Mai

Jasperoids of the Pando Area, Eagle County, Colorado

GEOLOGICAL SURVEY BULLETIN 1474

Jasperoids of the Pando Area, Eagle County, Colorado

By T. G. LOVERING *and* A. V. HEYL

GEOLOGICAL SURVEY BULLETIN 1474

Tungsten-rich outcrops may indicate concealed tungsten and beryllium deposits

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1980

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Library of Congress Cataloging in Publication Data
Lovering, Tom Gray, 1921-
Jasperoids of the Pando Area, Eagle County, Colorado.
(Geological Survey Bulletin 1474)
Bibliography: p. 35
1. Jasperoid–Colorado–Eagle Co. 2. Tungsten ores–Colorado–Eagle Co. 3. Beryllium ores–Colorado–Eagle Co. I. Heyl, Allen Van, 1918- joint author. II. Title. III. Series: United States Geological Survey Bulletin 1474.
QE475.J3169 552'4 79-11345

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock No. 024-001-03273-2

CONTENTS

ILLUSTRATIONS

TABLES

METRIC-ENGLISH EQUIVALENTS

[SI, International System of Units, a modernized metric system of measurement]

SI unit		U.S. customary equivalent	
Length			
millimeter (mm)	=	0.039 37	inch (in)
meter (m)	=	3.281	feet (ft)
	=	1.094	yards (yd)
kilometer (km)	=	0.621 4	mile (mi)
	=	0.540 0	mile, nautical (nmi)
Area			
centimeter^2 (cm^2)	=	0.155 0	inch^2 (in^2)
meter^2 (m^2)	=	10.76	feet^2 (ft^2)
	=	1.196	yards^2 (yd^2)
	=	0.000 247 1	acre
hectometer^2 (hm^2)	=	2.471	acres
	=	0.003 861	section (640 acres or 1 mi^2)
kilometer^2 (km^2)	=	0.386 1	mile^2 (mi^2)
Volume			
centimeter^3 (cm^3)	=	0.061 02	inch^3 (in^3)
decimeter^3 (dm^3)	=	61.02	inches^3 (in^3)
	=	2.113	pints (pt)
	=	1.057	quarts (qt)
	=	0.264 2	gallon (gal)
	=	0.035 31	foot^3 (ft^3)
meter^3 (m^3)	=	35.31	feet^3 (ft^3)
	=	1.308	yards^3 (yd^3)
	=	264.2	gallons (gal)
	=	6.290	barrels (bbl) (petroleum, 1 bbl=42 gal)
	=	0.000 810 7	acre-foot (acre-ft)
hectometer^3 (hm^3)	=	810.7	acre-feet (acre-ft)
kilometer^3 (km^3)	=	0.239 9	mile^3 (mi^3)
Volume per unit time (includes flow)			
decimeter^3 per second (dm^3/s)	=	0.035 31	foot^3 per second (ft^3/s)
	=	2.119	feet^3 per minute (ft^3/min)
Volume per unit time (includes flow)—Continued			
decimeter^3 per second (dm^3/s)	=	15.85	gallons per minute (gal/min)
	=	543.4	barrels per day (bbl/d) (petroleum, 1 bbl=42 gal)
meter^3 per second (m^3/s)	=	35.31	feet^3 per second (ft^3/s)
	=	15 850	gallons per minute (gal/min)
Mass			
gram (g)	=	0.035 27	ounce avoirdupois (oz avdp)
kilogram (kg)	=	2.205	pounds avoirdupois (lb avdp)
megagram (Mg)	=	1.102	tons, short (2 000 lb)
	=	0.984 2	ton, long (2 240 lb)
Mass per unit volume (includes density)			
kilogram per meter^3 (kg/m^3)	=	0.062 43	pound per foot^3 (lb/ft^3)
Pressure			
kilopascal (kPa)	=	0.145 0	pound-force per inch^2 (lbf/in^2)
	=	0.009 869	atmosphere, standard (atm)
	=	0.01	bar
	=	0.296 1	inch of mercury at 60°F (in Hg)
Temperature			
temp kelvin (K)	=	[temp deg Fahrenheit (°F) +459.67]/1.8	
temp deg Celsius (°C)	=	[temp deg Fahrenheit (°F) −32]/1.8	

JASPEROIDS OF THE PANDO AREA, EAGLE COUNTY, COLORADO

By T. G. LOVERING and A. V. HEYL

ABSTRACT

In the upper valley of the Eagle River, near the old townsite of Pando in central Colorado, carbonate rocks of Devonian and Mississippian age have been hydrothermally altered and extensively replaced by bodies of jasperoid. Despite the widespread hydrothermal and limonitic alteration, suggestive of proximity to large ore deposits, no important orebodies have been found, although there are abundant prospect pits and a few small abandoned mines in the area.

The jasperoid bodies are complex, and they record a complicated history of at least three separate episodes of silicification, each episode reflecting a different environment of formation. The oldest and most abundant generation of jasperoid is a dense gray rock, commonly containing sericite and fresh pyrite, with no consistently anomalous concentrations of minor elements; jasperoid of this type is widely distributed in carbonate rocks for many kilometers to the north, east, and south of Pando. The second generation of jasperoid is light colored (in varying shades of pink, orange, yellow, and brown) and has less sericite than the oldest jasperoid, some limonite pseudomorphous after pyrite, and abundant dust particles of limonite clouding the matrix quartz; it commonly contains anomalous concentrations of arsenic, beryllium, germanium, manganese, niobium, antimony, scandium, tungsten, and yttrium. This second type is restricted to the mid-Paleozoic carbonate rocks exposed on the hills surrounding Pando from about 3 km (kilometers) south to about 3 km north of the townsite. Jasperoid of the third generation consists of an early deep-red variety with abundant hematite, and later reddish-brown to deep-brown varieties, which are vuggy and contain relatively clean phaneritic quartz in a matrix of dark-brown limonite, goethite, and manganese oxides. These later jasperoids commonly contain highly anomalous concentrations of arsenic, beryllium, germanium, niobium, antimony, and tungsten—with tungsten concentrations as high as 1 percent—and are largely restricted to a belt about 4 km long extending southeasterly from the divide between Homestake Creek and the Eagle River, across the upper end of the Eagle River canyon, to the mouth of Resolution Creek; the highest tungsten concentrations occur near the north end of the belt.

Evidence is presented that the oldest generation of jasperoid is unrelated to the other two, that it came from a source in the Gore Range to the east, that it formed at moderate temperature and depth in a reducing environment, and that if it was genetically related to any large sulfide ore bodies, they have probably been largely removed by erosion. The second and third generations of jasperoid are thought to have had a magmatic source, beneath the north end of the Eagle River valley and the ridge northwest of Pando, that moved upward during genesis of these jasperoids to form a shallowly buried intrusive stock. If such a stock is present, it may contain commercial concentrations of tungsten and beryllium minerals in portions of its hood.

INTRODUCTION

The Pando area is in central Colorado, in the valley of the upper Eagle River, north of Tennessee Pass, 25–32 km (kilometers) north of Leadville, and about 120 km west-southwest of Denver. It consists of a nearly level parklike area approximately 1 km wide and 7 km long and the adjacent lower slopes and ridges of the Sawatch Range, which rises steeply on the west, and of the Gore Range on the east. The site of the former Camp Hale Military Reservation occupies the center of this flat area. The Eagle River valley narrows abruptly to a steep-walled canyon at the north end of this area. Prominent masses of rusty-brown-weathering jasperoid crop out on the hills to the east, north, and northwest of the valley flats.

Pando is near the north end of the Colorado jasperoid province recognized by Lovering (1972, p. 4, 5, 96); other jasperoid-bearing mineralized areas and mining districts lie a few kilometers away to the north, east, and south (fig. 1).

The jasperoids near Pando were first discussed by Crawford and Gibson (1925, p. 56–59). Tweto (1953), in the text of a geologic map of the area, discussed the distribution and characteristics of these bodies, their probable genesis, and their economic implications. Lovering (1972, p. 99–100) briefly summarized the earlier observations of Crawford and Gibson, and of Tweto, and added some descriptive information on a few samples from the area.

In addition to the jasperoid bodies in this area, there are other indications of widespread hydrothermal alteration and mineralization, such as hydrothermal dolomitization, sanding of dolomite in the lower Paleozoic carbonate rocks, iron oxide impregnation of the underlying quartzite, and the presence of pyritic quartz veins cutting the Precambrian basement rocks. Although the area has been extensively prospected and a few small mines in the northern part of it have produced a little gold, silver, and copper, no large ore deposits have been discovered.

Tweto (1953) suggested that the rock alteration at Pando might reflect updip leakage from a major ore deposit to the east or northeast. The present investigation was conducted in the hope that a detailed study of the jasperoids could provide evidence of the nature and location of any major ore deposits with which they might be associated.

Precambrian basement rocks are exposed in the Sawatch Range on the west and are overlain by Cambrian to Pennsylvanian sedimentary rocks in the Gore Range on the east. The Precambrian rocks consist largely of schists and gneisses intruded by plutonic granite and diorite. These are overlain by about 150 m (meters) of lower and middle Paleozoic rocks (table 1) consisting (in ascending order) of the

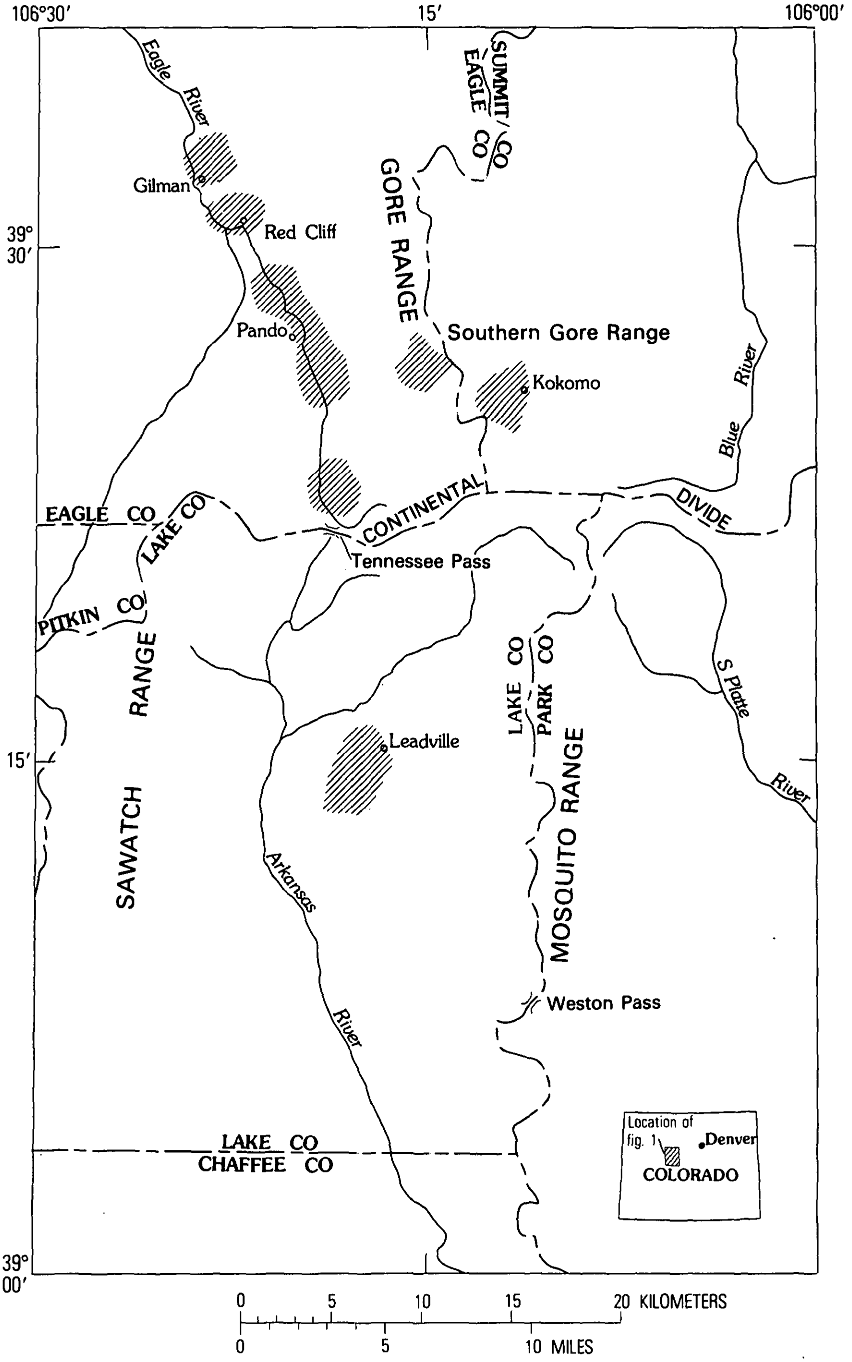


FIGURE 1.—Location of Pando area relative to nearby jasperoid-bearing mineralized areas (patterned).

TABLE 1.—*Sedimentary rocks of the Pando area, Colorado*

[Modified from Tweto, 1953, 1974; and Tweto and Lovering, 1977]

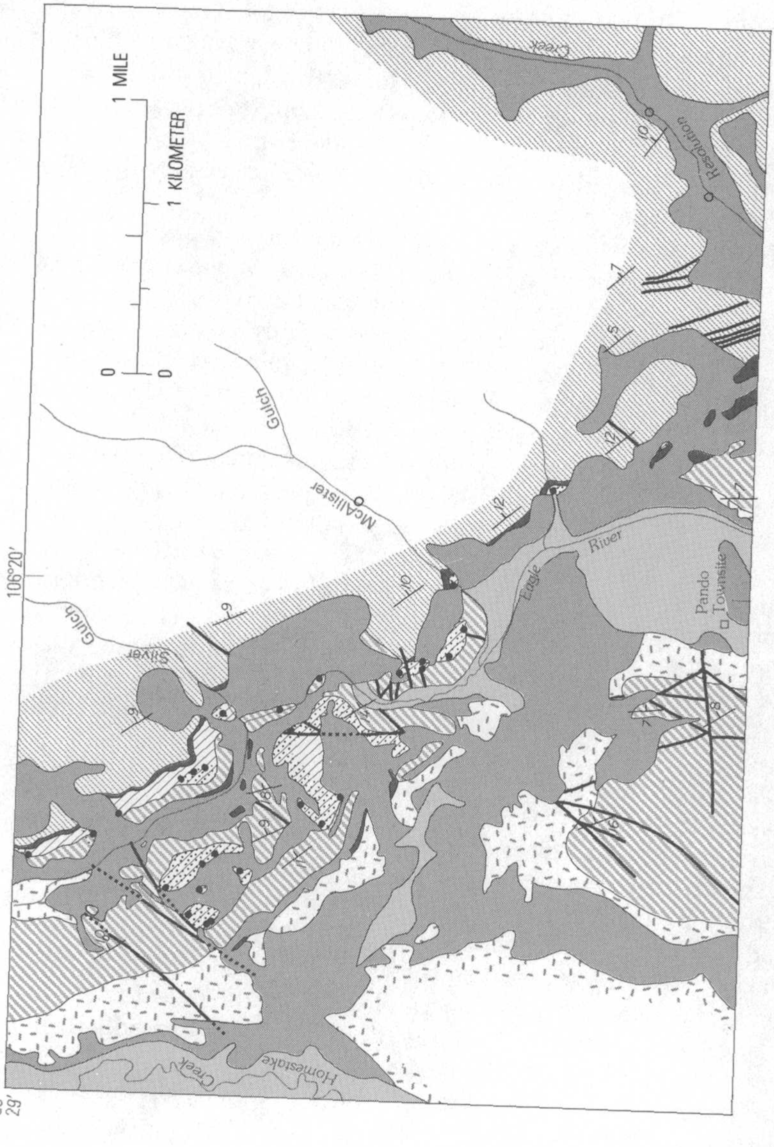
Series	Formation		Thickness (meters)	Character
Middle Pennsylvanian	Minturn Formation		1,800+	Predominantly grayish lenticular grit, shale, conglomerate, arkose, and sandstone, with a few beds and reefs of limestone and dolomite.
	Belden Formation		8-61	Interbedded dark-gray shale and thin-bedded dark-gray limestone.
	- - UNCONFORMITY - - - -			
Lower Mississippian	Leadville Dolomite		20-29	Massive gray to black crystalline cherty dolomite.
Lower Mississippian(?) and (or) Upper Devonian	Chaffee Group	Gilman Sandstone	5- 7	Dolomitic sandstone, sandy dolomite, chert, and dolomite breccia in lenticular beds.
		- UNCONFORMITY -		
		Dyer Dolomite	5-24	Dark-gray to black, fine-grained, thin-bedded dolomite.
Upper Devonian		Parting Quartzite	14-17	White and tan quartzite and conglomerate; locally shaly at base.
	- UNCONFORMITY -			
Middle Ordovician	Harding Quartzite		6- 8	Tan, white, and greenish sandstone and quartzite.
	- - UNCONFORMITY - - - -			
Upper Cambrian	Peerless Formation		11-34	Thin-bedded, variegated sandy dolomite and dolomitic sandstone.
	Sawatch Quartzite		30-56	Fine-grained white quartzite; pink near base and top.

Upper Cambrian Sawatch Quartzite and Peerless Formation, the Middle Ordovician Harding Quartzite, the Upper Devonian and Lower Mississippian(?) Chaffee Group (which comprises the Parting Quartzite, the Dyer Dolomite, and the Gilman Sandstone), and the Lower Mississippian Leadville Dolomite. The maximum thickness of this lower and middle Paleozoic carbonate section is about 60 m. This section is overlain by approximately 2,000 m of predominantly clastic Pennsylvanian sedimentary rocks of the Belden and Minturn Formations. The Minturn Formation contains carbonate beds and reefs in its upper part.

Monzonitic sills of Late Cretaceous and Tertiary age have intruded the sedimentary section (Tweto, 1974) from the base of the Sawatch Quartzite to just above the top of the Leadville Dolomite in the Pando area. The uppermost sill is remarkably persistent and can be found either at the top of the Leadville or just above it (in the black shale of the Pennsylvanian Belden Formation) from the east fork of the Eagle River northward as far as Gilman. A few small dikes of Tertiary quartz latite porphyry and quartz monzonite porphyry cut both the Precambrian rocks and the overlying pre-Pennsylvanian sedimentary rocks near Pando. Many large sills of quartz monzonite porphyry have also been emplaced in the upper part of the Pennsylvanian Minturn Formation, both a few kilometers east of Pando, and south of the East Fork of the Eagle River southeast of Pando.

Numerous high-angle normal faults cut the older Paleozoic rocks and the underlying basement complex near Pando, and the upper part of the Minturn Formation a few kilometers to the east is cut by a complex network of large faults.

Jasperoid bodies varying in size from small pods to large irregular masses as much as 300 m long and 60 m thick are exposed in the Dyer and Leadville Dolomites at invervals from the valley of the East Fork of the Eagle River northward for approximately 8 km to an isolated outcrop in the Eagle River canyon about 1½ km south of the town of Red Cliff (fig. 1). Large masses of jasperoid replacing these same formations are also exposed to the west along the top of the ridge that forms the divide between the Eagle River and Homestake Creek; and a large isolated mass of jasperoidized Dyer and Leadville Dolomites also forms an erosion remnant on the eastern flank of the Sawatch Range opposite the southernmost jasperoid body on the east side of the Eagle River (fig. 2).


0
1 MILE
0
1 KILOMETER
106°20′
39°
29′
McAllister
Gulch
Silver
Gulch
Eagle
River
Pando
Townsite
Homestake
Creek
Resolution
Creek
10
7
5
12
12
10
6
6
4
8
6
7
16
8
7

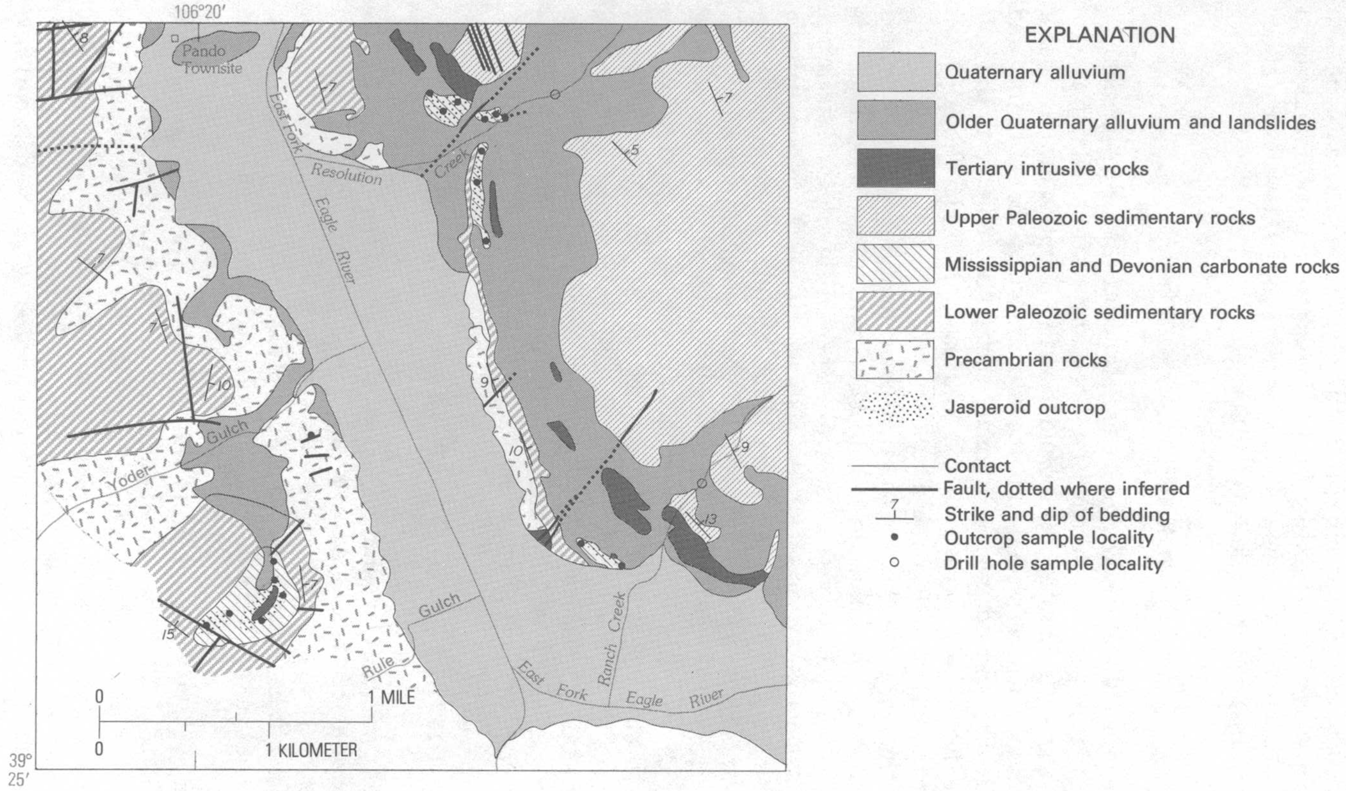


FIGURE 2.—Generalized geology of the Pando area, showing distribution of jasperoid bodies and sample localities. *A*, North end of Pando area; *B*, South end of Pando area.

Small bodies of jasperoid also locally replace the carbonate rocks in the upper part of the Minturn Formation in the vicinity of faults in an easterly trending belt about 3 km wide, high in the Gore Range about 5½ km east of the Eagle River valley.

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of J. M. Brown and J. S. Merchant of the New Jersey Zinc Company staff at Gilman in providing us with samples of jasperoid from five diamond drill holes east of Pando, which furnished valuable information on the continuity and nature of jasperoid in the carbonate section downdip from the outcrops in the Eagle River valley. C. N. Bozion, M. L. Heyl, and David Lovering helped collect the samples.

Of the many members of the U.S. Geological Survey that assisted in this study, the following were most helpful. Irving Friedman made oxygen isotope analyses of several jasperoid samples. Quantitative gold assays were made by J. A. Thomas and G. D. Shipley using a combination of fire assay and atomic absorption methods. Spectrographic analyses were provided by Leon Bradly and J. C. Hamilton. Sherman Marsh made mineral separations from several samples of igneous intrusive rocks. John Viets extracted limonite from a suite of altered rock samples and also made quantitative analyses for mercury, gold, tungsten, and fluorine on the leachates, the residues, and the whole-rock samples. Spectrographic analyses on these leachates were provided by Elwin Mosier. Fieldwork was done at intervals during the summers of 1970, 1971, and 1972.

DISTRIBUTION AND APPEARANCE OF JASPEROID

Nearly all the Devonian and Mississippian dolomitic rocks that are exposed along the Eagle River valley, from the east fork of the Eagle River northward to a point about 1 km north of the junction of Silver Creek and the Eagle River, have been partly replaced by jasperoid. In some places the entire carbonate section has been silicified through a thickness of more than 50 m, and the resulting jasperoid bodies form prominent, rusty-brown reefs and monoliths. Crawford and Gibson (1925, p. 56–59) first studied and described these bodies, which were further studied and mapped by Tweto in 1953. Tweto also found and mapped scattered bodies of jasperoid in carbonate rocks in the Minturn Formation to the east. Most of these bodies are high in the Gore Range on Pearl Peak, in the upper drainage basins of Pearl and Cataract Creeks, and on Sheep Mountain, where they replace the Hornsilver and Resolution Dolomite Members of the Minturn Formation, generally in close proximity to large faults. A thin, persistent dolomite bed, informally called the Jack 8 bed, in the lower part of the Minturn Formation, about 150 m above the base, has also been largely converted to jasperoid (Tweto, 1974).

We did not study the jasperoid bodies in the upper part of the Minturn Formation, most of which are far above and several kilometers to the east of those along the Eagle River valley. They have been described and discussed by Tweto (1953) in the text that accompanies his map of the area. Spectrographic analyses of some of Tweto's jasperoid samples from this area have been used in this paper for comparison with those at Pando. Many of them were collected within 3 km of the old Kokomo mining district east of Pando (fig. 1), and they may represent leakage of silica-bearing solutions from that center of mineralization.

The largest and most abundant jasperoid bodies in the Pando area are concentrated in two areas: (1) along the crest of the ridge that forms the divide between Homestake Creek and the Eagle River north of the low saddle crossed by U.S. Highway 24 and opposite this ridge on the east side of Eagle River; and (2) at the mouth of Resolution Creek (fig. 2). Jasperoid in this area extends for at least 1.6 km back of the outcrop and to a depth of at least 215 m, as shown by drill core samples. A large, isolated body of jasperoid partly replaces Leadville and Dyer Dolomites to the west of the Eagle River in the Sawatch Range on top of the ridge between Rule Gulch and Yoder Gulch at an elevation of 3,125–3,275 m.

Although high-angle faults with small displacement are present in the vicinity of most of the larger jasperoid bodies, these faults do not appear to have greatly influenced the distribution of the jasperoid, and in many places such bodies are displaced along small faults. The distribution of many smaller jasperoid bodies in the Dyer Dolomite, however, does appear to be controlled by joints and fracture zones. Tweto (1953) observed that the largest and most persistent jasperoid bodies are concentrated in the Chaffee Group, at the stratigraphic level of the Gilman Sandstone, between the Leadville Dolomite above and the Dyer Dolomite below. This relationship suggests that relatively permeable breccia and sandstone of the Gilman was a major channelway for the silicifying solutions. Channels in the upper part of the Leadville Dolomite, related to a pre-Pennsylvanian karst erosion surface, also locally provided conduits for these solutions, resulting in the silicification of the adjacent parts of the Leadville Dolomite.

Although many of the larger jasperoid bodies appear as rugged, homogeneous, rusty-brown masses, standing out in relief above the surrounding terrain, on closer inspection these masses are seen to be composed of breccia fragments of many different jasperoid types set in a siliceous matrix. Some of these bodies are cut by still younger jasperoid of a different type, and locally the siliceous matrix forms breccia fragments within the younger jasperoid. Both Crawford and Gibson (1925, p. 56, 57) and Tweto (1953) recognized the earliest and most abundant gray jasperoid as representing the primary siliceous replacement of dolomite, of dolomite breccia fragments, and of the macerated carbonate matrix around these fragments. Tweto also recognized that the presence of fragments of this early type in a matrix of younger jasperoid provides evidence that this early siliceous replacement breccia was locally shattered and recemented by later silica.

Our study has revealed the presence of three major generations and types of jasperoid in the area, with each generation consisting of two or three subtypes (table 2). The three major types appear to be consistent in their relationship to each other throughout the Pando area, although the interrelations of the subtypes within the major types are equivocal, one appearing to be older at one locality and younger at another.

Type 1 is the oldest jasperoid; it is various shades of gray, generally dense, and ranges in texture from fine grained to aphanitic. Type 2 is generally colored light shades of red, pink, yellow, orange, and yellowish brown; it is also generally dense and ranges from very fine grained to aphanitic texture. Type 3 is dark red, reddish brown, or dark brown; it is commonly porous and vuggy with a fine- to medium-grained texture.

Type 1 jasperoid consists of two subtypes: (A) a light-gray to medium-gray variety that has a variable texture, grading from a fine granular texture resembling quartzite to an aphanitic texture resembling chert; and (B) a dark-gray, dense, aphanitic variety. Commonly the lighter gray varieties form breccia fragments in the dark-gray matrix, but in some places this relationship is reversed. Medium-gray to dark-gray nodules of primary chert preserved in unbrecciated light-gray jasperoid may closely resemble the darker gray jasperoid in both color and texture.

Type 2 jasperoid includes three main subtypes, each of which displays color variations. Type 2A, generally the oldest, varies from olive gray through dark yellowish brown to yellowish orange and yellowish gray. It is generally dense and aphanitic in texture. In some places it forms a matrix for fragments of Type 1 gray jasperoid; in others it forms breccia fragments cemented by other Type 2 or Type 3 jasperoids. Type 2B consists of pale-red, grayish-red, pink, and tan color variants, which commonly form breccia fragments in Type 3 jasperoid. This subtype is generally very fine grained and dense, though it locally contains sparse tiny vugs. Type 2C is pale pinkish or yellowish gray, fine grained, and dense. It is less common

TABLE 2.—*Appearance, texture, and mineralogy of jasperoid varieties in the Pando area*

Subtype	Color	Texture	Microtexture	Accessory minerals
1A	Light gray to medium gray.	Dense, generally aphanitic, but locally fine grained	Jigsaw puzzle texture <0.01 mm diameter, grading to xenomorphic texture, 0.1 mm diameter.	Carbonate "dust" in quartz; pyrite and sericite; rare barite, jarosite, apatite.
1B	Dark gray	Dense, aphanitic	Jigsaw puzzle texture, quartz grains <0.01 mm in diameter.	Pyrite and sericite; rare sphalerite and fluorite.
2A	Olive gray, dark yellowish brown, yellowish orange, yellowish gray.	do	Texture varies from jigsaw puzzle to very xenomorphic to granular, quartz grains 0.01 mm in diameter and larger.	Yellow to brown limonite "dust" in quartz; carbonate dust and sericite; rare apatite.
2B	Pale red, grayish red, pink, tan.	Generally dense, but locally has sparse small vugs, very fine grained.	Xenomorphic, reticulated, and granular with small vugs and open fractures, grains 0.01-0.1 mm in diameter.	Hematite and yellow limonite "dust" inclusions; sericite, goethite, hematite, pyrite, and barite.
2C	Pale pinkish gray, pale yellowish gray, pale brown.	Dense, fine grained	Xenomorphic texture, quartz grain diameter about 0.03 mm.	Carbonate "dust" inclusions; brown limonite and barite; rare goethite pseudomorphs after pyrite.
3A	Dark red	Generally dense, locally has small vugs, fine to medium grained.	Granular to xenomorphic texture, average grain diameter 0.03 mm, locally vuggy with colloform banding.	Carbonate and hematite "dust"; hematite and goethite.
3B	Dark reddish brown	Porous, vuggy, fine to medium grained.	Jigsaw puzzle, granular and xenomorphic texture, vuggy, quartz grain diameter 0.01-0.1 mm.	Reddish brown and orange limonite "dust"; limonite, hematite, Mn oxides, quartz, and barite.
3C	Dark brown	Porous, vuggy, medium grained	Xenomorphic to reticulated, vuggy, quartz grains average 0.05-0.25 mm diameter, colloform banding.	Carbonate "dust" in coarse quartz; brown limonite, goethite, jarosite, Mn oxides, and barite.

than the other two subtypes and forms a matrix for fragments of the Type 1 and Type 2A jasperoids. In an isolated hand specimen, it may strongly resemble the light-gray Type 1A jasperoid.

Type 3 jasperoid differs strikingly in appearance from the other two types. It consists of three subtypes, the relative ages of which cannot be firmly established from field evidence. Type 3A is a dark brick-red color, is generally dense and fine grained, and locally contains small vugs. Type 3B is dark reddish brown, has an aphanitic texture, and is commonly porous and vuggy. Type 3C is dark brown, aphanitic, and vuggy; locally, it grades into the reddish-brown variety (3B).

The distribution of sample localities of the three generations of jasperoid in the Pando area is shown in figure 3.

Type 1 jasperoids are represented in samples from all areas, though they are sparse on the Homestake Creek–Eagle River divide. Type 2 jasperoids are present in all areas except the two drill hole localities farthest up Resolution Creek and are sparsely represented in the northernmost localities east of the Eagle River and north of the mouth of Silver Gulch. Type 3 jasperoids are abundantly represented in samples from near the mouths of Resolution Creek and McAllister Gulch and from the Eagle River–Homestake Creek divide, but they are very sparse south of Resolution Creek and are largely missing east of the Eagle River north of a point midway between McAllister and Silver Gulches. They appear to be largely confined to a belt extending northwesterly from near the mouth of Resolution Creek, across the nose of the ridge west of the mouth of McAllister Gulch, to the northernmost jasperoid outcrops on the Homestake Creek–Eagle River divide.

This youngest generation (Type 3) is present in small amounts in many of the Type 1 and Type 2 jasperoid bodies on the east side of the Eagle River, where it forms fracture fillings in the older types. On top of the divide between the Eagle River and Homestake Creek to the west, Type 3 is the dominant type.

MICROTEXTURE AND MINERALOGY OF JASPEROID SAMPLES

The three main types of jasperoid in the Pando area can generally be distinguished from each other and from primary chert by their accessory minerals and microtextures, as well as by their appearances. The mineral assemblages are more diagnostic than the textures (table 2); only Types 3B and 3C have distinctive textures.

Type 1 jasperoid generally contains both sericite and pyrite. The most distinctive feature of Types 2A and 2B jasperoids is the prevalence of iron oxides (hematite, goethite, or limonite) in the matrix quartz; but Type 2C lacks these features, and the light-yellowish-gray variety of this subtype is readily distinguishable from

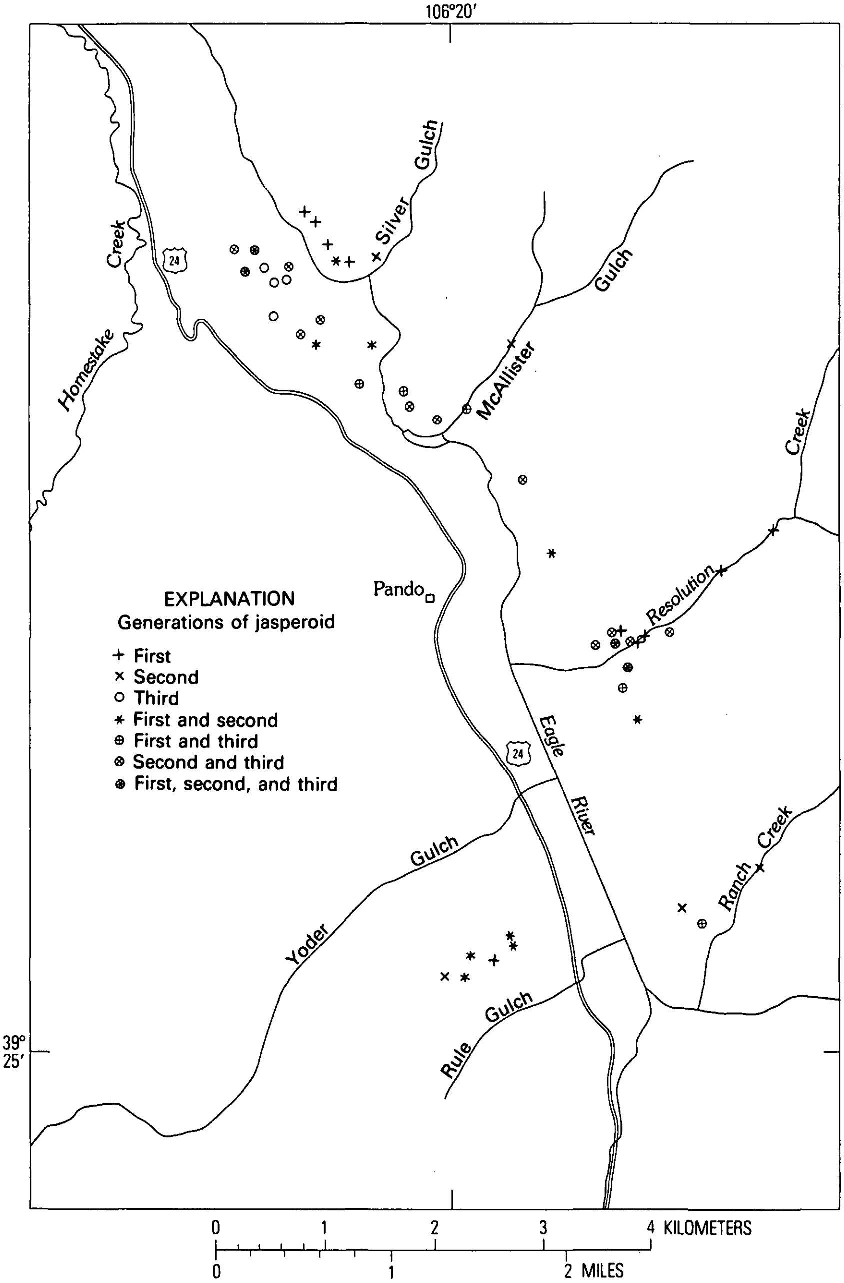


FIGURE 3.—Sample localities in the Pando area, showing jasperoid generations 1, 2, 3, and combinations.

chert only where it forms a matrix cement for breccia fragments of older jasperoid. Type 3 jasperoid differs strikingly in appearance from the older varieties, contains no sericite, and commonly displays numerous vugs surrounded by colloform bands of iron and manganese oxides; its matrix quartz is also generally coarser grained than that of the other types.

Types 1A and 1B jasperoid probably represent hypogene silicic alteration of dolomite and dolomite breccia. Type 1A varieties appear to be products of replacement of massive dolomite and dolomite breccia by silica and commonly preserve the texture of the host rock. The Type 1B jasperoid seems to largely represent colloidally deposited silica that filled interstices between larger fragments in an original dolomite breccia when these fragments were replaced by jasperoid. Identification of Type 1B jasperoid is complicated by the fact that primary chert preserved in the jasperopid bodies is indistinguishable in both color and texture from the dark-gray jasperoid. Consequently, the true identity of dark-gray siliceous fragments cemented by younger jasperoid can often be determined only by exmination with a petrographic microscope. Primary chert does not contain either sericite or pyrite, which are common accessory minerals in Type 1B jasperoid.

Type 1A jasperoid exhibits a broad range in both texture and grain diameter. Some specimens consist of tiny, sinuously interlocking quartz grains (jigsaw puzzle texture) having an average diameter <0.01 mm (millimeters). Others are composed of relatively coarse grains averaging about 0.1 mm in diameter showing a xenomorphic microtexture. Commonly, a single specimen will consist of a mixture of both types with local aggregates of coarser quartz grading outward into the aphanitic variety. In some samples isolated grains of coarser quartz are scattered through a relatively homogeneous, very fine grained matrix. The Type 1B jasperoid is much more uniform, generally consisting of grains with an average diameter of about 0.01 mm interlocking in a jigsaw puzzle texture; however, this matrix may also contain scattered, isolated grains of coarser quartz.

Most of the samples of both subtypes of Type 1 jasperoids exhibit minute carbonate inclusions a few micrometers in diameter in both matrix quartz and the coarser quartz grain inclusions. The most common interstitial accessory minerals are sericite and pyrite. In some specimens the pyrite is present as tiny pyritohedrons, though more commonly it forms cubes or small anhedral grains, generally less than half a millimeter in diameter. Barite, jarosite, sphalerite, apatite, and fluorite are present as minor accessory minerals in a few samples of Type 1 jasperoid.

Type 2 jasperoid contains breccia fragments of the Type 1 jasperoid, and occurs as breccia fragments in Type 3 jasperoid. It is extremely variable both in microtexture and associated accessory minerals. The matrix quartz in Type 2A is cherty and homogeneous with an average quartz grain diameter in some samples of about 0.01 mm. In other samples, the grain size varies from <0.01 mm to as much as 0.1 mm, and the texture also varies from jigsaw puzzle through xenomorphic to granular. The cementing matrix quartz of this subtype is characteristically clouded by tiny, dusty inclusions of yellow, yellowish-brown, or yellowish-orange limonite, which impart the color to the rock. The matrix quartz also commonly contains carbonate dust inclusions, and interstitial sericite is abundant in some specimens. One of the coarser grained samples also contains apatite inclusions in large quartz grains.

Type 2B jasperoid consists of both aphanitic homogeneous quartz and coarser grained heterogeneous quartz with variable textures, including xenomorphic, granular, and reticulated. Vugs and small open fractures are more common in this subtype than in Type 2A. Tiny dust particle inclusions of carbonate, hematite, and yellow limonite are commonly present in the matrix quartz of the aphanitic variety. Interstitial sericite, hematite, and goethite or limonite are also abundant in some specimens. The former presence of accessory pyrite in the majority of samples of this subtype is shown by the presence of scattered cubes and pyritohedrons of hematite or goethite, a few of which contain pyrite cores. Kaolinite, sphene, chalcedony, and late barite are less common accessory minerals. A feature that distinguishes Type 2B from Type 2A is the presence of primary hematite or the oxidation products of primary pyrite. Some samples with yellow limonite dust inclusions in the matrix quartz also contain oxidized accessory pyrite, but the combination of red hematite dust inclusions and oxidized pyrite was not observed.

Type 2C jasperoid is characterized by a relatively homogeneous, xenomorphic texture with quartz grains averaging about 0.03 mm. Carbonate dust particles are common in the quartz grains. The pale-brown variety also has abundant interstitial brown limonite, and some specimens contain late barite and goethite pseudomorphs after pyrite. The light-yellowish-gray variety shows only sparse carbonate and allophane dust particles in the matrix quartz. This subtype differs from Types 2A and 2B in that it contains no iron oxide dust particles in the quartz and no interstitial sericite.

Type 3 jasperoids also show textural variations. Types 3A and 3B varieties are dense in some samples and vuggy in others, and Type 3C, which appears to be the youngest, is characteristically porous and vuggy.

Type 3A typically consists of granular to xenomorphic quartz with an average grain diameter of about 0.03 mm and has carbonate dust and red hematite dust inclusions in the matrix quartz, abundant interstitial red hematite, and local orange goethite. Grains of red hematite in the matrix of some samples appear to be pseudomorphous after pyrite. In others, a late stage of hematite forms colloform crusts lining vugs.

Type 3B exhibits more variation in texture and grain size than Type 3A. Some samples have a jigsaw puzzle texture, and some are xenomorphic to granular; vugs filled with coarse, clean xenomorphic quartz are common. Grain size of the matrix quartz ranges from 0.01 mm to 0.1 mm. Orange to reddish-brown accessory limonite occurs as dust particles in the quartz and as an interstitial matrix or disseminated grains. Other common accessory minerals include disseminated and interstitial hematite, carbonate dust particles in coarser quartz grains, and goethite, manganese oxide, and barite as late cavity and vug fillings.

Type 3C is the most uniformly coarse grained jasperoid. It has a xenomorphic to reticulated texture with an average grain diameter of 0.05 mm and individual grains as much as 0.25 mm in diameter, commonly containing carbonate dust inclusions. In some samples the quartz grains are scattered through an amorphous, dark-brown limonite matrix, in others quartz bands alternate with limonite bands, and in still others brown or dark-reddish-brown limonite is interstitial to the matrix quartz. Vugs are numerous and are commonly lined with limonite, goethite, jarosite, and manganese oxide. Many samples have crystals of late barite. Thin crusts of an unknown late secondary mineral are commonly observed; the mineral is pleochroic from pale yellowish brown to dark yellowish brown, anisotropic with moderate birefringence, and has strong relief above quartz. This mineral either forms crusts on goethite or thin interstitial selvages on late quartz, filling vugs in limonite. It is too fine grained for determination of its optical character, too strongly colored for accurate determination of its birefringence, and too sparse to be isolated for chemical analysis. It is only present in samples containing more than 1,000 ppm (parts per million) tungsten, and may be a secondary tungsten mineral.

The presence of carbonate dust in the matrix quartz of all three generations of jasperoid suggests that all of them formed by replacement of carbonate rock. Iron minerals associated with the jasperoid quartz appear to change progressively through the generations of jasperoid. Iron occurs as discrete grains, cubes, and pyritohedrons of pyrite in Type 1 jasperoid, as opaque yellow limonite dust inclusions in Type 2A jasperoid, and as brown limonite or red hematite dust in Type 2B jasperoid; Types 2A and 2B also contain iron oxide pseudomorphs of original pyrite. However, these types do not represent surficial oxidation of older jasperoids, because unaltered breccia fragments of Type 1 jasperoid containing fresh pyrite are commonly enclosed in a matrix of Type 2 jasperoid. Type 3A jasperoid is characterized by abundant red hematite as dusty inclusions in the quartz and as an interstitial matrix to the quartz. Type 3C jasperoid consists of coarser quartz free of iron oxide inclusions but closely associated with hydrous iron oxide as brown limonite or goethite, with no pyrite pseudomorphs (table 2).

MINOR ELEMENT DISTRIBUTION IN JASPEROID

Two hundred jasperoid samples from the Pando area were analyzed spectrographically for 27 elements by Leon Bradley and J. C. Hamilton, and they were also quantitatively assayed for gold, using a combination of fire assay and atomic absorption spectroscopy, by J. A. Thomas and G. D. Shipley.

At Pando, the three types of jasperoid display differences in concentration of associated minor elements. Although most of the Pando samples that were analyzed consist of mixtures of more than one generation, a sufficient number of samples composed dominantly of a single type of jasperoid representative of each of the three generations were analyzed to illustrate these differences (table 3). The subtypes within each generation were grouped together in order to obtain sufficient analyses of each generation for comparison.

The median concentrations of all elements except barium in Type 1 jasperoid are close to normal background values. Barium is abnormally high, but it is also very erratic in its distribution in all three jasperoid types. Barite always appears as a late mineral, younger than the matrix quartz, in veinlets and lining vugs, so the high Ba content of the jasperoid may not reflect the composition of the original siliceous replacement of the carbonate rocks.

Type 2 and Type 3 jasperoid samples from Pando show a progressive increase in median concentrations of manganese, arsenic, beryllium, germanium, niobium, nickel, antimony, scandium, tungsten, and yttrium. Sodium, boron, and zirconium are relatively abundant in the Type 2 jasperoid samples. Figure 4 illustrates these differences graphically.

Type 2 jasperoid samples exhibit appreciably higher concentrations of all the elements shown in figure 4, except boron and zirconium, than do those of Type 1. The samples of Type 3 jasperoid are noticeably depleted in sodium, boron, and zirconium, relative to Type 2 jasperoid, but they have higher concentrations of the other 11 elements shown in figure 4.

The concentration of tungsten in Type 3 ferruginous jasperoid on the ridge between Homestake Creek and the Eagle River canyon in the northern part of the area is illustrated in figure 5, which also

TABLE 3.—*Measures of central tendency and dispersion in three generations of Pando jasperoid*

[Med., median; G.M., geometric mean; G.D., geometric deviation; N, not detected at lower limit of determination (limit given in parentheses); ----, could not be determined from available data]

Element[1]	Normal[2] background Med. (ppm)	Type 1 (48 samples)			Type 2 (43 samples)			Type 3 (18 samples)		
		Med. (ppm)	G.M. (ppm)	G.D.	Med. (ppm)	G.M. (ppm)	G.D.	Med. (ppm)	G.M. (ppm)	G.D.
Fe	7,000	3,000	3,600	3.7	15,000	15,000	3.9	90,000	55,000	3.0
Mg	700	700	850	4.9	500	640	2.1	600	450	2.5
Ti	200	200	220	3.0	300	280	2.7	200	150	2.5
Mn	80	50	47	3.6	100	95	2.6	300	240	3.6
As	N(<700)	N(<700)	N	----	N(<700)	460	2.2	2,000	1,500	4.1
B	N(<15)	15	15	1.4	N(<15)	13	1.8	N(<15)	7.6	1.3
Ba	100	200	230	10.0	200	380	7.2	600	530	5.4
Be	N(<.5)	1	1.1	2.3	5	4.0	5.3	20	16	2.6
Co	N(<1)	N(<1)	1.8	2.6	2	2.5	2.7	3	2.5	2.4
Cr	7	5	6.1	2.3	7	7.9	2.3	6	5.6	1.9
Cu	15	10	9.9	2.6	17	19	2.6	15	15	2.6
Ga	N(<1)	2	2.3	1.5	N(<1)	1.7	2.2	N(<1)	1.4	2.3
Ge	N(<5)	N(<5)	5.2	2.1	15	11	2.8	40	38	2.2
Hg	.2	.3	.34	6.9	.15	.21	5.4	.15	.16	5.6
Li	N(<30)	N(<30)	25	1.9	N(<30)	15	2.0	N(<30)	N	----
Mo	N(<2)	N(<2)	1.3	1.8	N(<2)	1.6	2.2	N(<2)	N	----
Nb	N(<10)	N(<10)	4.4	1.6	N(<10)	4.7	1.7	10	8.7	2.4
Ni	4	7	5.7	2.8	15	11	4.9	15	15	2.5
Pb	15	15	13	2.9	15	12	3.5	10	11	3.4
Sb	N(<70)	N(<70)	N	----	N(<70)	72	3.2	300	360	3.7
Sc	N(<3)	N(<3)	N	----	N(<3)	2.0	2.5	7	6.0	2.2
Sr	17	10	13	3.6	15	11	3.8	15	15	3.2
V	7	7	6.2	2.4	15	11	2.8	15	11	3.2
W	N(<150)	N(<150)	N	----	200	130	4.3	2,000	1,100	4.2
Y	N(<10)	N(<10)	N	----	N(<10)	6.2	2.0	15	11	2.6
Zn	N(<200)	N(<200)	N	----	N(<200)	N	----	N(<200)	N(<200)	----
Zr	15	20	15	3.4	20	16	2.8	10	8.8	2.9

[1] Hg by atomic absorption analysis, all other elements by six-step spectrographic analysis.

[2] From reference suite of >500 jasperoid samples representing >100 districts and mineralized areas in the U.S. (T. G. Lovering, unpub. data, 1978).

shows a few sample localities of tungsten-bearing fractures in quartzite and Precambrian rocks. All the localities from which multiple samples averaged 0.2 percent tungsten or more are within this area. Three localities to the southeast yielded samples averaging more than 0.05 percent tungsten; one of these is at the mouth of McAllister Gulch, one between McAllister Gulch and the mouth of Resolution Creek, and one at the mouth of Resolution Creek. Tungsten concentration declines rapidly eastward in jasperoid samples from the Resolution Creek area, and tungsten was not detected in core samples from the drill hole in McAllister Gulch nor in those from upper Resolution Creek.

Anomalous tungsten concentrations are not confined to jasperoid replacing carbonate rocks. Samples of siliceous brown limonite in veins from fracture zones cutting the Sawatch Quartzite also yielded anomalous tungsten values: for example, tungsten anomalies were found on (1) the west side of the ridge between Homestake Creek and the Eagle River, within and close to the strong northeasterly trending fault that crosses this ridge; and (2) east of this ridge in the Eagle River canyon between McAllister Gulch and Silver Gulch. A sample of limonite-impregnated fault breccia also contains anomalous tungsten; it was collected along the northeasterly trending fault where it cuts Precambrian rocks just below the Sawatch Quartzite on the southwest side of the ridge. The presence of the anomalous tungsten in the fault breccia suggests that fissures in the basement, not just in the sediments, were involved in the mineralization.

A comparison was made of the distribution of minor elements in samples of jasperoid from the Pando area with those in jasperoids from the three closest areas to Pando that have numerous jasperoid bodies (fig. 1). These are the Red Cliff district, about 3 km to the north; a mineralized area north of Tennessee Pass and east of Piney Creek, 5 to 7 km to the south; and the high Gore Range from 5 to 6½ km east (fig. 1; table 4).

The Red Cliff district is a small silver-lead district that has jasperoid associated with replacement orebodies in the lower and middle Paleozoic carbonate rocks. The area north of Tennessee Pass contains a few small gold mines and abundant prospects in this same carbonate section, and here also, mineralization appears to be closely

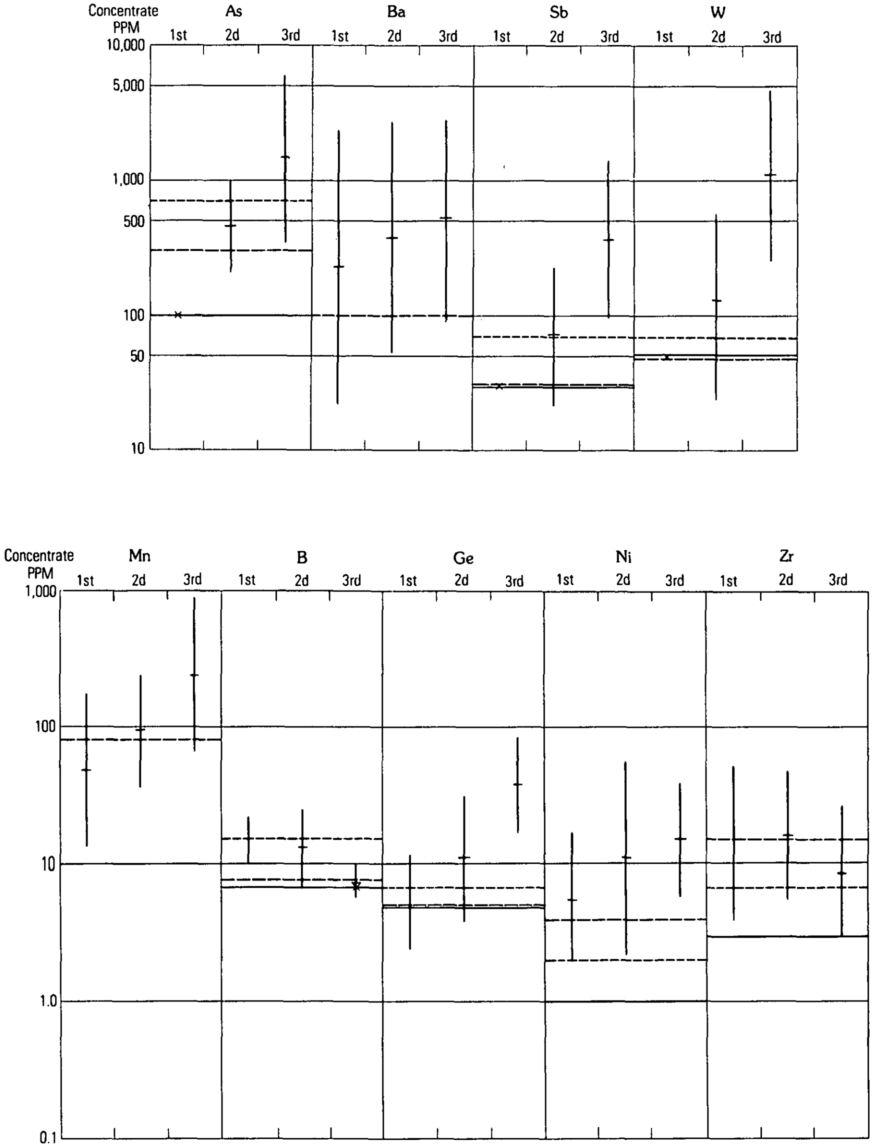
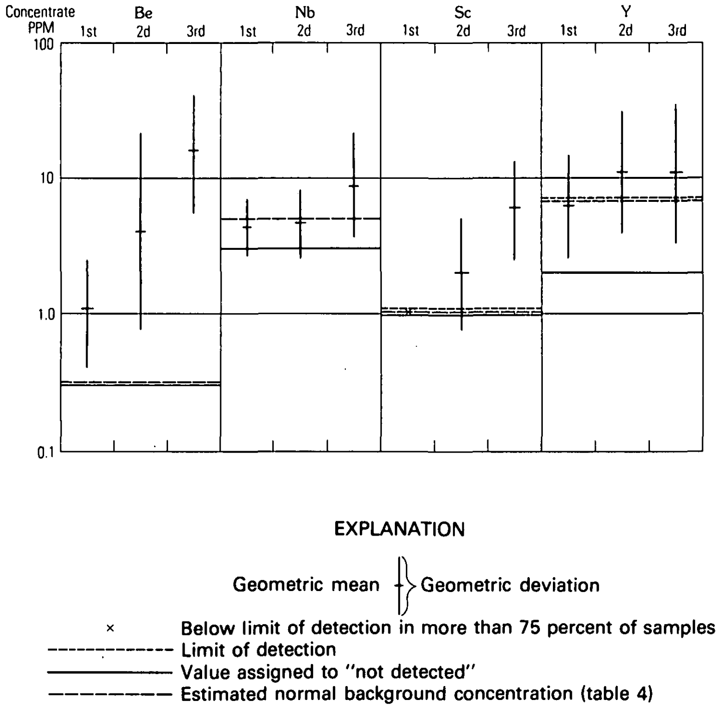


FIGURE 4 (above and facing page).—Geometric means and deviations of selected elements in samples of three generations of jasperoid from the Pando area.

associated with silicification; total production from this area has been only about $250,000. Jasperoid in the high Gore Range locally replaces dolomite beds in the upper part of the Minturn Formation, more than a 1,000 m above the Devonian and Mississippian rocks



that contain jasperoid in the other two areas and at Pando. There are no mines in this part of the Gore Range, although the Kokomo mining district, about 3 km farther to the east, has produced lead, zinc, and silver from orebodies in carbonate beds of the upper part of the Minturn Formation.

Table 4 shows medians (Med), geometric means (G.M.), and geometric deviations (G.D.) for 28 elements in the entire group of jasperoid samples collected from each of these four areas. A column of normal background (median) concentrations of each of these elements, derived from a reference file containing the analyses of more than 500 jasperoid samples representing more than 100 mining districts and mineralized areas in the United States (T. G. Lovering, unpub. data, 1978), is also included for comparison.

Median concentrations of titanium, barium, beryllium, antimony, tungsten, and zirconium are appreciably higher in the Pando samples than in those from the other three areas, and germanium is also high. High values for silver, boron, germanium, lead, and zinc characterize the Red Cliff area jasperoids. Samples from the area north of Tennessee Pass showed distinctively higher concentrations of gold and the rare earth elements lanthanum and yttrium than those from the other areas. The median concentration of arsenic is high in samples

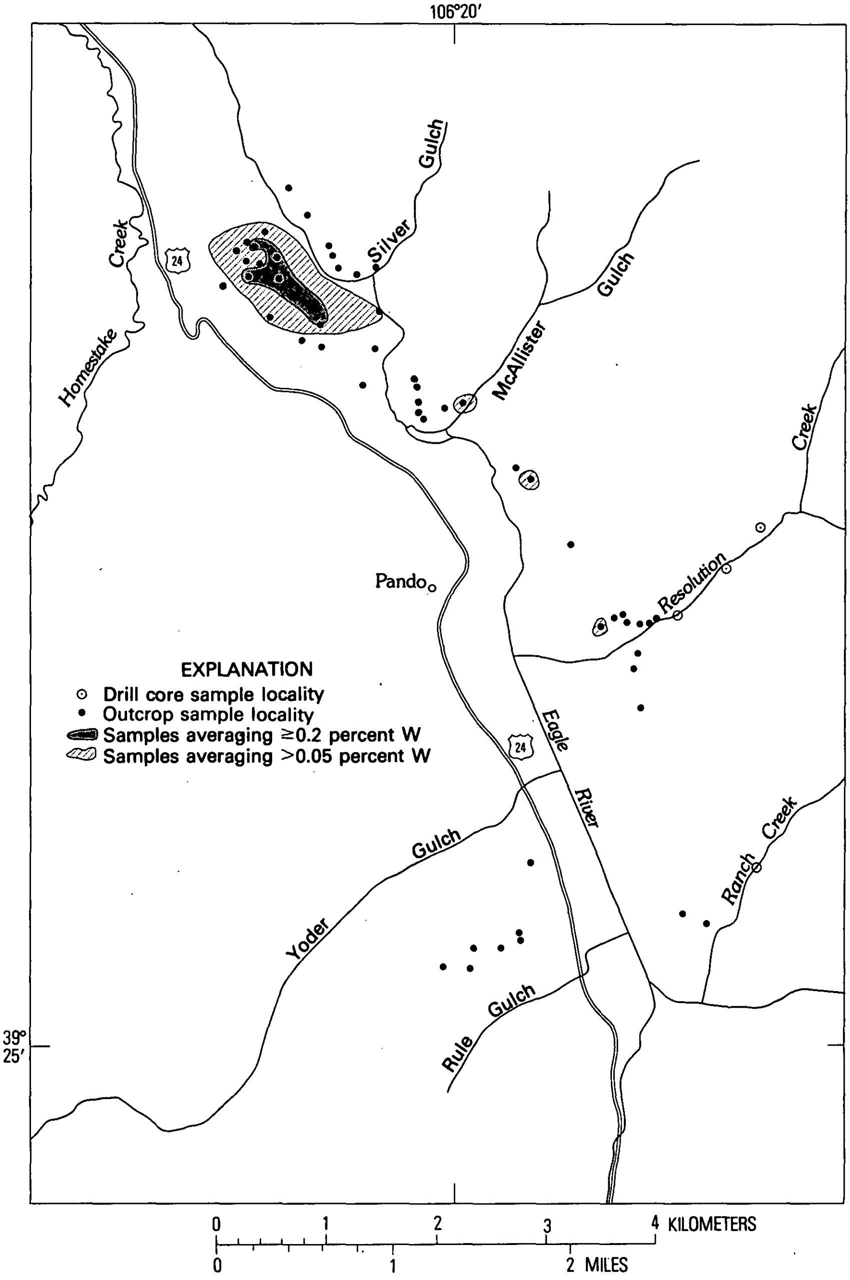


FIGURE 5.—Sample locality map of Pando area showing tungsten anomalies.

TABLE 4.—*Measures of central tendency and dispersion of selected elements in jasperoid samples from Pando and adjacent areas*

[Med., median; G.M., geometric mean; G.D., geometric deviation; I G.D. Range, I geometric deviation ranges; N, not detected at lower limit of determination (limit given in parentheses); —, could not be determined from available data]

		Pando (200 samples, 64 localities)				Red Cliff (31 samples, 14 localities)				N. of Tennessee Pass (32 samples, 10 localities)				Gore Range (8 samples, 8 localities)			
Element[1]	Normal[2] background Med.	Med. (ppm)	G.M. (ppm)	G.D.	I G.D. Range (ppm)	Med. (ppm)	G.M. (ppm)	G.D.	I G.D. Range (ppm)	Med. (ppm)	G.M. (ppm)	G.D.	I G.D. Range (ppm)	Med. (ppm)	G.M. (ppm)	G.D.	I G.D. Range (ppm)
Ti	150	250	289	3.2	90-925	150	224	3.5	64-780	150	101	7.2	14-730	15	29	4.4	6.6-130
Na	30	N(150)	229	2.5	N-570	N	156	2.0	N-310	N	215	2.0	N-430	300	254	2.7	N-650
Mn	100	100	103	4.1	30-420	70	66	4.0	15-26	150	171	6.2	28-1,100	300	261	2.3	110-600
Ag	1	N(0.1)	.11	1.7	N-.2	2	2.1	14.1	N-30	N	.3	2.4	N-.7	N	N	----	----
As	<100	N(100)	183	3.4	N-620	N	134	2.5	N-335	N	223	1.4	N-314	N	N	----	----
Au	<.01	N(0.01)	.011	1.6	N-.02	N	.02	3.8	N-.076	N	.09	7.1	N-0.64	N	N	----	----
B	5	N(7)	12.4	1.8	>22	15	16	2.7	N-43	N	9.3	2.0	N-19	N	8	1.5	N-12
Ba	150	200	333	6.6	50-2,200	50	58	1.6	35-93	60	60	2.3	26-140	40	33.5	2.9	12-97
Be	<.3	2	2.6	4.6	0.6-12	.8	1.0	2.7	N-2.7	N	.5	5.3	N-2.7	N	N	----	----
Co	<1	N(1)	2.5	3.0	N-7.5	N	1.8	2.5	N-4.5	N	2.0	6.1	N-12	N	1.2	1.8	N-2.2
Cr	15	7	7.9	2.5	3-20	7	6.6	2.8	2-18	7	4.6	4.0	N-18	3	3.3	2.4	N-7.9
Cu	30	10	15.9	2.8	6-45	10	10.0	3.7	3-7	15	17	2.6	6.5-44	10	7.4	1.3	5.7-9.6
Ga	<1	N(1.5)	2.4	1.9	N-5	N	1.7	2.1	N-3.5	N	1.9	1.7	N-3.2	N	N	----	----
Ge	<5	8	7.8	3.9	N-30	N	7.7	2.4	N-18.5	N	N	----	----	N	N	----	----
La	<10	15	7.1	2.1	N-15	N	N	----	----	N	10.4	2.0	5.2-21	N	N	----	----
Li	<10	N(10)	17.4	2.1	N-37	N	N	----	----	N	N	----	----	N	N	----	----
Mo	2	N(1)	1.4	2.0	N-3	N	1.3	1.8	N-2.3	N	1.1	1.5	N-1.7	N	N	----	----
Nb	<3	N(3)	4.3	2.7	N-12	N	N	----	----	N	4.1	1.6	N-6.6	N	N	----	----
Ni	6	7	7.2	3.1	N-22	5	4.8	3.5	N-17	4	5.6	6.0	N-34	N(1)	1.7	2.8	N-4.8
Pb	20	15	13.6	2.5	5-34	15	29	7.1	4-210	10	7.5	2.9	N-22	7	8.5	1.9	4.4-16
Sb	<30	N(30)	63.4	2.8	N-180	N	41	2.7	N-110	N	N	----	----	N	N	----	----
Sc	<1	N(1)	1.7	2.4	N-4	N	1.3	1.9	N-2.4	N	1.3	1.9	N-2.5	N	N	----	----
Sr	10	15	15.5	3.8	N-60	10	6.7	1.9	N-13	7	9.1	2.6	N-24	30	17.5	4.0	N-70
V	10	10	7.2	4.6	N-33	7	6.6	3.8	N-25	8	9.2	2.9	N-27	7	4.7	2.6	N-12
W	<50	100	98.2	5.7	N-560	N(50)	N	----	----	N	N	----	----	N	N	----	----
Y	4	N(2)	5.1	3.1	N-16	N	3.7	1.5	N-5.6	10	9.4	2.1	4.4-20	N	N	----	----
Zn	<30	N(30)	58.3	1.7	N-100	N	92	3.8	N-350	N	N	----	----	N	N	----	----
Zr	10	20	18.0	5.5	N-100	7	14	4.5	N-63	8	12.3	5.1	N-63	N(3)	4.9	2.5	N-12

[1] Au by fire assay and atomic absorption, all other elements by six-step spectrographic analysis.

[2] Calculated from data on >500 samples representing 2,100 districts and mineralized areas in the U.S. (T. G. Lovering, unpub. data, 1978)

from all areas except the Gore Range. The Gore Range samples have higher median concentrations of sodium, manganese, and strontium than the samples from the other three areas, but are lower in most of the other minor elements, particularly titanium. These differences in the minor element content of jasperoids from the four areas suggest different sources for the silica in each of them; differences caused by differing compositions of the host rock are not likely, since all but the small group from the Gore Range represent siliceous replacement of the same stratigraphic units, and in all four areas the same rock type (dolomite) was replaced.

The distribution of elements in Type 1 jasperoid at Pando (table 3) strongly resembles that of the suite of samples from the Red Cliff district (table 4), except that the Pando samples contain more barium and less lead, zinc, and silver than do the Red Cliff samples. Most of the samples from Red Cliff also resemble the Type 1 Pando jasperoids in appearance, being dominantly dense, medium-gray rocks.

ASSOCIATIONS OF ELEMENTS

Four different types of samples from the Pando area were analyzed spectrographically. The largest group is composed of jasperoid of each of the three major types previously discussed. In addition to the jasperoid samples, we have analyzed whole-rock samples of Tertiary intrusive dike and sill rocks, samples of mineralized shear and fracture zones in the more siliceous impermeable rocks below the Dyer Dolomite, and samples of limonite concentrates extracted from rocks of various kinds along and near the northeast-trending fault that crosses the Homestake Creek–Eagle River divide. Minor element associations that characterize each of these sample types are summarized in table 5.

The 48 Type 1 jasperoid samples show no consistent minor element associations. The only elements that displayed anomalously high concentrations in more than 10 percent of the samples are barium, titanium, mercury, and cobalt. Neither the barium-rich samples nor the titanium-rich samples showed any other element consistently present in abnormally high amounts, and some high-barium and high-titanium samples show no other minor elements present in greater than normal amounts. Most of the samples with >1 ppm mercury and 11 of the samples with >5 ppm cobalt are anomalous in at least one other element, but neither mercury nor cobalt shows any consistent associations. Thus, the most conspicuous feature of the group is its general lack of anomalies.

TABLE 5.—*Associated minor elements in samples of various types from the Pando area*

Type of sample material	Characteristic minor element associations
Type 1 jasperoid---------	None.
Type 2 jasperoid---------	Fe-Ni-Sc-Sb; Be-Ge-W; Co-Pb; Cu-V.
Type 3 jasperoid---------	As-Be-Nb-Y; Co-Mo-Mn-Ni; Ge-W; Ni-Co.
Tertiary igneous intrusive rocks.	Ba-Sr-Pb.
Veins and shear zones in Precambrian rocks and Sawatch Quartzite.	(A) As-Be-Ge-Sb-W; (B) Cr-La-Sr-Ti; (C) Ni-Sc-V-Y.
Limonite concentrate from veins and fractures.	(D) As-Be-Ge-Nb-Sb-W; (E) La-Zn; (F) Cr-Ni-V; (G) Co-Cr-Ni; (H) Cr-Cu-Ni.

The group of 43 samples of Type 2 jasperoid, in strong contrast to the Type 1 jasperoid group, displays high concentrations of many minor elements in a large proportion of the samples. Beryllium, germanium, tungsten, nickel, iron, scandium, and antimony are anomalous in more than 30 percent of these samples. A statistical qualitative test of association (the chi square test) reveals highly significant associations among two groups of elements (Fe-Ni-Sc-Sb and Be-Ge-W); and also between two pairs of elements (Co-Pb and Cu-V) in samples representing Type 2 jasperoid.

The late ferruginous Type 3 jasperoid is represented by 18 samples. More than 30 percent of these samples display anomalously high concentrations of tungsten, iron, arsenic, barium, beryllium, cobalt, germanium, niobium, nickel, antimony, and scandium. This suite of elements includes all those that are characteristically high in the Type 2 jasperoid, with arsenic, barium, cobalt, and niobium in addition. A chi square test of element associations in samples of Type 3 jasperoid shows a highly significant mutual association within the group Be-As-Nb-Y, and also between the element pairs Ge-W and Ni-Co. Molybdenum is anomalous in 20 percent of the samples in this group, and shows a strong affinity for manganese, cobalt, and nickel. Copper and vanadium are present in normal background concentrations in these samples, as contrasted with samples representing Type 2 jasperoid, in which these two elements were anomalous and strongly associated in several samples. Barium is also abundant in the Type 3 jasperoids, but it shows no significant correlation with any of the other elements.

Whole-rock analyses were made on 25 samples of Tertiary porphyry dikes and sills that intrude the Precambrian basement rocks, the Cambrian Sawatch Quartzite and overlying Peerless Formation, and the Pennsylvanian Belden Formation. Many of these intrusives exhibit intense sericitic alteration, but they all appear to have consisted originally of quartz, sodic plagioclase, and biotite phenocrysts in a groundmass of fine-grained quartz and orthoclase, with minor accessory magnetite, apatite, sphene, and zircon.

The least altered dike samples contained anomalously high concentrations of barium (0.1–0.2 percent), strontium (0.07–0.1 percent), and lead (0.005–0.007 percent), although the intensely altered samples closest to bodies of mineralized jasperoid showed much lower concentrations of these elements. Barium, strontium, and lead were probably originally present largely in the feldspars, and the hydrothermal sericitization of these minerals may have released much of the barium to the altering solutions and may thus account for the abundant barite in some of the jasperoid. Biotite separated from six of the least altered samples showed high concentrations of titanium, lead, and zinc, plus the rare earth elements cerium, lanthanum, neodymium, and yttrium, compared to normal biotite from felsic intrusive rocks. Neither the less altered whole-rock samples nor their biotite showed anomalous concentrations of tungsten or beryllium, or of germanium, niobium, and scandium, with which tungsten is closely associated in the mineralized jasperoid. However, tungsten, beryllium, and germanium do show up in sericite concentrates from some of the samples of intensely altered intrusive rocks in the mineralized area.

Forty samples taken from small veins and mineralized shear zones that cut the Sawatch Quartzite and the Precambrian basement rocks were also analyzed spectrographically. These samples were taken at 15 localities in the Eagle River valley and on the ridge between Homestake Creek and the Eagle River to provide information on the assemblage of elements that had migrated along channelways through the impermeable and nonreactive rocks beneath the jasperoid bodies in the carbonate section.

Three groups of mutually associated elements appear in these samples. The first group (group A) includes arsenic, beryllium, germanium, antimony, and tungsten. The second group (group B) consists of titanium, lanthanum, chromium, and strontium; this group shows some affinities with a third group (group C) consisting of nickel, scandium, vanadium, and yttrium, but neither group B nor C shows any significant association with elements in group A, although individual samples contain elements found in the other groups.

Small veins cutting Precambrian rocks on both sides of the Eagle River valley at the south end of Camp Hale are characterized by anomalous concentrations of the elements in groups B and C. Anomalous, as used here, means concentrations in the upper decile of the normalized distribution of the reference collection of jasperoid samples, median values of which are given in tables 3 and 4. Veins cutting Sawatch Quartzite along the Eagle River west of the mouth of McAllister Gulch are high in group B elements and slightly high in group A elements. A mineralized fracture zone cutting Sawatch Quartzite in the Eagle River canyon south of the mouth of Silver Gulch is high in group C elements and slightly high in group A elements. A fracture zone in Sawatch Quartzite on the west side of the Homestake Creek–Eagle River divide approximately 1½ km west of this locality, is high only in elements of group A. However, fractures and shear zones cutting both Sawatch Quartzite and Tertiary porphyry intrusives about 100 m northwest of this locality are high only in elements of groups B and C. (See fig. 2 for sample locations.)

Several elements, although present in anomalous concentrations in many samples, show no significant associations with any other elements in the vein samples. These independent elements are Mn, Ba, Co, Cu, Li, and Nb.

Samples of Tertiary porphyry, Sawatch Quartzite, and Precambrian basement complex were collected along the northeast-trending fault zone that crosses the Homestake Creek–Eagle River divide and marks the northern boundary of the mineralized area. Samples from quartzite and porphyry on the east side of the ridge and across the top of it are high in elements of group A (As, Be, Ge, Sb, and W). Those from quartzite just above the Precambrian on the west side are anomalous in group A elements and group C elements (Ni, Sc, V, and Y), and the southwesternmost sample of this series from Precambrian host rock shows anomalous concentrations of elements belonging to group B (Ti, La, Cr, and Sr) and not group A.

Fracture fillings at seven sample localities on the Eagle River–Homestake Creek divide at the north end of the mineralized area consist largely of siliceous brown limonite very similar in appearance to the ferruginous tungsten-bearing jasperoid that forms replacement bodies in the overlying carbonate section. Iron oxide was selectively leached from these samples with oxalic acid and analyzed separately for comparison of minor element associations with those of the Type 3 ferruginous jasperoids.

This limonite concentrate (table 5) shows strong mutual affinities among arsenic, beryllium, germanium, niobium, antimony, and tungsten (group D). All these elements correlate negatively with lanthanum and zinc (group E), which show a strong positive correlation with each other. Chromium, nickel, and vanadium (group F) also show a strong mutual affinity, but none of these three elements correlates significantly with those of group D. Cobalt shows significant associations with chromium and nickel, but not with vanadium. Copper also correlates most strongly with chromium and nickel but not with cobalt or vanadium. Lead shows barely significant positive correlations with copper and yttrium; and zinc shows a moderately strong correlation with nickel in addition to its strong correlation with lanthanum.

Although neither the Type 1 jasperoid nor the igneous intrusive rock samples shows any geochemical similarities to the other types of samples, the other four types do show common affinities, particularly in the elements associated with tungsten. The absence of any significant association among the common base metal elements, copper, lead, and zinc, in any of these sample groups is unusual, as these three elements normally show significant intercorrelations in jasperoid or mineralized fracture zones that are related to base metal sulfide deposits.

GENESIS OF JASPEROID

The jasperoid bodies in Leadville and Dyer Dolomites exposed on the hills around the Eagle River valley near the townsite of Pando, exhibit local variations in color and texture. Although the Type 2 and Type 3 jasperoids show certain similarities, the Type 1 jasperoid differs so markedly in distribution, appearance, and composition from the other two as to suggest that it was derived from a different source. A brief recapitulation of the distribution and distinguishing characteristics of each of these types is given in the following paragraphs, to provide a basis for an hypothesis concerning their origin.

Type 1 jasperoid is widely distributed throughout the surrounding region. Bodies of this type are present in the Devonian and Mississippian carbonate rocks in the Eagle River drainage basin, at intervals, all the way from the north side of Tennessee Pass to the flanks of the Sawatch Range west of Minturn, and also in limestone and dolomite beds high in the Minturn Formation in the Gore Range near the heads of Pearl and Cataract Creeks.

The distribution of Type 2 jasperoid is shown in figure 3. This type of jasperoid is abundantly represented in exposures near the south end of the Eagle River canyon and eastward to the mouth of McAllister Gulch. It also occurs in large bodies both north and south of the mouth of Resolution Creek, although jasperoid recovered from a drill core to the east along Resolution Creek is of the early gray variety (Type 1, fig. 3).

The late brown variety of jasperoid (Type 3, fig. 3) is still more restricted in distribution. It crops out in abundance on the divide between Homestake Creek and the Eagle River from the boundary fault southward for about 1 km and is also common in association with intermediate stage jasperoid from the south end of the Eagle River Canyon to the mouth of Resolution Creek.

The three generations of jasperoid also show distinctive differences in appearance, mineralogy, and composition (tables 2, 4). The progressive increase of arsenic, antimony, beryllium, germanium, and tungsten from near normal background values in the Type 1 jasperoid, through intermediate concentrations in Type 2, to concentrations an order of magnitude or more above background in the Type 3 jasperoid suggests that the second and third generations may be derived from a common source, different from the one responsible for the first generation jasperoid. The decrease in sodium, boron, and zirconium in Type 3 jasperoid probably reflects a marked difference in depositional environment. The porous, vuggy texture and the abundance of manganese oxide and hydrous iron oxide characteristic of this late jasperoid suggest deposition under low-pressure, near-surface conditions.

The presence of limonite veinlets, which are similar both in appearance and composition to Type 3 jasperoid, cutting Sawatch Quartzite and Tertiary intrusive rocks well below the base of the carbonate section, suggests that Type 3 jasperoid is not supergene, but was formed by solutions moving upward along feeding channels.

Isotopic analysis of oxygen derived from jasperoid representing each of the three generations of Pando jasperoid was performed on four selected samples (one sample of each type, plus one sample of Type 1 breccia fragments and the Type 2 matrix that cements them). Such analytical data on a larger group of representative samples of each type is needed to firmly establish any conclusions. Nevertheless, the results from these four samples, which are presented in table 6, suggest that some real differences may exist in the oxygen isotope ratios in the jasperoid of each of the three types.

The two samples of Type 1 jasperoid, from localities several kilometers apart, yield very similar δO^{18} values. The two samples of Type 2 jasperoid come from within less than two kilometers of each other; not only do they yield δO^{18} values less than half those of the

TABLE 6.—*Oxygen isotopic analysis of silica from Pando jasperoid*

Sample No.	Description	δO^{18} SMOW
20T49	Type 1 jasperoid----------------------	+21.7
VI21A-1	Type 1 jasperoid in Type 2 matrix-----	+22.7
VI21A-2	Type 2 jasperoid matrix of VI21A------	+ 7.4
52T47	Type 2 jasperoid----------------------	+10.1
VI34D	Type 3 jasperoid----------------------	+ 4.3

Type 1 samples, but they also have a much greater variation in $\delta 0^{18}$ values. Sample 52T47, of Type 2 jasperoid, was taken on the north side of the large fault crossing the ridge between Homestake Creek and the Eagle River, adjacent to an altered body of Tertiary quartz latite porphyry and within 150 meters of the Type 3 sample VI34D, which came from a jasperoid body in the Leadville Dolomite on the south side of this fault. The Type 3 jasperoid sample has a $\delta 0^{18}$ value less than half that of the nearby Type 2 sample.

In summary, the Type 1 jasperoid in the Pando area differ so strikingly in distribution, appearance, mineralogy, chemical composition, and oxygen isotopic ratios from the Type 2 and Type 3 jasperoids as to indicate that the source of the first type was separate and unrelated to the source of the other two. The Type 2 and Type 3 jasperoids, on the other hand, show many similarities and may have been derived from the same source, but formed in different physical chemical environments. The low $\delta 0^{18}$ ratio of the type 3 sample suggests that the solution that deposited this silica was the hottest. If so, this hot solution may have contained a larger proportion of magmatic components or may have been exposed to greater heat than the fluid that deposited jasperoids Types 1 and 2.

Fluids that formed the Type 1 jasperoid probably emanated from a large, regional igneous source many kilometers to the east or northeast, under the Gore Range, possibly the same source from which some of the Tertiary porphyry sills in the upper Paleozoic rocks of these mountains were derived at a slightly earlier time. The fluids may have moved updip in the carbonate section or more directly upward along fault zones for a considerable distance from their source until they had cooled sufficiently to replace carbonate rock with silica. This process appears to have occurred under stable conditions, such that isotopic equilibrium was established between the silica and the solutions from which it was deposited. The solutions were probably hot, either neutral or alkaline, and charged with silica, potassium, iron, and sulfur, and they may have locally contained base and precious metals as well. The jasperoid bodies appear to have formed at considerable depth.

Jasperoids in the Gilman district, to the north of Pando, form barren replacement bodies in the carbonate section both updip and downdip from the orebodies and also along faults cutting limestone beds in the Minturn Formation more than 600 m above an orebody. Most of these Gilman jasperoids resemble in appearance and composition the Type 1 jasperoids at Pando, and samples of Gilman jasperoid taken from bodies closest to orebodies contain traces of silver as well as slightly anomalous concentrations of lead and zinc, suggesting that these jasperoid bodies may represent a fringe zone type of alteration that is genetically related to mineralization.

The Type 1 jasperoids in the Pando area may have a relation to sulfide mineralization similar to that of the jasperoids at Gilman. If so, the occurrence of scattered sphalerite in some samples of Type 1 jasperoid in outcrops along the eastern edge of the valley at Pando, considering that the jasperoid both downdip to the east and updip to the west is barren, suggests that orebodies once could have existed in the carbonate section above the Eagle River valley; and remnants of these bodies may still exist in some places, such as the vicinity of Ranch Creek, where composite samples of Type 1 and 3 jasperoid from the southeasternmost jasperoid body exposed in the Pando area (figs. 2, 3) yielded anomalously high concentrations of copper, lead, and zinc.

The Type 2 jasperoids appear to have been derived from a local source, beneath the valley of the Eagle River near Pando and beneath the southern end of the divide between Homestake Creek and the Eagle River northwest of Pando. The earlier subtypes of Type 2 jasperoid contain both sericite and limonite pseudomorphs after pyrite, as do the altered Tertiary intrusives beneath the carbonate section northwest of Pando. This evidence suggests a common source, and also that this source was probably quite deep.

Both pyrite and sericite suggest formation of Type 1 and Type 2 jasperoid from alkaline or neutral solutions in a reducing environment. However, a change in this environment, before the earliest subtype of Type 2 jasperoid had become completely impermeable by lithification, is suggested by the oxidation of early pyrite to hematite and by the iron-stained character of the sericite.

During the next stage of formation of Type 2 jasperoid, the hot solutions apparently precipitated iron in an oxidizing environment as hematite dust in the jasperoid quartz and as irregular masses and veinlets of hematite cutting the quartz. This change from pyrite to hematite was probably not brought about by a deficiency of sulfur in the system, because barite is a common accessory mineral in these rocks, although most of the barite is late.

The final stage in formation of Type 2 jasperoid is marked by disseminated limonite particles in quartz, imparting pale-yellow, pale-orange, and pale-brown colors to the rock. This change from anhydrous to hydrous ferric oxides seems to indicate formation at lower temperatures.

Changing conditions during the formation of second generation jasperoid are reflected not only by these changes in mineralogy and by a sporadic and irregular distribution of the various subtypes, but also by considerable variation both in the minor element content and the δO^{18} isotope values of these rocks over short distances.

Type 3A jasperoid, which contains abundant red hematite, forms a matrix for breccia fragments of second generation jasperoid that contain disseminated limonite in some places. This circumstance suggests that during the initial stage of formation of Type 3 jasperoid, hot silica and iron-bearing fluids locally invaded and engulfed masses of Type 2 jasperoid that had formed in a cooler environment. Elsewhere in the district, fragments of Type 3A jasperoid are cemented by a matrix of Type 3C jasperoid. The open vuggy texture, colloform banding, and abundance of limonite, goethite, and manganese oxides that characterize the youngest, tungsten-rich, Type 3C jasperoid all suggest that it must have formed in an epithermal environment.

The anomalously high concentrations of beryllium, niobium, and tungsten, elements commonly found in high-temperature deposits, in close association with hydrous iron oxide, arsenic, and antimony, suggest a very steep temperature gradient in the feeding fissures; such conditions are typical of deposition in a shallow epithermal environment. The low δO^{18} value of silica from a sample of Type 3 jasperoid (+4.3) may reflect deposition from a very hot solution.

The tungsten-rich jasperoid at Pando is probably not related to the Pando porphyry, because veinlets of silicious brown limonite similar in composition to this jasperoid cut a sill of hydrothermally altered and pyritized Pando porphyry close to the area in which the Type 3 jasperoid is most abundant. This porphyry has an approximate age of 70 million years (Pearson and others, 1962); it is the oldest of the Laramide intrusives in this area (Tweto, 1974) and is the only porphyry exposed in the immediate vicinity of the area of Type 3 jasperoid mineralization. The ultimate source of Type 3 jasperoid is probably a buried intrusive as yet unknown, which provided some elements but also mobilized heated meteoric solutions that supplied many of the more common elements, such as silicon, magnesium, iron, and potassium.

An Oligocene rhyolite porphyry sill (approximately 29 m.y. old) (Tweto, 1974) is exposed at intervals just north of the East Fork of the Eagle River. The westernmost outcrop of this porphyry is within about 30 m of the southeasternmost exposure of jasperoid shown in figure 2. This jasperoid body consists of breccia fragments of Type 1 jasperoid in a matrix of tungsten-bearing Type 3 jasperoid, but it is an isolated occurrence more than 6 km southeast of the main center of Type 3 jasperoid mineralization on the ridge between Homestake Creek and the Eagle River (fig. 3). Nevertheless, there is a possibility of a genetic relationship between the Oligocene magma that formed this porphyry and the late jasperoid of Types 2 and 3. Such a relationship is indirectly supported by Tweto's suggestion of an Oligocene age for the epithermal, iron-rich tungsten veins of Boulder County (Tweto, 1968a, p. 579), and also by the Oligocene age of the Climax stock about 16 km southeast of Pando, which is genetically related to both molybdenum and tungsten mineralization (Wallace and others, 1968, p. 615).

If a pluton similar in age and composition to the Climax stock had been emplaced in the Precambrian rock beneath the upper valley of the Eagle River, siliceous fluids rising from it along northeastward-trending fractures and shear zones could have formed Type 2 jasperoid bodies in the carbonate rocks of the Pando area. The period of intrusion could also have accounted for the large body of Oligocene rhyolite porphyry in the lower part of the Minturn Formation that is shown on the geologic map of the Holy Cross quadrangle (Tweto, 1974) to the southeast of the jasperoid-bearing area.

This genetic hypothesis for the formation of Type 2 and 3 jasperoid leaves at least two serious questions unresolved: (1) Why are there no dikes or sills of Oligocene porphyry in the vicinity of the areas of abundant jasperoid east and north of Pando? (2) How could bodies of limonite-bearing jasperoid have formed under the temperatures and pressures that must have existed in Oligocene time, when the mid-Paleozoic carbonate section was presumably buried beneath 2 or 3 km of younger rock? Wallace and others (1968, p. 639) estimated that approximately 9,000 feet (3 km) of post-Oligocene uplift and erosion were required to expose the Climax stock and its associated mineral deposits; and this stock is only about 16 km southeast of Pando. Although the Type 2 jasperoid bodies might conceivably have formed at such a depth, it is unlikely that the open, vuggy, coloform-banded, epithermal jasperoid bodies of Type 3 could have done so!

There is one younger episode of tectonic activity and igneous intrusion in this region to which the formation of Type 3 jasperoid, and possibly of Type 2 jasperoid, might be related. Rhyolite dikes and a rhyolite breccia plug that postdate oxidation of the orebodies at Leadville are present in the southern part of the Holy Cross quadrangle, are thought to be of late Miocene or Pliocene age, and are intruded at shallow depth (Tweto, 1974). By the end of Miocene time, erosion had carved canyons hundreds of meters deep into bedrock below Leadville; canyons that were subsequently filled and buried beneath younger sediments (Tweto, 1968b, p. 686). It seems probable that this Miocene erosion had also removed much of the younger rock overlying the carbonate section at Pando, although there is no direct evidence of this.

Although no intrusive as young as Miocene has been recognized at the surface in the Pando area, a blind intrusive of this age could be present beneath the divide between the Eagle River and Homestake Creek. The presence of such an intrusive would provide a logical explanation for the epithermal, ferruginous Type 3 jasperoid, which is rich in tungsten, beryllium, and niobium, and such an intrusive could be responsible for the Type 2 jasperoid as well. The peculiar suite of minor elements in the Type 3 jasperoids could have been remobilized from older deep-seated deposits related to an Oligocene pluton. Possibly this suite of elements was carried upward in fluids generated by the emplacement of a shallow upper Miocene or Pliocene intrusive, which lies within a tectonically active belt in the northward extension of the San Luis–Arkansas Valley graben. This structure, which has been traced northward from the Rio Grande graben of New Mexico as far as the Continental Divide north of Leadville, has been marked by recurrent fault movement throughout the late Tertiary Period. Epithermal fluorspar deposits, hot springs, and geothermal areas are localized along this structural trough (Tweto, 1968a, p. 566, 582).

An alternative explanation worth considering is that the Type 3 jasperoids are entirely of supergene origin and represent deposition of elements leached from deposits of Oligocene age by ground water. However, this hypothesis is somewhat discredited by the complete absence of tungsten anomalies to the east of Pando, by the presence of what appear to be feeding fractures filled with limonite cutting the quartzite beneath the carbonate section, by the isotopic evidence that this jasperoid was deposited form hot solutions, and by the general lack of mobility of tungsten ions in ground water. Although the tungsten oxide ion ($WO_4^{=}$) is somewhat soluble in neutral and alkaline aqueous solutions at low temperature and pressure, in the presence of either iron or calcium, it readily precipitates as insoluble tungstates of these elements (Garrels, 1960, p. 184–185).

SUGGESTIONS FOR PROSPECTING

Despite the uncertainty regarding the age and ultimate source of the Type 3 tungsten-bearing jasperoid in the Pando area, the available evidence suggests that the fluids from which it formed moved upward through the lower Paleozoic sedimentary rocks from a concealed source below. If this hypothesis is correct, there is a reasonable possibility that a large felsic intrusive body, from which fluids bearing tungsten, beryllium, germanium, and niobium emanated, underlies the southern part of the Eagle River–Homestake Creek divide northwest of Pando and the adjacent part of the Eagle River valley to the east at least as far south as the mouth of Homestake Creek. Mineable veins of ferberite, and possibly deposits of beryl, either in pegmatites or disseminated, might reasonably be expected to occur either in a greisen zone at the top of such an intrusive or in metasomatically altered wallrock adjacent to it.

The most favorable site for exploration is the highly altered tungsten-rich area on top of the ridge between Homestake Creek and the Eagle River, adjacent to the northeasterly trending fault and just east of the escarpment formed by the Sawatch Quartzite. Both the fault zone and the ground adjacent to it on the southeast could be explored. Drill holes at this locality should penetrate the source of the surface mineralization at a fairly shallow depth.

Two alternative drilling sites that are somewhat less favorable geologically, but more readily accessible, are (1) at the mouth of McAllister Gulch north of the old gravel pit and (2) near the road junction at the mouth of Resolution Creek. Masses of tungsten-bearing jasperoid in the Leadville Dolomite are exposed near the mouth of McAllister Gulch, across the nose of the adjacent ridge to the west, and on the north side of the mouth of Resolution Creek. Although the tungsten anomalies in jasperoid at these places are smaller than the one on the divide between Homestake Creek and the Eagle River, they are still appreciable and are highest in the outcrops closest to the valley of the Eagle River.

REFERENCES CITED

Crawford, R. D., and Gibson, Russell, 1925, Geology and ore deposits of the Red Cliff district, Colorado: Colorado Geological Survey Bulletin 30, 89 p.

Garrels, R. M., 1960, Mineral equilibria at low temperature and pressure: New York, Harper and Brothers, 254 p.

Lovering, T. G., 1972, Jasperoid in the United States—its characteristics, origin, and economic significance: U.S. Geological Survey Professional Paper 710, 164 p.

Pearson, R. C., Tweto, Ogden, Stern, T. W., and Thomas, H. H., 1962, Age of Laramide porphyries near Leadville, Colorado, *in* Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 450-C, p. C78-C80.

Tweto, Ogden, 1953, Geologic map of the Pando area, Eagle and Summit Counties, Colorado: U.S. Geological Survey Mineral Investigations Field Studies Map MF-12 [1954].

______1968a, Geologic setting and interrelationships of mineral deposits in the mountain province of Colorado and South-central Wyoming, *in* J. D. Ridge, ed., Ore deposits of the United States, 1933-1967 (Graton-Sales Volume), v. 1: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 551-588.

______1968b, Leadville district, Colorado, *in* J. D. Ridge, ed., Ore deposits of the United States, 1933-1967 (Graton-Sales Volume), v. 1: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 681-705.

______1974, Geologic map and sections of the Holy Cross quadrangle, Eagle, Lake, Pitkin, and Summit Counties, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-830, 2 sheets.

Tweto, Ogden, and Lovering, T. S., 1977, Geology of the Minturn 15-minute quadrangle, Eagle and Summit Counties, Colorado: U.S. Geological Survey Professional Paper 956, 96 p.

Wallace, S. R., Muncaster, N. K., Jonson, D. C., MacKenzie, W. B., Bookstrom, A. A., and Surface, V. E., 1968, Multiple intrusion and mineralization at Climax, Colorado, *in* J. D. Ridge, ed., Ore deposits of the United States, 1933-1967 (Graton-Sales Volume): New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, p. 605-640.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980–677-129/29