are anomalously high in Fe and Ba, and some are also high in Na, Cr, Ni, Pb, Sr, V, and Zn. Their indicator-element scores range from +1 to +19 and average about +9.

The three remaining samples from the mineralized area are of silicified Pilot Shale in breccia zones close to the Nevada Limestone contact. These, too, contain gray and brown angular chert inclusions in a slightly coarser, gray, red, yellow, or brown locally vuggy matrix, which, in two of the samples, is itself brecciated and cemented by coarse white vein quartz. The matrix is heavily clouded with dust-sized particles of carbon, limonite, and hematite, and it contains abundant shreds of sericite. These breccia-zone samples, which contain several different kinds of fragments and which are from mineralized zones, display more elements in anomalously high concentration than do the samples of jasperoid from the Joana Limestone. Ba, Pb, and Sr are high in all three samples; Al, Mg, Na, P, Ag, B, Cu, La, Ni, Y, Yb, Zn, and Zr are high in two of them. Their indicator-element scores are +6, +12, and +16.

Five samples of barren jasperoid from the Joana Limestone represent four localities, two of which are several miles south and southwest of the district, and two of which are several miles north and northeast of the district. These five samples are pastel shades of red, yellow, brown, pink, and orange. Some of them contain chert fragments; the matrix jasperoid has a fine-grained jigsaw-puzzle texture and a grain diameter that averages about 0.01 mm and ranges from <0.005 to about 0.03 mm. The microtexture of jasperoid samples from this stratigraphic zone is remarkably consistent in all 10 samples collected at intervals over a distance of about 30 miles. These unfavorable samples also contain hematite, limonite, and, locally, jarosite inclusions both as small discrete grains and as dust-sized particles. They differ most notably from the samples in the mineralized area in that they contain fewer minor elements in higher than normal concentration. Most of them are high in Ba and Sr; those from the southwest are high in B and Ni, and those from the northeast are high in Na. The indicator-element scores of these samples range from −1 to −3.

WILLOW CREEK DISTRICT

(52, fig. 44)

The Willow Creek district in Nye County is about 12 miles north of lat 38° N. and 15 miles east of long 116° W. on the northwest side of the Quinn Canyon Mountains and near the south end of Railroad Valley. Oxidized argentiferous base-metal deposits are found here in veins cutting shaly siliceous Ordovician limestone near a small intrusive stock of quartz monzonite.

At the Queen of the Hills mine, 3 miles southeast of Mormon Well, limonitic jasperoid replaces a massive limestone bed just above its contact with a shaly limestone. This jasperoid contains copper carbonates and a little silver (Hill, 1916, p. 144–145, 150).

WYNDYPAH DISTRICT

(53, fig. 44)

The Wyndypah district is in south-central Esmeralda County on the northeast flank of the south end of the Silver Peak Range, about 15 miles southwest of Silver Peak. Argentiferous copper deposits occur here in veins close to the contact of a small intrusive granitic stock with lower Paleozoic calcareous sedimentary rocks.

At the Chloride mine a vein containing breccia fragments of brown jasperoid and partly silicified limestone in a quartz gangue follows the contact between an alaskite porphyry dike and altered limestone a few hundred feet from the granite contact. This vein contains some disseminated black silver-copper sulfide ore. A similar vein, in altered limestone near the granite contact about a mile south of the Chloride mine, has also been explored (Spurr, 1906b, p. 90–91).

OTHER OCCURRENCES

Silicified limestone containing barite is the host rock for small oxidized zinc and argentiferous lead replacement ore bodies along bedding planes adjacent to basalt dikes in the Antelope district (1, fig. 44) southwest of Eureka, Nev. Nearly all the ore is oxidized and consists of cerussite, smithsonite, hemimorphite, manganese oxides, and jasperoid. In the Diamond district (15), also, the prevailing formation is silicified limestone cut by veins containing argentiferous galena, cerussite, and stibnite in a quartz and calcite gangue (Vanderburg, 1938, p. 17, 28–29). Both of these districts are in Eureka County.

In the Belmont district (4, fig. 44), a few miles east of Manhattan, in Nye County, cerargyrite pods are found in quartz veins and lenses in metasomatized slate and limestone close to an intrusive granite stock. Slate is altered to mica schist, and limestone to jasperoid near this contact (Kral, 1951, p. 20). Emmons (1910, p. 73) mentioned "decomposed silicified limestone" gangue enclosing base-metal sulfides in the Jack Pot mine, Columbia district (10), in Elko County.

Ore bodies of the Delano district (13, fig. 44), also in northern Elko County, occur in two parallel beds in Paleozoic carbonate rocks adjacent to a quartzitic sandstone. These ore beds consist of cerussite, residual galena, anglesite, and copper carbonates in a brecciated gangue of amorphous silica. The beds are separated by a partly silicified dolomite bed 6–8 feet thick (Granger and others, 1957, p. 45–46).

The small, isolated Fireball district (22, fig. 44) in northwestern Churchill County contains gold- and silver-bearing quartz veins in silicified limestone that is cut by rhyolite and andesite dikes (Vanderburg, 1940, p. 30). Gold- and silver-bearing quartz veins are also reported along shear zones that cut highly silicified Tertiary rhyolite in the Gold Banks district (25), Pershing County. Dreyer (1940, p. 15) described this rock as having a conchoidal fracture and closely resembling chert, and wrote: "The feldspar is in part replaced by a chalcedonic silica which in some places is in contrast with the more coarsely silicified groundmass, and thereby preserves the feldspar outlines."

At the Victorine mine, Kingston district (29, fig. 44), Lander County, pockets of base-metal sulfide in a quartz gangue are irregularly scattered through a 25-foot-thick bed of silicified Paleozoic limestone, interbedded with black shale and slate (Hill, 1915, p. 128).

Spurr (1906a, p. 376) reported silver-bearing quartz and jasperoid veins cutting Cambrian and Silurian limestone in the southern Klondike district (30, fig. 44), about 10 miles south of Tonopah in Esmeralda County. These limestones are intruded by granitic rocks and are surrounded by Tertiary rhyolitic extrusive rocks.

The Nevada district (39, fig. 44), in White Pine County, about 10 miles southeast of Ely, contains pods and pipes of manganese oxides in Devonian limestone. The host rocks for these ore bodies are "irregular jaspery quartz lodes that replace the limestone along fractures, joints, and bedding planes" (Lincoln, 1923, p. 252).

Cameron (1939, p. 582, 593, 621), in discussing the geology and ore deposits of the northeastern Humboldt Range, Pershing County, stated that chert bands and nodules are locally conspicuous in limestone of the Triassic Star Peak Group, and that several limestone specimens "show partial replacement by quartz of the jasperoid variety." However, he also noted that silicification of calcareous wallrocks adjacent to ore deposits had been observed in only a few places, principally at the Sheba-De Soto mine (42, fig. 44), where bands of aphanitic cherty silica in the lower limestone beds are tentatively ascribed to hydrothermal silicification. This mine produced silver from argentiferous sulfides and sulfosalts in veins and stockworks that cut the limestone.

The Yerington district (54, fig. 44), in central Lyon County, contains economically important contact-metasomatic copper deposits in calc-silicate rocks resulting from the intense metamorphism of Triassic limestone by intrusions of granodiorite and quartz monzonite (Knopf, 1918, p. 7). Although contact metamorphism within the mineralized area was evidently too intense for the development of jasperoid, I have two samples of dense light-gray jasperoid taken from unmetasomatized limestone at localities about 3 miles south of the district. Both of these are unfavorable.

In the Lone Mountain district (33, fig. 44), at the Alpine mine about 15 miles west of Tonopah in Esmeralda County, replacement ore bodies of galena and cerussite surrounded by jasperoid zones in white dolomitic limestone near an intrusive granitic stock were described by Spurr (1906b, p. 81). He (p. 12) also referred to bedded replacement "veins" of gold and silver in a siliceous gangue in Paleozoic limestone and dolomite in this district.

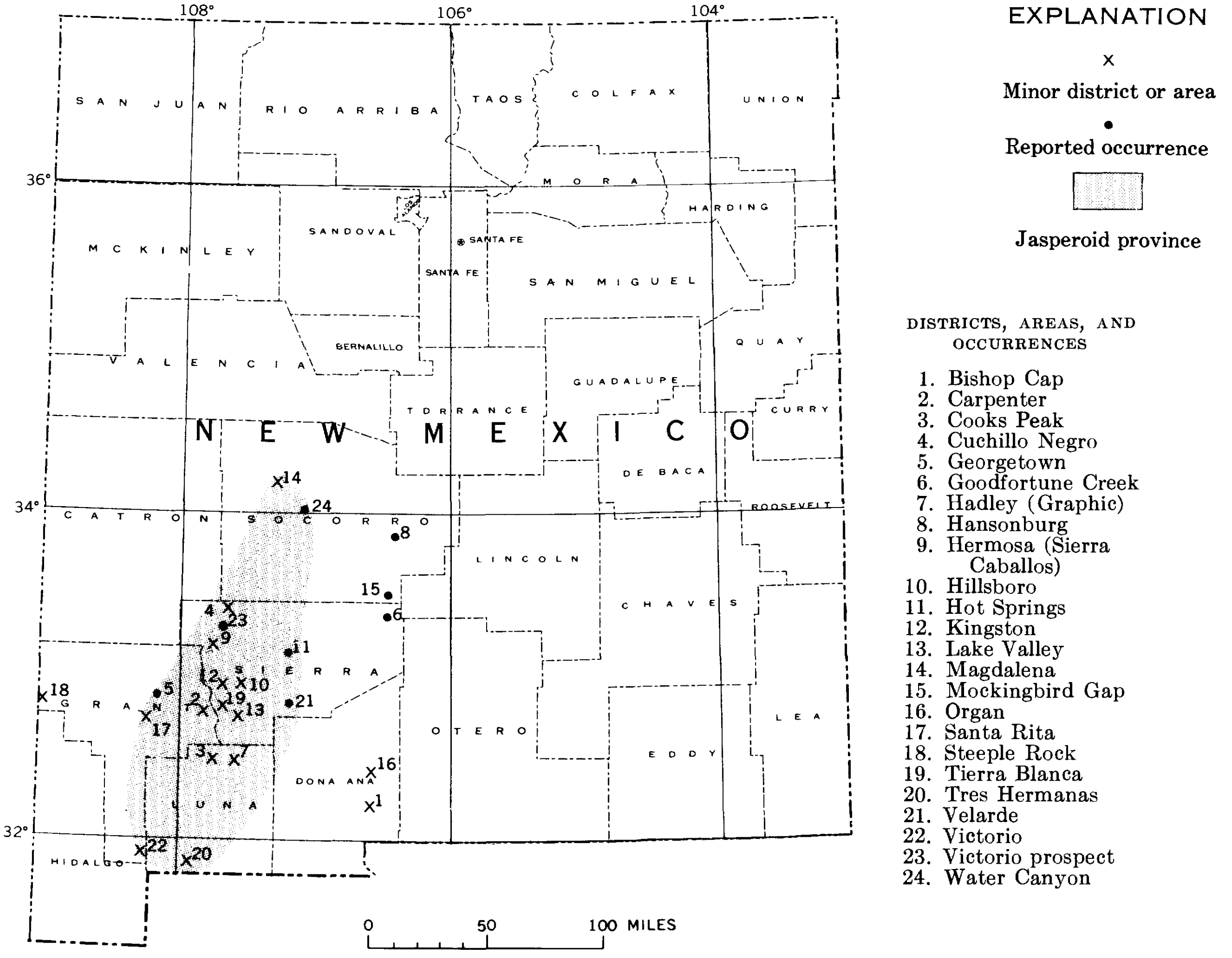
In the Chief (Caliente) district (8, fig. 44), near Caliente in Lincoln County, the presence of jasperoid associated with oxidized gold-silver-lead ore in veins cutting limestone was mentioned by Callaghan (1936, p. 16, 17, 28). A. V. Heyl (written commun., 1967) also reported abundant jasperoid in this district.

The Spruce Mountain district (45, fig. 44), at the south end of the Goshute Range in southeastern Elko County, contains prominent masses of jasperoid near the Spruce Standard mine (Schrader, 1931b, p. 9, 24). These jasperoid "blowouts" consist of masses of iron-stained quartz breccia as much as 500 feet in diameter.

A. V. Heyl (written commun., 1967) further reported that jasperoid is also common to abundant in the lead and zinc deposits of the Duck Creek (17, fig. 44) and Success (46) districts in White Pine County, the Mount Hope district (37) in Eureka County, the Mud Springs district (38) in southern Elko County, and the Lida district (32) in southern Esmeralda County.

NEW MEXICO

Information is available on jasperoids from 16 mining districts in New Mexico (fig. 45), and jas-



EXPLANATION

x
Minor district or area

●
Reported occurrence

▨
Jasperoid province

DISTRICTS, AREAS, AND OCCURRENCES

1. Bishop Cap
2. Carpenter
3. Cooks Peak
4. Cuchillo Negro
5. Georgetown
6. Goodfortune Creek
7. Hadley (Graphic)
8. Hansonburg
9. Hermosa (Sierra Caballos)
10. Hillsboro
11. Hot Springs
12. Kingston
13. Lake Valley
14. Magdalena
15. Mockingbird Gap
16. Organ
17. Santa Rita
18. Steeple Rock
19. Tierra Blanca
20. Tres Hermanas
21. Velarde
22. Victorio
23. Victorio prospect
24. Water Canyon

FIGURE 45.—Map showing location of jasperoid-bearing districts and prospects in New Mexico.

peroid is known to be present in eight other districts. All these localities are in the southwestern part of the State—in Dona Ana, Grant, Luna, Sierra, and Socorro Counties; most of them are concentrated in an irregular belt or province extending south-southwest from the Magdalena district in Socorro County at least as far as the Mexican border.

Most of these jasperoid-bearing districts contain oxidized, locally argentiferous base-metal sulfide vein and replacement deposits in silicified Paleozoic limestone and dolomite. In the Hadley (7, fig. 45) and Steeple Rock (18) districts, base-metal sulfide vein deposits are in silicified Tertiary volcanic rocks. Replacement deposits in jasperoidized Paleozoic limestone in the Bishop Cap (1) district and at the Hot Springs (11), Velarde (21), and Victorio (22) prospects consist of fluorspar rather than base metals. The Lake Valley (13) and the Georgetown (5) districts have produced high-grade oxidized silver ore associated with manganese oxides.

BISHOP CAP DISTRICT

(1, fig. 45)

The Bishop Cap district is 11 miles southeast of Las Cruces at the south end of the Organ Mountains in Dona Ana County.

Limestones and interbedded shales of the Pennsylvanian Magdalena Formation are cut by three distinct sets of faults in the mineralized area. The oldest faults strike north and contain the principal fluorspar deposits; a younger set of barren faults strikes northeast. The third, and youngest set, strikes nearly east and occupies an intensely silicified zone. Within this zone, fluorite and jasperoid quartz are largely concentrated along the footwall; in contrast, calcite and barite are abundant along the hanging wall. The jasperoid quartz is white, largely massive, and aphanitic, and it contains local vugs and fractures coated by drusy quartz deposited by descending surface water. The mineralization is of probable Tertiary age and genetically related to intrusion of the Organ Mountains batholith (Rothrock and others, 1946, p. 62).

CARPENTER DISTRICT

(2, fig. 45)

The Carpenter district is in Grant County, about 6 miles southwest of Kingston on the west slope of the Black Range.

Base-metal sulfide deposits are concentrated along shear zones in the Ordovician Montoya Dolomite. Locally, this limestone has been replaced by jasperoid containing small bunches and veinlets of sulfide ore. At the Grand Central mine such a shear zone about 25 feet wide strikes northerly, dips steeply to the east, and has ore-bearing jasperoid on the footwall side (Harley, 1934, p. 110–111).

COOKS PEAK DISTRICT

(3, fig. 45)

The Cooks Peak mining district is about 2 miles north of Cooks Peak, a conspicuous landmark about 18 miles north-northeast of Deming, in Luna County. Silver and base metals were produced from oxidized replacement and fissure vein ore bodies in the Silurian Fusselman Dolomite close to its contact with the overlying Devonian Percha Shale.

Both the upper part of the Fusselman Dolomite and the lower part of the Percha Sale are intensively silicified in the mineralized area. According to Jicha (1954, p. 62), this jasperoid layer has been brecciated and recemented at different times by successive generations of silica as shown by the presence of several different colors and types of jasperoid. Some of these types contain conspicuous vugs lined with small quartz crystals. Silicification extended over a considerable period of time. Some jasperoid is postore, but some may also be preore. Most of the ore bodies are encased in jasperoid, and the intensity of silicification tends to diminish away from them.

Three jasperoid samples from the Fusselman Dolomite in this district are included in my collection. Two samples were collected near the east end of the east-trending mineralized Othello fault, and the third, from the same area about 500 feet north of the fault; all three samples were taken about a quarter of a mile from the nearest mine workings.

Both samples from the fault zone are gray on fresh surface, shades of brown on the weathered surface, fine grained, and vuggy, and they have a reticulated microtexture. One has hematite pseudomorphs after pyrite and breccia fragments of dense aphanitic cherty jasperoid. These two samples have slightly anomalous concentrations of Ba, Be, Ga, Pb, and Zn, yielding indicator-element scores of +6 and +2.

The single sample from the locality north of the fault zone is similar in color but has an aphanitic jigsaw-puzzle texture and fewer vugs, and it contains detrital-looking quartz grains. This sample is slightly high in Na, Ti, Ba, Be, Ga, and Ni, yielding a score of −2.

CUCHILLO NEGRO DISTRICT

(4, fig. 45)

The Cuchillo Negro district is in northwestern Sierra County in the Cuchillo Mountains, about 5 miles east of the small town of Fairview. In this area Pennsylvanian limestones of the Magdalena Group have been intruded by a large sill of Tertiary quartz monzonite porphyry, which intrusion has caused local contact metasomatism of the limestone. Small oxidized base-metal sulfide replacement deposits are in the limestone close to the intrusive contact. Limestone on the Black Knife property has been converted to jasperoid along the intrusive contact and along small fractures extending upward from this contact, above the ore bodies. A 10-foot-wide north-northwest-trending silicified shear zone cuts the limestone a few hundred feet east of the Black Knife claims. This silicified zone with jasperoid contains fluorite and calcite, and it is slightly mineralized at its contact with the porphyry a quarter of a mile to the south (Harley, 1934, p. 113–122).

HADLEY (GRAPHIC) DISTRICT

(7, fig. 45)

The Hadley (Graphic) district is in northern Luna County, about 16 miles north of Deming and 5 miles east of Cooks Peak. Lead and zinc ores have been mined here from fissure veins cutting Tertiary andesite. According to Jicha (1954, p. 67–68), silicification of the country rock is conspicuous along veins and faults near the mines, but the richest ore occurs in the less intensely silicified areas. Extensive silicification preceded ore mineralization, and more localized silicification accompanied or followed it.

Two jasperoid samples taken from an outcrop near the southwestern end of this district are included in my collection. This body of jasperoid is massive and grayish brown, and is partly surrounded by a zone of bleached kaolinized andesite.

Both samples are dense and massive. One is grayish orange to pinkish gray and consists of homogeneous medium-grained quartz that has a jigsaw-puzzle texture and contains local concentrations of fibrous chalcedony. The other is white to pale orange with local dusky-brown spots of limonite; it has an aphanitic cherty texture and contains disseminated clay as well as limonite. Both samples are slightly high in Mg, Ti, Ba, and Pb; one also contains a little Ag, and the other shows anomalous concentrations of Ga, Mo, and Sr. One sample yields an indicator-element score of +9, the other, +2.

HERMOSA (SIERRA CABALLOS) DISTRICT

(9, fig. 45)

The Hermosa silver-lead district is on the east slope of the Black Range in Sierra County; it extends from Monument Creek southward to Seco Creek, about 25 miles west of Truth or Consequences.

Pennsylvanian limestone has been extensively silicified near the north-trending Pelican fault north of Palomas Creek. The Pelican shaft, on the west side of this fault, passed through jasperoid cut by galena-bearing quartz veinlets above a black shale bed; below the shale it entered unsilicified limestone cut by veinlets of high-grade lead-silver ore (Harley, 1934, p. 96).

HILLSBORO DISTRICT

(10, fig. 45)

The Hillsboro district is in southwestern Sierra County along Percha Creek in the western foothills of the Black Range. Most of the mineral production from this district has come from gold, silver, and base-metal-bearing quartz veins cutting Tertiary andesitic rocks.

A belt of jasperoidized Silurian Fusselman Dolomite forms a prominent escarpment on the east side of a strong north-trending fault about a mile east of Hillsboro on the north side of Percha Creek. This rock is red to brown and strongly brecciated and is cut by numerous veinlets of white quartz. The jasperoid is locally vuggy and weathers to a rubble of large iron-stained boulders. The base of the Devonian Percha Shale above the Fusselman Dolomite has also been altered locally to a dense red jasperoid. No mines have been developed in this large jasperoid body, and Harley (1934, p. 125–126, 130) regarded it as barren.

I have six samples of the Fusselman jasperoid from the top of the escarpment about midway between the north end of the ridge and Percha Creek. These samples range in color from light gray through yellowish brown, yellowish orange, and grayish red to moderate red. Most of them are brecciated, vuggy, and aphanitic.

The samples consist of an older generation of cherty jasperoid that has a jigsaw-puzzle texture and a younger generation of medium- to coarse-grained heterogeneous xenomorphic quartz that fills vugs and fractures in the older jasperoid and locally forms the matrix in which angular breccia fragments of older jasperoid are embedded.

The older jasperoid contains abundant red hematite as both disseminated particles and red stain; it also contains carbonate particles locally. The younger quartz is associated with penecontemporaneous yellow to brown limonite and fibrous chalcedony.

Most of the five samples that were analyzed are anomalously high in Fe, Ba, Be, Pb, and Zn, and one sample is also high in Mn, Cu, and Ga. The suite of samples yields indicator-element scores of +3, +3, +8, +9, and +10. The presence of jasperoid with probably favorable characteristics in this body suggests that ore may exist downdip in the Fusselman Dolomite.

KINGSTON DISTRICT

(12, fig. 45)

The Kingston base-metal district in Sierra County extends from the crest of the Black Range eastward between the North and South Forks of Percha Creek about 1½ miles beyond the town of Kingston.

Fusselman Dolomite has been silicified in an irregular zone at its contact with Percha Shale adjacent to a small stock of quartz monzonite porphyry. In this zone the replacement jasperoid is a fine-grained white to pink breccia partly cemented by white crystalline quartz. Elsewhere in the district, Percha Shale has been converted to dense red jasperoid, which contains disseminated pyrite, adjacent to its contact with unaltered Fusselman Dolomite.

Silicifying solutions, considered by Harley (1934, p. 98–102) to be genetically related to the quartz monzonite intrusive, rose along fractures and shear zones in the dolomite and spread out along the contact with the overlying shale, locally converting the adjacent rock to jasperoid; this jasperoid apparently formed an impermeable seal that trapped later ore solutions rising along the same conduits. Locally, the jasperoid is slightly auriferous; the younger sulfide ore bodies are vein and replacement deposits of galena, sphalerite, chalcopyrite, and pyrite in a gangue of quartz, rhodochrosite, and manganiferous calcite.

LAKE VALLEY DISTRICT

(13, fig. 45)

The Lake Valley district is in southwestern Sierra County, about 15 miles south of Hillsboro and 18 miles west of the Rio Grande.

Manto deposits of silver and manganese ores were formed here in Mississippian Lake Valley Limestone that is now exposed in a fault block of Paleozoic sedimentary rocks, largely surrounded by Tertiary volcanic rocks.

A thin persistent layer of "chert" or jasperoid at the contact between the Alamogordo Member (blue limestone) and the Nunn Member (crinoidal limestone) of the Lake Valley Limestone forms the footwall of many silver and manganese ore mantos in the central part of the district. Near the major fault that bounds the district on the southwest, this layer has been brecciated and recemented with younger ferruginous, manganiferous, and argentiferous jasperoid that displays a variety of colors (Harley, 1934, p. 176–177).

Silurian Fusselman Dolomite has also been extensively replaced by jasperoid beneath the Percha Shale west of the mined area in the district. Younger quartz has recemented breccia blocks of silicified limestone in large irregular masses with rough craggy outcrops that weather to a rubble of talus blocks (fig. 2*A*). The older jasperoid in the breccia fragments is milky and granular, and, in some places, it resembles quartzite; elsewhere, it is stained red with abundant hematite. The younger cementing quartz is slightly coarser and has abundant vugs lined with quartz crystals (Harley, 1934, p. 173). No known ore deposits are associated with the jasperoid bodies in the Fusselman Dolomite, although the texture, mineralogy, and chemical composition of some of them furnish criteria that place them in the favorable category (Young and Lovering, 1966).

Many jasperoid samples collected from this district have been described in detail (Young and Lovering, 1966); therefore, these descriptions will not be repeated here.

According to Harley (1934, p. 177), early mineralizing solutions, preceding the primary ore stage in the district, were rich in silica, but those that emplaced the primary ore minerals were rich in calcium carbonate and relatively poor in silica. This conclusion, together with the occurrence of favorable jasperoid in the Fusselman Dolomite close to the south boundary fault and the known occurrence of sulfide ore bodies in this stratigraphic zone at Kingston and Cooks Peak, led Young and Lovering (1966, p. D24–D26) to the opinion that similar ore bodies may exist in the Lake Valley district at the top of the Fusselman Dolomite close to the south boundary fault.

MAGDALENA DISTRICT

(14, fig. 45)

The Magdalena district in Socorro County, about 20 miles west of Socorro, at the north end of the Black Range, has been one of the major lead, zinc, and copper producers in the State. Most of the ore deposits are concentrated in a zone of contact-metasomatized upper Paleozoic sedimentary rocks surrounding quartz monzonite stocks and smaller intrusive bodies of Laramide age.

The same siliceous emanations that formed lime-silicate rock adjacent to the intrusives also rose along fractures in the Mississippian Kelly Limestone and spread out beneath overlying shale at the base of the Pennsylvanian Sandia Formation, forming jasperoid in the southern part of the district, farther from their source (Loughlin and Koschmann, 1942, p. 53).

The jasperoid is light gray and various shades of brown, and it contains abundant drusy vugs that are lined with quartz crystals and are elongated parallel to the bedding of the limestone host rock. In some places, the jasperoid has been brecciated and recemented by white vein quartz containing vugs that are locally lined with crystals of quartz, barite, and sulfides. Boundaries between jasperoid and host rock appear to be sharp, but petrographic study of thin sections cut across the contact reveals the presence of euhedral quartz crystals disseminated in the limestone. The primary jasperoid is preore, but the white vein quartz that cuts and cements it belongs to the ore stage of mineralization. The relationships of jasperoid to contact-metasomatic skarn and ore deposits at Magdalena are suggestive of those at Yerington, Nev.

ORGAN DISTRICT

(16, fig. 45)

The Organ district is in Dona Ana County, 15 miles northeast of Las Cruces at the west base of San Augustine Pass between the Organ Mountains and the San Andrés Mountains. In this district, base-metal sulfides were deposited in veins and as replacements in limestones of the Magdalena Group along a strong north-trending fault and fracture zone.

Bodies of white fine-grained locally vuggy jasperoid crop out within this zone in the vicinity of the ore bodies. The jasperoid commonly preserves the primary textures of limestone and dolomite breccia fragments it has replaced. Sparse vugs within it are locally lined with crystals of quartz, aragonite, and dolomite. An unusual feature of these jasperoid bodies is that they are present only near the surface and die out abruptly at depths of less than 200 feet into a rubble of breccia fragments of unaltered carbonate rock (Dunham, 1935, p. 126–129, 160).

A sample of this jasperoid from a brecciated outcrop near the center of the district is light yellowish gray, fine grained, and vuggy. In thin section it has a heterogeneous xenomorphic to locally reticulated texture with small vugs. It contains sparse disseminated grains of apatite and of hematite pseudomorphs after pyrite, also disseminated dust-sized particles and local aggregates of a yellowish-orange clay mineral, probably nontronite. Spectrographic analysis shows slightly high concentrations of Mn, Ba, and Cu, yielding an indicator-element score of +3.

SANTA RITA DISTRICT

(17, fig. 45)

The Santa Rita mining district in Grant County is the foremost producer of copper, lead, and zinc in the State. Because of its commercial importance, this district would have been discussed under the major mining districts but for the fact that jasperoid bodies are not abundant.

Of three samples taken from small masses of jasperoid in and near the district, two are from exposures in the town of Santa Rita, one about a quarter of a mile northeast and the other about the same distance north-northeast of the old north pit of the Chino copper mine; the third is from an outcrop close to the Georgetown Road, about 2 miles northeast of Santa Rita in an unmineralized area. All three samples are of silicified limestones in the Magdalena Group.

Both samples from Santa Rita are brecciated and vuggy, and they weather brown on the outcrop. Their breccia fragments are aphanitic and light brown. The matrix of one sample consists largely of hematite and orange goethite, which contains numerous veinlets and drusy vugs of coarse vein quartz; the matrix of the other sample is fine-grained medium-gray quartz with lenticular vugs, parallel to the bedding, that are coated and locally filled with brown limonite. The breccia fragments have a homogeneous aphanitic jigsaw-puzzle texture and are heavily impregnated with yellowish-brown limonite particles. Matrix quartz in the second specimen is medium grained and heterogeneous; it has a xenomorphic to locally reticulated texture and contains inclusions of jarosite, goethite, specular hematite, and a little sericite.

The sample of aphanitic jasperoid from the unmineralized area 2 miles northeast of Santa Rita is aphanitic and pale red to moderate red. It has a fine-grained heterogeneous xenomorphic to jigsaw-puzzle texture. Some of the numerous original microvugs have been filled with somewhat coarser xenomorphic quartz. This matrix contains a few granules of chalcedony and breccia fragments of silicified grayish-brown coquina in which the original shell textures are well preserved.

Although both samples from Santa Rita are high in Fe, Hg, Ni, Y, and Zn, they show a marked difference in the accompanying suites of other minor elements. The sample with the iron oxide matrix is slightly high in Be, Co, Ga, In, Mo, Sn, and V. The sample with the quartz matrix is slightly high in Ag, Bi, Cu, Pb, and Te. This difference in minor-element content may be caused, in part, by the difference in iron oxide content; colloidal iron oxide may selectively retain a different suite of minor elements than does colloidal silica. The third sample, from northeast of Santa Rita, shows traces of Ag and Hg, but otherwise it contains no unusual concentrations of minor elements. The indicator-element scores of these three samples are +15, +16, and +2.

Although bodies of jasperoid are not numerous in the Santa Rita area, those that are present seem to conform to the criteria for the recognition of favorable and unfavorable jasperoids.

STEEPLE ROCK DISTRICT

(18, fig. 45)

The Steeple Rock district is in the northwest corner of Grant County about 50 miles northwest of Silver City. Base-metal sulfide ore deposits in the district are localized by a strong fault in Tertiary andesitic rocks.

The country rock has been strongly brecciated, and locally replaced by silica adjacent to the fault, in the vicinity of the ore bodies. These ore bodies consist of fissure-vein and replacement deposits of sphalerite, galena, and chalcopyrite in a gangue of vein quartz or jasperoidized andesite. The ore occurs both as coarse-grained masses relatively free of gangue and as fine-grained disseminations in vein quartz and jasperoid (Russell, 1947, p. 5, 6).

TIERRA BLANCA DISTRICT

(19, fig. 45)

The Tierra Blanca district is in Sierra County on the east slope of the Black Range near the head of Tierra Blanca Creek, about 6 miles south of Kingston. Lower Paleozoic sedimentary rocks in the area have been intruded by a small stock and numerous dikes of Tertiary quartz monzonite. Silver-lead replacement deposits occur in the Lake Valley Limestone along north-trending faults. The Fusselman Dolomite, at its contact with the overlying Percha Shale, has been extensively replaced by a fine-grained pink and white jasperoid. This jasperoid is commonly brecciated, and the breccia fragments are cemented by coarser grained vuggy quartz. The jasperoid contains a little gold and is similar to the jasperoid in the Fusselman Limestone at Kingston (12) (Harley, 1934, p. 108–110).

TRES HERMANAS DISTRICT

(20, fig. 45)

The Tres Hermanas district is in southern Luna County, about 30 miles south-southwest of Deming and 5 miles north of the Mexican border. It has produced small quantities of base-metal sulfide and oxidized ores from replacement deposits in contact-metasomatized Paleozoic sedimentary rocks close to a quartz monzonite stock. A large xenolith of Mississippian Escabrosa Limestone in the northern part of the district has locally been replaced by nodules and larger irregular masses of massive fine-grained gray to white jasperoid. Silicified fault zones in the limestone have been prospected without result. This jasperoid is thought to be genetically related to the quartz monzonite intrusion, but it appears to be older than, and unrelated to, the ore mineralization (Griswold, 1961, p. 50–53).

In spite of Griswold's conclusion that jasperoid is not related to ore in the district, some jasperoid bodies are, at least spatially, related to sulfide ore. A sample of jasperoidized Escabrosa Limestone from the Mahoney mine in the northern part of the district contains fine-grained galena and is taken from a body adjacent to ore. This jasperoid is dense, fine grained, and light gray. It has a homogeneous granular texture and an average grain diameter of 0.05 mm. The rock is cut by veinlets of coarse white calcite, but the quartz matrix is unusually clean and free of inclusions. In spite of its unpromising appearance, the rock is high in several indicator elements. It is rich in Ag, Ce, Cu, Pb, and Zn, and yields a score of +23, and thus it is markedly favorable.

VICTORIO DISTRICT

(22, fig. 45)

The Victorio district is in the southeast corner of the panhandle of Grant County. It is about 60 miles south of Silver City and 25 miles west of Tres Hermanas.

Griswold (1961, p. 79) reported several large irregular masses of jasperoid in Fusselman Dolomite on Mine Hill, near the center of this base-metal sulfide district. These masses he regarded as having formed contemporaneously with barren quartz veins that commonly fill preore fault zones. He stated that most of the jasperoid bodies are barren, but that a little galena, chalcocite, and tetrahedrite are present in one of them.

A sample of jasperoid from the Victorio district, taken from a large boulder near the portal of the Chance mine adit, presumably represents this body of ore-bearing jasperoid referred to by Griswold. It consists of coarse-grained vuggy light-yellowish-gray jasperoid resembling quartzite in texture and color; it contains coarse inclusions of galena as much as an inch in diameter. The vugs are lined with clear quartz crystals.

In thin section the sample appears to be a breccia of coarse-grained, relatively homogeneous jasperoid fragments that have a reticulated texture and a grain diameter that averages 0.1 mm, in a matrix of even coarser grained heterogeneous xenomorphic to reticulated quartz that ranges in grain diameter from 0.2 to 3 mm. The older jasperoid contains rutile needles and some fluid inclusions in negative quartz crystals. Both generations contain local inclusions of diopside and small pyritohedral pseudomorphs of hematite after pyrite, as well as abundant dust-sized particles of allophane and an unidentified yellowish-gray opaque mineral with high relief.

The sample is unusually high in Ag, Ba, Cu, Pb, Sb, Sn, and Zn and yields an indicator-element score of +22 and thus is very favorable.

OTHER OCCURRENCES

At the old Georgetown district (5, fig. 45) in Grant County, about 5 miles northeast of Santa Rita, high-grade silver ore was mined from replacement deposits in silicified Fusselman Dolomite beneath the Percha Shale. Silicification of the limestone and deposition of the primary ore probably were caused by solutions genetically related to the intrusion of Tertiary latite porphyry dikes in the area (Paige, 1916, p. 14).

In the Hansonburg district (8, fig. 45), along the west front of the Sierra Oscura in eastern Socorro County, Lasky (1932, p. 67–69) reported jasperoid that locally replaced limestone of the Magdalena Group. This jasperoid is locally cut by veins containing galena and chalcopyrite. Lasky (p. 79, 81) also mentioned silicified breccia zones along faults in Paleozoic limestone in the Goodfortune Creek (6) and Mockingbird Gap (15) districts near the north end of the San Andres Mountains.

In the Water Canyon district (24, fig. 45), which adjoins the Magdalena district on the southeast, base-metal sulfide vein and bedded replacement deposits have formed at the intersections of faults and fractures in the Lake Valley Limestone, which has been locally silicified (Lasky, 1932, p. 48–53), but it is not clear whether this is jasperoid or a coarser form of quartz.

Sheridan (1947, p. 4–5) reported a small fluorspar deposit with minor galena along fault zones in partly jasperoidized Paleozoic limestone in Sierra County just across the Rio Grande from Hot Springs (11, fig. 45), now known as Truth or Consequences.

At the Velarde prospect (21, fig. 45), 6 miles northeast of Garfield in the southern Caballos Mountains, southeastern Sierra County, fluorite fills cavities in a bed of jasperoidized limestone in the Magdalena Group (Rothrock and others, 1946, p. 156). The Victorio prospect (23) in the Sierra Cuchillo Range, 2 miles east of Chise in northwestern Sierra County, explores a fluorite-quartz vein cutting jasperoidized Paleozoic limestone (Rothrock and others, 1946, p. 169).

NORTH CAROLINA AND SOUTH CAROLINA

The only reference I have found in the literature to rock that could be considered jasperoid in these States is contained in Pardee and Park's discussion (1948, p. 35, 42–44, 50) of rock alteration at the Howie (3, fig. 41), Whitney (3), and Gold Hill (2) mines in North Carolina, and the Haile (5) and Brewer (4) mines in South Carolina, and Sundelius and Bell's report (1964, p. 212–214) on the Heglar prospect in the Gold Hill district (2), North Carolina.

The gold-mining region in which these mines are located is in the Piedmont belt east of the Blue Ridge Mountains just east of the Catawba River where it crosses the border between North Carolina and South Carolina, from about 20 to about 50 miles south of Charlotte, N.C. These deposits are in metamorphosed Paleozoic volcanic rocks.

Pyritic gold ore is disseminated through intensely silicified zones. The ore bodies grade transitionally outward into barren quartz. The quartz is dense, fine grained, and light gray to dark bluish gray, commonly preserving primary textures of the metamorphosed volcanic rocks it replaces. Silicification preceded mineralization but followed regional metamorphism. It probably occurred in late Paleozoic or Triassic time.

The Heglar prospect in the Gold Hill district (2, fig. 41) of North Carolina, is in a belt of lower Paleozoic amphibolite, which is intruded by granitic rocks. The prospect is in a deeply weathered contact-metamorphic zone consisting largely of pyrite and garnet in a siliceous gangue, and of subordinate epidote, allanite, apatite, chalcopyrite, magnetite, and barite. Allanite, or its alteration products, is largely responsible for both the rare-earth elements and the radioactivity. Silica, in the form of opal, chalcedony, and aphanitic quartz, was introduced late in the paragenetic sequence, and has replaced garnet, sulfides, allanite, and other gangue minerals (Sundelius and Bell, 1964, p. 214–215).

PENNSYLVANIA AND NEW JERSEY

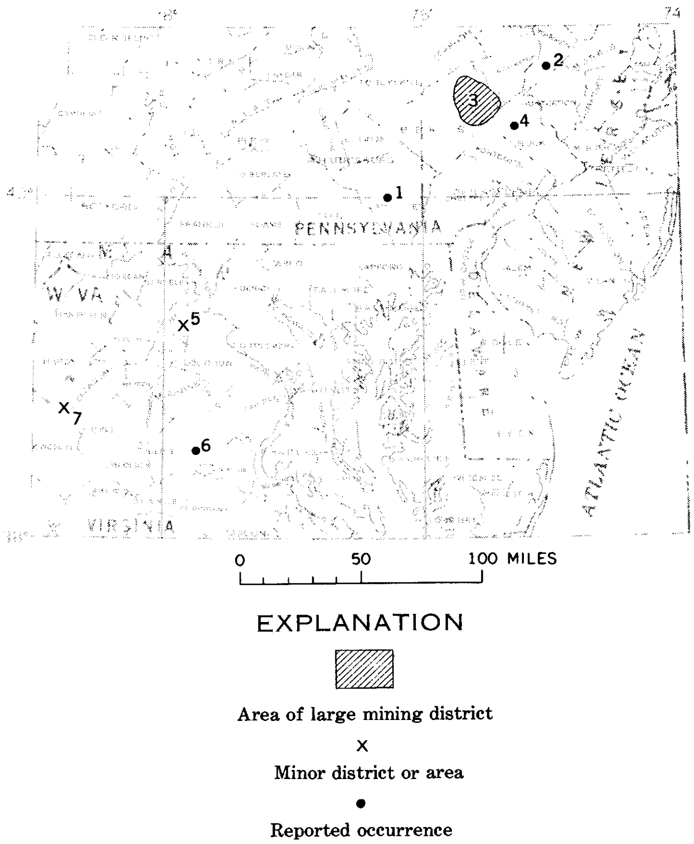


FIGURE 46.—Map showing location of jasperoid-bearing areas in parts of Pennsylvania, New Jersey, northern Virginia, and West Virginia. 1, Bamford; 2, Califon (German Valley); 3, Friedensville; 4, New Galena; 5, Howell; 6, Rappahanock; 7, Timberville.

Jasperoid is associated with zinc deposits in lower Paleozoic carbonate rocks in southeastern Pennsylvania. Miller (1924, p. 62; 1941, p. 337, 340) mentioned silicified Ordovician Beekmantown Limestone associated with zinc ore in the Friedensville district (3, fig. 46) near Bethlehem in eastern Lehigh County. He noted a similar occurrence in the same approximate stratigraphic zone in the Bamford district (1) near Lancaster, and in the Califon (German Valley) district (2) in northwestern New Jersey. Argentiferous base-metal sulfide ores are associated with jasperoid replacing Triassic shale at New Galena (4) in Bucks County. Miller (1941, p. 260) also referred to "jasperoid quartzite" associated with iron ores in Lehigh County; however, these rocks are metaquartzites formed by silica cementation of Cambrian sandstone, and hence are not jasperoids in the sense used here. However, A. V. Heyl (written commun., 1967) reported the presence of large bodies of true jasperoid at the contact of this quartzite or sandstone with the overlying Cambrian limestone at

Allentown, Topton, Macungi, and Zionsville, all in the vicinity of Friedensville.

FRIEDENSVILLE DISTRICT

(3, fig. 46)

Sphalerite in the Friedensville district forms both vein and replacement ore bodies in the Ordovician Beekmantown Limestone associated with pyrite and vein quartz. No galena is found in these deposits, and the sphalerite is so low in iron that it is light bluish gray, resembling dolomitic limestone. Miller (1941, p. 340) stated:

> Quartz is especially abundant and occurs as a compact quartzite produced by metasomatic replacement of limestone, as thin veins cutting the limestones in all directions, and as small crystals lining cavities in the somewhat porous altered limestones.

The jasperoid at Friedensville is older than the sulfides, but it appears to be closely related to them both spatially and genetically. I have two samples of this rock, which is slightly darker gray than the dolomitized aphanitic limestone it replaces, but which resembles it closely in texture. Indeed, this jasperoid is so dense and so fine grained that, except for its field relations, it could easily be mistaken for common chert. The contact between jasperoid and host dolomite is megascopically sharp; however, a thin section shows abundant tiny relict grains and rhombs of dolomite in the jasperoid and incipient silicification of dolomite along grain boundaries close to the contact. Both dolomite and jasperoid are cut by veinlets of coarse calcite that contains vugs lined with sphalerite and pyrite and filled with late vein quartz. This rock is remarkably deficient in associated minor elements for an ore-bearing jasperoid. It contains, in addition to Ca, Mg, Fe, and Zn (which are present in visible inclusions of dolomite, pyrite, and sphalerite), slightly abnormal concentrations of Na, Ce, Ga, and Mo.

Jasperoid is also present in large bodies in Cambrian limestone and quartzite at Allentown, Topton, Macungi, and Zionsville, all within a few miles of Friedensville and included in the Friedensville district as shown in figure 46. This jasperoid is red or brown from abundant iron oxide, and it differs strikingly in appearance from the dark-gray jasperoid that is characteristic of the main Friedensville district (A. V. Heyl, written commun., 1967).

OTHER OCCURRENCES

Jasperoid at Bamford (1, fig. 46), in Lancaster County, is light gray and is closely associated with galena and sphalerite. At New Galena (4), in Bucks County, dark-gray jasperoid replaces black Triassic shale in a mineralized fault zone. It is associated with galena, sphalerite, and white vein quartz (A. V. Heyl, written commun., 1967).

At Califon (German Valley), in Warren County, N.J., jasperoid replaces Beekmantown Dolomite, and is closely associated with oxidized lead and zinc ore and iron deposits.

SOUTH DAKOTA

In South Dakota, jasperoid-bearing mining districts are concentrated in a roughly triangular area, about 5 miles on a side, in Lawrence County in the northwestern Black Hills. The apices of this triangle are formed by the West Lead district (3, fig. 47) about 3 miles west of Lead, on the southeast, the Ragged Top Mountain district (2) just east of Spearfish Creek on the southwest, and the Carbonate district (1) north of Squaw Creek near its junction with Spearfish Creek on the north.

The West Lead district contains gold-bearing jasperoid that replaces thin dolomite beds in the Cambrian and Ordovician Deadwood Formation. In the Ragged Top Mountain district, jasperoid bodies in Carboniferous limestone have been mined for gold and silver. In the Carbonate district, jasperoid

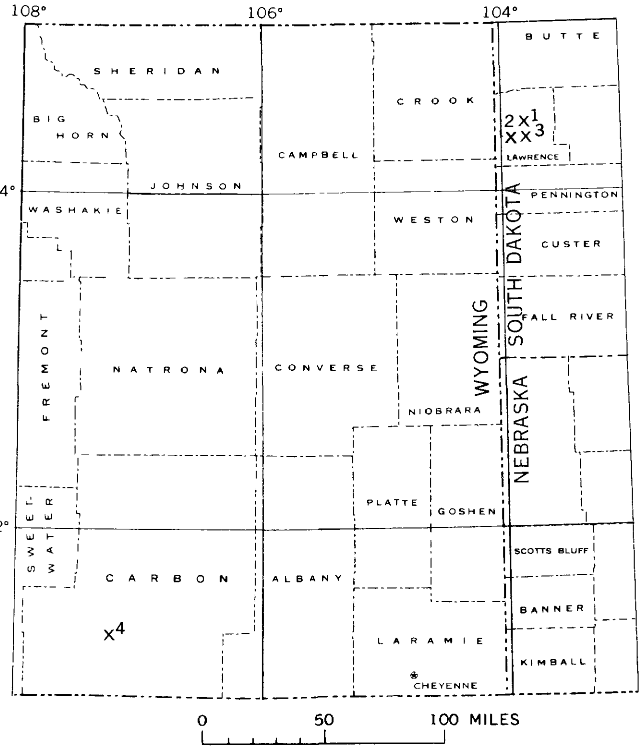


FIGURE 47.—Map showing location of minor jasperoid-bearing districts or areas in South Dakota and Wyoming. 1, Carbonate; 2, Ragged Top Mountain; 3, West Lead; 4, Miller Hill.

in the same limestone forms the gangue of argentiferous galena ore bodies.

WEST LEAD DISTRICT

(3, fig. 47)

According to Irving (1904, p. 112), auriferous jasperoid replacement deposits in the Deadwood Formation have been developed at West Lead and Bald Mountain, and also in the neighboring mining camps of Yellow Creek, Garden, and Squaw Creek a few miles northwest of Lead. The nature of the occurrence of ore and jasperoid is similar in all these places, and these deposits have been described as a group by Irving under the heading "Refractory Siliceous Ores." The deposits are in blankets very similar to those in the Mississippi Valley.

These jasperoid bodies are flat-banded masses of channellike form, following fracture zones in thin beds of impure dolomite that alternate with beds of shale and siltstone. The banding in the jasperoid preserves original bedding texture in the host dolomite (fig. 2). Where this rock is fresh, it is dense, gray, hard, and brittle, and contains pyrite, fluorite, and other minor accessory minerals. At and near the outcrop, however, it has been oxidized to various shades of red and brown and has local porous layers that contain abundant small vugs. Individual bodies commonly terminate abruptly against impervious shale beds. They exhibit a complete gradation from narrow stringers closely confined to the feeding fractures to broad mantolike conformable masses whose widths are many times their thicknesses (Irving, 1904, p. 124).

In thin section the unoxidized ore consists of irregularly bounded quartz and chalcedony with finely divided disseminated pyrite. The proportions, of chalcedony to quartz vary, but quartz is commonly more abundant. Detrital quartz grains and residual masses of glauconite, as well as fluorite, calcite, barite, and sufide minerals, are locally abundant (Irving, 1904, p. 137).

I have suites of jasperoid samples from the Deadwood Formation at two localities. One is the dump of the Clinton portal of the Bald Mountain mine about a mile northwest of the summit of Bald Mountain; the other is the dump of the Annie Creek mine near the head of Annie Creek about 2 miles west of Bald Mountain.

Six of the seven samples from the Bald Mountain mine show conspicuous banding or layering parallel to the original bedding; the seventh sample is a silica-cemented breccia of various types of rock. The rock is extremely variable in color, showing variegated bands of black, dusky red, and various shades of brown; many of the thinner bands are porous and friable, and as a result, the rock tends to break along these zones of weakness into flat slabs. Some layers are poorly sorted ferruginous siltstone, and these alternate with layers of impure silty dolomite. Both siltstone and dolomite have been replaced by silica, but replacement is more extensive and complete in the dolomite.

In thin section the jasperoid samples show detrital grains of quartz, microcline, dolomite, tourmaline, chert, muscovite, glauconite, clay, and zircon. The replacing silica contains penecontemporaneous pyrite, sericite, and fluorite; the samples are heavily stained and are cut by anastomosing veinlets of supergene hematite, limonite, goethite, and jarosite. Matrix quartz in different layers ranges in texture from aphanitic homogeneous with jigsaw-puzzle texture to medium-grained moderately heterogeneous with xenomorphic texture. Many of the apparently detrital quartz grains contain hematite pseudomorphs after pyrite; some exhibit peculiar braided microveinlets of goethite, with a strong preferred orientation, which terminate at the grain boundaries.

The suite of samples from the Annie Creek mine area is similar in appearance to the one from the Bald Mountain mine. These rocks are also variegated in color and are banded or laminated with local thin porous vuggy layers. Most of the samples under the microscope are revealed as silicified impure siltstones with a supergene liesegang banding caused by alternating bands of fibrous chalcedony and iron oxides (limonite, goethite, and hematite). The iron oxide-rich bands commonly are conspicuously vuggy, and many of the original vugs have been filled or lined with opal. In one sample, vugs in limonite are lined with lussatite rather than ordinary opal.

One sample consists of breccia fragments of dense medium-gray jasperoid cemented by fine-grained medium- to light-gray silica, which is locally porous and vuggy. The jasperoid has a heterogeneous jigsaw-puzzle texture and a grain diameter that averages 0.01 mm and ranges from 0.005 to 0.05 mm; it contains numerous microvugs. Sparse rounded detrital grains of tourmaline form inclusions, and fine-grained pyrite and barite are heavily disseminated through the matrix; some of the vugs have been filled with opal. The silica cement consists of xenomorphic quartz that has an average grain diameter of 0.04 mm.

The samples from both the Bald Mountain and Annie Creek mines contain an unusually large number of minor elements present in greater-than-normal abundance. Many of these elements can be attributed to the abundant and varied detrital mineral inclusions in these rocks, but some appear to have been introduced by the hydrothermal silicifying solutions. The following elements are abnormally high in most of the samples from both localities: Al, Fe, Na, K, Ag, As, Ba, Be, Ga, Ni, Pb, Sr, V, Y, and Yb. One or more samples also contain higher-than-normal concentrations of Mn, Co, Cu, In, Nb, Nd, Sc, Tl, Zn, and Zr.

Indicator-element scores on eight samples analyzed ranged from +23 to +4. Three of these samples yielded scores of $>+15$, three yielded scores between +10 and +15, and two yielded scores of +4.

RAGGED TOP MOUNTAIN DISTRICT

(2, fig. 47)

At Ragged Top Mountain a laccolith of phonolite has been intruded at the base of massive Carboniferous limestone. Locally, this limestone has been replaced by jasperoid, which contains gold and silver telluride ore along fracture zones north, south, and west of the intrusion.

On the Dacy claims just north of the mountain, locally brecciated limestone in a northeast-trending fracture zone has been replaced by fine-grained dense gold-bearing jasperoid that preserves both the texture and the color of the host rock, yet has a sharp contact with this rock. In the zone of oxidation near the surface the jasperoid consists of irregular boulders and masses of iron-stained silicified limestone breccia fragments cemented by coarser quartz which contains many sharp angular cavities lined with quartz crystals (Irving, 1911, p. 646; 1904, p. 172–176).

At the Ulster mine on the south side of Ragged Top Mountain, according to Irving (1904, p. 176),

> The ore occurs as irregular masses of silicified limestone with which are associated quantities of brilliant purple fluorite. These masses are generally in the limestone at the contact of that rock with irregular bodies of porphyry * * *. The portion containing fluorite is usually lower in gold than other parts of the rock, and the highest values are contained in the dark-colored silicified limestone.
>
> * * * * * *
>
> The general character of the ores is such that they may readily be seen to be replacements of limestone by silica and fluorite with small quantities of gold, silver, and tellurium.

Five samples of jasperoid taken from blocks that were excavated from opencuts of a mine between Johnson Gulch and Calamity Gulch about a mile west of the summit of Ragged Top Mountain consist largely of angular dense jasperoid breccia fragments. They are light gray, medium gray, pinkish gray, and grayish orange, and have an aphanitic, locally vuggy, quartz matrix that is heavily impregnated with iron oxides, which impart to it various shades of brown and red.

The breccia fragments are homogeneous to slightly heterogeneous quartz that has a jigsaw-puzzle texture and a grain diameter that averages about 0.01 mm and ranges from 0.005 to 0.05 mm. The fragments contain sparse microvugs, allophane particles, local concentrations of tiny black opaque particles, and tiny hematite cubes pseudomorphous after pyrite. Some of them contain aggregates of coarser (0.01–0.15 mm) xenomorphic to subhedral quartz grains with abundant carbonate particles in their cores.

The matrix quartz is vuggy and has a heterogeneous xenomorphic texture that is coarser than that of the breccia fragments; its grain diameter averages about 0.05 mm and ranges from <0.01 to 0.3 mm. It contains abundant goethite, brown and orange limonite, hematite, and irregular masses of fluorite.

Irving (1904, p. 174–175) mentioned the occurrence of a pinkish-brown pigment uniformly distributed as a thin coating on quartz grains of jasperoid ore from the Dacy claims. This material was thought to be an oxidation product of sylvanite.

Standard oxide analyses of two samples of this ore (Irving, 1904, p. 174) are given, in percent, in the following table. It is noteworthy, though possibly fortuitous, that the sample that showed the higher silica content also showed more Ag and Au. (In the table, "N.d." indicates not detected.)

	Sample			Sample	
	1	2		1	2
SiO_2	90.990	96.27	H_2O- 105°	0.110	0.03
Al_2O_3	2.970	.26	H_2O+ 105°		.42
Fe_2O_3	....	.26	CO_2	......	.96
FeO	3.024	.19	Volatile	.802	....
MgO	Trace	.19	S	N.d.	.05
CaO	1.138	1.16	Au	.053	.06
BaO	N.d.	.06	Ag	.003	.02
Na_2O	N.d.	.05	Te	.091	.03
K_2O	N.d.	.11			
Li_2O	N.d.	Strong trace	Total	99.181	100.12

Most of the five samples from the mine west of Ragged Top Mountain are high in Fe, Ba, Be, Mo, Ni, Pb, and V, as shown by spectrographic analyses. The richest sample also contains abnormally high concentrations of As, In, Sb, and Zn. Indicator-element scores on the five samples are +20, +12, +7, +3, and +3. Although fewer minor elements are included in this list than in the one for samples from the West Lead district, all these samples contain detectable amounts of molybdenum (0.15 percent in one sample), whereas this element was not detected in most of the samples from the West Lead district.

CARBONATE DISTRICT

(1, fig. 47)

In the Carbonate district, on the north side of Squaw Creek, Carboniferous limestone is intruded by sills, dikes, and irregular masses of porphyry. Locally, replacement deposits of argentiferous galena, oxidized near the surface to cerussite, are present in silicified limestone adjacent to these intrusives. At the Iron Hill mine, the largest in the district, an ore body of this type was developed to a depth of 300 feet on the east side of a thick dike of fine-grained white porphyry. In the Seabury mine a fracture filled with pinkish-red auriferous gouge is encased in ferruginous jasperoid that replaces the limestone for as much as 3 feet from the fracture. This jasperoid locally contains galena, cerussite, and cerargyrite in amounts sufficient to be profitably worked (Irving, 1904, p. 177–178).

TENNESSEE

In Tennessee, bodies of jasperoid are known in the mining districts of Bumpass Cove (6, fig. 41), Eastern Tennessee (8), Central Tennessee (7), and Sweetwater (9). In the Bumpass Cove area large masses of jasperoid are associated with iron and manganese deposits in a residual clay overlying Lower Cambrian Shady Dolomite and with the oxidized base-metal sufide deposits in this dolomite.

The Eastern Tennessee district is characterized by extensive zinc sulfide replacement deposits in dolomitized limestone of the Ordovician Kingsport Formation; in some places the host rock has been replaced by jasperoid adjacent to these ore bodies. The Central Tennessee district covers a large area south and east of Nashville in which small fissure vein deposits of sphalerite, galena, barite, and fluorite cut Ordovician limestone and dolomite; breccia fragments of carbonate host rock in some of these veins have been replaced by buff to gray jasperoid, but silicification of the host rock outward from the veins is not abundant. It is more abundant in the Hoover and Knight zinc veins than in some of the others.

BUMPASS COVE DISTRICT

(6, fig. 41)

Bumpass Cove is near the east end of Tennessee in Washington and Unicoi Counties a few miles north of the North Carolina State line. Masses of ferruginous, manganiferous, and zinciferous jasperoids are locally abundant in this area in residual clay overlying the Shady Dolomite, although, commonly, the fresh dolomite beneath the clay contains little jasperoid. Similar jasperoids are also present south of Mountain City at the northeast tip of Tennessee. Here, the jasperoid is locally jointed and brecciated and is most abundant where the underlying dolomite has been cut by faults. In the Bumpass Cove district, however, most of the jasperoid is apparently unrelated to faults, although it is concentrated in areas where the dolomite shows considerable deformation (King and others, 1944, p. 22–23).

This jasperoid forms irregular, but approximately, equidimensional bodies ranging in size from small nodules to masses 20 feet in diameter. Generally, it is yellowish brown, but, locally, it is white, gray, black, red, or dark brown. In some places it forms open boxworks lined with light-colored drusy saccharoidal quartz or mammillary cryptocrystalline silica. Silicified oolites and molds of dolomite rhombs in this jasperoid provide evidence that it formed by replacement of dolomite. The jasperoid is commonly associated with deposits of iron, manganese, and zinc oxides, which have replaced the matrix clay and, in some places, the jasperoid (Rodgers, 1948, p. 15–16).

Silica in the dolomite beneath the clay is largely limited to light-colored friable quartz, which coats fractures and open cavities but which does not replace the dolomite. It is similar in appearance and mode of occurrence to the late quartz found in voids in the jasperoid.

The clay in which the jasperoid is found is largely confined to high dissected terraces and is overlain in most places with old terrace gravels. Jasperoid is thought to have formed by silicification of dolomite contemporaneous with its weathering during an ancient, more humid climatic cycle (King and others, 1944, p. 24; Rodgers, 1948, p. 17).

EASTERN TENNESSEE ZINC DISTRICT

(8, fig. 41)

Large replacement deposits of sphalerite in the Ordovician Kingsport Formation in the Eastern Tennessee district, north and northeast of Knoxville, are associated with extensive preore dolomitization of limestone beds and brecciation of the dolomite. Locally, replacement of the carbonate host rock by early gray and black jasperoid has occurred adjacent to the ore bodies. This jasperoid, which generally extends only a few feet from the ore bodies, contains disseminated sphalerite, with which it is considered to be penecontemporaneous (Hoagland and others, 1965, p. 708).

Two samples of this jasperoid are aphanitic in hand specimen and have a greasy luster and irregular color bands of light gray, olive gray, greenish gray, and moderate brown; locally, they contain small irregular masses of white calcite.

In thin section the matrix is seen to consist largely of homogeneous aphanitic jigsaw-puzzle-textured quartz, which contains scattered relict grains and small masses of dolomite. Chalcedony is abundant, both as small spherical or ellipsoidal masses with concentric colloform bands and as coarser grained feathery masses filling former vugs. Some former vugs have been filled with medium-grained xenomorphic quartz. A rounded mass of white coarsely crystalline calcite surrounded by matrix jasperoid in one of the samples is probably an inclusion, but it could also be a late vug filling. This calcite mass contains abundant disseminated euhedral quartz crystals which, in turn, contain dust-sized carbonate particles. Thin veinlets of late calcite and pale-yellow opal cut the matrix in places. The contact between the dense jasperoid and equally dense dolomitic host rock is sharp in some places, though generally it is marked by a transition zone about 0.1 mm wide that consists of slightly coarser recrystallized dolomite with intergranular veinlets and scattered disseminated masses of jasperoid quartz.

Spectrographic analyses of these samples show that they contain only Na, Ba, and Sr in greater-than-average abundance. The absence of indicator elements from this list is unusual in view of the close association of the jasperoid with sphalerite ore, both spatially and genetically. The cherty appearance of this jasperoid and the abundance of colloform textures and chalcedony suggest that it was originally deposited as a silica gel.

CENTRAL TENNESSEE DISTRICT

(7, fig. 41)

The Central Tennessee district is within the Nashville Dome south of Nashville. Middle Ordovician limestone and dolomite exposed in this broad upwarp have been cut by many faults and small fractures. These locally are filled by base-metal sulfide, barite, and fluorite veins. Breccia fragments of host rock in these fissures locally have been completely silicified, and in a few places the vein walls also have been converted to jasperoid for a distance of 1–2 feet outward from the vein (A. V. Heyl, written commun., 1965).

Two jasperoid samples from the Hoover mine, south of Milton in the Central Tennessee district, are replacements of limestone breccia fragments—one from the vein and the other from the vein wall. Both samples are dense, fine grained, and dark gray, and the one from the vein also contains abundant disseminated dark-yellowish-orange sphalerite. The matrix quartz is fine grained and somewhat heterogeneous; it has a reticulated to xenomorphic texture, a mean grain diameter of about 0.02 mm, and a size range of 0.005–0.15 mm. Relict carbonate grains and dust-sized carbonate particles are abundant in the quartz. Narrow veinlets of white calcite cut the matrix. Sphalerite grains locally surround matrix quartz grains. The sample from the vein wall shows a well-marked transition zone about 1 cm wide between jasperoid and limestone host rock. This zone is marked by a gradual change from fine-grained quartz with sparse interstitial calcite to fine-grained calcite with sparse interstitial quartz. These specimens and those of typical black jasperoid from the Blue Goose mine in the Joplin area of the Tri-State district are strikingly similar in appearance.

The sphalerite-bearing jasperoid sample from the breccia fragment in the vein is abnormally high in Cu, Ga, Pb, and Zn, and yields an indicator-element score of +15. The sample from the vein wall shows high Nb, Sr, and Zn and yields an indicator-element score of +3.

OTHER OCCURRENCES

Jasperoid, which contains barite and fluorite but which otherwise is similar to that of the East Tennessee district, is present in the Sweetwater district (9, fig. 41) in northwestern Polk County, about 50 miles southwest of Knoxville (A. V. Heyl, written commun., 1967).

TEXAS

Jasperoid has been reported from two mining districts in western Texas, close to the Rio Grande. One is the Shafter silver-lead-zinc district (3, fig. 48) in south-central Presidio County, about 200 miles southeast of El Paso, where structurally controlled sulfide replacement deposits occur in Permian limestone. The other district, the Eagle Mountains (1), is a fluorspar district near Eagle Peak in southern Hudspeth County, about 100 miles southeast of El Paso, where the ore deposits are replacement bodies in Cretaceous limestone and vein fillings in Tertiary rhyolite.

SHAFTER DISTRICT

(3, fig. 48)

A massive section of Permian limestone 1,000 feet thick contains most of the ore in the Shafter district. This limestone is overlain unconformably by about 1,500 feet of Lower Cretaceous rocks that also consist largely of limestone. The ore is principally in the form of mantos, controlled by high-angle normal faults and, to a lesser extent, by low-angle thrust faults and related shear zones in the Permian limestone. There has also been some mineralization of the overlying Cretaceous rocks, but it has not re-

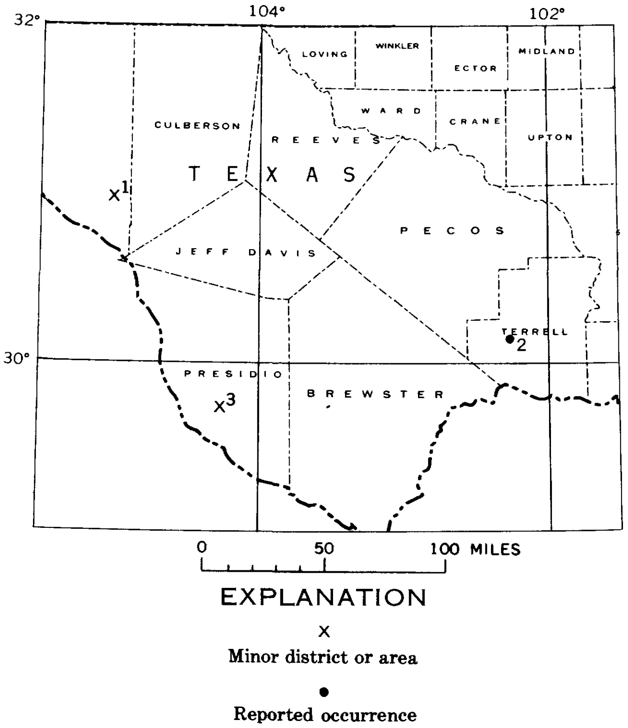


FIGURE 48.—Map showing location of jasperoid-bearing areas in Texas. 1, Eagle Mountains; 2, Sanderson; 3, Shafter.

sulted in minable ore deposits. Hydrothermal alteration and mineralization in the district apparently occurred in the following sequence: (1) Dolomitization of limestone, (2) siliceous replacement of limestone and dolomite, (3) deposition of calcite and ore sulfides, and (4) supergene alteration of sulfide ore (Ross, 1943, p. 45). Hypogene ore and gangue minerals include dolomite, calcite, quartz, pyrite, sphalerite, galena, and argentite and minor chalcopyrite and tetrahedrite. Extensive supergene alteration of the ore bodies has largely converted the primary sulfide minerals into a variety of minerals, including iron and manganese oxides, plumbojarosite, cerargyrite, native silver, cerussite, anglesite, descloizite, covellite, and chrysocolla.

The ore bodies contain abundant fine-grained jasperoid, and the limestone host rock adjacent to the ore bodies has locally been replaced by silica, partly as disseminated quartz grains in the host rock and partly as massive jasperoid in irregular masses and layers along bedding planes. Ross (1943, p. 104) stated that "In much of the better ore, silicification appears to have been nearly complete." Although quartz veins are not found in the ore zone, much of the ore has been brecciated and recemented by silica, after the original jasperoidization of the limestone. Andesite and basalt dikes in the area are partly silicified, and beds of the Lower Cretaceous Presidio Formation have been locally silicified along fractures (Ross, 1943, p. 104–105).

EAGLE MOUNTAINS DISTRICT

(1, fig. 48)

The Eagle Mountains district consists of several small fluorspar deposits that are concentrated in the vicinity of a Tertiary syenite stock at Eagle Peak, in southern Hudspeth County. These deposits consist of replacement mantos in Lower Cretaceous limestone and also of fillings and breccia cement in veins and faults cutting the limestone and the overlying Tertiary rhyolite (Gillerman, 1953, p. 1, 91).

Quartz occurs in the limestone manto deposits both as detrital sand grains and as recrystallized quartz intimately associated with fluorite. Locally, the host limestone adjacent to such replacement deposits has also been extensively silicified. In Spar Valley and in deposits at Rocky Ridge, fluorspar veins in limestone are encased in conspicuous masses of fine-grained dense brown or bluish-gray jasperoid. Gillerman (1953, p. 85) wrote of the deposits at Rocky Ridge:

> The effects of recrystallization and silicification are present throughout the limestone sequence, and it is generally difficult to determine the original nature of the rock. Complete silicification of the limestone resulted in a brown or blue-gray hard quartzitic-appearing rock that breaks with a conchoidal fracture and a smooth surface. Gradations from pure unaltered limestone to these quartzitic-appearing rocks can be observed in the same boulder or outcrop. The recrystallization and silicification of the limestone is due primarily to mineralizing solutions travelling along many faults and other fractures in the area.

OTHER OCCURRENCES

Near Sanderson (2, fig. 48) in Terrell County, high terrace gravels presumed to be of Pleistocene age contain abundant rounded pebbles which consist of light-gray aphanitic silica shells surrounding irregular cores of altered Cretaceous limestone (V. L. Freeman, oral commun., 1965). Examination of a thin section cut through one of these pebbles shows that the outer part of the limestone core is weathered and porous with numerous large irregular vugs in the contact zone. The shell consists of vuggy heterogeneous medium-grained quartz that has a jigsaw-puzzle texture, masses of flamboyant chalcedony, and abundant carbonate particles in the quartz. This suggests that the limestone core fragment was partly weathered before the silica shell was formed, that silica was precipitated as a colloidal gel, and that it partly replaced limestone in the contact zone.

UTAH

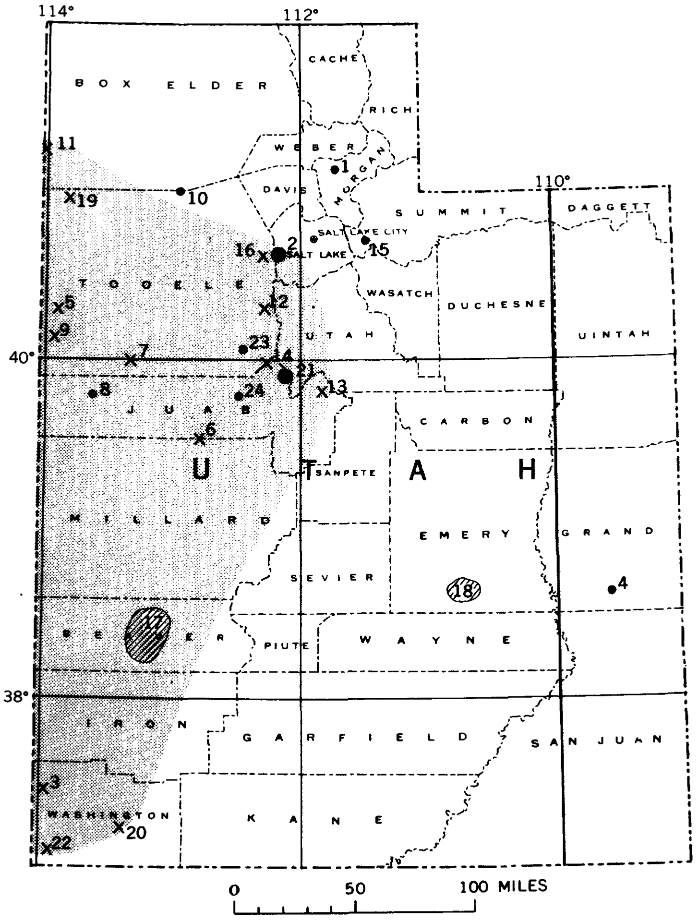
Jasperoids in the major districts (21, fig. 49) of Utah, the Tintic and East Tintic, have been discussed previously in this report. Fifteen other districts in the State also contain abundant jasperoid, and nine additional localities are known in which siliceous replacement bodies have been noted (fig. 49).

Most of the jasperoid-bearing districts of Utah are scattered through the Great Basin province, which occupies approximately the western third of the State; however, jasperoid is also present in the San Rafael Swell, west of Moab, in eastern Utah. Most Utah mining districts that are distinguished by jasperoid bodies are argentiferous base-metal sulfide producers in which both jasperoid and ore formed as structurally controlled replacements in Paleozoic carbonate rocks. The Bull Valley district (3, fig. 49) produced gold from veins that cut Pennsylvanian limestone. In the uranium mines of the San Rafael Swell area (18) and the silver mines at Silver Reef (20), silica has replaced Triassic siltstone or shale below the ore zone.

BINGHAM DISTRICT
(2, fig. 49)

In the Bingham mining district in Salt Lake County, north-central Utah, a thick Pennsylvanian quartzite, containing interbedded limestone, has been folded into an open syncline that plunges northwest; it is intruded by quartz monzonite porphyry stocks and several dikes and sills. Both the sedimentary and the intrusive rocks are cut by numerous northwest- and northeast-trending faults. One of the quartz monzonite porphyry stocks contains a large low-grade disseminated "porphyry copper ore body"; numerous smaller, higher grade copper, lead, and silver deposits replace the limestone beds south and west of the stock. The ores show a zonal distribution in which copper predominates in and close to the stock, and lead and silver predominate farther out. Mineralization was preceded and accompanied by marmarization and jasperoidization of the carbonate beds (Boutwell, 1905; Cook, 1961).

Although Bingham is the largest mining district in Utah, the abundance and significance of jasperoid



EXPLANATION

▨ Area of large mining district

● Major district

× Minor district or area

• Reported occurrence

░ Jasperoid province

DISTRICTS, AREAS, AND OCCURRENCES

1. Argentia
2. Bingham
3. Bull Valley (Goldstrike)
4. Castle Creek
5. Clifton
6. Drum Mountains (Detroit)
7. Dugway
8. Fish Springs
9. Gold Hill
10. Lakeside
11. Lucin
12. Mercur and Ophir
13. Mount Nebo
14. North Tintic
15. Park City
16. Rush Valley (Stockton)
17. San Francisco and vicinity
18. San Rafael Swell
19. Silver Islet
20. Silver Reef
21. Tintic and East Tintic
22. Tutsagubet
23. Vernon
24. West Tintic

FIGURE 49.—Map showing location of jasperoid-bearing areas in Utah.

in it are uncertain. Boutwell (1905, p. 67–68, 118, 133, 189–192, 202) discussed at length the jasperoid at Bingham; however, Hunt (1924, p. 879) stated that much of the presumed "jasperoid" is only altered quartzite and that suites of samples from highly mineralized limestone show very little silicification. According to Winchell (1924, p. 898), much silica was deposited with the replacement ore bodies in the limestone, but very little silica was deposited elsewhere. A more recent comprehensive report (Cook, 1961) on the Bingham district and surrounding area does not mention jasperoid.

Jasperoid is present in many limestone beds in the mineralized area but is most abundant in limestone of the Oquirrh Group. Large, siliceous bodies are present on the east flank of Clipper Peak, others are scattered irregularly through a belt about a mile wide between the stock and the ridge running easterly from West Mountain to the head of Bear Gulch, and a large mass caps the northeast-trending ridge at the head of Yosemite Gulch, east of the Bingham stock.

Mineralization was accompanied, or immediately preceded, by jasperoidization that was localized along fractures. This silicification started with small isolated masses of fine-grained quartz, followed by coarse crystalline quartz with contemporaneous pyrite and chalcopyrite; it resulted in selective replacement of favorable carbonate beds outward from northeast-trending fractures (Boutwell, 1905, p. 189–192, 199).

The jasperoids are closely related both spatially and genetically to some of the sulfide replacement deposits in limestone, and pockets of barren altered material within the ore bodies commonly consist largely of jasperoid quartz.

According to Boutwell (1905, p. 38, 118, 133, 202), the jasperoids of the Bingham district vary widely in physical appearance. Some bodies retain the texture and color of the original host rock, which they resemble so closely as to be indistinguishable, except for their superior hardness; others are dense, white, and coarse grained with a saccharoidal texture. Locally, beds of white marble alternate with beds of dense cherty jasperoid that are white, black, bluish gray, and various shades of yellow, brown, and red. Limestone in mineralized areas is commonly replaced by porous spongy masses of quartz.

Incipient jasperoidization of the carbonate rocks is marked, in some areas, by thin, anastomosing veinlets of quartz and chalcedony following joint planes and fractures. In other places it takes the form of tiny disseminated quartz particles in recrystallized limestone. In the Commercial mine thin veinlets of green and brown opal cut brown recrystallized limestone (Boutwell, 1905, p. 68).

I have only four jasperoid samples from the Bingham district. One is from a small outlying jasperoid body on the divide about 1½ miles east of West Mountain. The other three are from a larger jasperoid body near the quartz monzonite contact a few hundred feet north of a saddle on the divide, which is about two-tenths of a mile east of Copperfield.

The sample from the ridge east of West Mountain has a dense, heterogeneous, largely xenomorphic groundmass with a few scattered elongated laths. The grain size of the quartz particles ranges from 0.01 to 0.3 mm, and the large grains are locally segregated in irregular masses. Many of the larger grains show zoning of allophane inclusions around cores. The matrix contains abundant disseminated grains of red hematite, a few of which have small residual pyrite cores. The jasperoid is cut by veinlets and irregular masses of earthy yellow to orange limonite and also by narrow veinlets of jasperoid microbreccia particles in a clay matrix (probably kaolinite and halloysite).

The three samples from the ridge above Copperfield consist of angular breccia fragments of jasperoid in a matrix of orange-brown limonite and, locally, of jarosite. The larger fragments contain abundant irregular open vugs. In texture the matrix quartz ranges from medium-grained homogeneous xenomorphic to heterogeneous xenomorphic. The diameter of the quartz particles ranges from 0.02 to 0.4 mm; local masses and bands of finer grained quartz average 0.01 mm. The quartz contains interstitial brown limonite with local concentrations of carbonate dust particles and scattered flakes of sericite.

The four whole-rock samples previously discussed were ground and submitted to semiquantitative spectrographic analysis. The three samples from the vicinity of Copperfield contained an appreciable quantity of matrix limonite in addition to jasperoid quartz, and the abnormally high concentrations of some of the elements detected in these samples may reflect this contamination.

All four samples showed greater-than-average concentrations of lead and zirconium. Zinc was detected in the single outlying sample but not in any of the three close to the stock. Copper is an order of magnitude higher in these three samples than in the outlying sample. Silver is distributed erratically; in the outlying sample it shows 3 ppm, and in other samples it shows 3 ppm, 30 ppm, and below the limit of detection. None of the remaining elements detected in the single sample from the ridge east of West Mountain are present in greater-than-average abundance. The group of samples from near Copperfield on the edge of the Bingham pit contains abnormally high concentrations of Fe, Na, As, Ba, Bi, Mo, Ni, and Sn in addition to the elements previously discussed.

The scores of these four samples suggest that the single sample from the ridge east of West Mountain is in the probably favorable category, probably near the fringe of the zone of sulfide mineralization; the other three samples from the edge of the pit, above Copperfield, all fall in the favorable category.

BULL VALLEY (GOLDSTRIKE) DISTRICT

(3, fig. 49)

The Bull Valley mining district is in western Washington County near the north end of the Beaver Dam Mountains, about 50 miles west-southwest of Cedar City and about 10 miles from the Nevada State line. In this area Pennsylvanian limestone has been highly silicified locally along fractures, forming conspicuous outcrops of jasperoid that is stained yellow and brown by iron oxides. This rock contains free gold disseminated in the gangue of quartz, calcite, jarosite, and limonite (Butler and others, 1920, p. 598).

CLIFTON DISTRICT

(5, fig. 49)

The Clifton district is in western Tooele County at the north end of the Deep Creek Range, a few miles north of Gold Hill and about 12 miles east of the Nevada State line. Here, a thick Mississippian limestone has been intruded by a small stock of Tertiary quartz monzonite. Sulfide ore bodies formed in fissure veins that cut the stock; they are also in the zone of contact metasomatic alteration surrounding it. Beyond this zone of high-temperature alteration the limestone has been replaced by large bodies of cherty fine-grained jasperoid associated with some limonite. These bodies form conspicuous outcrops near the Gold Hill-Clifton road about 1½ miles south of Clifton. A small amount of prospecting on these "reefs" has failed to locate any ore bodies (Butler and others, 1920, p. 479).

DRUM MOUNTAINS (DETROIT) DISTRICT

(6, fig. 49)

The Drum Mountains, or Detroit, district straddles the line between Juab and Millard Counties about 30 miles northwest of Delta. The small desert range in which the district lies is situated between the Sevier Desert on the east and Whirlwind Valley on the west. This range is a westward-tilted block, composed of a thick series of Precambrian and Cambrian quartzite overlain by Cambrian limestone and dolomite. In the mineralized area these rocks are cut by numerous east- to northeast-trending faults that have displacements ranging from a few feet to a few thousand feet.

The district was originally worked for gold and copper, mostly during 1895–1918, but more recently it has produced manganese ores. The ore bodies are localized by the intersection of fractures with favorable carbonate beds. Although the manganese and gold-copper ores are related genetically, they are separate and distinct in occurrence and composition. Manganese ore bodies contain only traces of gold and copper, and gold-copper ore bodies contain little manganese (Crittenden and others, 1961, p. 507).

Many of the stronger faults served as conduits for silica-bearing hydrothermal solutions that silicified adjacent limestone and dolomite locally and formed conspicuous yellowish-brown jasperoid reefs. These reefs contain disseminated pyrite or limonite after pyrite, chalcopyrite and its oxidation products, and small amounts of other sulfides in and near gold-copper ore bodies (Butler and others, 1920, p. 464). Crittenden, Straczek, and Roberts (1961, p. 515) believed that jasperoid may be closely related genetically to manganese, as well as to copper and gold, and recommended the exploration of jasperoid bodies where they intersect the basal carbonate beds near the Martha mine.

Ten samples of jasperoid from the Drum Mountains district were collected by Lovering (in Lovering and others, 1963, p. B1) in the course of an investigation of hydrothermal dolomite in the area. All these samples were taken from bodies along faults and strong fractures; three are from mine prospects, and seven are from bodies that have not been prospected.

The jasperoid samples appear to represent two distinct types of rock. Most of the samples, including the three from prospected bodies, are crystalline, vuggy, and heavily iron stained in various shades of yellow, brown, and red. They have a relatively coarse-grained heterogeneous and distinctly reticulated texture and distinct zonal overgrowths on some of the larger quartz crystals. The quartz crystals are locally disseminated through coarse-grained patches of calcite. The jasperoid samples also contain abundant hematite, goethite, and brown limonite; sparse patches of malachite are visible in one sample from a mine adit, and chalcedony locally lines vugs in the quartz.

The other type of jasperoid is represented by three samples from faults and fracture zones near the abandoned townsite of Joy, northwest of the main mining district. These samples consist of light-gray, yellowish-gray, and brownish-gray cherty-looking quartz which locally is stained brown by iron oxides and which in some places contains large irregular open vugs. The quartz is fine grained and homogeneous and has a xenomorphic to jigsaw-puzzle texture. Yellow limonite and fine-grained calcite are abundant, and chalcedony locally lines vugs.

Most jasperoid samples of both types contain anomalously high concentrations of Ag, Au, Bi, Cu, Pb, and Sb. The coarser grained jasperoid with reticulated texture generally shows more minor elements with abnormally high concentrations than does the aphanitic variety. In addition to the elements listed above, most samples in this group also show abundant Ba, Ni, and Zn; one or two of them are also high in As, Co, Ga, Sn, and V. All but two of the samples contain >0.02 ppm of Au, and one sample contains 26 ppm Au.

Indicator-element scores for the group range from +2 to +22. The sample that yielded the highest score contains >1 percent Cu, 0.05 percent Ag, 0.05 percent Zn, and 1.7 ppm Au.

The association of Ag, Bi, Cu, and Pb in this group of samples is noteworthy because it also characterizes jasperoids of the Bingham (2, fig. 49) and Ely (19, fig. 44) districts. This similarity and the high gold content of the jasperoid suggest that the Drum Mountains district may contain considerably more ore than has thus far been mined.

DUGWAY DISTRICT

(7, fig. 49)

The Dugway district is in south-central Tooele County, near the north end of the Granite Range, about 55 miles southwest of Tooele. Faults and fractures cutting Mississippian limestone in this district have localized replacement ore bodies of argentiferous galena and sphalerite, all partly oxidized. In the northern part of the district, in the vicinity of the Four Metals mine, the limestone has been highly fractured and replaced with jasperoid near the oxidized ore bodies (Butler and others, 1920, p. 463).

GOLD HILL DISTRICT

(9, fig. 49)

The Gold Hill district is in southwestern Tooele County in Tps. 7 and 8 S., R. 18 W., at Gold Hill, a few miles south of the Clifton district and about 15 miles east of the Nevada State line. Paleozoic shales and carbonate rocks in this area have been broken by both low-angle thrust faults and high-angle faults and intruded by a Tertiary quartz monzonite stock and several smaller igneous bodies. Mining activity in the district centered at Gold Hill, a small northwest-trending ridge, about 1½ miles west of Gold Hill townsite, and at the U.S. mine about half a mile south of the townsite. Large replacement ore bodies of arsenopyrite and base-metal sulfides associated with jasperoid were developed here in Carboniferous and Permian limestone. Many other jasperoid bodies are present in various parts of the district in the Mississippian Ochre Mountain Limestone and in carbonate beds of the Mississippian to Permian Oquirrh Formation. These jasperoids are thoroughly discussed by Nolan (1935) and are also shown on the geologic map of the district that accompanies his report.

Nolan (1935, p. 93) stated that jasperoid bodies tend to be concentrated close to the quartz monzonite contact or along faults in the Ochre Mountain Limestone and the Oquirrh Formation that predate the quartz monzonite, and that large jasperoid bodies are exposed on Gold Hill, near the mouth of Barney Reevey Gulch, and at the U.S. mine south of Gold Hill townsite. The district map that accompanies Nolan's report also shows a mass of jasperoid that is more than 1 mile long and as much as 1,000 feet wide in places along an east-trending fault about 1½ miles south of the summit of Ochre Mountain, outside the main mining area in the district.

Nolan (1935, p. 152–153) described these outcrops as consisting of jagged reddish-brown-weathering jasperoid that has been brecciated and recemented by several generations of quartz exhibiting different textures and colors. This jasperoid is commonly vuggy, with breccia fragments of unreplaced limestone and, locally, visible plates of barite, oxidized copper minerals, and masses of green chalcedony. The jasperoid outcrop on Gold Hill is more than 100 feet wide and has been cut by mine workings at a depth of 700 feet, where it has a sharp contact with unreplaced limestone.

The older jasperoid quartz matrix is fine grained, crystalline, and free of fluid inclusions; it shows features that may be desication cracks which partly controlled the location of younger veinlets of coarser quartz. These veinlets commonly exhibit vague outlines of crystals which are normal to the walls and which are now recrystallized to aggregates of anhedral quartz grains; contacts of veinlets with matrix quartz are gradational. Where associated with ore the jasperoid commonly contains pyrite, arsenopyrite, galena, sphalerite, and tetrahedrite or their oxidation products. Elsewhere, barite, chlorite, chalcedony, opal, calcite, and sericite are common accessory minerals. Contacts between sulfide ore bodies and jasperoid tend to be gradational in contrast to the characteristically abrupt contacts between jasperoid and host rock.

Nolan (1935, p. 94) expressed the opinion that the silica that formed the original jasperoid was deposited as a gel and that the younger quartz veinlets in it may have formed by the expulsion of silica-bearing fluid into shrinkage cracks during the crystallization of this gel.

The jasperoid of the Gold Hill district is younger than the contact metasomatism and recrystallization of carbonate rocks that accompanied intrusion of the quartz monzonite. In the major arsenic replacement ore bodies of the U.S. mine, quartz is continuous and contemporaneous with jasperoid replacing the limestone host rock. At the Gold Hill mine, jasperoid is closely related to tetrahedrite-bearing quartz veins in the limestone, and limestone adjacent to ore bodies is locally replaced by fine-grained pale-gray jasperoid. Within these ore bodies, in some places arsenopyrite ore has been brecciated and recemented by fine-grained quartz resembling jasperoid; however, it seems that sphalerite is nearly contemporaneous with the silica, and that galena, jamesonite, and stibnite are somewhat younger.

Of nine samples from the vicinity of Gold Hill, two are from outcrops about 5 miles northwest of the townsite, one is from the townsite, and six are from exposures on the south side of Ochre Mountain, 5–6 miles southwest of the townsite. Unfortunately, I have no samples of the jasperoid described by Nolan as being associated with the ore bodies on Gold Hill or at the U.S. mine.

The two samples from the area northwest of Gold Hill may represent the bodies of barren jasperoid mentioned by Butler, Loughlin, Heikes, and others (1920, p. 479) in their description of the Clifton district (5, fig. 49). These two samples were taken from conspicuous outcrops close to the road about midway between the two districts. Both samples represent brecciated and silicified fault zones in Paleozoic limestone. Both consist of gray breccia fragments enclosed in a dense grayish-orange to moderate-brown matrix. Breccia fragments consist of dense dark-gray material that looks like chert and of medium-gray heterogeneous quartz that has a xenomorphic to jigsaw-puzzle texture and an average grain diameter of about 0.02 mm, cemented in a matrix whose appearance is so similar to that of the fragments that, commonly, the boundaries between fragments and matrix are clearly visible only by reflected light. The matrix contains irregular masses of yellow to brown limonite, and locally shows disseminated grains of hematite that may be pseudomorphs of original pyrite. Small vugs in the matrix, and fractures cutting it, are commonly lined with coarse xenomorphic quartz, some of which show crystal faces and zonal overgrowths; these fractures and vugs are locally filled with coarse late calcite. Both samples are slightly higher than normal in Ba, Ni, and Pb, but not sufficiently so to place them in the favorable category.

The single sample from Gold Hill townsite was taken from a prominent knob adjacent to an old millsite about 100 yards west of some abandoned buildings. It is not a true jasperoid, but rather a fault breccia composed of comminuted chert and limestone fragments, cemented by indurated calcite microbreccia that shows incipient replacement by quartz that has a coarse jigsaw-puzzle texture and wavy extinction. Opaque orange limonite forms irregular veinlets cutting the carbonate. The sample shows slightly anomalous concentrations of Na, Ba, Cr, Pb, Sr, V, and Zr, but it yields an indicator-element score of only +2.

The six samples from outcrops on the south side of Ochre Mountain, well beyond the limits of the main productive area, are mostly breccias that consist of chert or jasperoid fragments in a matrix of younger jasperoid. The matrix is commonly light olive gray to pale yellowish brown on fresh exposures, grayish orange to yellowish orange on weathered surfaces; breccia fragments are commonly dark yellowish brown to dark gray, darker than the matrix. The breccia fragments are uniformly aphanitic and dense; the matrix is also aphanitic but is locally porous and vuggy. In thin section, both matrix and inclusions have a relatively homogeneous jigsaw-puzzle to locally xenomorphic texture and an average grain size of 0.01 mm; both commonly contain relict dolomite rhombs and carbonate particles. The inclusions are dense, and some are full of opaque carbon particles; whereas the matrix is free of carbon and locally contains abundant open microvugs. Veinlets of calcite, brown limonite, and coarser grained xenomorphic quartz cut the matrix. Two samples taken about 100 yards from a small abandoned shaft contained disseminated pyrite that is largely altered to hematite, and one of these samples also exhibits late veinlets filled with goethite and jarosite. All six samples are higher than average in Ba, and most of them are also high in Ni and Sr. The two samples that contain disseminated pyrite also show traces of Pb. One of them contains a little Ag and Zn, and the other, detectable As and Bi; their indicator-element scores are +8 and +4, respectively. The other four samples yielded scores ranging from −2 to +3.

LUCIN DISTRICT

(11, fig. 49)

The Lucin district is in Box Elder County in T. 6 N., R. 19 W., about 10 miles southwest of Lucin. The district overlaps the Utah-Nevada State line, but most of it is in Utah. Ore deposits consist of copper and lead-zinc-silver fissure replacement ore bodies in Pennsylvanian limestone, which has been intruded by a small stock of Tertiary quartz monzonite with local contact metasomatic alteration. The Copper Mountain mine developed copper replacement ore in jasperoid in, and adjacent to, a strong north-trending fault. At the south end of the deposit, massive copper-bearing limonite grades into barren iron-stained jasperoid along this fault (Butler and others, 1920, p. 493).

A jasperoid sample from this district taken from near the head of a gulch about 3 miles north of Bald Eagle Mountain and 1 mile east of the Nevada line, about half a mile from the nearest mine workings, consists of sparse dense dark-gray breccia fragments cemented by a porous fine-grained dark-yellowish-orange matrix. A thin section shows heterogeneous matrix quartz that has a xenomorphic texture and a size range of 0.01 to 0.06 mm; it contains numerous small rounded inclusions of older quartz, minor sericite, carbonate particles, and allophane. Orange-brown limonite is abundant in short veinlets, irregular masses, and as a coating on quartz grains. The sample is slightly high in Ba, Be, Cu, Li, Mo, and Sr, yielding an indicator-element score of +5.

MERCUR AND OPHIR DISTRICTS

(12, fig. 49)

These two districts are about 4 miles apart in eastern Tooele County on the western flank of the Oquirrh Mountains, 15–20 miles south-southeast of Tooele. In both districts the ore deposits are largely localized by intersections of faults and fractures with favorable carbonate beds of Mississippian age. Mercur, the southern district, was a famous gold camp early in the 20th century, and it also produced some silver. The Ophir district produced silver, lead, zinc, and copper, but relatively little gold.

According to Gilluly (1932, p. 97), jasperoid is abundant between Mercur and Lion Hill, near West Mercur, near the mouth of Silverado Canyon, in Dry Canyon, and in the hills between Dry Canyon and Ophir. Although most jasperoid bodies in the two districts are in Mississippian rocks of either the Great Blue Limestone or the Humbug Formation, their distribution is erratic and discontinuous. Structural control of the distribution of jasperoid bodies is shown by their tendency to transgress bedding and by their local association with fracture zones. The outcrops typically are conspicuous, jagged, rusty brown, and thoroughly brecciated, and they contain angular blocks of unreplaced limestone. Contacts between jasperoid and host rock are sharp with no visible transition zone. Coarse-grained white vein quartz commonly cements jasperoid breccia and lines vugs in the jasperoid. Many of these vugs are filled with white calcite. Fresh jasperiod is light gray to black and aphanitic to fine grained.

Two common varieties of jasperoid are readily distinguished under the microscope. One consists of cryptocrystalline anhedral interlocking quartz grains <0.03 mm in diameter and accessory chalcedony, tourmaline, sericite, calcite, epidote, apatite, and zircon. The other variety consists of interlocking euhedral to subhedral quartz crystals averaging about 0.2 mm in diameter (reticulated texture) and carbon and carbonate dust particles in addition to the accessory minerals that characterize the first variety. The aphanitic variety commonly contains streaks and lenses of coarser quartz with wavy extinction, which is associated with barite and, locally, with stibnite. Younger flamboyant vein quartz with barite cuts both varieties of jasperoid and, locally, this vein quartz is cut, in turn, by still younger brown-stained veinlets of cryptocrystalline quartz and accessory tourmaline, apatite, calcite, and zircon.

Gilluly (1932, p. 100) concluded that the first stage in the formation of jasperoid at Mercur was the replacement of carbonate rock by colloidal silica gel. Rapid crystallization of this gel led to the formation of aphanitic cherty jasperoid, whereas more gradual crystallization produced the coarser grained (reticulated) variety. Crystallization of the gel was accompanied by shrinkage. Coarser grained vein quartz associated with barite and, locally, stibnite and chalcopyrite then filled the shrinkage cracks. Brecciation and fracturing of this mass was followed by introduction of the late-stage cryptocrystalline brown quartz; local replacement was marked by blended contacts. The association of tourmaline with early jasperoid was cited by Gilluly (p. 101) as evidence favoring a relatively high temperature of replacement of limestone by silica. He pointed out that barite and stibnite are not present in the oldest jasperoid, and that calcite is abundant only in the youngest.

The genetic and spatial relationships between the various types of jasperoid and the primary ore deposits were not stressed by Gilluly (1932, p. 135), although he noted that in certain parts of the districts (near Mercur and in the hills between Ophir and Dry Canyon) ore deposits are commonly localized within or beneath jasperoid bodies. His detailed description of the various types and ages of jasperoid and the minerals commonly associated with each suggests that the original replacement of limestone by silica gel preceded ore-stage mineralization, but that the later silica, which cements jasperoid breccia and forms quartz veinlets cutting jasperoid, was approximately contemporaneous with it.

Sixteen samples of jasperoid from the Mercur-Ophir area are in my collection; eight are from the main mineralized area close to the old town of Mercur, three are from outcrops in the relatively unmineralized area between the two districts, and five are from the Ophir district.

The samples from Mercur were taken in the vicinity of the Franklin Lease mine west of the townsite and the Sacramento mine south of the townsite. They contain examples of the two types of older gray jasperoid and of the younger brown jasperoid described by Gilluly (1932). The aphanitic variety with jigsaw-puzzle texture is largely free of inclusions, but it contains sparse carbonate and allophane dust particles. The coarser grained reticulated variety contains pyrite, or its oxidation products, and barite in addition to sericite, and carbonate particles. The brown jasperoid contains all these minerals plus abundant limonite particles and, locally, tourmaline.

The three specimens from outside the main mining districts were collected from near the top of Rover Hill, near the mouth of Silverado Canyon, and about half a mile up Silverado Canyon. The sample from Rover Hill is of the coarser grained reticulated older jasperoid and contains sericite, carbonate particles, and sparsely disseminated pseudomorphs of jarosite after pyrite. Both samples from Silverado Canyon are of the aphanitic older jasperoid and contain only sparsely disseminated sericite, allophane, and carbonate particles.

Of the five samples from the Ophir district, two are from the vicinity of the Chloride Point mine about a mile south-southeast of Ophir, two are from the outskirts of the townsite of Ophir, and one is from an outcrop near the Lakes of Killarney mine about 2 miles west of Ophir. Four of these samples show the coarse-grained reticulated jasperoid, but the fifth one, which was collected close to a porphyry contact, has a coarse-grained heterogeneous xenomorphic texture. The sample from near the Lakes of Killarney mine is from a fault zone and is the only one in the suite that shows well-defined examples of both the older jasperoid types described by Gilluly (1932). In this specimen, breccia fragments of aphanitic jasperoid are cemented by a matrix of coarser reticulated jasperoid that is cut by veinlets of still coarser xenomorphic quartz; the whole mass was then rebrecciated and cemented by coarse calcite. Accessory minerals in these jasperoids are the same as in their counterparts from the Mercur district: carbonate particles, sericite, pyrite, or its oxidation products, and, locally, barite.

There appears to be some difference between the suites of minor elements present in abnormally high concentrations in the jasperoid samples from the two districts. Nearly all the Mercur samples are high in Ba and Hg, and most of them are high in Ag, Sr, and Te. Nearly all the Ophir samples are high in Sr, Ag, Cu, Pb, and Zn, and most of them are high in Ba, Hg, Ni, Sb, Te, and Zr. Two of the Mercur samples contain detectable amounts of As and Mo, elements not found in any of the Ophir samples. Two samples from Ophir, however, contain Bi, Nb, and Sc, elements not found in the Mercur samples.

Only three of the eight samples from the Mercur district yield indicator-element scores greater than +5, and the highest was +11. Four of the five samples from the Ophir district yield scores greater than +10. The highest score for this group was +18, and the lowest, +1. All three of the samples taken between the two districts gave scores of −1.

MOUNT NEBO DISTRICT

(13, fig. 49)

The Mount Nebo district is in the northeast corner of Juab County in the Wasatch Range, about 10 miles northeast of Nephi. Sulfide ore deposits in the district form replacement bodies along faults and fractures in Paleozoic carbonate rocks.

At the Santaquin Chief mine a pipelike ore body of galena in a gangue of quartz and calcite has been developed at the intersection of north- and east-trending fractures in jasperoidized Mississippian limestone. This jasperoid contains sericite, chlorite, titanite, fluorite, limonite after pyrite, and galena as both disseminated grains and narrow streaks and lenses. Vugs in the jasperoid are lined with crystalline quartz and calcite (Butler and others, 1920, p. 332).

NORTH TINTIC DISTRICT

(14, fig. 49)

The North Tintic district is on the line between Utah and Tooele Counties, about 5 miles north of Eureka in the northern East Tintic Mountains. It lies just north of the Tintic and East Tintic districts (21, fig. 49), which were previously discussed in the present report. Oxidized lead and zinc deposits, lean in silver, were mined in the district. Paleozoic sedimentary rocks in the area, consisting largely of limestones and dolomites, have been folded into a north-trending asymmetrical anticline and syncline; these folds are cut by several north-trending, west-dipping thrust faults that were, in turn, cut by north- and northeast-trending high-angle faults before early Tertiary volcanism that blanketed the area with flows and pyroclastics (Proctor, 1964, p. 1565–1567).

Dikelike and bedded replacement bodies of jasperoid are abundant in and near Chiulos Canyon, largely in the Deseret and Humbug Formations, but, locally, in the Great Blue Limestone above the Humbug. These dark-brown to reddish-brown bodies are as much as 100 feet thick and several hundred feet long and form conspicuous outcrops. North and northeast of this area of intense jasperoidization is a zone in which smaller bodies of fine-grained gray jasperoid occur as replacement masses in brecciated fault zones. Intensity of jasperoidization is greatest in the southwestern part of the area closest to the Tintic and East Tintic mining districts.

The jasperoid consists of fine-grained quartz that has an average grain diameter of <0.1 mm. Vugs are abundant locally, and they are commonly lined with euhedral quartz crystals. Brecciation of jasperoid and recementation by later quartz are conspicuous in some places. Red iron oxide commonly accompanies this late quartz, a few hematite pseudomorphs after pyrite have been noted in thin sections, and late calcite also fills some fractures in jasperoid (Proctor, 1964, p. 1575).

In this area, as in the Tintic and East Tintic districts (21, fig. 49) to the south, hydrothermal dolomitization preceded jasperoidization which, in turn, preceded sulfide mineralization.

RUSH VALLEY (STOCKTON) DISTRICT

(16, fig. 49)

The Rush Valley district is in eastern Tooele County, about 8 miles south of Tooele and 10 miles northwest of the Ophir district.

In this district replacement base-metal sulfide deposits have been formed close to the axis of a northward-plunging anticline in favorable beds of Carboniferous limestone and quartzite, where fractures and small faults, parallel to the anticline, cut these rocks. Highly altered felsic dikes fill some of these fissures. Jasperoid replacing limestone adjacent to the fractures is locally abundant, as it is in the Ophir district.

At the Muscatine mine, near the SW cor. T. 4 S., R. 4 W., abundant jasperoid and hornfels are associated with pyrite, sphalerite, and galena replacement bodies in limestone (Gilluly, 1932, p. 163).

SAN FRANCISCO DISTRICT AND VICINITY

(17, fig. 49)

The San Francisco mining district is at the south end of the San Francisco Mountains in Beaver County, about 15 miles west-northwest of Milford. A much larger area, which extends from the Escalante Valley on the east to the Wah Wah Mountains on the west and from the Iron County line on the south to the Millard County line on the north, contains many widely scattered small silver, lead, zinc, and copper mines and areas of hydrothermally silicified rocks. This larger area is considered here, for convenience, with the San Francisco district.

At the Horn Silver mine, in the main San Francisco district, volcanic rocks on the hanging-wall side of a strong mineralized fault zone have been extensively leached of all their principal constituents, except iron and silica, yielding a rock composed chiefly of fine-grained quartz with disseminated pyrite and some barite. Limestone on the footwall side of this zone is much less altered, although it has been generally recrystallized and locally silicified along fissures (Butler, 1913, p. 168).

At the Harrington-Hickory mine in the Star district on the east side of the Star Range, 5 miles from Milford, Triassic limestone, interbedded with siliceous shale and quartzite, has been replaced by argentiferous galena and sphalerite ore bodies along small fractures, and has been converted to jasperoid for as much as 30 feet outward from the fractures, although the associated shale and quartzite are only slightly altered. The jasperiod quartz contains accessory galena, pyrite, orthoclase, apatite, titanite, garnet, and magnetite (Butler, 1913, p. 195).

Of 10 samples from the San Francisco district and surrounding area in my collection, three are from the south end of the main district along State Highway 21, close to Squaw Spring; three are from a prominent jasperoid ridge surrounded by altered Tertiary volcanic rocks about 10 miles south of Squaw Spring; and the remaining four were collected in T. 30 S., R. 14 W., at intervals along a dirt road running from Milford around the south end of the Wah Wah Mountains far south of the old Wah Wah lead-zinc district. Two of this last group are jasperoid samples, and the other two are dolomite showing incipient silicification.

The samples from near Squaw Spring weather yellowish brown to reddish brown; one of these is light brownish gray on fresh surfaces, and the other two are pale red. They were collected from an east-trending breccia zone in Cambrian limestone, about a mile from the nearest large mines. The rocks are microbreccias of small angular jasperoid and limestone fragments cemented by aphanitic quartz that has a jigsaw-puzzle texture. Some of the jasperoid fragments are coarser grained and have a heterogeneous, locally xenomorphic texture, and contain abundant carbonate dust particles. The matrix is cut by veinlets of xenomorphic quartz that has an average grain diameter of about 0.1 mm. Hematite is locally abundant in irregular masses and anastamosing veinlets that cut the matrix, but it shows no evidence of derivation from original pyrite. Sparse irregular inclusions of barite as much as 1 mm in diameter were observed in one sample. All three samples are slightly high in Pb and Sr, one is slightly enriched in Ba, and another in Hg. The indicator-element scores for the three are +2, −2, and −3, respectively.

The three samples from the locality 10 miles south of Squaw Spring were collected from the north end, center, and south end of a strongly jasperoidized limestone ridge about a quarter of a mile long, surrounded by argillized and pyritized Tertiary volcanic rocks. The nearest known ore deposits are in the Star Range 5 miles to the northeast. All three samples are aphanitic, dark gray on fresh exposures and yellowish brown on weathered surfaces; the sample from the north end of the ridge contains aphanitic olive-gray breccia fragments, and the one from the south end is cut by small veinlets of yellowish-gray fine-grained quartz with sparse tiny vugs. Petrographic study reveals three generations of silica. The oldest of these is aphanitic with jigsaw-puzzle texture, is pale brown by transmitted light, and contains rounded detrital quartz grain inclusions. The intermediate generation has a heterogeneous xenomorphic to reticulated texture and an average quartz grain diameter of 0.02 mm; carbonate particles are abundant in the grains, and opaque amorphous brownish-black carbonaceous material is concentrated along the grain boundaries. In one specimen the quartz of this generation contains disseminated jarosite and hydromica. The youngest generation of quartz fills veinlets. It is coarser grained, has a xenomorphic texture, and is free of inclusions. All three samples contain traces of Ag, Y, and Yb and slightly anomalous Zr. Two of the three also show higher-than-normal Ba, La, Ni, and Sr. The indicator-element scores are all low (−1, −1, and +2).

The four samples from near the south end of the Wah Wah Mountains represent bodies located many miles from the nearest known mineral deposits. These bodies are localized by fracture zones in Paleozoic limestone and dolomite, and many of them exhibit a well-marked transition zone characterized by an interlacing network of quartz veinlets in the host rock. Two samples are from these transition zones, and the other two are from the main jasperoid bodies. Both of the jasperoid samples have a moderate-gray medium-grained locally vuggy matrix, cut by coarser grained quartz veinlets. The matrix consists of heterogeneous xenomorphic to locally reticulated quartz that has an average grain diameter of about 0.05 mm; it contains abundant carbonate particles, small ragged masses of relict calcite, and numerous open vugs. The veinlets have a xenomorphic texture and an average grain diameter of about 0.2 mm, and they are free of inclusions. Although the texture of these samples is promising, the scarcity of accessory minerals in them is reflected in the chemical analyses, which show only Ba, Sr, and Zr in slightly abnormal concentrations. Both samples yield scores of −1.

The samples from the transition zones are carbonate breccias consisting of angular fragments of coarse-grained recrystallized dolomite in a matrix of intimately mixed fine-grained carbonate and quartz in various proportions. The quartz in this matrix has a heterogeneous texture and contains abundant carbonate particles. Numerous veinlets of clear homogeneous xenomorphic quartz cut the matrix; although these contain local inclusions of coarse-grained calcite, the vein quartz is free of carbonate particles. The rock was thoroughly brecciated before silica was introduced; however, it is not clear from examination of these samples whether the brecciated host rock was first cut by the coarser quartz veinlets and then replaced by the finer grained matrix jasperoid, or whether replacement was followed by vein filling.

SAN RAFAEL SWELL AREA

(18, fig. 49)

The San Rafael Swell is a broad anticlinal flexure in southwestern Emery County between the San Rafael River on the north and the Muddy River on the south. Uranium deposits in continental mudstones, sandstones, and conglomerates of Triassic age have been mined in this area since early in the 20th century, but mining was most active in the late 1940's and early 1950's. Most of these deposits are in the lower part of the Chinle Formation near the erosional unconformity that separates it from the underlying Moenkopi Formation.

At several localities in this area, basal siltstones, mudstones, and shales of the Chinle Formation have been silicified, dolomitized, and argillized beneath, and adjacent to, uranium deposits. The following information has been abstracted from a report by Abdel-Gawad and Kerr (1963, p. 27–33).

At the Magor mine, 11 miles southwest of Temple Mountain, a silicified green clay about 2 feet thick underlies uranium-bearing sandstone. Reddish-tan and light-tan silica layers and lenses with abundant chalcedony are prevalent in this clay. Coalified logs in the ore zone have been partly replaced by dark-brown to black silica, a jasperoid that is cut by veinlets of white quartz and calcite. Ore minerals consist of galena, sphalerite, pyrite, uraninite, chalcopyrite, bornite, covellite, and their oxidation products. Silicification disappears within a few hundred feet of the ore. At the Green Dragon 3 mine, uranium ore occurs at the base of a sandstone channel scoured into the siltstone, in a silicified zone surrounded by a halo of argillic alteration.

At the Dirty Devil 6 mine a layer of altered greenish-gray siltstone contains abundant layers, lenses, and veins of reddish-tan cherty jasperoid. Rounded quartz pebbles are sparsely distributed through this bed, and in its silicified parts, chalcedony locally cements these pebbles as well as sand and clay. Pyrite-, marcasite-, sphalerite-, and coffinite-bearing asphaltite are disseminated through the silicified zones in close association with the younger chalcedony veinlets that cut the jasperoid. Cavities in this silica are rimmed with chalcedony and filled with cockscomb quartz.

At the Lucky Strike mine, two types of jasperoid are distinguishable in siltstone. One forms thinly banded brick-red layers and lenses a few inches thick. The other is more crudely banded, brownish to bluish gray, and contains urano-organic material filling fractures and cavities. The silicified zone is surrounded by a bleached argillized halo.

At the Conrad mine, layers of jasperoid are associated with dolomite in green clay in the basal siltstone of the Chinle Formation. Radioactive asphaltite fills fractures and cavities in these silicified layers.

These jasperoid zones consist largely of chalcedony and microcrystalline quartz with local late coarse quartz filling cavities. Much of the original silica probably precipitated in colloidal form from hydrothermal solutions supersaturated with silica. This process probably was accompanied by a drop in temperature and an increase in pH from slightly acid to slightly alkaline. Temperature of silica deposition probably was slightly above 100°C. Silicification was accompanied by argillic alteration and closely followed by deposition of carbonates and sulfides; this deposition, in turn, was followed by urano-organic mineralization (Abdel-Gawad and Kerr, 1963, p. 34, 44).

SILVER ISLET DISTRICT

(19, fig. 49)

The Silver Islet district is in northwestern Tooele County, just south of the Box Elder County line, and about 15 miles northeast of Wendover, near the north end of the Desert Range.

In this area Ordovician limestone has been cut by north-northeast-trending faults and fractures and by northwest-trending dikes of diorite porphyry. The limestone adjacent to one such dike on the west side of the range has been recrystallized near its junction with a north-trending vein. Outward from the recrystallized zone for a distance of 10–12 feet the limestone is replaced by red jasperoid containing abundant hematite, calcite, and muscovite. The vein contains argentiferous lead and copper carbonates and limonite in a quartz gangue (Butler and others, 1920, p. 488).

TUTSAGUBET DISTRICT

(22, fig. 49)

The Tutsagubet district is in southwestern Washington County in the Beaver Dam Mountains, about 15 miles west of St. George. At the Dixie mine in this district, an irregular, chimney-shaped replacement deposit of oxidized ore cuts Pennsylvanian limestone. This limestone has locally been replaced by brown and yellow jasperoid adjacent to the pipe, which contains carbonates and sulfates of iron, lead, and copper associated with limonite.

OTHER OCCURRENCES

Abdel-Gawad and Kerr (1963, p. 33) mentioned silicification of the lower part of the Chinle Formation 11 miles northeast of Moab, Grand County, near the junction of Castle Creek and the Colorado River (4, fig. 49). No ore deposits are known in the immediate vicinity of this occurrence.

At Silver Reef (20, fig. 49) about 34 miles southwest of Cedar City, in Washington County, red "jasper" replaces a green shale in the Chinle Formation a few feet beneath the silver-, copper-, vanadium-, and uranium-bearing "Silver Reef sandstone," a local economic term. The "jasper" replaces shale, as an aggregate of very fine grained red quartz, over a large area (Proctor, 1953, p. 120). From Proctor's description, this material apparently is very much like the red cherty jasperoid in the Chinle Formation in the San Rafael Swell, as described by Abdel-Gawad and Kerr.

I have a specimen of jasperoid from Paleozoic limestone just east of Vernon (23, fig. 49) in southeastern Tooele County. This locality is only about 12 miles northwest of the Tintic district (21), but there are no known ore deposits in the vicinity. The sample is grayish red, has a heterogeneous xenomorphic to reticulated texture, and contains abundant carbonate particles and hematite; some of the hematite is pseudomorphous after pyrite. In spite of its favorable texture and mineralogy, the sample is slightly high only in Ga, Sr, and Zr, and has a trace of Zn.

Butler, Loughlin, Heikes, and others (1920, p. 441) mentioned the occurrence of a bed or vein of jasperoid in Paleozoic limestone at the "88" mine in the West Tintic district (24, fig. 49), about 15 miles southwest of the Tintic district, in Juab County. However, H. T. Morris (oral commun., 1965) reported very little jasperoid from this district.

Abundant masses of hypogene jasperoid are associated with lead-zinc replacement deposits in the Argentia district (1, fig. 49) in Morgan County, the Fish Springs district (8) in western Juab County, and the Lakeside district (10) in northeastern Tooele County (Heyl, 1963, p. B44, B57, B79). Hypogene jasperoid is also present in small amounts, in a few of the lead-zinc ore bodies of the important Park City district (15) in southwestern Summit County (C. S. Bromfield, written commun., 1967).

VIRGINIA AND WEST VIRGINIA

Jasperoid bodies have been recognized in three areas in these two States: the Austinville district (10, fig. 41) in Wythe County in southwestern Virginia, the Timberville district (7, fig. 46) in Rockingham County in western Virginia, and the Howell property (5, fig. 46) in Jefferson County at the eastern tip of West Virginia. In all three places gray and grayish-black jasperoid is associated with sphalerite and galena breccia and replacement deposits in lower Paleozoic limestone or dolomite. In addition to these areas, the north end of the piedmont gold belt (6, fig. 46) in Fauquier County, Va., on both sides of the Rappahannock River, contains disseminated gold deposits in massive quartz along shear zones in schist; field evidence indicates partial replacement of the host rock by silica before mineralization.

AUSTINVILLE DISTRICT

(10, fig. 41)

At Austinville, in southern Wythe County, Va., large replacement deposits of sphalerite have been localized by breccia zones in the Lower Cambrian Shady Dolomite. In the main mine cherty quartz of two types has been noted: One is dense "black chert" that appears to be older than both recrystallization of dolomite and sulfide mineralization. The other variety is also dense, but it is nearly white and is much younger than the first type; it may be younger than the sulfide mineralization (Currier, 1935, p. 79). Although the silica at Austinville strongly resembles chert in appearance, the bodies are structurally controlled, giving evidence of their epigenetic replacement origin (A. V. Heyl, written commun., 1964).

HOWELL MINE AREA

(5, fig. 46)

A small zinc deposit in Jefferson County, W. Va., known as the Howell mine, has been developed along a breccia zone in the Cambrian Tomstown Formation. In this zone a core of coarse white dolomite is surrounded by sphalerite ore which, in turn, is enveloped by a marginal zone of jasperoid (Ludlum, 1955, p. 860; A. V. Heyl, written commun., 1964).

TIMBERVILLE DISTRICT

(7, fig. 46)

Small replacement deposits of sphalerite are present in the Ordovician Beekmantown Dolomite in an area about 50 miles long and 25 miles wide in western Virginia, centered near the town of Timberville, in Rockingham County. These deposits probably were formed from low-temperature hydrothermal solutions, according to Herbert and Young (1956, p. 1–3). Although they did not mention silica associated with these deposits, dense black cherty-looking jasperoid that cemented dolomite breccia at an early stage during the general period of sulfide deposition is common at the Tri-State Zinc Co.'s Bowers-Campbell mine (A. V. Heyl, written commun., 1964).

OTHER OCCURRENCES

On both sides of the Rappahannock River (6, fig. 46) in Fauquier County in northeastern Virginia, a belt of Precambrian schist has been cut by shear zones that locally are strongly silicified. This silicification has resulted in large coarse-grained quartz bodies which replace the schist but locally preserve its texture, and which contain disseminated gold deposits at the Vauclause, Mellville, and Franklin mines (Pardee and Park, 1948, p. 35, 47).

WASHINGTON

Abundant masses of jasperoid are closely associated with replacement deposits of sphalerite and galena in the Cambrian Metaline Limestone in the Metaline district (2, fig. 50), Pend Oreille County, near the northeast corner of Washington. A similar, but much smaller, deposit, known as the Anderson prospect (1, fig. 50), is also in Metaline Limestone in northeastern Stevens County, a few miles west of the Metaline district.

METALINE DISTRICT

(2, fig. 50)

The close association between jasperoid and lead-zinc replacement ore bodies in breccia zones in the upper part of the thick Metaline Limestone in the Metaline district has been described and discussed by Park (1938), Park and Cannon (1943), and Dings and Whitebread (1965).

Park (1938, p. 723) described typical Metaline jasperoid as a dense dark-gray to black rock that commonly preserves the texture of the carbonate host rock it replaces and shows gradational contacts with it, merging outward through a zone of anastomosing quartz veinlets and disseminated quartz crystals into unreplaced dolomite or limestone. Small vugs in this jasperoid are commonly lined with quartz crystals.

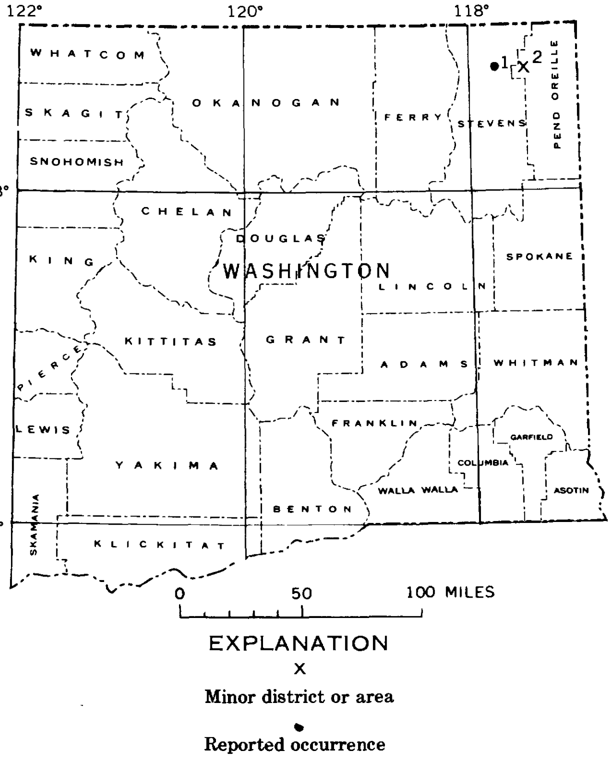


FIGURE 50.—Map showing location of jasperoid-bearing areas in Washington. 1, Anderson; 2, Metaline.

Park and Cannon (1943, p. 44–46) reported that, although jasperoid is widespread throughout the district, it is particularly abundant at the Lead Hill and Pend Oreille mines, where it commonly forms the gangue of the sulfide ore. Both jasperoid and ore appear to have formed from the same, presumably hydrothermal, solutions, but the ore for the most part is younger than the jasperoid. Nodules and small masses of light-gray chert are locally abundant in the upper part of the Metaline Limestone.

Dings and Whitebread (1965, p. 18) reported that this chert is composed of fine- to medium-grained, locally recrystallized quartz. Some chert nodules are surrounded by a rim of coarse-grained calcite. The chert is most abundant in the upper 200 feet of the Metaline Limestone on Lead Hill and Lead King Hill. In some places near ore bodies this chert grades transitionally into dark-gray jasperoid.

The jasperoid is most abundant in breccia zones 30–200 feet beneath the contact of the Metaline Limestone with the overlying Ordovician Ledbetter Slate. The jasperoid commonly occurs as irregular bodies as much as 200 feet across, replacing limestone and dolomite breccia fragments and the more coarsely crystalline dolomite that forms the matrix for these fragments. Most of the sphalerite and galena occurs either within the jasperoid or adjacent to it; however, some jasperoid bodies are barren of sulfides, and some sulfide deposits are not associated with jasperoid. The coarsely crystalline white dolomite that forms the original matrix in the breccia zones is presumed to be largely of hydrothermal origin, and this dolomite is the preferred host material for the jasperoid and sulfides. Dolomitization, silicification, and mineralization are thought to have resulted from hydrothermal fluids that originated in the deep-seated magma chamber of a large body of plutonic rock related to the Jurassic Kaniksu batholith (Dings and Whitebread, 1965, p. 54, 62–64, 68).

A sample of dark-gray sphalerite-bearing jasperoid from the Metaline district in my collection is relatively coarse grained and has a very heterogeneous xenomorphic to locally reticulated texture. The quartz grains range in diameter from about 0.02 to about 1.5 mm, and the smaller grains commonly form inclusions in the larger ones. Ragged remnants of coarse crystalline dolomite are scattered through the quartz, and carbonate dust particles are abundant in the larger quartz grains. Irregular masses of light-gray sphalerite cut the jasperoid quartz and locally contain quartz grain inclusions. Spectrographic analysis of the sample showed slightly high Cd, Ga, Ge, Mo, and Sr, as well as very high Zn. The indicator-element score is +11.

OTHER OCCURRENCES

The Anderson prospect (1, fig. 50) in northeastern Stevens County, a few miles west of the Metaline district, consists of galena, sphalerite, and minor pyrite disseminated through jasperoid gangue in the Metaline Limestone. The ore-bearing bed is about 100 feet thick; the silicified ore zone is about 50 feet wide and follows the general course of a lamprophyre dike (Lorain and Gammell, 1947, p. 4).

WYOMING

A jasperoid occurrence in Wyoming is reported from the Miller Hill area (4, fig. 47), about 25 miles south of Rawlins in Carbon County (Vine and Prichard, 1959). At this locality small amounts of uranium are concentrated in silicified fresh-water limestone in Tertiary rocks that have been tentatively correlated with the North Park Formation.

MILLER HILL AREA

(4, fig. 47)

The North Park(?) Formation in this area is about 800 feet thick and consists largely of porous tuffaceous sandstone with some interbedded fresh-water limestone. These limestone beds are 3–10 feet thick, and have locally been brecciated and replaced by chalcedonic jasperoid, which locally contains concentrations of uranium ore. Silica and uranium are thought to have been leached by ground water from the porous tuffaceous sandstone and precipitated from the ground water by reaction with the limestone (Vine and Prichard, 1959, p. 210, 215–217, 225).

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