Geology and Ore Deposits Of the Lawson-Dumont-Fall River District Clear Creek County Colorado

GEOLOGICAL SURVEY BULLETIN 1231

Prepared on behalf of the U.S. Atomic Energy Commission

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By C. C. HAWLEY *and* FRANK BAKER MOORE

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A description of the general geology and ore deposits of the district which forms the northwestern part of the important Central City-Idaho Springs mineralized area

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GEOLOGY AND ORE DEPOSITS OF THE LAWSON-DUMONT–FALL RIVER DISTRICT, CLEAR CREEK COUNTY, COLORADO

By C. C. Hawley and Frank Baker Moore

ABSTRACT

The Lawson-Dumont-Fall River district, a mining district with an area of 15-square-miles in the Front Range mineral belt, is in Clear Creek County, Colo., just west of the highly productive Central City and Idaho Springs districts. It has a recorded yield of more than $3,675,000 worth of ore and has probably yielded more than $7,000,000 worth of ore, principally from silver-bearing galena-sphalerite veins in the western part of the district.

The district is underlain by Precambrian rocks, which are cut by small bodies of early Tertiary igneous rocks. The Precambrian rocks consist of a generally conformable succession of metamorphic gneiss intruded by igneous rocks, some of which are metamorphosed. The gneiss consists chiefly of fine- to medium-grained biotite gneiss and two types of quartzo-feldspathic gneiss—microcline-quartz-plagioclase-biotite gneiss and granite gneiss and pegmatite. Interlayered with these dominant types are amphibolite, calc-silicate gneiss, and quartz gneiss. Most of the gneiss is metamorphosed sedimentary rock; the granite gneiss and pegmatite, however, is possibly an anatectite or a metasomatic rock. The Precambrian igneous rocks show both concordant and discordant relations to the layered gneiss and, in order of apparent decreasing age, are granodiorite, quartz diorite gneiss and quartz diorite, and biotite-muscovite granite. They also include granite pegmatites of several ages.

The rocks of Tertiary age are prophyritic and occur as dikes, stocks, and partly concordant bodies. They belong to three petrographic groups, (1) hornblende granodiorite, (2) quartz monzonite, and (3) bostonite. The quartz monzonite group is represented by only one rock type in the district, but each of the other two groups is represented by four rock types. Within each of the quartz monzonite and bostonite groups, the younger members are generally more radioactive than the older.

Unconsolidated Quaternary deposits, mainly moraines, outwash, solifluction debris, and alluvium, mantle the bedrock surface in the stream valleys and on some gently rolling uplands and north-facing forested slopes. All but the alluvium are related to Pleistocene glaciation.

The Precambrian gneiss is bent into three large open folds which dominate the structure of the area. These folds trend north-northeast and, from west to east, are the Lawson syncline, the Dumont anticline, and the Bald Mountain syncline. Lineations, such as mineral alinements, drag folds, and boudins, are well formed in the gneiss. If grouped by direction of plunge, the lineations fall into four sets. The best formed set trends north-northeast and parallels

axes of the major folds of the district. A second set trends at about right angles to the major north-northeast-trending folds and, like the dominant set, is probably related to the deformation that formed the major folds. The other two sets trend east-northeast and north-northwest; they are best formed near Lawson where they parallel the axes of small folds superposed on the north-northeast-trending Lawson syncline, and thus they probably reflect a second period of Precambrian deformation.

All the rocks are jointed. Some conspicuous joint sets confined to the Precambrian rocks possibly are cross joints and longitudinal joints formed during the Precambrian folding.

The faults of the district were formed in Precambrian and in Laramide time. The largest faults, which are traceable for miles in and near the district, strike northwest and northeast. They probably belong to the "Breccia Reef" and closely related north-northeast fault groups of the Front Range. These faults probably formed in Precambrian time, after the second period of folding. Smaller faults generally traceable for distances of a few hundred feet to a mile probably formed during the Laramide orogeny. These smaller faults strike east, east-northeast, and west-northwest, and they contain most of the major veins of the district. Shorter poorly mineralized faults, which probably formed near the close of the early Tertiary vein formation, strike north to northeast and displace faults of other trends.

The ore deposits are in fissure veins which formed by a combination of open-space filling and replacement. Most of the veins are narrow; their sulfide-rich parts probably average less than 1 foot in thickness. The sulfide-bearing shoots rich enough to constitute ore are scattered sparsely along the veins and are localized along relatively open parts of irregular premineralization faults, at intersections of fractures, and also in more competent or in chemically favorable wallrock. Ore shoots are generally thicker than the average vein and extend to a maximum strike length of about 1,000 feet.

The ore deposits are dominantly gold- and silver-bearing base-metal sulfide deposits. Uranium ores have also been produced from one mine. The most common ore minerals, in their general paragenetic sequence, are pyrite, sphalerite, chalcopyrite, tennantite, and galena. Gold is dominantly in native form. Silver, partly in native form, occurs in argentite, freibergite, pearceite, and proustite, as well as in the crystal lattice of base-metal minerals. Quartz, carbonates, barite, and clay minerals form the gangue.

The productive veins can be classed according to mineralogy into three main types—pyrite, composite, and galena-sphalerite. Composite veins contain abundant pyrite and one or more base-metal minerals such as galena, sphalerite, chalcopyrite, or locally tennantite. The gold and silver content of the ores correlates with the vein type. Pyrite veins have been mined principally for gold but are generally low in grade. Composite veins are locally rich in gold and contain moderate amounts of silver. Galena-sphalerite veins are rich in silver but contain little gold.

Veins of the three types are distributed in a zonal pattern. Except for a small area northeast of Dumont, the southeastern part of the district contains pyrite veins; north and west of this area the pyrite veins give way to composite veins which in turn give way to galena-sphalerite veins. The zonal pattern of the district, together with that observed in nearby districts, shows that, in general, the pyrite veins occur in a central core surrounded by composite and galena-sphalerite veins.

The wallrock of all the veins is altered. The character of the alteration varies somewhat with vein type and rock type, but in general the veins are surrounded by an envelope of sericitized and silicified rock, which grades outward through argillized rocks into fresh rock.

Some ores were formed or enriched by supergene processes. Gold was generally residually enriched in oxidized parts of veins; silver was locally residually enriched but in other places was dissolved and redeposited below the water table. This redeposition formed rich supergene silver ores.

The ores were deposited late in the period of Laramide igneous and structural activity, probably by carbon dioxide- and sulfur-rich solutions carrying metals in complex ions. The zonal arrangement of the ores can be explained either by a change in the composition of vein-forming solutions at the source with time or by differentiation of the solutions in the vein system. Some of the uranium deposits may be minor variants of the sulfide mineralization; others, as for example those in the Jo Reynolds mine, probably formed during an early stage of mineralization, before the deposition of most sulfide minerals.

INTRODUCTION

The Lawson-Dumont-Fall River district, centered about 5 miles west-northwest of Idaho Springs, Colo., constitutes a small part of the Front Range mineral belt and is closely related geologically to the adjacent and better known Central City and Idaho Springs districts. The district has a recorded production of more than $3,675,000, and has probably produced ores valued at more than $7,000,000. The most productive deposits have been in argentiferous galena-sphalerite veins in the western part of the district near the town of Lawson. These deposits have yielded silver, lead, and zinc ores containing small amounts of gold and copper. Gold and copper ores have been produced chiefly from mines in the southeastern part of the district. Uranium occurs at several places scattered throughout the district, and a small amount of uranium ore has been produced from the Jo Reynolds mine. Some of the uranium deposits in the eastern part of the district are of special interest because of a marked wallrock control; the uranium minerals, chiefly hard and sooty pitchblende, occur in parts of veins in garnetiferous gneiss.

This report discusses the general geology and the ore deposits of the district. Descriptions and maps of more than 175 individual mines, prospects, and veins are contained in a separate report entitled "Mines and Prospects, Lawson-Dumont-Fall River District, Clear Creek County, Colorado," by C. C. Hawley and Frank Baker Moore, which has been released to open file. The following table indicates which mines are described and illustrated in the open-file report. Copies of part, or all, of the open-file report may be obtained at cost from the U.S. Geological Survey's Denver library, Denver Federal Center, Denver, Colo., 80225.

Mines, prospects, or veins

[Asterisk (*) indicates limited information]

Mine, prospect, or vein	Location by coordinate No.	Open-file report: Map figure No.	Open-file report: Description page No.
*Akron	B-III, 56		63
*Alabama	D-III, 10		87
Albro		30-31	64-68
Albro (lower west adit) (see Albro)	D-III, 14		
Albro (upper west adit) (see Albro)	D-III, 13		
Albro (Veta Grande) shaft (see Albro)	D-III, 15		
Albro (west shaft 1) (see Albro)	D-III, 11		
Albro (west shaft 2) (see Albro)	D-III, 12		
Albro crosscut (see Albro)	D-III, 16		
Alexander	C-II, 6		73
Alkire (Puzzler) tunnel (see Earl of Kent group)	D-III, 25		
Almaden		63	99-101
Almaden shaft (see Almaden)	E-II, 1		
*Alpha	B-II, 10		33
Amboy	A-III, 4	17	28-29
*American Eagle	C-IV, 3		98
American Sisters		19	34-37
American Sisters vein	B-IV, 8	19	34-37, 46-47
(American Sisters vein) Kauffman shaft (see American Sisters)	B-IV, 9	19	
*American-Standard	F-II, 13		
*Andrew Lowe	C-IV, 6		98
Angeline	D-I, 1	38	77-78
Annamosa tunnel (see Bellevue-Hudson)	A-IV, 2	20	
Arrowhead(?) vein (see Silent Friend)			
Aubrey vein		24	51, 55
*Aztec(?)	F-II, 9		115
*Bald Mountain(?)	F-1, 3		115
*Baltic	B-IV, 15		63
*Bedford	B-III, 31		33
Bellevue-Hudson		20	37-41
Bellevue-Rochester tunnel	A-III, 8	20	37-41
*Ben Harrison(?)	D-II, 8		
Berry	F-III, 7	66	106
*Big Dipper	D-III, 32		98
*Black	B-II, 11		33
*Black Extension 1 West	B-II, 5		33
Blazing Star (Lower Almaden) tunnel (see Almaden)	E-II, 3		
Blue Ridge and Senator		52	88-90
Blue Ridge vein (see Blue Ridge and Senator)	C-IV, 1		
*Blue Wing	B-III, 38		33
*Bonanza(?)	D-II, 11		87
*Boston adits	B-III, 40		33
*Boston shaft	B-III, 39		33
Boulder Nest-Free America vein		3, 8	10-13, 28-30
Boulder Nest shaft (Boulder Nest vein)	B-III, 2	3, 8	
*Brooklyn(?) shaft	F-II, 10		
*Burton tunnel	B-III, 53		
Bush Willis shaft (see Boulder Nest-Free America vein)	B-III, 1	3	
*Caledonia	E-III, 20		87
*California adit	E-III, 24		
California vein		31	68-70

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
Capitol shaft (Senator vein) (see Blue Ridge and Senator)	C–IV, 4		
*Cash			33
Central America (Tinker)	B–III, 5	5	21
*Channel(?)	E–IV, 5		
*Chicago Belle	C–II, 1	32	87
*(Cincinnati) Copenhagen	C–II, 5		73–74
Cleveland(?)	A–II, 2	9	20
*Clifford	E–1, 9		115
Climax (DeCaprivi vein) tunnel	B–III, 59	22, 26	46, 56–57
Columbian Chief	B–III, 61	24	51, 55
Columbine	D–II, 12	39	78
Commodore tunnel	B–III, 52	3, 8	17–18
Commonwealth	C–IV, 9	53, 56	91–92
Comstock crosscut (see Comstock vein)	B–III, 8	15	
(Comstock) Sutro tunnel (see Comstock vein)	C–III, 1	10, 15	
Comstock vein			21–22, 26–27
*Congress			63
*Copenhagen (Cincinnati)	C–II, 5		73–74
*Crescent City(?)	F–II, 11		
Cross vein (see Jo Reynolds)		22	
*Crows Nest and Mable H			63
Cuba tunnel	E–III, 5	40	78
Cymric tunnel	B–IV, 3		57
Daily tunnel (see Jo Reynolds)	B–IV, 14		
*Dead Jack and Chihuahua			63
(DeCaprivi vein) Climax tunnel	B–III, 59	22, 26	46, 56–57
Desbro or Horatio Parker	B–III, 34	5	13–15
Dexter		11	22–23
Dexter tunnel (see Dexter)	B–III, 22	11	
*Dictator	B–IV, 6		63
Doctor tunnel	A–III, 6	18	29–30
*Double Eagle	D–III, 5		
Drummond	B–III, 65	27	58
Dubuque	F–III, 9	67	106–107
*Dundee tunnel	D–III, 1		87
*Dunderberg(?)	B–II, 3		
*Eagle	F–II, 4		
Eagle vein	D–III, 8		78–79
Earl of Kent group		54	91
East Albro shaft (see Albro)	E–III, 14	31	
East Murray crosscut (see Murry vein)	B–III, 58		
East Murray vein			47–49
Eastern Syndicate (see Syndicate vein)	E–IV, 1		
Elida tunnel (Jo Reynolds mine)	B–III, 60	22	42–47
Elky(?)	D–III, 24	55	91–92
Ella(?)	F–III, 10	48	84
Elm City (Great Northern)	C–II, 2		74
Elmira tunnel	D–II, 2	32	
*Emmet(?)	B–III, 63		
*Equinox vein	D–III, 19	31, 46	69, 83
*Estrella(?)	C–III, 11		98
*Eureka	D–II, 16		87
*Europe(?)	D–II, 10		87
*Fairfield(?)	F–IV, 1		
*Fanny	E–II, 20		

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
Fault vein (see Silent Friend)			
Firemen and Conductors tunnel	E–II, 15	49	85
Flat Iron shaft (see Flat Iron vein)	B–III, 12		
Flat Iron tunnel (see Flat Iron vein)	B–III, 13	3	
Flat Iron vein			20
*4–C tunnel	C–III, 7		
*Fox			87
Franklin County vein		24	51, 55
*Franklin D	D–III, 23		98
*Frederick	B–III, 42		33
Free America Extension shaft (Free America vein)	B–III, 4	3	
Free America shaft (Free America vein)	B–III, 3	3	
*Freeland (McClelland) tunnel	D–III, 34		
Giesicke vein		20	37–41
(Gilpin and Clear Creek) Specht tunnel (see also Albro)	D–III, 22	31	68–70
Girard	B–III, 44		29
*Girt vein	B–III, 46		33
Golconda shaft (see Golconda tunnel)	E–II, 7		
Golconda tunnel	E–II, 6	64	101–104
Golconda vein (see Golconda tunnel)			
*Gold Belt(?) tunnel	A–IV, 1		
Gold Chloride	E–III, 2	42	80
Gold Chloride vein (Pioneer tunnel)		32	
*Gold Crown	F–I, 5		
*Gold Pot	D–II, 1		87
Gold Quartz (Ivan Gold)	E–I, 2	68	107–108
*Gold Queen	E–III, 6		
Golden Calf	D–III, 17	41	67, 79–80
*Golden Cycle	D–III, 7		87
Golden Eagle	E–III, 4	43	80–81
Golden Eagle(?) (lower) (see Golden Eagle)	E–II, 18		
Golden Hope	C–II, 7	35	74–75
*Golden Queen	C–III, 4		
*Good Luck(?)	E–II, 19		
*Grand Central	B–III, 35		33
*Gray Copper	F–II, 6		
*Great Britain	D–II, 3		
*Great East(?)	F–III, 5		
(Great Northern) Elm City	C–II, 2		74
*Great West(?)	F–111, 4		
*H. B. shaft	F–II, 1		
*Hamilton shaft (see Murry vein)	B–III, 57		
*Happy Thought	D–III, 2		75
Hecla vein (see Silent Friend)			
Heliotrope		44	81–82
Heliotrope tunnel (see Heliotrope)	E–III, 16		
Heliotrope vein (see Heliotrope)			
Hiawatha tunnel (see also Albro)	E–III, 25	31	68–70
*Highland Chief			63
*Highland Laddie	B–III, 20		33
*Highland Lassie	C–III, 5		33
*Homestake	B–III, 16		33
*Hopewell			68
Horatio Parker or Desbro	B–III, 34	5	13–15

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
*Howard(?) group	B–IV, 2		63
*Hugo			63
*Ingham (see also Gold Quartz)	E–I, 3		115
*Iowa(?)	C–II, 8		33
Iron Mask vein		32	
(Ivan Gold) Gold Quartz		68	107–108
(Jack Rabbit) Little Superior	C–III, 3	13	25
*Jay Eye See	B–III, 17		33
Jo Reynolds		21, 22, 26	41–47
(Jo Reynolds) Daily tunnel	B–IV, 14	21	
(Jo Reynolds) Elida tunnel	B–III, 60	21, 22, 26	42–47
Jo Reynolds 1 vein (see Jo Reynolds)		21	
Jo Reynolds 2 vein (see Jo Reynolds)	B–IV, 11	21, 22	
Jo Reynolds 3 vein (see Jo Reynolds)	B–IV, 13		
Jo Reynolds 4 vein (see Jo Reynolds)		19	
John D. Long vein		25	55–56
*Johnson group	B–II, 4		23
*Jumbo	F–I, 4		108
Kanawha vein	A–III, 3	18	29–30
Kauffman shaft (American Sisters vein) (see American Sisters)	B–IV, 9	19	
*Kaverne crosscut and Lee shaft	D–III, 9	45	82–83, 87
Kaverne shaft (see Milton vein)	D–III, 6		
Kaverne vein (see Milton vein)			
Keith			75–76
Keith shaft (see Keith)	C–II, 3		
Keith tunnel (see Keith)	C–II, 4		
Kohinoor			58
L. D. B. vein (see Magdalena)			
La Crosse Extension (see American Sisters)		19	
La Crosse tunnel (see American Sisters)		19	
La Crosse vein (see American Sisters)	B–IV, 7	19	
*La Munyon prospects	A–I, 1		33
Last Chance	B–III, 23	12	23–24
Do*	B–IV, 16		63
*Last Chance(?)	C–I, 1		
*Lee shaft and Kaverne crosscut	D–III, 9	45	82–83, 87
*Legal Tender	C–IV, 8	56	91–92
*Liberty			63
*Lincoln(?)	E–II, 10		
*Lincoln adit	B–III, 49		33
Do	B–III, 49		33
Lincoln tunnel (See also Albro)	D–III, 21	31	68–70
*Lincoln vein	B–III, 32		33
Little Giant	B–III, 15	3, 5	24–25
*Little Hatchet			87
Little Superior (Jack Rabbit)	C–III, 3	13	25
Logan vein (see Golconda tunnel)			
*Lorraway(?)	E–III, 13		
*Lost Treasure			63
(Lower Almaden) Blazing Star tunnel (see Almaden)	E–II, 3	63	
Lower Kent (see Earl of Kent group)	D–III, 28	54	
Lower West End(?) (see West End(?))	D–III, 3		
*Lucania tunnel	F–III, 8		
*Lucky Find	D–III, 30		

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
Lucky group (see Mary mine)			
*Lulu	A–III, 2		14, 33
*Lyons	E–II, 9		
*(McClelland) Freeland tunnel	D–III, 34		
*Mackay	E–III, 22		
Magdalena		69	108
Magdalena tunnel (see Magdalena)	F–II, 2		
*Maggie Burns and Hayes			63
*Mahany	E–I, 4		
Major C. and Little Colonel (see Heliotrope)	E–III, 18		
*Mammoth	E–III, 11		
Mandolina vein (see also Martha vein)	F–III, 2	70	109–110
*Maple Leaf	F–I, 1		115
Marshall and Russell tunnel	A–III, 7		30
Martha vein	F–III, 1		109–110
Mary (Philips)	E–II, 14	65	103, 105
*Mattie Jack tunnel	C–III, 9		92, 98
*Mauch Chunk			63
*Mayflower crosscut	B–III, 50		
Merry May vein		22, 26	56–57, 63
*Metallic	B–III, 66		63
Millington			59–60
Millington 1 (see Millington)	B–IV, 4		
Millington 2 (see Millington)	B–IV, 5		
Millington 3 (see Millington)	A–IV, 6		
Millington 4 (see Millington)	A–IV, 7		
*Millionaire(?) vein	F–II, 3		
Milton crosscut (see Milton vein)	E–III, 1		
Milton shaft (see Milton vein)	E–III, 3		
Milton vein		42	82–83
*Monarch	B–III, 64		
Monarch adit (upper) (see Syndicate vein)		62	
Monarch vein (see Syndicate vein)	E–IV, 2		
Monitor shaft (see Albro)	E–III, 15	31	
*Monster(?)	D–II, 13		87
Moore shaft (Jo Reynolds 2 vein) (see Jo Reynolds)	B–IV, 12	21	
Morning Star	C–III, 8	57	93
*Multum in Parvo			63
Murry (see Murry vein)	B–III, 55	24	
Murry vein		24	47–49
*N and H	D–II, 14		87
Nabob	B–IV, 18	23	48–49
*Nabob(?)	F–III, 3		
Native American shaft (see American Sisters)		19	
New (see Earl of Kent group)	D–III, 27		
*New England and Sunburst(?) mines	B–III, 43		30
*Night Hawk			63
*Nil Desperandum group			63
No. 4 vein (see Golconda tunnel)			
*Noran			63
*Ohio	C–IV, 7		98
Ohio Belle(?)	C–IV, 2	58	93
*Old Chief	E–III, 19		
*Oregon	E–IV, 3		

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
Orient	B-III, 25	11, 14, 16	25–26, 22–23, 27–28
Orvetta and Little Ruby (see Heliotrope)	E-III, 17	----------	----------
*Oshkosh	B-III, 45	18	33
*Ouija	C-III, 12	----------	----------
Panama group	----------	15	26–27
Panama No. 2 (see Panama group)	B-III, 18	15	----------
Panama No. 3(?) (see Panama group)	----------	15	----------
Panama (Teddy Bear) tunnel (see Panama group)	B-III, 19	15	----------
*Paragon(?)	D-II, 15	----------	----------
Peabody (Robineau) prospect	A-IV, 8	----------	59, 61
Pennsylvania tunnel	F-II, 12	71	110–111
Pennsylvania vein (see Pennsylvania tunnel)	----------	----------	----------
(Philips) Mary	E-II, 14	65	103, 105
Pioneer tunnel	D-II, 7	32	70–71
Platts adit	B-III, 62	25	51–56
Platts vein	----------	24, 25	51, 55–56
Polar Star	E-I, 5	72	111
*Prince Albert	A-IV, 4	----------	63
Princess of India group	----------	24	51–56
Princess of India tunnel	B-III, 54	24	51–55
*Pumpkin	B-III, 48	12	33
(Puzzler) Alkire tunnel (see Earl of Kent group)	D-III, 25	----------	----------
Puzzler shaft (see Earl of Kent group)	D-III, 26	----------	----------
*Puzzler vein	C-III, 2	----------	----------
*Range Line (see also Mattie Jack)	C-III, 10	----------	98
*Recompense(?)	E-II, 11	----------	----------
Red Elephant group	----------	3–8	9–20
*Rexall	D-II, 6	----------	----------
*Robat or Roeback(?)	B-III, 24	----------	33
(Robineau) Peabody	A-IV, 8	----------	59, 61
*Ruby	E-III, 26	----------	----------
Saginaw (see also Pennsylvania tunnel)	F-II, 8	73	111–112
St. James adit (see St. James vein)	B-III, 33	3, 6	----------
St. James discovery shaft (see St. James vein)	B-III, 36	3	----------
St. James shaft (see St. James vein)	B-III, 37	3	----------
St. James vein	----------	3, 6, 7, 8	15–16
*Sampson	F-II, 7	----------	----------
Schwarz shaft—6th-level adit (White vein) (see White vein)	B-III, 10	4	----------
Schwarz shaft (White vein) (see White vein)	B-III, 9	3, 4	----------
Senator tunnel (see Blue Ridge and Senator)	C-IV, 5	----------	----------
(Senator vein) Capitol shaft (see Blue Ridge and Senator)	C-IV, 4	52	----------
*Seven Forty	E-I, 1	----------	----------
*Shenandoah Valley	B-III, 14	----------	33
Silent Friend	----------	59	93–94
Silent Friend (lower adit) (see Silent Friend)	D-III, 31	----------	----------
Silent Friend (upper adit) (see Silent Friend)	D-IV, 1	----------	----------

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
*Silver Bell	B-II, 1		
*Silver Belt(?)	B-IV, 10		63
*Silver Coin		3	33
Silver King crosscut (see Silver King group)	E-III, 9	34	
Silver King Extension (see Silver King group)	E-III, 7		
Silver King group		33, 34	71-72
Silver King (lower) (see Silver King group)	E-III, 8		
Silver King (upper) (see Silver King group)	E-III, 10		
*Silver Nest	B-III, 41		
Silver Treasure vein	A-IV, 5		59
*Skidoo(?)	E-II, 16		
*Sound	E-III, 23		
*Sound(?) vein		31	69
Specht (Gilpin and Clear Creek) tunnel (see also Albro)	D-III, 22	31	68-70
Standard or No. 2 vein (see Standard tunnel)			
Standard tunnel	E-II, 5	74	112-113
*Startle	C-IV, 10	53	98
*Stella-Independence	D-III, 20		87
*Stem-Winder			63
*Stevens(?)	E-IV, 4		
*Stevens vein	B-III, 47		33
*Sub Treasury	E-II, 4		
*Summit	F-III, 6		
Sunburst and New England(?) (see New England and Sunburst(?) mines)	B-III, 43		
Sunshine	D-III, 18	46	83
*Surplus	B-III, 7		33
Sutro (Comstock) tunnel (see Comstock vein)	C-III, 1	10, 15	
Syndicate vein	D-IV, 2	60, 61, 62	94-97
Tabor shaft (see Tabor vein)	B-III, 29		
Tabor tunnel (see Tabor vein)	B-III, 30		
Tabor vein		3, 7-8	16-17
(Teddy Bear) Panama tunnel (see Panama group)	B-III, 19	15	
Tim Tarsney (see Eagle vein)	E-III, 12		
(Tinker) Central America	B-III, 5	5	21
Tom Moore	B-IV, 1	28	61
*Tomahawk	E-II, 12		
Torrey tunnel	F-III, 11	50	85
*Torrey 2	E-III, 21		
*Treasury	E-I, 7		
United tunnel	A-III, 5	17	30-31
*University	F-I, 2		
Upper Almaden adit (see Almaden)	E-II, 2		
Upper Bellevue (see Bellevue-Hudson)	A-IV, 3	20	
Upper Dexter adits (see Dexter)	B-III, 21	11	
Upper Kent (see Earl of Kent group)	D-III, 29		
Upper West End(?) (see West End(?))	D-III, 4		
*Venice	F-II, 5		

Mines, prospects, or veins—Continued

Mine, prospect, or vein	Location by coordinate No.	Open-file report	
		Map figure No.	Description page No.
(Veta Grande) Albro shaft (see also Albro)	D-III, 15	30, 31	
Virginia (see Golconda tunnel)	E-II, 8		
Virginia(?) vein (see Golconda tunnel)			
*Wall street	B-IV, 19		63
Washington tunnel	E-II, 13	75	114
*Washoe	A-III, 1		
Watt Stemble mine	B-IV, 17	29	61-62
West End(?)		47	83-84
West Golconda(?) shaft (see Golconda tunnel)	D-II, 4		
*Western(?)	E-I, 8		115
Western Syndicate (see Syndicate vein)	D-III, 33		
Wheeler shaft (White vein) (see White vein)	B-III, 11	3	
White vein		4, 5, 8	13-15
(White vein) Schwarz shaft (see White vein)	B-III, 9	3, 4	
(White vein) Schwarz shaft—6th level adit (see White vein)	B-III, 10	3, 4	
Wild Wagoner	D-II, 9		84
Wolverine	B-I, 1	36	76
*Yellow Jacket(?)	E-I, 6		
Young America adit (see Young America vein)	B-III, 26	12	
Young America crosscut (see Young America vein)	B-III, 51		
Young America shafts (see Young America vein)	B-III, 27	16	
Young America vein		12, 16	27-28
Young America West shafts (see Young America vein)	B-III, 28		
Unknown			
C4-3	A-II, 1	9	31
*C4-10	A-II, 3		33
*C5-14	B-II, 6		33
*C5-16	B-III, 6		33
*C5-21	B-II, 8		33
*C5-22	B-II, 9		33
*C5-24	B-II, 7		33
C6-45	B-II, 2	36	76-77
*G452	E-II, 17		
G454	D-II, 5	51	85-86
G643	D-II, 17	37	77

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GEOGRAPHY

The Lawson-Dumont-Fall River district in Clear Creek County, Colo., is part of an almost continuous mineralized area that includes the Idaho Springs and Central City districts to the east and the Freeland-Lamartine district to the south. It constitutes an area of about 15 square miles and includes all or part of several old mining districts, namely the Montana, Downieville, Morris, Spanish Bar, Fall River, and Lincoln. For descriptive purposes, the district is considered to be made up of three parts: the Lawson, Dumont, and Fall River areas (fig. 1).

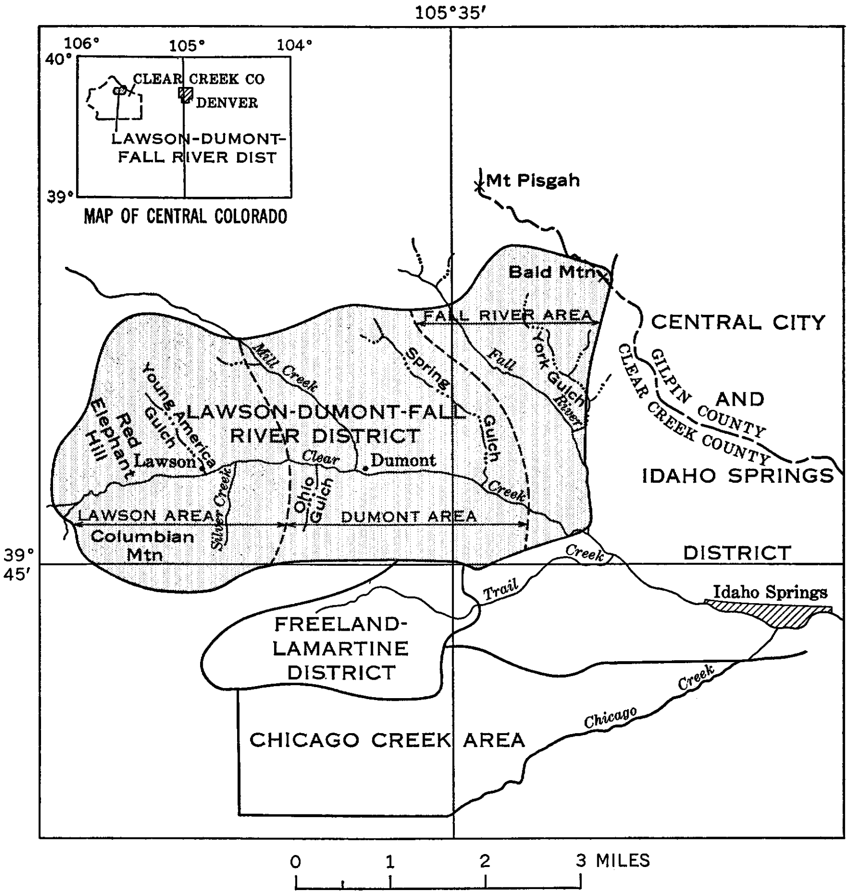

FIGURE 1.—The Lawson-Dumont-Fall River district and adjacent districts.

The district is accessible from U.S. Highway 6 and 40 which follows Clear Creek, a tributary of the South Platte River. Access to the Fall River area is furnished by a graded road that follows Fall

River and to part of the Dumont-Lawson area by a graded road that follows Mill Creek. The Jo Reynolds mine and nearby mines in the Lawson area are accessible from a road south of Lawson. Access roads also extend to some other mine areas, but parts of the district are now accessible only by foot trails.

The maximum topographic relief of the district is about 2,800 feet; the altitude ranges from 7,700 feet at the junction of Fall River and Clear Creek in the eastern part of the district to more than 10,500 feet on the high ridge south of Lawson in the western part (pl. 1). The valley walls along parts of Clear Creek and Fall River are steep, but the upland topography is rolling and the ridges are subdued. Rocks are poorly exposed in the north-facing forested slopes, but are well exposed in the generally barren south-facing slopes.

HISTORY AND PRODUCTION

Mining and settlement of the Lawson-Dumont-Fall River district began in 1859 when gold was discovered in placer deposits near the junction of Clear Creek and Fall River and in oxidized veins northeast of Dumont. Little information about early mining and production is available, but records show that gold was produced from the Albro (Burchard, 1883, p. 429) and nearby veins northeast of Dumont. Primitive methods were used in the earliest mining and milling. At first, ore from the veins near Dumont was sacked at the mines and crushed in five arrastres on Clear Creek a few hundred feet east of Dumont (E. B. Dingle, oral commun., 1963). Somewhat later, several stamp mills were operated in Dumont and, at one time, the crushers were so numerous that the village was known as Mill City. As the depth of mining increased and unoxidized ore was found, the arrastres and early-type stamp mills proved inadequate to free the gold from the rocks. Very likely the early history of the district paralleled that of Gilpin County, where mines began to shut down as early as 1861, and production remained low until the development of the Gilpin type of stamp mill and of a successful type of smelter in 1868 (Bastin and others in Bastin and Hill, 1917, p. 153–162).

The discovery of rich silver ore near Lawson in the late 1870's was the next important event in the history of the district. Silver quickly became the most important product of the district, and the one-time towns of Red Elephant north of Lawson and of Silver Creek south of Lawson were important mining centers. Some of the silver mines closed in the panic of 1893, but some, like the Jo Reynolds, remained open into the 1900's.

Mining in general has declined since 1900. The chief gold mine of the district, the Albro, was operated intermittently through 1937, and other gold mines, notably the Golconda, Pioneer, Syndicate, and California (vein), have produced small amounts of ore since 1900. Of the silver mines, the Jo Reynolds has had the largest and most continuous output, producing regularly from 1877 to 1929 and again from 1940 through 1949. The Almaden, American Sisters, Bellevue-Hudson, Commodore tunnel (Red Elephant mines), Millington, Murray, Nabob, Princess of India, Senator, and several small silver mines have produced ore intermittently since 1900. The 1901–52 production of some of the larger mines is summarized in table 1. More detailed production figures are included in the mine descriptions of Hawley and Moore (1967).

TABLE 1.—*Production from some of the larger mines in the Lawson-Dumont-Fall River district, 1901–52*

[Published with permission of U.S. Bureau of Mines. Some production data for the Bellevue-Hudson are from records of the Idaho Springs sampler and are published with permission of Mr. J. Price Briscoe]

Mine	Years	Ore (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
Albro	1907–37	4,097	3,473.62	26,419	201,854	17,538	4,174
Almaden	1904–34	1,064	201.98	45,041	1,359	48,338	7,507
American Sisters	1902–38	5,943	80.55	71,387	8,621	166,096	128,809
Bellevue-Hudson	1907–48	≈17,331	1,217.12	138,703	3,976	815,249	220,408
Blue Ridge and Senator	1907–27	>3,317	224.40	50,991	2,168	549,691	112,212
Commodore tunnel (Red Elephant group)	1907–48	6,098	56.80	58,753	5,979	527,033	116,643
Golconda tunnel	1902–12	271	433.6	3,604	6,201	----------	----------
Jo Reynolds	1902–49	36,330	467.61	397,061	13,515	1,234,557	921,273
Millington	1907–34	500	62.16	14,742	97	11,161	3,265
Murry vein	1901–36	186	102.09	11,190	1,727	14,661	2,067
Nabob	1949–52	3,545	147	79,974	18,573	286,314	----------
Pioneer tunnel	1908–11	753	168.12	585	41	11,500	10,111
Princess of India group	1910–37	2,094.5	153.04	40,888	7,088	236,163	107,820
Specht tunnel (California vein?)	1925–40	14,888	2,576	25,744	165,725	155,693	8,850
Standard tunnel	1903–39	>926	294.19	3,545	70	1,990	79
Syndicate	1902–37	>4,998	352.05	5,366	1,967	14,121	631

PREVIOUS GEOLOGIC WORK

Bastin and Hill (1917) mapped the district at a scale of 1:62,500 as part of their study of the Central City 15-minute quadrangle. They examined and briefly discussed most of the important mines of the district, and described in some detail the silver-bearing ores of the Lawson area. Their data were summarized and in part reinterpreted in a later report on the Front Range mineral belt by Lovering and Goddard (1950, p. 161–164). Reports on parts of the district by Smith and Baker (1951) and by Wells and Harrison (1954) gave the results of reconnaissance studies of uranium deposits, and a report by Harrison and Leonard (1952) described an area around the Jo Reynolds mine, former producer of small quantities of pitchblende.

PRESENT INVESTIGATION

The Lawson-Dumont-Fall River district was studied from 1952 to 1954 as a part of a comprehensive investigation of the mining districts in the central part of the Front Range mineral belt by the U.S. Geological Survey on behalf of the U.S. Atomic Energy Commission. These studies, under the supervision of P. K. Sims, consisted primarily of geologic mapping and economic studies of the ore deposits in the districts, but in addition included intensive investigations of the Tertiary igneous rock sequence (Wells, 1960) and of wallrock alteration (Tooker, 1963). Major reports that have resulted from the mapping in the mining districts include those by Harrison and Wells on the Freeland-Lamartine district (1956) and the Chicago Creek area (1959); reports by Sims, Armstrong, and others (1963) and Sims and Sheridan (1964) on the uranium deposits of the Front Range mineral belt; a report by Sims, Drake, and Tooker (1963) on the Central City district; and a report by Moench and Drake (1966) on the Idaho Springs district. The geologic map of the Central City quadrangle (Sims, 1964) shows the eastern part of the district in slightly generalized form.

The studies in the Lawson-Dumont-Fall River district consisted of geologic mapping at a scale of 1:6,000 and compilation at 1:12,000, and mapping of all accessible mines, mostly at a scale of 1:600. Moore mapped most of the Dumont area, the northern part of the Fall River area, and the southern part of the Lawson area during 1952, 1953, and 1954. Except for a small area near the mouth of the Fall River, mapped by R. S. Sears in 1952, Hawley mapped the remaining area in 1953 and 1954. The authors did most of the mine mapping, although a few mines were mapped by R. S. Sears and Max Shafer and a geologic map of part of the Mary mine was furnished us by A. G. Bird, formerly with the U.S. Atomic Energy Commission.

ACKNOWLEDGMENTS

We wish to thank Mel White, Frank Jones, Ed Rice, and the late P. P. Barbour and Henry deLinde for furnishing maps and other useful data on the mines, and J. Price Briscoe for furnishing records from the Idaho Springs sampler. Many other mine owners and former miners also furnished data on nearly forgotten or inaccessible mines; E. B. Dingle, formerly of Dumont, was particularly helpful. Mr. A. R. Baldo, superintendent of the Jo Reynolds mine during part of the period of investigation, helped in many ways, including the preparation of the plan map of the Elida tunnel level of the Jo Reynolds mine. The staffs of the Colorado School of Mines

Library and the Denver Public Library were most helpful in locating and making available unpublished reports from their files.

We were capably assisted in the field, at various times, by Peter Buseck, A E. Dearth, J. R. MacDonald, and Max Schafer.

Chemical and spectrographic analyses were made in the laboratories of the U.S. Geological Survey and are credited to individual analysts at appropriate places in the text. Dolores J. Gable assisted in petrographic studies and modal analysis of the Precambrian rocks.

GENERAL GEOLOGY

The bedrock of the Lawson-Dumont-Fall River district is composed dominantly of conformably interlayered gneissic rocks of Precambrian age (pl. 1). These rocks are intruded by igneous rocks, also of Precambrian age, in the form of small stocks and partly concordant bodies, particularly in the western part of the district. Both the igneous and metamorphic Precambrian rocks are intruded locally by igneous rocks of early Tertiary age, which occur as dikes, small stocks, and sill-like bodies. At places, especially in valleys and gently sloping or forested uplands, the bedrock surface is mantled by deposits of Quaternary age—chiefly alluvium, glacial outwash and moraines, and solifluction debris.

The gneiss and some of the Precambrian igneous rocks have been deformed by folding, and rocks of both Precambrian and Tertiary age have been faulted and jointed. Folds and small-scale lineations in the Precambrian rocks belong to four main sets and can be interpreted as having been formed in two episodes of deformation in Precambrian time. The major folds trend about north-northeast and are, from west to east, the Lawson syncline, Dumont anticline, and Bald Mountain syncline. These folds, together with lineations which parallel their axes, and west-northwest-trending small folds and related lineations formed plastically during the "older period" of deformation recognized by Moench, Harrison, and Sims (1962, p. 40–45). During a later tectonic episode, folds were formed whose trends were east-northeast and north-northwest. These folds and associated small-scale lineations are well formed only in the western part of the district where they are mainly superposed on the Lawson syncline. The east-northeast-trending folds resemble the folds of the "younger deformation" of Moench, Harrison, and Sims (1962, p. 45–55) in chevron and terracelike form, asymmetry, and in structural elevation of their northwest limbs; they differ in being dominantly plastic rather than dominantly cataclastic in origin. Following the folding, but still in Precambrian time, large northwest-trending faults of the breccia-reef type and a related set of north-northeast-trending faults formed (Tweto and Sims, 1963, p. 1001); they are probably represented in the district by continuations of the John L. Emerson-Gem vein system, the Apex fault, and the Idaho Springs fault. Most faults are probably Laramide in age; these younger faults contain most of the significant veins of the district.

PRECAMBRIAN ROCKS

The metamorphic rocks consist of a sequence of interlayered gneiss of various compositions belonging to the almandine amphibolite facies of Fyfe, Turner, and Verhoogen (1958, p. 228–232). These rocks were mapped by Bastin and Hill (1917) as Idaho Springs Formation and granite gneiss, but at the scale of the present map, it was possible to differentiate lithologic units within the Idaho Springs Formation as quartz gneiss, calc-silicate gneiss, amphibolite, and biotite-quartz-plagioclase gneiss (biotite gneiss), which locally can be even further subdivided. Similarly, the granite gneiss of Bastin and Hill has been subdivided into microcline-quartz-plagioclase-biotite gneiss (microcline gneiss) and quartz diorite gneiss. The gneissoid granite of Ball (in Spurr and Garrey, 1908, p. 49–51), the granite gneiss and gneissic aplite of Lovering and Goddard (1950, p. 25), and some pegmatites of earlier studies are about equivalent to the granite gneiss and pegmatite unit of this and related reports. Most of the metamorphic rocks are sedimentary in origin, although some are of uncertain origin.

The Precambrian igneous rocks are granodiorite, quartz diorite gneiss, quartz diorite, biotite-muscovite granite, and pegmatite. Except for the pegmatites, which are not all of the same age, the igneous rocks are named above in order of decreasing age. The rock mapped as granodiorite was largely mapped as Silver Plume Granite by Bastin and Hill (1917) and partly as Silver Plume and partly as Boulder Creek Granite by Lovering and Goddard (1950). It is presumed to be approximately equivalent to the Boulder Creek Granite of the Boulder Creek batholith. The biotite-muscovite granite is equivalent to the type Silver Plume Granite at Silver Plume, Colo.

The naming of metasedimentary rock units according to their principal minerals was started early by Ball (1906; in Spurr and Garrey, 1908) in his work on the Georgetown quadrangle and has been followed in all the modern work on the central Front Range. Lithologic names such as biotite-quartz-plagioclase gneiss indicate average mineralogic character, although individual specimens may depart considerably from the average of a particular rock unit.

Muscovite is not included in the mineralogic names because most of it is a product of retrograde metamorphism.

METAMORPHIC ROCKS

In mapping, the metamorphic rocks were divided into six main lithologic units, biotite gneiss, quartz gneiss, calc-silicate gneiss, amphibolite, microcline gneiss, and granite gneiss and pegmatite. The biotite gneiss and microcline gneiss units predominate. They are interlayered on a large scale and form the upper three units of the lithologic sequence recognized by Moench, Harrison, and Sims (1962, p. 39) in the central part of the Front Range mineral belt. In this sequence, a thick layer of microcline gneiss, called by those authors the Central City layer but now called the Quartz Hill layer, is overlain by a thick layer of biotite gneiss, which in turn is overlain by the Lawson layer of microcline gneiss (Moench and others, 1962, pl. 1, 2; this report, pl. 1, section *A–A′*).

BIOTITE GNEISS

Biotite-quartz-plagioclase gneiss, biotite-quartz gneiss, and sillimanitic and garnetiferous varieties of these are collectively referred to as biotite gneiss. These gneiss units and variants of each are in layers that generally range in thickness from a few inches to 5 or 6 feet but locally they are in layers large enough to map.

The biotite gneiss unit underlies most of the eastern part of the Lawson-Dumont-Fall River district and is widely exposed in the western part. It is approximately equivalent to the combined biotite-sillimanite schist and biotite schist "members" of the Idaho Springs Formation as described by Ball (in Spurr and Garrey, 1908, p. 38–41). It is lithologically similar to the rocks near Central City that were classed as biotite gneiss by Sims, Draker, and Tooker (1963) and also to the combined biotite-quartz-plagioclase gneiss and sillimanitic biotite-quartz gneiss of Harrison and Wells (1959) in the Chicago Creek area.

The biotite gneiss ranges from fine to medium grained and from light to dark gray, and has poor to good fissility. The biotite-quartz-plagioclase gneiss is a uniformly fine grained granular light-gray rock which on close inspection has a characteristic salt-and-pepper appearance; it is massive and has poor fissility but has a marked planar arrangement of fine biotite flakes. The garnetiferous biotite gneiss is similar in grain size, color, and fissility but contains scattered garnets about 2 millimeters in diameter. Hornblende-biotite gneiss is also similar but is darker in color. Biotite-quartz gneiss and sillimanitic biotite-quartz gneiss are coarser grained and darker than the biotite-quartz-plagioclase gneiss and, because of the greater abundance and coarser size of biotite flakes, they are also more fissile. Sillimanite can generally be distinguished megascopically as almost white elongate aggregates of crystals which give the rocks a mottled appearance. As seen microscopically, the sillimanite crystals average about 10 mm in length.

In many places, the abundance of accompanying granitic material and the mode of deformation are clues to the composition of biotite gneiss. Granitic material is commonly more abundant in the more fissile biotite-quartz gneiss than it is in the biotite-quartz-plagioclase variety. Similarly, the sillimanitic gneiss is less competent than the more massive biotite-quartz-plagioclase gneiss and in places is complexly folded whereas adjacent layers of the plagioclase-bearing gneiss are in simple folds.

Microscopically the biotite-quartz-plagioclase gneiss is seen to consist principally of quartz and plagioclase but also to contain about 20 percent biotite, as much as 5 percent potassic feldspar, and small amounts of opaque oxides, muscovite, and zircon (table 2). A chemical analysis of a quartz-rich biotite-quartz-plagioclase gneiss (modal analysis, A1–27A–55, table 2) is given in table 3. (Modal composition of rocks reported in this paper were determined by point counts of single standard-sized thin sections. On most sections, 500–1,000 points were counted; on some small sections, or in sections of less abundant rock types such as quartz gneiss, as few as 200 points were counted; modes reported by Dolores J. Gable were based upon 800–1,000 counts.)

TABLE 2.—*Modes, volume percent, of biotite-quartz-plagioclase gneiss, sillimanitic biotite-quartz gneiss, and garnetiferous biotite gneiss*

Field sample	A1-27A-55	C9-103	E7D-6	C7-32a	E4-57	A7-8b	D5-3-53
Quartz	43	37	38	48	30	44	30
Plagioclase	35	39	37	Tr.	16.5	15	17
Potassic feldspar	Tr.	3	5	Tr.	.5	0	2
Biotite	20	19	20	41	24	29	35
Muscovite	1	1	Tr.	1	21.5	1	Tr.
Sillimanite	0	Tr.	0	10	6.5	8	0
Opaque oxides	1	1	Tr.	Tr.	1	3	Tr.
Garnet	Tr.	0	0	0	0	0	14
Chlorite	0	0	0	0	0	0	2
Apatite	Tr.	0	Tr.	0	Tr.	0	0
Sphene	0	0	0	0	0	0	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	0	0	Tr.

Biotite-quartz-plagioclase gneiss:
A1-27A-55. Blazing Star tunnel, about 3 miles above mouth of Fall River.
C9-103. Half a mile west of Lawson, north of Clear Creek.
E7D-6. About 1,500 ft ESE. of the mouth of Spring Gulch.
Sillimanitic biotite-quartz gneiss:
C7-32a About 3,000 ft NE. of Lawson.
E4-57. North side of Fall River, about 1,000 ft W. of Bald Mountain syncline.
A7-8b. North side of Fall River; about 1,000 ft N. of the district.
Garnetiferous biotite gneiss:
D5-3-53. West of East Albro shaft, about 3,500 ft. ENE. of Dumont.

TABLE 3.—*Chemical analysis of biotite-quartz-plagioclase gneiss, Almaden mine*

[Rapid rock analysis by H. F. Phillip, P. L. D. Elmore, P. W. Scott, and K. E. White. Field sample A1-27B-55; lab. analysis 140575]

SiO_2	72.0	TiO_2	.58
Al_2O_3	11.9	P_2O_5	.15
Fe_2O_3	1.9	MnO	.12
FeO	3.2	H_2O	1.0
MgO	1.5	CO_2	.64
CaO	1.7		
Na_2O	2.6	Total	99
K_2O	2.2		
		S as S	.25

QUARTZ GNEISS

Quartz gneiss is a mappable unit only in the northeastern part of the district, south of Bald Mountain, where it occurs as a lenticular body between biotite gneiss and quartz diorite gneiss; elsewhere it forms local thin layers in biotite gneiss.

The quartz gneiss is fine grained and poorly foliated; it is generally gray and lighter in color than the biotite gneiss. Locally it has a green cast due to the presence of epidote. The mineralogic composition of three specimens of quartz gneiss is given in table 4. The rock is called quartz gneiss rather than quartzite because of its relative impurity. Some of it is intermediate in composition between quartzite and biotite-quartz-plagioclase gneiss (sample E4–27, table 4), and some is approximately intermediate between quartzite and calc-silicate gneiss (sample C7–41, table 4).

TABLE 4.—*Modes, volume percent, of quartz gneiss*

Field sample	C7–41	E2–41	E4–27
Quartz	75.3	59	61
Potassic feldspar	0	2	0
Plagioclase	3.5	30	[1] 16
Biotite	0	6	17
Garnet	0	0	1
Epidote	18	0	0
Amphibole	2.5	0	0
Muscovite	.5	0	0
Sphene	1	0	0
Apatite	1	0	0
Opaque oxides	0	3	5

[1] Altered feldspar; inferred to be plagioclase.
C7–41. Epidote bearing; about 1,000 ft NW. of Downieville.
E2–41. Layer at contact of biotite gneiss and quartz diorite gneiss, 1,500 ft W. of Magdalena tunnel, south of Bald Mountain.
E4–27. Pennsylvania tunnel about 7,000 ft above the mouth of Fall River.

CALC-SILICATE GNEISS

Layers and lenses of calc-silicate gneiss and closely related garnetiferous gneiss are interlayered with biotite gneiss at several places. One lens of epidote-bearing gneiss is well exposed in a roadcut west of Spring Gulch on U.S. Highway 6 and 40, and thin layers of calc-silicate gneiss are exposed in Fall River northwest of the Pennsylvania tunnel. Thin layers (not mapped) of garnetiferous gneiss occur in biotite gneiss northeast of Dumont, and layers of the same rock as much as 90 feet thick are exposed underground in the Golconda, Mary, and Almaden mines in Fall River. The garnetiferous gneiss of the Fall River area forms the walls of uranium-bearing parts of veins.

Three main mineralogic varieties of calc-silicate gneiss were recognized. One variety is composed principally of quartz, garnet, hornblende, and magnetite and is here called garnetiferous gneiss; a second type is characterized by abundant epidote or garnet but is poor in magnetite; a third type is characterized by hornblende and, locally, by diopside. Similar rocks were included by Ball (in Spurr and Garrey, 1908, p. 41–43) in the lime-silicate member of the Idaho Springs Formation in the Georgetown quadrangle. The garnetiferous gneiss is approximately equivalent to the quartz-magnetite gneiss of Ball, although it contains only half as much magnetite as the rock in the Georgetown quadrangle. The epidote-rich calc-silicate gneiss of the district probably corresponds generally to the quartz-epidote-garnet gneiss of Ball and the hornblende gneiss to his hornblende-diopside gneiss. The garnetiferous gneiss, or the quartz-magnetite gneiss of Ball, might be referred to as skarn by some authors, but the term "skarn" generally implies metasomatic addition of iron, and we believe (p. 27) that these rocks formed by the nearly isochemical metamorphism of originally ferruginous rocks, possibly with loss of carbon dioxide as the only major chemical change involved. Harrison and Wells (1959, p. 8) and Sims, Drake, and Tooker (1963, p. 14) also included the iron-rich rocks in the calc-silicate group.

The garnetiferous gneiss, exposed in several mines in the Fall River area and in garnetiferous biotite gneiss near Dumont, typically is a dark-red or red and white layered rock, but locally where it contains abundant hornblende it is almost black. Feldspar is sparse if present at all in the gneiss, which is composed principally of garnet, quartz, and hornblende and subordinately of biotite and magnetite (table 5). Pyrite, which replaces magnetite, is abundant near the veins; if all the pyrite in the rock is assumed to represent former magnetite, the original magnetite content averaged about 10 percent. Chemical analyses of two samples of garnetiferous gneiss from the Golconda mine confirm the high iron and low alkali content deduced from the modes; the analyses also show several percent each of CaO, MgO, and MnO (table 6).

TABLE 5.—*Modes, volume percent, of garnetiferous gneiss and calc-silicate gneiss*

Field sample	Al-7A-55	Go-51A-55	Go-51B-55	Go-28B-55	D9D-3A	D9D-3B
Quartz	41	37	20	43	35.5	18
Potassic feldspar	0	0	0	0	19.5	0
Plagioclase	0	0	0	0	11	15
Biotite	5	11	7.5	0	0	19
Hornblende	10.5	11	28.5	13	11	44
Garnet	30.5	32	30	36	0	0
Epidote	0	0	0	0	22	.5
Magnetite	11	8	12	4	0	Tr.
Apatite	1	.5	2	0	Tr.	.5
Sphene	Tr.	Tr.	Tr.	Tr.	1	3
Pyrite	1	.5	0	4	0	0

Gartnetiferous gneiss:
Al-7A-55. Blazing Star vein, upper tunnel Almaden mine; Fall River area.
Go-51A-55. Golconda tunnel, 22 ft SW. of Virginia(?) vein; Fall River area.
Go-51B-55. Same area as above.
Go-28B-55. Golconda tunnel, 38 ft SW. of Virginia(?) vein; Fall River area.
Calc-silicate gneiss:
D9D-3A. Epidote bearing; U.S. Highway 6 and 40, 400 ft W. of Spring Gulch, Dumont area.
D9D-3B. Hornblendic; U.S. Highway 6 and 40, same area as above.

TABLE 6.—*Chemical analyses of garnetiferous gneiss*

[Rapid rock analyses by H. F. Phillip, P. L. D. Elmore, P. W. Scott, and K. E. White]

Field sample Laboratory analysis	Go-51A-55 140577	Go-51B-55 140578
SiO_2	52.4	51.4
Al_2O_3	8.2	9.4
Fe_2O_3	11.7	10.9
FeO	13.9	15.0
MgO	2.8	3.8
CaO	5.4	3.0
Na_2O	.10	.09
K_2O	.49	1.8
TiO	.32	.52
P_2O_5	.70	.59
MnO	3.5	3.2
H_2O	.74	.87
CO_2	.25	.13
Total	101	101
S as S	1.2	.94

Go-51A-55. Golconda tunnel, 22 ft SW. of Virginia(?) vein; Fall River area.
Go-51B-55. Same as 51A.

Modal analyses (table 5) and chemical analyses (table 6) of garnetiferous gneiss indicate that the garnet is mainly almandite-spessartite in composition. The garnet has an index of refraction of 1.807 and a cell edge of 11.58 A, properties consistent with the composition deduced above. Almandite-spessartite garnet has also been found by Harrison and Wells (1959, p. 8–9) in a similar quartz-garnet-magnetite rock in the Chicago Creek area and by D. M. Sheridan (oral commun., 1964) in garnetiferous biotite gneiss of the Ralston Buttes quadrangle. Harrison and Wells (1959) determined that a garnet from a quartz-epidote-pyroxene-garnet rock was about half grossularite and half andradite.

The bulk composition of garnetiferous gneiss (table 6) resembles that of some Precambrian iron-formation from other regions, although it contains less iron and more alumina and manganese oxide than do some iron-formatons. According to Gruner (1946, p. 65), the average Biwabik Iron-Formation in the Mesabi Range is as follows:

	Percent (approximate)		*Percent (approximate)*
SiO_2	51.0	CaO	1.1
Al_2O_3	1.0	CO_2	5.0
Fe_2O_3	38.6	P	.035
MgO	2.8	Combined H_2O	2.2

Lower grade beds from the slaty units of the Biwabik Iron-Formation are more similar to the garnetiferous gneiss in composition. Gruner (1946, table 9) gives the composition of the slaty units as:

	Percent		*Percent*
SiO_2	49.04	CaO	2.08
Al_2O_3	6.19	CO_2	.53
Fe_2O_3	30.73	C (organic)	3.20
MgO	4.21	S	3.17

The mineralogy of the quartz-magnetite gneiss described by Ball indicates that it more closely approximates typical iron-formation in composition than the garnetiferous gneiss does.

The epidote- or hornblende-rich calc-silicate gneiss, which occurs separately from thick layers of garnetiferous gneiss is a conspicuously layered rocks which range in color from almost black in the hornblende-rich varieties to green in those rich in epidote. Local garnetiferous layers are pale brown. Unlike the magnetite-bearing gneiss, these rocks contain plagioclase and locally potassic feldspar (table 5), but the plagioclase is not as abundant as in the amphibolite; paucity of plagioclase and abundance of quartz distinguish the hornblendic calc-silicate gneiss from amphibolite.

AMPHIBOLITE

Amphibolite is commonly associated with the microcline gneiss and, accordingly, is found most abundantly in the Lawson area and in the southeastern part of the Fall River area. It forms layers and lenses that are conformable with the foliation of the associated gneiss and that range in thickness from a few inches to about 100 feet. Most of the layers are too thin to be mapped at a scale of

1:6,000, but mappable layers are exposed north of Lawson at and near the lower contact of the Lawson layer of microcline gneiss. Much of the amphobolite is lithologically like the hornblende schist and gneiss mapped by Bastin and Hill (1917) and the Swandyke Hornblende Gneiss mapped by Lovering and Goddard (1950).

Amphibolite is a greenish-black to black-and-white poorly foliated rock, less well layered than hornblende-rich calc-silicate gneiss. It is composed principally of hornblende and plagioclase but contains 1–16 percent quartz and locally contains clinopyroxene and biotite (table 7).

TABLE 7.—*Modes, volume percent, of amphibolite*

Field sample	C5–10	C10–52B	C6–35	C7–26	G–640	E7–107
Plagioclase	33	54	47	28	31	30
Hornblende	41	31	44	60	52	56
Clinopyroxene	6	0	8	0	8	0
Quartz	16	6	1	8	5	8
Biotite	0	9	0	1	0	3
Chlorite	1	0	0	0	0	0
Sphene	0	0	0	.5	Tr.	Tr.
Opaque oxides	1	Tr.	0	2	4	2
Apatite	1	Tr.	Tr.	.5	Tr.	1
Zircon	1	Tr.	0	0	0	Tr.

C5–10. Lens at contact of microcline gneiss and biotite gneiss, about 1 mile NNW. of Lawson.
C10–52B. North side of roadcut, about 400 ft W. of junction of U.S. Highways 6 and 40, Lawson area.
C6–35. Layer in microcline gneiss near head of Black Gulch, Lawson area.
C7–26. Layer at contact of microcline gneiss and biotite gneiss; 1,500 ft NW. of Downieville.
G–640. 2,000 ft NW. of Dumont.
E7–107. Layer in microcline gneiss in outcrop on U.S. Highway 6 and 40, 1,400 ft W. of the mouth of Fall River.

MICROCLINE GNEISS

The microcline gneiss (microcline - quartz - plagioclase - biotite gneiss) underlies most of the northern part of the Lawson area and a large part of the lower Fall River area. It occurs mainly in two thick layers conformably interlayered with biotite gneiss. The Lawson layer, exposed in the western part of the district, is at least 2,500 feet thick. The Quartz Hill layer (Central City layer of Moench and others, 1962, p. 38–39) has a maximum thickness of about 3,000 feet of which approximately the upper 1,000 feet is exposed along Fall River.

The gneiss typically is a leucocratic well-foliated rock of the type commonly called granite gneiss or quartzo-feldspathic gneiss. It is approximately equivalent to the granite gneiss of Bastin and Hill (1917, p. 30–32) and to the rocks mapped as quartz monzonite gneiss by Lovering and Goddard (1950) and Harrison and Wells (1959). The change in name from quartz monzonite gneiss to a nongenetic mineralogic name reflects the present uncertainty as to the origin of the unit. Most of the early workers regarded the gneiss as a metamorphosed igneous rock; Moench, Harrison, and Sims (1962) classed it as a metasedimentary rock.

The microcline gneiss is a medium-grained granoblastic finely layered rock; thin quartz-feldspar-rich layers alternate with thin biotite- or hornblende-rich layers. The gneiss is pink to gray on fresh surfaces and weathers tan or gray. In most places it is darker and more strongly foliated than that of the granite gneiss and pegmatite unit but lighter and somewhat coarser grained than the biotite gneiss. Microcline gneiss contains thin layers of amphibolite, pegmatite, and less gneissic granite, and locally the amphibolite and pegmatite layers are thick enough to be mapped. Thin amphibolite layers have been boudined, particularly in the Lawson area, and the intervening spaces are filled with granitic rock which is less well foliated than the gneiss, but which otherwise resembles it.

The microcline gneiss varies widely in composition (table 8); that in the Lawson-Dumont-Fall River district has, on the average, the composition of a granodiorite, whereas in the adjacent Idaho Springs district the average composition is that of a quartz monzonite. Plagioclase (andesine) and quartz are the major components and average about 42 and 37 percent, respectively; potassic feldspar (mainly microcline-perthite) averages about 15 percent but in some varieties constitutes only a trace. Biotite or chlorite generally greatly exceeds hornblende, but hornblende is relatively abundant in areas where interlayered amphibolite is abundant and in certain local areas (sample C6–7b, table 8).

GRANITE GNEISS AND PEGMATITE

The granite gneiss and pegmatite unit is widely distributed south of Clear Creek and in the Dumont and Fall River areas north of the creek. It occurs in generally conformable layers and lenses that range in thickness from an inch or less to several hundred feet in thickness; these layers are intercalated with other gneissic units, but particularly with biotite gneiss. Thin layers of granite gneiss and pegmatite are present everywhere in the more micaceous varieties of biotite gneiss, and, with increasing abundance of granitic material, the biotite gneiss grades through migmatite to granite gneiss and pegmatite which contain only thin wisps of biotitic material. Foliation in the granite gneiss and pegmatite is due either to thin biotite- or quartz-rich layers but is less pronounced than in most of the other gneiss.

The granite gneiss and pegmatite is a leucocratic medium- to coarse-grained equigranular to pegmatitic rock. As may be inferred from its name, it varies widely in composition and texture. Much of it is an alaskitic granite in composition and is composed mainly

TABLE 8.—*Modes, volume percent, of microcline gneiss*

[Modes of C7-1, FM-3-52, G-247b, E7-142F determined by Dolores Gable]

Field sample	C6-35	C6-19b	C6-23	C6-1	C6-7b	C7-1	C7-3	FM-3-52	G-247b	31-13	C-7-62	E7-142F	Average
Potassic feldspar (dominantly microcline-perthite)	43	1	6	13	Tr.	12	12	25	20	8	29	9	15
Plagioclase	28	53	47	39	45	42.5	36	37	48	48	25	54	42
Anorthite content	----------	44-47	36-40	36-38	----------	----------	----------	----------	----------	----------	32-37	----------	----------
Quartz	24	40.5	44	44	52	39	39	37	22	33	34	33	37
Biotite or chlorite	2.5	3	1	2	1.5	3	10	Tr.	5	11	9.5	1	4
Muscovite	2.5	0	.5	0	0	2	1	1	Tr.	0	0	1	} 1
Hornblende	0	2.5	Tr.	.5	1	0	0	0	Tr.	0	0	0	}
Opaque oxides	0	Tr.	1.5	1.5	.5	1.5	2	Tr.	Tr.	0	2	2	1
Sphene	0	0	0	0	Tr.	0	Tr.	Tr.	3	0	.5	0	Tr.
Apatite	0	0	0	0	Tr.	Tr.	Tr.	0	0	Tr.	Tr.	Tr.	Tr.
Epidote	0	0	0	0	0	0	0	0	2	0	Tr.	Tr.	Tr.
Garnet	0	0	0	0	0	Tr.	0	Tr.	0	0	0	0	Tr.
Zircon	0	0	0	0	0	0	0	0	0	0	0	Tr.	Tr.

C6-35. Adjacent to amphibolite layer, near head of Black Gulch, Lawson area.
C6-19b. 2,000 ft N. of Downieville, Lawson area.
C6-23. About 2,500 ft N. of Downieville, Lawson area.
C6-1. About 9,000 ft above the mouth of Mill Creek, Lawson area.
C6-7b. Hornblende bearing, quartz diorite in composition; about 2 miles above the mouth of Mill Creek, Lawson area.
C7-1. Sutro or Comstock crosscut, about 3,000 ft NE. of Lawson.
C7-3. Caved shaft on Comstock vein, Lawson area.
FM-3-52. Mouth of Fall River.
G-247b. Small outcrop (not mapped), about 2,500 ft N. of the mouth of Spring Gulch.
31-13. Road cut, U.S. Highway 6 and 40, 1,200 ft W. of mouth of Fall River.
C-7-62. 1,000 ft NW. of the mouth of Fall River.
E7-142F. About 2,500 ft above the mouth of Fall River, west side of gulch.

of quartz, potassic feldspar (microcline or a nontwinned type), and generally subordinate plagioclase (oligoclase or andesine); mafic minerals (biotite or opaque oxides) generally comprise less than 2 percent of the rock (table 9).

TABLE 9.—*Modes, volume percent, of the granite gneiss and pegmatite*

Field sample	E2-103	E7-161	C7-43	C-7-55	G-70	G-271	G-465
Quartz	46	32	40.5	8	29	29	26
Potassic feldspar:							
Microcline	28	-------	51.5	51	68	------	69
Nontwinned	------	55	-------	-------	------	70	------
Plagioclase	18	12	6	40	2	0	3
Anorthite content	------	26–29	24–26	38–40	------	------	------
Biotite	1	Tr.	0	Tr.	0	0	0
Muscovite	7	1	2	1	Tr.	1	2
Opaque oxides	Tr.	Tr.	0	Tr.	1	Tr.	0
Epidote	Tr.	0	0	0	0	0	0
Sphene	Tr.	0	0	0	0	0	0
Zircon	0	0	0	Tr.	0	0	0

E2-103. Thin layer in biotite gneiss, York Gulch, Fall River area.
E7-161. Thin layer in microcline gneiss, about 4,000 ft N. of the mouth of Fall River, west side of valley.
C7-43. Thin layer in biotite gneiss, about 1,000 ft NW. of Downieville.
C7-55. Layer in quartz diorite gneiss, 3,000 ft NE. of Lawson.
G-70. Large body, about 3,000 ft NE. of Dumont and 300 ft ESE. of Eagle shaft.
G-271. Large body, north side of Spring Gulch about 400 ft SE. of Golconda shaft.
G-465. Large body near head of Spring Gulch.

ORIGIN OF THE METAMORPHIC ROCKS

The complex interlayering, together with the chemical and mineralogic composition, indicates that the quartz gneiss, calc-silicate gneiss, and biotite gneiss were formed by the metamorphism of sedimentary rocks. With the possible exceptions of highly migmatized biotite gneiss and some calc-silicate gneiss, these rocks show little evidence of metasomatism, and their metamorphism was probably nearly isochemical. The alternating layers of biotite-quartz-plagioclase gneiss and biotite-quartz gneiss which compose most of the biotite gneiss unit could have formed from alternating beds of, respectively, feldspathic sandstone and argillaceous siltstone. Similarly the quartz gneiss probably formed from impure quartz sandstone, and the amphibolitic or epidote-bearing calc-silicate gneiss from impure limestone with loss of carbon dioxide. The garnetiferous gneiss contains about 25 percent total iron oxides (table 6) and therefore resembles lean Precambrian iron-formations in composition. Assuming nearly isochemical conditions except for possible loss of carbon dioxide, the garnetiferous gneiss could have formed from a ferruginous carbonate or a ferruginous silicate sediment, either of which was somewhat more aluminous than typical Precambrian iron-formation.

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Somewhat less certainly, the microcline gneiss is classed as metasedimentary. Compositionally, it could be either igneous or sedimentary and, if igneous, intrusive or extrusive, but its continuity and conformable relations to undoubted metasedimentary rocks suggest a sedimentary parent, perhaps a feldspathic sandstone. Even here an igneous origin cannot be ruled out, for Buddington (1959, p. 715) has pointed out that the conformable sheet type of intrusive is a characteristic form for igneous rocks formed under deep conditions. In the past, Bastin and Hill (1917) and Lovering and Goddard (1950) classed it and similar rocks as igneous. More recently, Moench, Harrison, and Sims (1962) classed it as a metasedimentary rock because of its structure and lithology.

Origin of the amphibolite units is even less certain than that of the microcline gneiss. Within the district, amphibolite units have been observed only as conformable bodies, locally boudined and ranging in thickness from a few inches to about 100 feet. The bodies are interlayered with other gneissic rocks, particularly the microcline gneiss, and seem logically interpreted as metamorphosed sedimentary layers Tweto (1947, p. 47–65) proposed such an origin for similar amphibolitic rocks in the western part of the Front Range. He regarded these rocks as metamorphosed dolomite or calcareous shale. However, discordant relations consistent with the igneous origin proposed by Lovering and Goddard (1950, p. 20) have been found in places in nearby areas. In the Georgetown quadrangle, Ball (in Spurr and Garrey, 1908, p. 45) found both discordant and concordant relations of hornblende gneiss that presumably correspond with our amphibolite; near Black Hawk, R. B. Taylor (oral commun., 1962) found discordant amphibolite dikes which apparently act as feeders to conformable amphbolite interlayered with microcline gneiss. Quite possibly, both igneous and sedimentary source rocks are represented among the amphibolite units.

As indicated by its composition, the granite gneiss and pegmatite unit is of mixed origin, most likely a combination of ultrametamorphic and igneous. Its association predominantly with the interlayered biotite gneiss units as conformable bodies, and its gradational relations with the biotite gneiss seem to be more consistent with ultrametamorphic local derivation by anatexis than with igneous injection. Thin nondeformed wisps of remnant biotite gneiss in the unit also suggest either metasomatism or anatexis rather than igneous injection. Sparsity of mafic rocks associated with the larger bodies of granite gneiss and pegmatite is, however, a criterion against a strictly metasomatic origin because of the amounts of iron, magnesium, and calcium that would have been expelled from the biotitic gneiss in order to transform it into alaskitic granitic rocks, and the granite gneiss and pegmatite unit is tentatively regarded as an anatectite.

IGNEOUS ROCKS

Precambrian igneous rocks classed as granodiorite, quartz diorite gneiss, quartz diorite, and biotite-muscovite granite occur in phacoliths and partly discordant bodies in the thick sequence of interlayered conformable gneiss.

The granodiorite, quartz diorite gneiss, and quartz diorite are probably approximately equivalent to the rocks comprising the Boulder Creek batholith of Lovering and Goddard. Their variations in composition and structure—granodiorite versus quartz diorite—and in gneissosity are due to small differences in manner of occurrence and age. The biotite-muscovite granite correlates with the Silver Plume Granite.

Contacts of the Precambrian igneous rocks with the older gneiss are sharp, and the contact zones show little evidence either of granitization of the gneiss or of contamination of the igneous magmas.

The oldest igneous rocks, those correlated with the Boulder Creek Granite, are locally metamorphosed and were emplaced syntectonically with north-northeast plastic folding. The Silver Plume correlatve, biotite-muscovite granite, is cataclastically deformed in nearby areas and is at least partly older than the "younger deformation" of Moench, Harrison, and Sims (1962, p. 45–56).

GRANODIORITE

Granodiorite crops out in the western part of the district in small areas just north of the junction of U.S. Highways 6 and 40 and in the extreme northwestern part of the mapped area (pl. 1). The granodiorite exposed near the junction of U.S. Highways 6 and 40 is a part of a large body exposed mainly in the adjacent Empire district. It was mapped originally as Silver Plume Granite (Bastin and Hill, 1917), but it is of granodioritic composition and is probably a variety of the Boulder Creek Granite of Lovering and Goddard (1950).

The granodiorite can be subdivided megascopically into two facies, equigranular and porhyritic. The equigranular facies is the more abundant; it forms all the body in the northwestern corner of the mapped area and a large part of the body exposed near the highway juncton. The porphyritic facies occurs along the poorly exposed eastern side of this latter pluton and also as dikes on the south side. This occurrence suggests that it may be a border facies of the granodiorite. Both facies are weakly foliated as a result of subparallel orientation of biotite flakes. The foliation is approximately parallel to the foliation of the adjacent metamorphic rocks, and, as in the Chicago Creek area (Harrison and Wells, 1959, p. 12–13), is probably of metamorphic origin. Potassic feldspar crystals in dikes of porphyritic granodiorite are oriented parallel to the walls of the dikes, and this foliation is probably a primary-flow structure.

The granodiorite is a medium- to coarse-grained moderately dark gray rock which appears bluish gray in outcrop. The porphyritic facies contains potassic feldspar phenocrysts about 1 inch long. Labradorite is the most abundant constituent of both the porphyritic and nonporphyritic types (table 10). A pegmatitic facies that exists in small bodies consists principally of quartz and potassic feldspar.

The granodiorite is shown by intrusive relations to be younger than the biotite gneiss and amphibolite and older than the biotite-muscovite granite.

TABLE 10.—*Modes, volume percent, of granodiorite, Lawson area*

[Analyses of samples C10-8, C10-60, C10-67, C10-19 by Dolores J. Gable, U.S. Geol. Survey]

Field sample	C10-5	C10-8	C10-60	C10-67	C10-19	C10-66
Plagioclase	46	51	41	44	51	40
Anorthite content	-------	-------	50–52	51–52	44–48	45
Quartz	23	27	28	31	31	31
Potassic feldspar	10	7	5	13	7	18
Biotite	17	12	20	10	9	8
Amphibole	Tr.	Tr.	0	0	0	0
Muscovite	0	Tr.	0	Tr.	Tr.	1
Sphene	Tr.	Tr.	0	0	0	1
Opaque oxides	3	3	5	2	1	1
Apatite	1	Tr.	1	Tr.	1	Tr.
Zircon	Tr.	Tr.	0	Tr.	Tr.	Tr.

Nonporphyritic facies:
- C10-5. Roadcut U.S. Highway 40, 1,000 ft W. of junction of U.S. Highways 6 and 40.
- C10-8. About same location as C10-5.
- C10-60. North of junction of U.S. Highways 6 and 40.
- C10-67. 1,200 ft NNW. of junction of U.S. Highways 6 and 40.

Porphyritic facies:
- C10-19. About 500 ft W. of junction of U.S. Highways 6 and 40.
- C10-66. About same location as C10-19.

QUARTZ DIORITE GNEISS AND RELATED ROCKS

Quartz diorite gneiss is exposed at Lawson, where it forms most of the prominent cliff just north of the village and extends northeastward to a point about 4,000 feet north of Mill Creek. It is also exposed south of Clear Creek at Lawson, and, along with small bodies of tonalite gneiss and hornblendite, at Bald Mountain in the northeastern part of the district. ("Tonalite" is used as a name for biotite-hornblende quartz diorite, not as a general synonym for quartz diorite.)

The quartz diorite gneiss bodies have conformable contacts with the other gneissic units, but are phacolithic in form; quartz diorite at Lawson is phacolithic to the Lawson syncline, and the main body at Bald Mountain and a smaller mass 5,000 feet southwest of the mountain are phacolithic to the Bald Mountain syncline. The tonalite gneiss and hornblendite associated with the quartz diorite gneiss near Bald Mountain are confined to axial parts of folds.

The foliation in the marginal parts of the quartz diorite gneiss bodies is conformable with the gently folded contacts of the enclosing gneiss, but internally the gneiss is locally tightly folded, particularly in the Bald Mountain area.

The typical quartz diorite gneiss is a gray mesocratic fine- to medium-grained granoblastic gneiss. Parallelism of biotite crystals produces a good foliation which is, however, less perfect than that of biotite gneiss, a rock that it may resemble. The quartz diorite gneiss consists principally of plagioclase (calcic andesine to sodic labradorite), quartz, and biotite (table 11).

TABLE 11.—*Modes, volume percent, of quartz diorite gneiss and tonalite gneiss*

Field sample	C5–40	C6–53	C8–30	BM–25	BM–130	E1–12	E1–133	BM–S2
Quartz	24	34	21.5	26	29	6	11	15
Potassic feldspar	0	0	0	.5	3	Tr.	3	0
Plagioclase	55	48	57.5	50	44.5	47	54	35.5
Anorthite content	50–51	------	49–52	43–53	46–48	53–55	------	------
Biotite	20.5	18	21	21	22.5	37	12	19
Hornblende	0	0	0	0	0	3.5	19	29
Muscovite	Tr.	0	0	Tr.	Tr.	0	0	0
Sphene	0	Tr.	Tr.	.5	Tr.	Tr.	Tr.	1
Opaque oxides	Tr.	Tr.	0	.5	.5	2.5	Tr.	Tr.
Apatite	.5	Tr.	Tr.	1.5	.5	4	1	.5
Zircon	0	Tr.	0	Tr.	0	0	0	0
Epidote	0	0	0	0	Tr.	0	0	0

Quartz diorite gneiss:
C5–40. Outcrop on foot trail, about 4,500 ft NW. of Lawson.
C6–53. North side of gulch, about 6,000 ft above the mouth of Mill Creek.
C8–30. Lawson.
BM–25. On ridge, 1,000 ft NW. of summit of Bald Mountain, Fall River area.
BM–130. On ridge, 2,100 ft SW. of the summit of Bald Mountain, Fall River area.
E1–12. Biotite-rich, mafic; near synclinal axis, York Gulch, Fall River area.
Tonalite gneiss:
E1–133. Near synclinal axis, 1,600 ft SW. of summit of Bald Mountain, Fall River area.
BM–S2. From small body of tonalite gneiss and hornblendite near synclinal axis, summit of Bald Mountain, Fall River area.

The tonalite gneiss (samples E1–133 and BM–S2, table 11) is a mesocratic granoblastic gneiss, less quartose than the quartz diorite gneiss. It is associated with mafic quartz diorite gneiss (E1–12, table 11) and hornblendite, a greenish-black massive rock composed principally of hornblende.

The composition, phacolithic form, and regional distribution of the quartz diorite gneiss and related rocks suggest that they are of syntectonic igneous origin. Regionally, the quartz diorite gneiss bodies of the district seem to belong to a group of well-foliated conformable bodies lying between the Boulder Creek batholith of Lovering and Goddard (1950) and a batholith composed of similar rock south of Idaho Springs. They are interpreted here as relatively mafic varieties of the Boulder Creek Granite (granodiorite of this report, and of Moench and others, 1962), and we propose that their marked foliation reflects their conformable mode of occurrence rather than an appreciable age difference between them and more typical Boulder Creek.

QUARTZ DIORITE

Quartz diorite, like the granodiorite, crops out only in the western part of the district. It is well exposed north of Clear Creek in a roadcut about 4,000 feet west of Dumont, south of Clear Creek in the Bellevue mine area, and on the Elida tunnel level of the Jo Reynolds mine. It is spatially associated with the biotite-muscovite granite and occurs as small discordant bodies near the granite. The quartz diorite is, however, cut by numerous dikes of biotite-muscovite granite, and the spatial association of quartz diorite and biotite-muscovite granite appears coincidental rather than genetic. Because of lithologic similarity, the quartz diorite is considered along with granodiorite and quartz diorite gneiss to be a facies of the Boulder Creek Granite. Crosscutting relations in the Chicago Creek area (Harrison and Wells, 1959) show that, in detail, quartz diorite is younger than granodiorite.

The quartz diorite resembles the equigranular facies of granodiorite but is generally darker and contains only trace amounts of potassic feldspar (microcline) (table 12). It is different from quartz diorite gneiss mainly in its discordant occurrence and more massive structure. Local facies of the quartz diorite contain hornblende in addition to, or in excess of, biotite.

TABLE 12.—*Modes, volume percent, of quartz diorite*

Field sample	C9-17b	C9-59	EWT-261-54
Quartz	21	35	11.5
Plagioclase	45	44	49
Anorthite content	-------	56–57	53–56
Potassic feldspar	Tr.	Tr.	Tr.
Biotite	31	15	7
Hornblende	0	0	23.5
Sphene	0	1	2
Opaque oxides	2	3	6
Apatite	1	2	1

C9-17b. Foliated; outcrop on U.S. Highways 6 and 40, 3,400 ft W. of Lawson.
C9-59. Poorly foliated; outcrop on jeep road to Red Elephant Hill, about 4,000 ft W. Lawson.
EWT-261-54. Elida level, Jo Reynolds mine, in American Sisters crosscut.

BIOTITE-MUSCOVITE GRANITE

Biotite-muscovite granite is exposed in many small bodies, especially in the part of the district west of Spring Gulch. Many of the bodies are in part concordant and in part discordant. A small body exposed about 1,000 feet north of Lawson is generally concordant with the foliation of the older quartz diorite gneiss, but dikes extend both uphill and downhill from the main sill-like mass. Another body, exposed near the crest of the divide about 3,500 feet northeast of Lawson, forms a concordant sill-like mass in microcline gneiss, but a discordant tongue extends southward and downhill.

The granite is generally massive, but locally it is slightly to moderately foliated owing to a preferred orientation of the micas, tabular feldspar crystals, or both. The foliation is subparallel to the contacts of the granite bodies and, in contrast to the foliation of older rock units, is probably of primary origin. A pseudofoliation caused by almost microscopic fractures (Harrison and Wells, 1959, p. 18) has formed locally.

Locally, the granite contains thin pegmatite dikes and large irregular pegmatite masses. Northeast of the junction of U.S. Highways 6 and 40 in the western part of the district, pegmatites are so intimately mixed with the granite that they were not differentiated, but were mapped together with the granite as biotite-muscovite granite and pegmatite.

The typical biotite-muscovite granite is a tan fine- to medium-grained seriate porphyritic rock. The phenocrysts, which are nearly euhedral carlsbad-twinned microcline, typify the rock. Less typical phases are gray or light-colored alaskitic rocks. The granite is fairly uniform in composition (table 13) and consists of plagioclase (oligoclase-sodic andesine), microcline, and quartz, in nearly equal proportions, and a small amount of biotite, muscovite, opaque oxides, and accessory minerals. As observed in thin section, biotite and plagioclase are characteristically altered, whereas the microcline is nearly fresh.

The biotite-muscovite granite intrudes the gneiss, the granodiorite, and the quartz diorite; it is intruded only by granite pegmatites and igneous rocks of Tertiary age. It is therefore one of the youngest Precambrian rocks in the area.

GRANITE PEGMATITE

Several varieties of granite pegmatite are exposed in the district and unquestionably not all are related in time and origin. Most are simple pegmatites and are not large enough to be mapped; a few are crudely zoned, but these are small and contain no concentrations of valuable minerals. Some discrete pegmatite bodies probably are

TABLE 13.—*Modes, volume percent, of biotite-muscovite granite*

[Analyses by Dolores Gable]

Field sample	C5-7	C8-96	C9-14	C9-17	C9-17A	C9-17C	G-168	G-604	G-833	G-839	G-1132	T-30a	Average
Plagioclase	30	33	32	28	40	32	35	31	34	32	28	34	32.5
Microcline	32	30	31	35	20	34	28	28	29	35	36	23	30
Quartz	30	25	30	33	27	29	29	31.5	30	25	33	26	29
Biotite	6	6	3.5	1	10	3	4	6	4	5	2	10	5
Muscovite	2	4	3.5	1.5	2	1	3	3	1	3	1	4.5	2.5
Opaque oxides	Tr.	2	Tr.	1.5	1	1	1	.5	2	Tr.	Tr.	2	1
Apatite	Tr.	Tr.	Tr.	0	Tr.	Tr.	Tr.	0	0	Tr.	Tr.	Tr.	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Allanite(?)	0	0	0	0	Tr.	0	0	0	0	0	0	.5	Tr.

C5-7. 4,000 ft NNW. of Lawson.
C8-96. 1,000 ft NW. of Lawson.
C9-14. Roadcut, U.S. Highway 6 and 40, 2,500 ft W. of Lawson.
C9-17. Light-colored phase; roadcut U.S. Highway 6 and 40, 3,500 ft WSW. of west end of Lawson.
C9-17A. Tan; roadcut U.S. Highway 6 and 40, same location as above.
C9-17C. Gray; roadcut U.S. Highway 6 and 40, same location as above.
G-168. 4,000 ft NNE. of Dumont.
G-604. Ohio Gulch, about 1 mile SW. of Dumont.
G-833. American Sisters mine, about 3,500 ft SSW. of Lawson.
G-839. Same location as G-833.
G-1132. About 1 mile SW. of Lawson; 1,000 ft SSE. of Bellevue-Rochester tunnel.
T-30a. 2,000 ft N. of Dumont; portal of Lower West End(?) mine.

related to the granite gneiss and pegmatite unit, others are related to the granodiorite, and still others are related to the biotite-muscovite granite. A less common variety of pegmatite occurs within the quartz diorite gneiss at Bald Mountain and may be related to that rock unit.

The common pegmatites, regardless of affiliation, are composed of quartz, microcline-perthite, and a sodic plagioclase; they contain muscovite or biotite and, locally, magnetite. The zoned pegmatites include two small tourmaline-bearing pegmatites near Bald Mountain that have quartz cores, a muscovite-bearing pegmatite having a quartz core in a roadcut west of Lawson, and several small dikes in the Commodore tunnel.

Some of the pegmatites are radioactive A uniformly coarse grained biotite pegmatite in the Gold Chloride adit locally contains more than 0.02 percent equivalent uranium.

TERTIARY IGNEOUS ROCKS

Tertiary porphyritic rocks, commonly termed "porphyries," occur in the district in dikes, small stocks, and in one partly concordant pluton—a body of trachytic granite porphyry north of Lawson (pls. 1, 3). Although these rocks are scattered throughout the district, they are less abundant, and the dikes are less continuous than in most parts of the adjoining Central City, Idaho Springs, and Chicago Creek districts (Wells, 1960, pl. 19). The dikes, the most numerous of the intrusive bodies, are commonly 10–12 feet wide but locally are as much as 100 feet wide. They occupy joints or faults of small displacement and of various orientations, as west-northwest, east, east-northeast, and north-northwest.

Following the system of Wells (1960), the porphyries were classed on the basis of age, petrography, and geographic distribution. Three of the four groups recognized in the central Front Range by Wells are represented in the Lawson-Dumont-Fall River district: (1) the hornblende granodiorite group, (2) the quartz monzonite group, and (3) the bostonite group. This grouping is somewhat similar to that of Lovering and Goddard (1950, p. 44–47).

All the Tertiary igneous rocks are appreciably radioactive; according to Wells (1960, p. 257), those in this part of the Front Range mineral belt average about 0.0061 percent equivalent uranium, and some of the younger members of the bostonite group are appreciably more radioactive than the average.

HORNBLENDE GRANODIORITE GROUP

The hornblende granodiorite group is represented in the district and in the larger area studied by Wells (1960) by four types of porphyry which are, in order of decreasing age, (1) hornblende granodiorite porphyry, (2) biotite granodiorite porphyry, (3) biotite-quartz monzonite porphyry, and (4) biotite-quartz latite porphyry. The hornblende granodiorite is inferred to be the oldest, and the biotite-quartz latite is the youngest porphyry within the area studied by Wells (1960, fig. 58). Biotite-quartz latite porphyry is at least partly younger than the ore deposits; it is younger than some veins of the Idaho Springs district (Spurr and Garrey, 1908, p. 344), but is probably older than the Cross vein in the Jo Reynolds mine in the Lawson area. All other porphyries are older than the ore deposits.

HORNBLENDE GRANODIORITE PORPHYRY

Hornblende granodiorite porphyry occurs in an irregular stock as much as about 4,000 feet across about 2½ miles above the mouth of Fall River near the Mary mine and Golconda tunnel; it also forms small dikes in the upper Fall River area. It is a seriate porphyritic gray rock containing characteristic zoned plagioclase phenocrysts as much as 1 inch long and smaller potassic feldspar, hornblende, and augite phenocrysts set in a medium-grained matrix of plagioclase, potassic feldspar, and quartz. Magnetite and sphene are trace constituents and rarely are visible megascopically.

In many places the rock is cut by veinlets of quartz and calcite, and specimens from the Mary mine show pyrite and molybdenite on joint surfaces.

BIOTITE GRANODIORITE PORPHYRY

Biotite granodiorite porphyry forms a small stock southeast of the hornblende granodiorite stock in the Fall River area, and it forms small dikes northeast and west of that stock and west of Lawson. The porphyry is a greenish-gray rock, has seriate porphyritic texture, and contains large plagioclase phenocrysts; it is easily distinguished from the hornblende granodiorite porphyry by the presence of biotite and by doubly terminated quartz phenocrysts. Both hornblende- and biotite-rich varieties have low radioactivity; according to Wells (1960, fig. 60), the hornblende-rich variety averages about 0.0020 percent equivalent uranium and the biotite-rich 0.0023 percent equivalent uranium.

The biotite granodiorite and hornblende granodiorite porphyries form a composite dike west of the biotite granodiorite porphyry stock. The biotite granodiorite porphyry forms the center of the dike, and it is inferred to be younger than the hornblende granodiorite porphyry.

BIOTITE-QUARTZ MONZONITE PORPHYRY

Biotite-quartz monzonite porphyry occurs within the district only in a single dike north of Dumont. The dike is 10–15 feet wide and because of a dip of about 50° N. has a sinuous trace.

This porphyry is characterized by doubly terminated quartz phenocrysts about one-fourth inch long which serve to distinguish it from all the other porphyries except the biotite granodiorite porphyry of the Fall River area. Plagioclase (andesine) forms small light-colored euhedral phenocrysts, generally 1/8–1/4 inch long, which are several times as abundant as the quartz phenocrysts. Biotite and somewhat less abundant hornblende together constitute about 5 percent of the rock volume. Accessory minerals are opaque iron oxides (probably mostly magnetite), apatite, and zircon. Much of the rock has a fresh appearance, and, unlike many of the Tertiary dike rocks, it forms resistant outcrops at several places.

About 3,500 feet north of Dumont, the biotite-quartz monzonite porphyry dike cuts a quartz monzonite porphyry dike; dikes of both these rocks are cut by a dike of garnetiferous bostonite porphyry east-northeast of Dumont.

BIOTITE-QUARTZ LATITE PORPHYRY

Biotite-quartz latite porphyry is represented by a few small dikes in the southwest part of the district near the Millington and Jo Reynolds mines. It is a fine-grained brown to gray rock that contains small but conspicuous and characteristic biotite phenocrysts.

The porphyry is appreciably more radioactive than the older members of the group, averaging about 0.0061 percent equivalent uranium (Wells, 1960, fig. 60).

QUARTZ MONZONITE GROUP

The quartz monzonite group is represented in the district only by quartz monzonite porphyry. The porphyry is probably younger than the biotite and hornblende granodiorite porphyries, and it is older than the bostonite group and the biotite-quartz monzonite porphyry of the hornblende granodiorite group.

The quartz monzonite porphyry forms dikes and small irregular dikelike plutons. Most of the dikes are less than 10 feet wide, but one in upper Mill Creek west of the Keith tunnel is about 100 feet wide. The dikes fill fractures whose strikes are west-northwest, north-northwest, and, rarely, east-northeast. One long dike which continues into the adjacent Idaho Springs district is in or fills a fracture parallel to the Idaho Springs fault. Vein deposits parallel quartz monzonite porphyry dikes in the Dubuque, Elm City, and Murry mines.

The quartz monzonite porphyry is typically gray and contains scattered gray and white plagioclase phenocrysts ¼–¾ inch long in a generally aphanitic groundmass. Locally the rock contains sparse ferromagnesian phenocrysts and magnetite crystals. The quartz monzonite porphyry is somewhat radioactive, and the north-northwest-trending dikes near the Dubuque mine in the Fall River area contain as much as 0.007 percent equivalent uranium. According to Wells (1960, fig. 62), quartz monzonite porphyry contains on the average about 0.0037 percent equivalent uranium.

BOSTONITE GROUP

The bostonite group is characterized by light red to light purple color and by a trachytic or bostonitic groundmass texture, which is observable in some hand specimens as well as in thin section. It includes four types of porphyry: (1) garnetiferous bostonite porphyry, (2) bostonite porphyry, (3) trachytic granite porphyry, and (4) quartz bostonite porphyry. The quartz bostonite porphyry is youngest, and the garnetiferous porphyry and bostonite porphyry predate the other two, but age relations between the latter two porphyries are unknown. All members of the group are appreciably radioactive.

GARNETIFEROUS BOSTONITE PORPHYRY

Garnetiferous bostonite porphyry is found in the central part of the district; one small dike is exposed west of the Stevens(?) mine south of Clear Creek, and several dikes are exposed east and northeast of Dumont north of Clear Creek. This porphyry is a spotted white and reddish-brown rock noticeably more porphyritic than the nongarnetiferous bostonite porphyry. In addition to white feldspar phenocrysts it contains sparse elongate phenocrysts of pyroxene and small euhedral dark garnets. Five samples of garnetiferous bostonite porphyry collected from dikes exposed north of Clear Creek show 0.004 percent equivalent uranium, which is less than that reported by Wells (1960) for other members of the bostonite group.

BOSTONITE PORPHYRY

Bostonite porphyry forms a pluton about 250 feet across and several short dikes in the upper York Gulch area, three dikes on the top of Bald Mountain, and a dike near the mouth of Spring Gulch (pl. 3). In addition, a short dike is exposed near the Stevens(?) mine and a dike crops out northeast of Downieville.

The bostonite porphyry consists of sparsely scattered phenocrysts of grayish-white feldspar and altered ferromagnesian minerals in a pink aphanitic groundmass. The feldspar phenocrysts are largely sodic plagioclase; they are zoned and locally mantled with potassic feldspar. The average radioactivity is 0.0056 percent equivalent uranium (Wells, 1960, fig. 63) ; a sample from the bostonite porphyry pluton in upper York Gulch 0.006 percent equivalent uranium.

TRACHYTIC GRANITE PORPHYRY

Trachytic granite porphyry is found mainly in the western part of the district, although several thin dikes are exposed west of the mouth of Fall River. A generally northeast-trending dike west of Dumont is in part paralleled by the Senator vein. The largest body, north of Lawson, is partly concordant to the foliation of Precambrian rocks.

The porphyry is light red and white and contains rounded feldspar phenocrysts about the size of a peanut, hence the colloquial name of "peanut porphyry." It resembles some bostonite porphyry and in general can be distinguished from the bostonite only by microscopic examination (Wells, 1960, p. 249) ; according to Wells the trachytic granite porphyry contains about 5–15 percent quartz, 20–40 percent plagioclase, and 45–65 percent potassic feldspar in contrast to the bostonite porphyry which contains 1–10 percent quartz, 20–45 percent plagioclase, and 50–70 percent potassic feldspar.

Samples from the district show a range from about 0.004 to 0.006 percent equivalent uranium; according to Wells (1960, fig. 63), the trachytic granite porphyry averages about 0.0047 percent equivalent uranium.

QUARTZ BOSTONITE PORPHYRY

Quartz bostonite porphyry forms a crudely oval-shaped pluton, whose maximum dimensions are about 1,000 by 2,000 feet, and which is exposed on the divide southeast of Dumont near the southern edge of the mapped area. A dike which averages about 30 feet in width continues eastward from the pluton for several thousand feet, and branching dikes as much as 100 feet wide extend generally northwestward from a point about 700 feet west of the pluton. Nearly continuous dikes can be traced west and northwest from this point to Silver Creek gulch, and the main dike is inferred to continue under the colluvium-filled gulch and through the Jo Reynolds mine and Princess of India tunnel. Quartz bostonite porphyry dikes exposed north of Clear Creek along the same general trend are possibly on a related fracture system. Thin quartz bostonite dikes are also exposed in the eastern part of the district, as near the crest of Bald Mountain and near the Gold Quartz mine in upper Fall River.

The quartz bostonite porphyry is a rather sparsely porphyritic rock characterized by a light purple color and very high radioactivity. Phenocrysts are generally less than a fourth of an inch long and are mostly composed of altered feldspar. According to Wells (1960), the rock is composed of about 10–25 percent quartz, 70–80 percent anorthoclase(?), 0–10 percent magnetite, and trace amounts of zircon, apatite, fluorite, and carbonate. The quartz bostonite porphyry contains an average of about 0.011 percent equivalent uranium and 0.0039 percent uranium (Wells, 1960, fig. 63), but analyses of a few samples suggest that the average in the Lawson-Dumont-Fall River district is less than this.

QUATERNARY DEPOSITS

Quaternary deposits, which were only partly differentiated in mapping, cover a considerable area, particularly in the western part of the district and in Clear Creek valley. They consist of alluvium, colluvium or poorly sorted rock and soil debris, glacial outwash, and terminal and lateral moraines. On the uplands the extensive deposits are mainly colluvial, whereas in the deeper valleys they are largely glacial outwash and alluvium.

Clear Creek valley, which was mapped as undifferentiated surficial deposits, is largely filled with glacial outwash, but the present stream is bordered with alluvium, and terminal moraines form part of the valley near Dumont. The narrower valley of Fall River is mainly mantled with alluvium, but this alluvium probably is a thin veneer covering glacial outwash.

The material mapped as colluvium is largely solifluction debris dating from glacial time, but it also includes small amounts of Recent talus on steep valley walls and residual deposits in relatively flat upland valleys. The solifluction-debris sheets cover many of the forested north-facing slopes; they are several tens of feet thick and where well formed completely mask the bedrock.

During the Bull Lake and Pinedale Glaciations there were three times of glacial advance (G. M. Richmond, oral commun., 1965) as shown by moraines, which have been mapped only locally. The oldest moraine belongs to the early stade of Bull Lake Glaciation; it is exposed on the south side of Clear Creek near the mouth of Turkey Gulch. The late stade of Bull Lake Glaciation is marked by a terminal(?) morine north of Clear Creek at Dumont and by extensive lateral(?) moraine deposits on the uplands west of Dumont. These lateral(?) moraine deposits have been mapped in the part of the Lawson area, which is north of Clear Creek. Apparently the late stade glacier front of Bull Lake Glaciation dropped about 1,400 feet between its eastern terminus near Dumont and the western edge of the district, where glacial boulders are found at an altitude of about 9,400 feet. The early stade of the younger Pinedale Glaciation is marked by extensive morainal deposits exposed south of Clear Creek near the junction of U.S. Highways 6 and 40.

STRUCTURE

Bedrock in the Lawson-Dumont-Fall River district is composed chiefly of a generally conformable series of metamorphic rocks of Precambrian age and subordinately of partly discordant plutonic igneous rocks of Precambrian age and hypabyssal igneous rocks of Tertiary age. The conformably interlayered rocks and at least some of the igneous rocks of Precambrian age were metamorphosed and folded in Precambrian time. The folds are expressed by the orientation of the metamorphic foliation This foliation parallels compositional layering and is inferred to be approximately parallel to the bedding of the sedimentary rocks which originally formed part of the sequence. Some folds are also outlined by lithologic layering. Some of the younger Precambrian rocks and the Tertiary rocks were not folded nor metamorphosed, but all rocks have locally been faulted and jointed in Precambrian and Laramide episodes of orogeny or regional uplift.

The deformational history of the area is complex. Moench, Harrison, and Sims (1962) recognized two periods of Precambrian folding in the Central City-Idaho Springs area. More recently, R. B. Taylor (oral commun., 1963–64) found evidence in the area east of Central City of a third fold system that appears to predate both previously recognized systems. The view of Precambrian deformation presented here is similar in general to the sequence proposed by Moench, Harrison, and Sims (1962). The effects of an older deformation were not recognized, but preservation of such structural features through widespread metamorphism and plastic folding of younger age would be uncommon. The following outlined sequence is thus undoubtedly oversimplified but appears to explain gross structural features of the district.

1. Precambrian folding and syntectonic emplacement of mafic and granitic rocks: Under plastic conditions, major folds with north-northeast-trending axes were formed; at the same time, partly discordant bodies of granodiorite and phacoliths of quartz diorite were emplaced; somewhat later, partly discordant bodies of quartz diorite were emplaced and cross and longitudinal joints formed as part of the fold geometry.

2. Precambrian folding and late syntectonic emplacement of the biotite-muscovite granite: Under reduced plastic conditions, small folds with east-northeast- and north-northwest-trending axes were formed; late in the folding, biotite-muscovite granite was emplaced as partly concordant phacolithic and partly discordant bodies, probably at the beginning of cataclastic deformation in the Idaho Springs and Central City districts to the east.
3. Precambrian faulting: Major faults in northwest and north-northeast sets were formed.
4. Laramide arching and faulting and syntectonic emplacement of porphyries: High-angle faults in sets trending east, west-northwest, east-northeast, and nearly north were formed; old faults and joints reopened and new joints were formed, and porphyries were emplaced as dikes, stocks, and smaller plutons.

FOLDS

Three large generally open and nearly symmetrical folds, the Lawson syncline, the Dumont anticline, and the Bald Mountain syncline, constitute the structural framework of most of the district. The axes of the folds trend about north-northeast and are expressed principally by reversals in the dip of foliation; in addition, the Lawson syncline is outlined by layers of the gneiss, and the Bald Mountain syncline is in part outlined by quartz diorite gneiss phacoliths. The major folds formed in the first recognized period of Precambrian folding.

The trace of the axial plane of the Lawson syncline trends about N. 12 E., and the axis plunges gently north. The syncline can be traced for about 2 miles, from about 2,000 feet south of Clear Creek at Lawson northward to the edge of the district; it is a gentle structural feature having limbs that generally dip inward 45° or less (pl. 1, section *A–A′*). To the east of the syncline is the Dumont anticline, which can be traced from a point about 2,000 feet south of Dumon northward at least to the hornblende granodiorite porphyry stock (Tertiary) in the Fall River area. This anticline is also an open fold but is somewhat more tightly compressed than the Lawson syncline. It trends about N. 35°E., and plunges gently northeast. To the east of the anticline is the Bald Mountain syncline, the axis of which can be traced from south of Clear Creek northward about 3 miles to Bald Mountain; it plunges gently northward on a general trend of N. 30°E. Near Clear Creek (pl. 1, section *A–A′*), the axis of the syncline is defined mainly by changes in strike and dip of the foliation, but north of Fall River it is defined also by phacolithic bodies of quartz diorite gneiss.

The Central City anticline of Moench, Harrison, and Sims (1962, pl. 1) probably continues south-southwestward into the Lawson-Dumont-Fall River district where it crosses Fall River about 2,000 feet above its mouth. The trace of the axial plane is inferred to be displaced by the Idaho Springs fault. The anticline apparently dies out near the junction of Fall River and Clear Creek. A monoclinal flexure about 1,200 feet to the west, expressed chiefly by an abrupt change in the westward dip of the microcline gneiss-biotite gneiss contact, may be a related en echelon feature.

Small drag and symmetrical folds that formed during the early folding are oriented either about parallel or about perpendicular to the trend of the major folds.

Asymmetric folds assigned to the second period of Precambrian folding trend approximately east-northeast and north-northwest. They are the largest secondary folds of the district and are mappable in the Lawson area. The east-northeast-trending folds are generally indicated by changes in the amount of dip of the foliation, because they have nearly flat northwest flanks and steeply dipping southeast flanks. In a small area on the east side of Young America Gulch, such folds are outlined also by layers of biotite gneiss and intercalated quartz diorite gneiss. The east-northeast-trending folds are best formed in the Lawson layer of the microcline gneiss. They have nearly straight axes and some continue without apparent deflection across the axis of the Lawson syncline. Distance from crest to trough of adjacent folds ranges from about 70 feet to more than 200 feet, and single axes can be followed for as much as about 2,000 feet. A partly concordant part of a biotite-muscovite granite body exposed on the main ridge north of Lawson is possible phacolithic to folds of this group.

North-northwest-trending folds of mappable scale are exposed west of Lawson on the west flank of the Lawson syncline, and occur principally in northwest-trending thick interlayers of microcline gneiss and biotite gneiss. Biotite-muscovite granite is apparently phacolithic to some of the folds. Distance from crest to trough ranges from about 100 feet to at least as much as 400 feet, and single axes can be followed for as much as about 1,500 feet.

LINEATIONS

Lineations are expressed by mineral alinement, warps (small gentle folds of low amplitude), crinkles (small sharp folds of relatively

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large amplitude as compared with warps), boudins, and slickensides. Lineations recorded in the field were plotted on an equal area net, then counted and contoured. The dominant bearing of the lineations, shown by the contour diagrams (fig. 2), is north-northeast, parallel to the axes of the major folds of the district. This trend is especially conspicuous in the Dumont and Fall River areas. Other maxima found locally are oriented west-northwest, east-northeast, and north-northwest. A considerable spread of lineations is found in the western part of the district near Lawson, where minor maxima occur in north-northwest, west-northwest, and east-northeast directions as well as in the north-northeast direction. In this area the lineations have east-northeast, north-northeast, and north-northwest directions and are approximately parallel to the axes of mappable folds. The north-northeast-trending set is approximately parallel to the Lawson syncline and is related to it in origin. The east-northeast-trending lineations are parallel to transverse folds that occur in the axial part of the Lawson syncline; the north-northwest-trending lineations are parallel to transverse folds on the west flank of the Lawson syncline (pl. 1).

Different types of lineations characterize the four dominant sets. North-northeast-trending lineations are principally drag folds, monoclinal flexures, mineral alinements, and crinkles. The drag folds range in size from minute crenulations in less competent rocks such as the sillimanitic biotite-quartz gneiss to folds of mappable size in biotite-quartz-plagioclase and microcline gneiss. The monoclinal folds are also locally of mappable size. Minerals showing distinct alinements are sillimanite, amphibole, and, less commonly, quartz and mica. West-northwest-trending lineations include boudins, drag folds, and warps. Drag folds of this trend are sparse in most of the district but are abundant locally in the Fall River area, particularly in York Gulch. One feature of the drag folds that is not explained by the structural hypothesis presented earlier is that all west-northwest-trending drag folds noted in the Fall River area show the same sense of drag—the north flank moving southward over the south flank. Warps and boudins oriented in the west-northwest direction can, however, be explained as having formed because of bending of the axes of the major north-northeast-trending folds, the boudins forming, because of local tension, on the convex sides of bends, and the warps forming, because of local compression, on the concave sides.

Lineations characteristic of the east-northeast direction are drag folds of two types and mineral alinements. As noted previously, these lineations are best formed in the western part of the district;

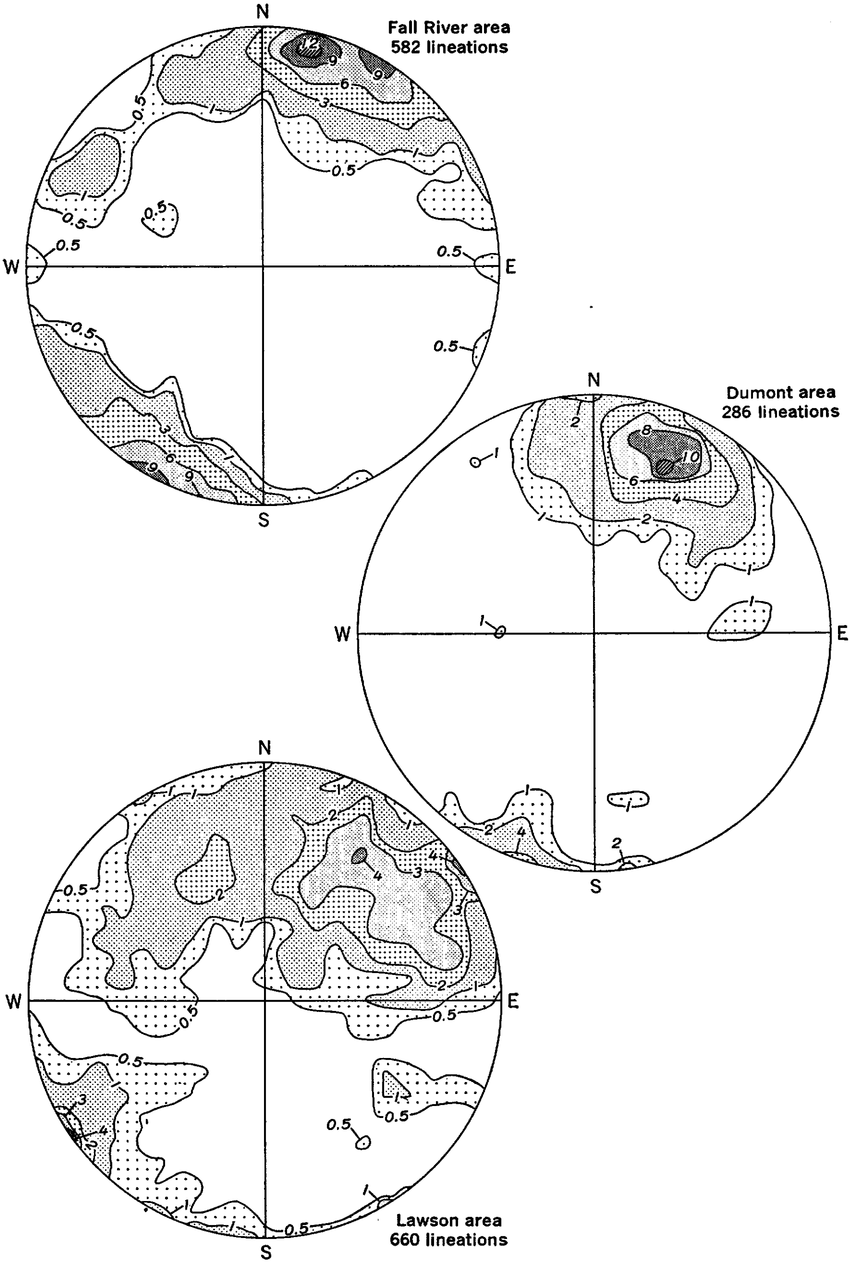

FIGURE 2.—Contour diagrams of lineations. Schmidt net, lower hemisphere plot Contour values are in percent.

the major lineations of the set are the axes of folds of mappable scale exposed north and northeast of Lawson (pl. 1). These folds form a series of asymmetric anticlines and synclines which warp the gently folded rocks of the Lawson syncline. Sharp, almost chevron-type drag folds are characteristic of the northwest flanks of the anticlinal folds, and open drag folds are characteristic of the southeast flanks. A strong mineral alinement, mainly shown by biotite and quartz in the microcline gneiss, parallels the axes of the folds. Linear elements in the north-northwest-trending set are mainly asymmetric drag folds, locally mappable (pl. 1) and found on the west flank of the Lawson syncline.

ORIGIN OF FOLDS AND LINEATIONS

The major north-northeast-trending folds and related small folds and mineral lineations formed during a Precambrian period of plastic folding at about the same time as emplacement of Boulder Creek Granite. The absence of cataclasis and the ubiquitous recrystallization that produced a conspicuous alinement of such minerals as sillimanite suggest that this folding took place during a period of relatively high temperature and high confining pressures; thus the high-grade regional metamorphism and plastic folding were probably at least partly contemporaneous. During the same period of deformation, secondary compression and tensional stresses occurred about parallel to the major fold axes and caused the small warps and boudins oriented in the west-northwest direction to form.

The east-northeast- and north-northwest-trending folds of the Lawson area are superposed on the Lawson syncline and are thus younger. East-northeast folds distort the gently folded rock of the syncline, particularly west of the synclinal axis (pl. 1, section *A–A'*). Similarly, mineral alinements in many places do not parallel the axis of the syncline, but instead parallel the axis of east-northeast-trending folds. These alinements suggest that recrystallization has obliterated the north-northeast set of lineations paralleling the axis of the Lawson syncline. The east-northeast folds die out westward and cannot be traced through the west flank of the Lawson syncline, but folds of the north-northwest trend are found there. These latter folds probably owe their mappable size to their location within northwest-trending microcline gneiss and biotite gneiss layers on this flank of the syncline.

Studies in the nearby Central City-Idaho Springs, Chicago Creek, and Freeland-Lamartine areas have shown that the central part of the Front Range mineral belt was affected by at least two Precambrian periods of deformation (Moench and others, 1962). The older and major folding at Lawson took place at the same time as the older and major folding in these nearby areas, as shown by the continuity of fold patterns. The relation of the younger folding at Lawson to the second deformation to the east is, however, not yet fully understood. Like the young folds to the east, those of the Lawson area are superposed on north-northeast-trending major folds and must be younger, although Meonch, Harrison, and Sims (1962, p. 44) classed the young folds at Lawson only as "a local manifestation of the older deformation." They did this largely because of the lack of cataclasis in young folds of the Lawson area. Further studies have shown, however, that plastic folds also formed in the young deformation near the intensely deformed Idaho Springs-Ralston zone (R. B. Taylor, oral commun., 1963). These results suggest that the younger deformation was a long-continued event, and was one which started plastically but was succeeded in major belts by cataclasis. Under this hypothesis only the plastic part of the young deformation affected rocks at Lawson.

In addition to superposition, a young age for north-northwest- and east-northeast-trending folds at Lawson is suggested by local phacoliths of Silver Plume Granite, rather than Boulder Creek Granite, in the folds. The east-northeast folds at Lawson are similar to young folds in the Idaho Springs-Ralston deformed belt because of their seemingly elevated northwest flanks and the occurrence of chevronlike folds on one limb and terracelike folds on the other limb of larger draglike folds (Harrison and Wells, 1959).

JOINTS

Several sets of joints exist in the Precambrian rocks of the district. Two conspicuous sets strike respectively about N. 70° W., and N. 80° E., and both dip steeply north; two other conspicuous sets strike about N. 40° E. and N. 25° E. and dip steeply (fig. 3). Other joints, less consistent in strike and dip, are found in the Tertiary rocks of the district.

The age and origin of many of the joints in the Precambrian rocks are uncertain, but some probably formed at least as incipient fractures during Precambrian folding. For example, the N. 70° W. joint set is very close to the expected position of cross joints and the N. 25° E. set to longitudinal joints; both joint sets are related to the early north-northeast-trending (major) folds. The N. 70° W. joint set, however, is also about parallel to one set of Laramide faults, and so its prominence may be due to both Precambrian and Laramide deformations.

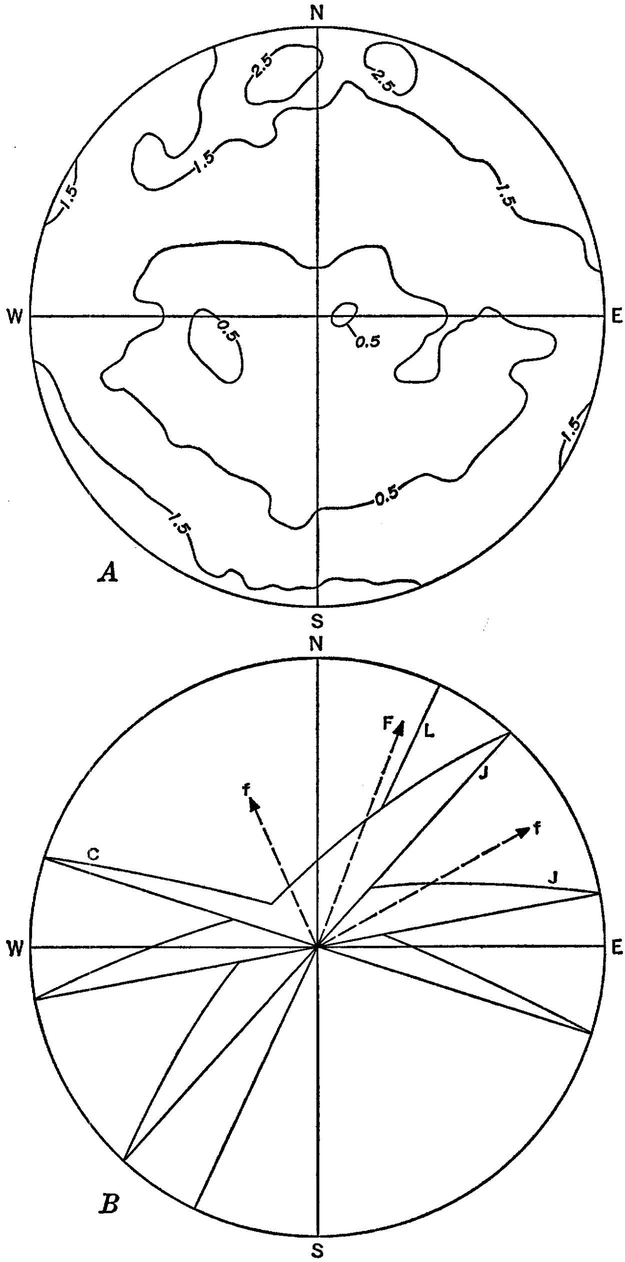

FIGURE 3.—Joint diagrams. *A*, Poles to 2,463 joints contoured on Schmidt net, upper hemisphere. *B*, Stereodiagram showing relation of conspicuous joint sets and fold axes. C, cross(?) joints related to major folds; F, axis of major folds; f, axes of minor folds; L, longitudinal(?) joints related to major folds; J, other joints.

Harrison and Moench (1961) concluded that joints in the Central City-Idaho Springs area (including the Lawson-Dumont-Fall River district) formed in each of the Precambrian episodes of folding and probably also during the Laramide arching of the Front Range.

FAULTS

Of the numerous faults in the district, many contain Tertiary veins and ore deposits and some contain Tertiary dikes. Most are steeply dipping shear zones a few inches to several feet wide that can be traced for no more than half a mile. A few faults are several tens of feet wide and can be traced for a mile or more. The faults typically have displacements of less than 50 feet. Some faults had both strike- and dip-slip movements, but most of the larger faults are probably predominantly strike slip. With a few exceptions, the faults are not conspicuous in outcrop, and because of this fact and their small displacement, most would not be recognized except for their relationship with veins or igneous rocks of Tertiary age.

The faults form a rather complex pattern (pl. 2) which can be resolved into three simpler components, namely a subrectangular grid pattern, a parallel pattern, and an acute-grid pattern (McKinstry, 1948, p. 307–314). The subrectangular pattern—the largest scale pattern—is made up of faults which strike northwest and north-northeast. The faults constituting major elements of this pattern are the Idaho Springs fault, the Wild Wagoner fault, and the John L. Emerson fault, all of which continue into adjacent districts. (See inset of pl. 2 for larger scale relations). The parallel fracture pattern is best seen in the central part of the district where the chief faults, represented by the Syndicate, California, and Albro veins, strike west-northwest and dip at low angles. The acute pattern is most conspicuous in the western part of the district; it is formed by faults that strike west-northwest, east, and east-northeast to northeast. Some of the principal faults of this pattern are the Jo Reynolds 2, American Sisters, and Cross (Jo Reynolds mine) veins south of Clear Creek, and the Boulder Nest, White, and St. James veins north of Clear Creek.

The north-northeast- and northwest-striking faults belonging to the subrectangular pattern are part of a larger system that dates from Precambrian time (Tweto and Sims, 1963). The east, east-northeast, and west-northwest faults belonging to the acute-grid and the parallel patterns are younger and apparently formed about contemporaneously in Laramide time. Some of the low-angle faults in the Dumont area probably formed in the Precambrian, but others probably formed during the Laramide revolution. A group of minor faults that strike north to north-northeast displace faults of all other sets and hence are the youngest in the area. The faults, however, are slightly mineralized.

OLDER FAULTS

The major older faults in the district are the Idaho Springs, John L. Emerson, and Wild Wagoner faults. All three faults are more extensively exposed in adjacent areas, and probably are related to the Precambrian subrectangular fault pattern of the Front Range. The Idaho Springs fault strikes northwestward, dips steeply to the northeast, and extends about 3 miles into the neighboring Idaho Springs district. The John L. Emerson fault is part of a complex fault zone that contains many veins, including the important Gem vein of the Central City-Idaho Springs area. It may be a branch of the Floyd Hill fault of Lovering and Goddard (1950, pl. 2). The Wild Wagoner fault continues northward from the district; it is probably the continuation or a main branch of the Hamlin Gulch-Apex fault of Lovering and Goddard (1950, pl. 2).

Within the district, the Idaho Springs fault can be traced for about 7,000 feet from Fall River to Spring Gulch. It or branches of it are exposed in the Dubuque mine near Fall River and in the Silver King Extension mine in Spring Gulch. The fault evidently consists of several fractures; various veins and dikes occur in or along it, and a quartz monzonite porphyry dike follows bordering fractures most of the way from Fall River to Spring Gulch.

A strong vein exposed about 4,500 feet northeast of the mouth of York Gulch at the eastern boundary of the district is the continuation of the John L. Emerson fault of the Idaho Springs district. To the northwest the fault possibly continues through prominent saddles near the Jumbo mine in upper York Gulch.

The Wild Wagoner fault, exposed in the north-central part of the district, is the major north-northeast-trending fault. Where exposed near the Pioneer tunnel, it is a steeply dipping shear zone about 50 feet wide. It is covered by surficial deposits to the south; possibly it continues down Pioneer Gulch, then crosses the prominent saddle about 4,000 feet northwest of Dumont. It projects toward the conspicuous northeast-trending fracture zone which is filled by porphyry dikes and the Senator vein on the south side of Clear Creek. Another possible course for the main branch of this northeast-trending fault, lying to the east, was shown by Sims (1964), who projected the Apex fault southward on a fault zone exposed just west of Dumont and parallel to Ohio Gulch south of Dumont.

Some less-continuous faults probably also belong to the group of older north-northeast- and northwest-trending faults. The University, H. B., and Gold Crown veins in the northeastern part of the district near Bald Mountain strike north-northeast to northeast and are subparallel to the steeply dipping axial planes of minor folds of Precambrian age which are well formed in the quartz diorite gneiss phacolith. They may have opened first in Precambrian time.

YOUNGER FAULTS

Faults of the younger group contain some of the most important veins of the district. These veins seem to be most abundant near Lawson, in a small area east and northeast of Dumont, and in a small area in upper Fall River. Veins of the Lawson area strike east to northeast and west-northwest to northwest in an acute-grid pattern. In the Dumont and upper Fall River areas they strike west-northwest in a parallel pattern, although a few near Dumont strike east-northeast.

As deduced from displacements and from the locations of ore shoots, both the west-northwest- and east-northeast-trending faults had a component of strike-slip movement, the north wall having moved relatively west on west-northwest-trending faults and relatively east on east-northeast-trending faults. Apparent lateral displacements along representative west-northwest-trending faults range from a few feet (on many veins) through about 20 feet on the Blazing Star fault to about 50 feet on the Comstock fault.

Fracture patterns suggest that many of the east-, east-northeast-, and west-northwest-trending faults formed nearly contemporaneously. For example, the Jo Reynolds vein fissure (NE.) joins the Cross vein fissure (NW.) in the Jo Reynolds mine by means of branching fractures that seem to have formed at the same time as the two veins. Similarly, in the Princess of India tunnel, the Platts vein fissure (NW.) is apparently contemporaneous with the Murry vein fissure (E.) and also with a third vein fissure which strikes N. 60° E. North of Lawson, the Orient vein fissure (ENE.) splits off the Young America vein (E.), and crosses the Dexter vein fissure (NW.) without apparent displacement. In the Dumont area the Golden Calf vein fissure (ENE.) probably splits from the Albro vein fissure (WNW.)

Most of the younger faults of the Lawson and Fall River areas have steep dips, but in the Dumont area both the east-northeast- and the west-northwest-trending faults have low dips. Most of these low-dipping faults lie in an area bounded by Spring Gulch on the northeast and by a line connecting the Senator and Wild Wagoner faults on the west. Spring Gulch has a general northwesterly trend, possibly because of a poorly defined fracture zone related to the Idaho Springs fault. The occurrence of the low-angle vein fissures in this area suggests a possible relation to the old subrectangular fault pattern, but some fissures are definitely younger than Precambrian. A long low-angle fissure south of the Albro vein contains a Tertiary quartz monzonite porphyry dike and thus is at least older than the porphyry; the fissure and the dike are cut and displaced by the low-angle Albro vein fissure, whose major movement thus must have occurred after the porphyry was emplaced. We tentatively concluded that at least some of the low-angle faults formed in Precambrian time in response to movement on major northwest- and northeast-trending faults and that in Laramide time some of these were reactivated and also that some new ones formed.

LATE NORTHWARD-STRIKING FAULTS

Late faults which strike northward are exposed in the Last Chance mine and United and Sutro tunnels near Lawson, in the Silver King and Silent Friend mines near Dumont and in the Pennsylvania and Washington tunnels in Fall River. The faults are high angle and range in strike direction from about north to northeast. They are all short and are only slightly mineralized.

ORE DEPOSITS

The ore deposits of the district are fissure veins that formed by deposition of vein minerals in open spaces and to a minor degree by replacement of country rock. They are composed chiefly of common base-metal sulfides in a gangue consisting of quartz, clay minerals and sericite, carbonate minerals, and, locally, barite. Locally the veins contain uraninite or, where oxidized, high-valent uranium minerals. Uranium ores have been produced from the Jo Reynolds mine. Inasmuch as the veins are small, they have been worked principally for gold and silver, and base metals have been produced only as byproducts.

Most of the veins are in faults or vein fissures which strike east-northeast, west-northwest, and east, and which are inferred to have been formed during the Laramide orogeny, probably in early Tertiary time, although a few of the older faults of the breccia-reef system are also mineralized. Although widely distributed (pls. 2, 3), the veins are most abundant in an area near Lawson, in a small area east and northeast of Dumont, and in a small area in upper Fall River. Like the Tertiary porphyries, the veins are generally less abundant and less continuous in this dictrict than in adjoining districts to the east and south.

The ore shoots are localized by irregularities in the dip or strike of the vein fissures, by fissure intersections, and in some places, by unknown factors. Most uranium deposits in the Fall River area are confined to parts of sulfide-bearing veins which cut garnetiferous gneiss. The garnetiferous rocks are more strongly pyritized and carbonitized than other rock units, and they probably provided a chemical wall rock control for the uranium deposition.

Most of the veins can be classed in one of three mineralogic types, pyrite, composite, and galena-sphalerite. The composite veins contain pyrite and at least one of the base-metal sulfide minerals. The pyrite veins contain only low-grade gold ores; the composite veins are locally rich in gold, moderately rich in silver, and contain copper, lead, or zinc recoverable as byproducts. The galena-sphalerite veins are locally rich in silver and contain lead, zinc, and rarely copper which are recoverable as byproducts or coproducts. Both the composite and the galena-sphalerite veins can be further subdivided by mineralogy.

The district shows a zonal distribution of vein types. Pyrite and composite veins occur chiefly in the southern parts of the Fall River and Dumont areas; they give way from north and west, to composite or galena-sphalerite veins. Galena-sphalerite veins seem to grade into nearly barren veins exposed in the far western and northwestern parts of the district.

VEINS AND ORE SHOOTS

Veins show different types of relations to wallrock depending largely on whether open-space filling or replacement was the dominant factor in their origin. In general, replacement was a greater factor in the formation of pyrite veins than in the formation of galena-sphalerite veins, and certain pyrite veins such as the Syndicate near Dumont and the Berry in the Fall River area were formed largely by replacement. Sulfide-rich parts of the composite and galena-sphalerite veins commonly occur in a fissure on the hanging wall or footwall side of the vein zone. These parts of the veins probably formed mainly by open-space filling; where sufficiently wide the sulfide-rich vein material was mined separately and shipped directly to the smelter, hence the term "smelting ore" found in many of the older descriptions of the mines. Many veins are bounded or cut by thin gouge-filled fractures reflecting postmineralization movement on the vein fissures.

The average width of the productive veins is perhaps 3 feet, of which a foot or less is sulfide rich, but many veins are thinner and a few are much wider. Parts of the Free America vein, for example, are more than 30 feet wide, and the Wild Wagoner lode is as much as 50 feet wide. The slightly metalized Watt Stemble vein averages about 10 feet in width.

Most of the ore shoots of the district apparently occupy former openings or porous parts of the vein fissures; such openings are related either to movement on irregular premineralization faults or to intersections of fractures. Examples of ore shoots localized by movement on curved faults occur along the Albro, California, and St. James veins, and possibly also along the Comstock, Boulder Nest, and Jo Reynolds veins. In general, because northwest-trending fissures had dominantly left lateral movements, the more west-striking parts of these veins tended to open and became the most favorable sites for mineralization, and hence, for ore bodies. Similarly, right lateral movements on northeast-striking faults tended to open up the more eaststriking segments of these veins. Ore shoots localized by fault intersections can be seen in several small mines and can be inferred in some larger mines. Massive pods of pyrite-rich ore are localized at the intersection of steep and nearly flat veins in the Ruby mine and the Torrey tunnel east of Dumont. The major ore shoots in the Silver King mine are possibly related to the juction of the low-angle east-northeast-trending Silver King vein and crosscutting steep north-striking veins.

The ore deposits range in size from small pods a few feet in maximum dimension to shoots having a strike length of as much as 1,000 feet. In general, the ore shoots in the Dumont and Fall River areas are smaller than those of the Lawson area. The more productive veins near Dumont, such as the Albro and California, contain shoots having a maximum strike length of only about 200 feet. In upper Fall River, one shoot on the Golconda vein reportedly had a strike length of more than 400 feet, but exposures in the Almaden, Golconda, and Standard mines indicate that most of the shoots were much smaller, perhaps no more than 50 feet. In contrast, the shoots on the Jo Reynolds and American Sisters veins in the Lawson area had maximum strike and pitch lengths of about 1,000 feet. Production and extent of workings indicate that the ore shoots in the White and Boulder Nest mines of the Lawson area must also have been large.

MINERALOGY

More than 30 ore and gangue minerals have been identified from the district. Of these, pyrite, quartz, sphalerite, galena, and carbonate minerals are very abundant in primary ores. Others such as chalcopyrite and tennantite are moderately abundant. A few minerals including ferberite and niccolite are known from only one locality. The minerals, exclusive of sericite and clay minerals found in altered wallrock, are listed in table 14, along with their relative abundance and classification as primary or secondary.

Samples of pyrite, sphalerite, chalcopyrite, galena, and pitchblende were separated by hand picking for semiquantitative spectrographic analyses; some samples were selected for fire assay and chemical analyses. In most samples, quartz and intergrown sulfides were the main impurities and were much less abundant than the separated mineral. Pitchblende samples, particularly those composed mainly of the sooty variety, were difficult to separate and hence were very impure. The results of analyses of sulfides (table 15) indicate that silver is associated with sphalerite and chalcopyrite as well as with galena. Analyses of pitchblende separates (table 16) show that pitchblende from the Fall River area is characterized by associated rare earths and nickel, but that zirconium, characteristic of many pitchblende samples from the Front Range (Sims and others, 1963, p. 53), is sparse except in pitchblende from the Jo Reynolds mine.

TABLE 14.—*Summary of vein mineralogy,*[1] *Lawson-Dumont-Fall River district*

[Abundance: S, sparse (but can be locally abundant); M, moderately abundant; A, abundant; O, known from one occurrence only]

Mineral	Composition	Abundance	Primary	Secondary
Argentite	Ag_2S	S	×	×
Ankerite	$Ca(Mg, Fe)CO_3$	S	×	------
Barite	$BaSO_4$	M	×	------
Bornite	Cu_5FeS_4	O	×	------
Calcite	$CaCO_3$	A	×	------
Cerargyrite	$AgCl$	S	------	×
Cerussite	$PbCO_3$	O	------	×
Chalcanthite	$CuSO_4 \cdot 5H_2O$	S	------	×
Chalcocite	Cu_2S	S	?	×
Chalcopyrite	$CuFeS_2$	M	×	?
Covellite	CuS	S	?	×
Dolomite	$Ca\,Mg\,(CO_3)_2$	M	×	------
Dumontite	$Pb_2(UO_2)_3(PO_4)_2(OH)_4 \cdot 3H_2O$	O	------	×
Ferberite	$FeWO_4$	O	×	------
Galena	PbS	A	×	------
Gold	Au	S	×	×
Hematite	Fe_2O_3	O	×	------
Limonite	$Fe_2O_3 \cdot nH_2O$	A	------	×
Marcasite	FeS_2	O	×	------
Molybdenite	MoS_2	S	×	------
Niccolite	$NiAs$	O	×	------
Pararammelsbergite(?)	$NiAs_2$	O	×	------
Polybasite-pearceite	$Ag_{16}Sb_2S_{11}$-$Ag_{16}As_2S_{11}$	S	×	?
Proustite-pyrargyrite	Ag_3AsS_3-Ag_3SbS_3	S	?	×
Pyrite	FeS_2	A	×	------
Quartz	SiO_2	A	×	------
Siderite	$FeCO_3$	M	×	------
Silver	Ag	S	?	×
Sphalerite	ZnS	A	×	?
Tennantite	$Cu_{10}(Fe,Cu)_2As_4S_{13}$	M	×	------
Tetrahedrite(?)	$Cu_{10}(Fe,Cu)_2Sb_4S_{13}$	O	----	×
Torbernite-zeunerite[2]	$Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$-$Cu(UO_2)_2(AsO_4)_2 \cdot 10$–$16H_2O$	S	----	×
Uraninite, variety, pitchblende.	[3] UO_2	S	×	?

[1] Exclusive of sericite or clay minerals.
[2] Possibly metatorbernite-metazeunerite, same chemically except $8H_2O$.
[3] Natural uraninites have the general formula $(U^{+4}_{1-x}U^{+6}_{x})O_{2+x}$.

TABLE 15.—*Semiquantitative spectrographic analyses and chemical analyses*[1,2] *of pyrite, sphalerite, chalcopyrite, and galena separates*

[Spectrographic analyses are reported as weight percent; logarithmically subdivided powers of 10 are used; reported values represent a theoretical range in percent, for example, 0.×+=0.46–1.0; 0.×=0.22–0.46; 0.×−=0.1–0.22; ××.=>10 percent. Analysts, R. G. Havens, N. M. Conklin, D. L. Skinner, and E. C. Mallory]

Sample	Si	Al	Fe	Au	Ag	As	Bi	Cd	Co	Cu	Mn	Ni	Pb	Sb	Zn
Pyrite															
7B-1	0.×	<0.005	××.	[1] 0.28	[1] 2.48	[1] 0.08	0.00×+	0.0×−	0.00×+	[2] 0.55	0	0.00×	0.×+	0.0×+	[2] 2.20
D5-22-1	.×	.0×	××.	[1] .88	[1] .12	0	0	0	.0×−	[2] .001	0	.0×−	0	0	[2] .93
1A	×.−	.0×+	××.	0	.00×	0	.0×−	0	.00×	.0×	.0×−	.00×	.×−	.0×	.×
Sphalerite															
JRC-11C-55	0.×+	0.0×−	[2] 3.7	0	[1] 63.36	0	0	0.×−	0.000×+	0.×+	0.0×	0.000×+	×.−	0.0×	××.
JRC-10B-55	.×	≤.005	×.	[1] Tr.	.×−	0	0	.×−	.00×	×.−	.0×	.00×	.0×+	.0×	××.
Tabor	.×+	≤.005	.×+	0	.0×	0	0	.×−	.000×+	.×	.0×	0	×.−	0	××.
Unknown	------	------	------	[1] Tr.	[1] 79.20	------	------	------	------	[2] .25	------	------	[2] 9.00	------	[2] 46.60
Chalcopyrite															
JRC-10A-55	0.×+	<0.005	××.	0.0×	0.×	0	0	0	0	××.	0.0×+	0.00×−	0.×	0	0.×
5	.0×	<.005	××.	0	.×−	0	0	0	0	××.	Tr.	0	.×−	.0×	.×−
Go-53-55	.×	.0×	××.	0	.×	0	.×	.0×−	.00×+	××.	.0×+	.00×−	>2	.0×	.×+
Galena															
JRC-11A-55	0.×	<0.005	×.	0	[1] 101.08	0	0	0.0×−	0.000×+	0.×−	0.00×	0.00×−	[2] 67.69	0.0×+	[2] 5.83
1A	.×	≤.005	.0×+	0	.0×−	0	.00×+	.00×	0	.0×+	.00×	.000×	××.	.0×−	.×−
4	<.01	<.005	<.002	0	.×−	0	0	0	0	.0×	0	.000×+	××.	0	0
Unknown 1	------	------	------	Tr.	[1] 6.24	------	------	------	------	[2] .35	------	------	[2] 61.0	------	[2] 2.1
Unknown 2	------	------	------	[1] .03	[1] 7.17	------	------	------	------	[2] .20	------	------	[2] 76.5	------	[2] 1.20
Unknown 3	------	------	------	[1] .08	[1] 3.10	------	------	------	------	------	------	------	[2] 51.0	------	------
Unknown 4	------	------	------	------	[1] 14.00	------	------	------	------	------	------	------	[2] 73.0	------	------

See footnotes on following page.

[1] Fire assay, reported in ounces per ton.
[2] Chemical analyses, reported in percent.

7B-1.	Medium-coarse-grained pyrite in quartz gangue. Albro mine, 3d level, west of shaft.
D5-22-1.	Dump specimen, coarse-grained pyrite in white quartz gangue; no associated metallic minerals. Prospect, Dumont area, 1,200 ft NE. of Happy Thought mine.
1A.	Medium-grained pyrite. Ella mine, 1,750 ft ESE. of mouth of Spring Gulch.
JRC-11C-55.	Resin sphalerite. Jo Reynolds mine.
JRC-10B-55.	Dark sphalerite; polished section shows polybasite. Jo Reynolds mine, raise on Cross vein.
Tabor.	Dark sphalerite. Tabor tunnel, from the Tabor vein.
Unknown.	American Sisters dump (Bastin and Hill, 1917, p. 340).
JRC-10A-55.	Intergrown with dark sphalerite. Jo Reynolds mine, Elida level, Cross vein.
5.	With green sphalerite in carbonate gangue. St. James mine.
Go-53-55.	Golconda tunnel, No. 4 vein, adjacent to overhand stope.
JRC-11A-55.	Medium-grained galena; associated with resin sphalerite and polybasite-pearceite. Split off Jo Reynolds vein exposed in drift northwest of shaft, Elida level.
1A.	Medium-grained galena, intergrown with green sphalerite and chalcopyrite. St. James drift adit.
4.	Medium-grained galena in crystalline quartz vein. Orient mine, 3d level west of shaft.
Unknown 1.	American Sisters dump (Bastin and Hill, 1917, p. 340).
Unknown 2.	Senator mine, 115 ft above tunnel level in raise 675 ft SW. of shaft (Bastin and Hill, 1917, p. 346).
Unknown 3.	Senator mine, just above tunnel level in raise 675 ft SW. of shaft (Bastin and Hill, 1917, p. 346).
Unknown 4.	Steel galena. Jo Reynolds mine, Elida level (Bastin and Hill, 1917, p. 341).

TABLE 16.—*Semiquantitative spectrographic analyses, in percent, of pitchblende separates*

[Analyses are reported as weight percent; logarithmically subdivided powers of 10 are used; reported values represent a theoretical range in percent, for example: XX.=>10; 0.X+=0.46–1.0; 0.X=0.22–0.46; 0.X−=0.1–0.22]

Sample	Si	Al	Fe	Ag	As	Co	Cu	Mn	Mo	Ni	Pb
Al-1-55	------	X.+	X.	X.+	XX.0	0.0X+	0.X	X.−	X.0	X.0	X.0
EWT-42A-54	------	--------	0	0	0	.X	.0X	X.−	.0X+	.X+	0
EWT-42B-54	X.−	.X−	.X+	.00X	.X	.0X−	.0X−	.X+	.0X+	.X+	.X−
EWT-20-54	X.	X.0	.X	.0X−	0	.0X−	.0X	.X+	.X+	.0X−	.X−
JRC-13-55	------	X.−	.X+	.X	0	0	.X	.X−	.0X	0	X.0

Sample	Sb	U	V	W	Y	Yb	Dy	Er	Nd	Zn	Zr
Al-1-55	0.X+	XX.0	0.00X+	0	0.X+	0.0X+	0.X−	0.X−	0.0X+	X.−	0.0X
EWT-42A-54	0	XX.	0	0	.0X	0	0	0	0	.X+	0
EWT-42B-54	.0X+	X.+	.00X+	0	.X	.0X	.0X	.0X	.0X	X.−	.0X−
EWT-20-54	.0X+	X.−	.00X+	0	.0X	.00X−	.00X−	.00X	Tr.	X.−	.000X
JRC-13-55	0	XX.	0	X.−	.0X	0	0	0	0	0	X.−

Au, Bi, Cd, looked for but not found.

Al-1-55. Thin veins of hard pitchblende, pyrite, and other metallic minerals cut garnetiferous gneiss on hanging wall of Blazing Star vein; Almaden mine, lower level, about 500 ft from portal.
EWT-42A-54. Sooty coatings in fractured garnetiferous gneiss; Almaden mine, upper level.
EWT-42B-54. Same as 42A.
EWT-20-54. Sooty; Golconda mine, No. 4 vein, footwall vein north of winze.
JRC-13-55. Pod in vein subparallel to Jo Reynolds cut at 130 ft in American Sisters crosscut on Elida level; hard pod, frozen on wall, cut by carbonate veinlets. Jo Reynolds mine.

ORE MINERALS

NATIVE ELEMENTS

Small amounts of both native gold and native silver occur in the ores of the district. The metal content of various ores indicates that the free gold is mainly in pyrite-rich veins and the free silver mainly in galena-sphalerite-rich veins. According to data given by Bastin and Hill (1917, p. 154), about 75 percent of the gold in the ores is in the native or free state and most of this is in microscopic or submicroscopic particles. Locally, however, gold can be seen megascopically. Coarse gold in a quartz gangue, presumed to be hypogene, has been reported from the Silent Friend (Bastin and Hill, 1917, p. 349) and Golden Calf mines (B. R. Stanhope, oral commun., 1953), and coarse gold—enlargement caused by supergene processes—occurs in the oxidized parts of the veins.

Native silver is described by Bastin and Hill from the Almaden mine in the Fall River area, and the Jo Reynolds, Panama and Millington veins near Lawson. With the exception of flakes of native silver reported from the ninth level of the Jo Reynolds mine, the silver occurrences are in the shallower workings and are probably of supergene origin.

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SULFIDES

PYRITE

Pyrite is the most abundant metallic mineral; it is the principal metallic mineral in many veins and is conspicuous in most others except some that are rich in galena and sphalerite. It occurs in white to gray quartz in siliceous veins as well as in sulfide-rich veins. It also is commonly disseminated in wallrock near the veins, where it preferentially replaces magnetite and other iron-bearing minerals. Most of the pyrite has a cubic habit, but pyrithohedral forms are not uncommon. The pyrite ranges in size from microscopic particles to crystals as much as 1 inch across. Microscopically, much of the pyrite shows slight to moderate anisotropism.

MARSCASITE

Marcasite is probably a rare mineral; it was positively identified only from the Mary mine where it occurs with pyrite, pitchblende, and very small amounts of galena, sphalerite, and chalcopyrite.

SPHALERITE

Sphalerite is abundant in some veins of the Lawson area and in the upper Fall River area, and is moderately abundant in a few veins northeast of Dumont. It is typically medium to coarsely crystalline, generally subhedral to massive, and is variously colored, ranging from white or very pale green to resinous and dark brown. Much of the sphalerite in the upper Fall River area is pale green and translucent; sphalerite in the Lawson area is generally brown, but green sphalerite, associated with chalcopyrite and galena, is conspicuous in the Boston and St. James dumps in Young America Gulch. Small light-greenish-gray sphalerite crystals that coat fractures in massive sulfide ores in the Silver King mine may be supergene.

Three hand-picked separates of sphalerite from the Lawson area were analyzed (table 15). All three contained about 0.15 percent cadmium and appreciable concentrations of silver. A polished section of JRC–10B–55, which contained about 0.3 percent silver, showed polybasite associated with the sphalerite. A polished section from the Tabor mine sample, which contained about 0.03 percent silver, showed no copper or silver minerals. Bastin and Hill (1917, p. 340) reported 79.2 oz of silver per ton in a sphalerite-rich sample from the American Sisters dump (table 15, this report).

CHALCOPYRITE

Chalcopyrite is most abundant in a small group of veins northeast of Dumont, including the Albro, Golden Calf, and Heliotrope. It is also moderately abundant in the Golconda and nearby veins in the upper Fall River area and in the Pioneer and adjacent veins northwest of Dumont. Chalcopyrite occurs in small amounts in most of the veins in the western part of the district and is mainly massive in form. Each of three analyzed chalcopyrite separates (table 15) contained appreciable silver, and one contained gold.

GALENA

Galena is the most abundant sulfide mineral in some veins of the western part of the district, as for example, the Boulder Nest-Free America vein northwest of Lawson. The galena is commonly crystalline, crystals ranging in size from extremely fine to coarse. Seven analyses of galena separates are shown in table 15; three of these are of samples collected by the authors, and four are taken from Bastin and Hill (1917). The samples showed a considerable range in silver content — from 3.10 to 101.08 oz per tone; none of the samples showed an appreciable gold content, but all were from gold-poor ores. The galena in sample JRC–11A–55, which assayed more than 100 oz of silver per ton, is known to be associated with polybasite-pearceite.

MOLYBDENITE

Molybdenite has been found or reported in six mines. It occurs with pyrite in fracture coatings in Tertiary hornblende granodiorite porphyry at the Mary mine and in fracture coatings in Precambrian gneiss in the Dubuque mine. Molybdenite occurs in a thin quartz vein 110 feet from the portal of the Pennsylvania tunnel, and it is reported also from the nearby Mandolina mine (Bastin and Hill, 1917, p. 311). A. R. Baldo (oral commun., 1955) reported sparse flakes of molybdenite on the Elida level of the Jo Reynolds mine. Recently molybdenite was also reported (K. E. Baker, oral commun., 1963) from the Clifford and nearby mines.

ARGENTITE

Argentite has been identified from two mines, and it probably occurs in small amounts in many of the silver-rich veins of the western part of the district. It was observed as fracture coatings in near-surface ore at the Almaden mine and in intergrowths with pearceite in polished sections taken from the Elida tunnel level of the Jo Reynolds mine.

CHALCOCITE, BORNITE, AND COVELLITE

The copper sulfides chalcocite, bornite, and covellite are now sparse in the district, but they probably were constituents of the supergene "sulphuret" ore mentioned in old reports (noted in the mine descriptions of Hawley and Moore, 1967). Covellite was observed only as late supergene(?) fracture coatings; bornite was reported by Bastin and Hill (1917, p. 335) from the 13th level of the Schwarz shaft on the White vein. (See table 14.)

SULFOSALTS

The sulfosalt minerals of the district belong to three mineral groups: the copper-rich tetrahedrite-tennantite group and the silver-rich polybasite-pearceite and proustite-pyrargyrite groups. All three groups are solid solution series in which the principal substitutions involved are in the metals—that is, copper and silver and arsenic and antimony. In the district, minerals of these series are mostly arsenic rich and so can be called, respectively, tennantite, pearceite, and proustite. The silver-rich variety of tetrahedrite freibergite—was identified by X-ray diffraction from the Almaden mine.

Tennantite occurs locally in many veins; it is abundant in copper-rich veins such as the Albro vein in the Dumont area and the No. 4 vein in the Golconda tunnel in the Fall River area. In most places the tennantite is massive and is intergrown with sphalerite, chalcopyrite, and galena. Pearceite is found principally in the silver-rich veins near Lawson and in the upper part of the Fall River area, where it occurs with tennantite. Proustite generally occurs as thin coatings on fractures which cut the sulfide-rich ores; locally, as in the Almaden mine (Bastin and Hill, 1917, p. 316–317), it occurs in veins and masses as much as several inches across and forms very rich silver ores.

OXIDES

URANINITE, VARIETY PITCHBLENDE

Pitchblende is known to occur in nine mines in the district, and occurrences of radioactivity in oxidized parts of other veins suggests that pitchblende is a relatively common mineral, although generally present only in small amounts. The main occurrences are in the Mary, Golconda, and Almaden mines in the Fall River area, in Albro and Golden Calf mines near Dumont, and in the Jo Reynolds and Bellevue-Hudson mines near Lawson.

The pitchblende is of two types. Most of it is in a soft finely divided form (sooty pitchblende), but some is in the hard botryoidal form. In the No. 4, Golconda, and Virginia veins exposed in the Golconda tunnel and in the Golden Calf and Albro veins, the pitchblende is of the sooty variety. In other veins, such as the Mary and

Almaden, both types are found. Hard botryoidal pitchblende was also noted in dump sample from surface workings on the Golconda vein. The hard botryoidal pitchblende is old paragenetically; it occurs locally with nickel arsenides and freibergite in addition to common sulfides and sulfosalts. The sooty pitchblende is young paragenetically.

Analyses of pitchblende separates (table 16) suggest that the pitchblende in the Fall River area has a different suite of trace elements than that in the Jo Reynolds mine, which resembles the pitchblende in the Central City district (Sims and others, 1963). The samples from the Fall River area are characterized by a relatively high concentration of nickel which is probably present in discrete mineral phases and in rare-earth elements. In contrast, the separate from the Jo Reynolds mine contains sparse rare earths but has a high content of tungsten and zirconium.

HEMATITE AND "LIMONITE"

Hematite was noted in plates as much as a fourth of an inch across associated with galena and chalcopyrite and sparse pyrite in a polished section from the Chicago Belle mine; it is probably primary. Hydrated ferric oxides; generally referred to as limonite, are abundant in the oxidized parts of veins where they formed principally by the oxidation of iron-bearing sulfides.

OTHER ORE MINERALS

Several other ore minerals, of various compositional groups, occur very sparsely in the district. Ferberite was noted as small crystals in dump rock from the Earl of Kent mine south of Dumont, and niccolite and pararammelsbergite(?) occur with pitchblende and freibergite in the Blazing Star tunnel of the Almaden mine in the Fall River area.

Cerussite, cerargyrite, chalcanthite, dumontite, and torbernite-zeunerite are sparse secondary minerals. Bastin and Hill (1917, p. 316, 339) mention cerargyrite as occurring at the Almaden and Millington mines, and cerussite has been reported from oxidized ores mined at the Syndicate mine. A lead uranyl mineral, dumonite (named for a Belgian geologist, not for the town of Dumont) is found at the Peabody (Robineau) prospect, and green platy copper uranyl minerals belonging to the torbenite-zeunerite group (or possibly the less hydrous metatorbernite-metazeunerite group) are found in thin veins which cut primary ore at the Mary, Golconda, and Almaden mines and also at the Peabody prospect.

GANGUE MINERALS

Quartz, of several types, is the most common gangue mineral and occurs in veins of all types. Coarse-grained milky and dark-gray vitreous quartz characterizes veins rich in pyrite; fine-grained to chalcedonic subvitreous quartz is found in veins rich in galena and sphalerite. Carbonate minerals, including calcite, siderite, dolomite, and ankerite, are locally abundant, particularly in veins containing galena and sphalerite. Barite has a more limited distribution than the carbonates, but it is common in some veins near Lawson and also in veins in upper Fall River.

The altered rocks adjacent to the veins are composed mainly of sericite, clay minerals, quartz, carbonate minerals, and pyrite. Clay minerals found in the altered rocks are kaolinite, illite, montmorillonite, and mixed-layer clays, Tooker, 1963).

CLASSIFICATION AND METAL CONTENT OF THE VEINS

Most of the veins of the district are sulfide bearing and, depending on their mineral content, are classed as (1) pyrite, (2) composite, or (3) galena-sphalerite. The composite type has a mixed sulfide suite consisting of abundant pyrite and at least one other sulfide or sulfosalt mineral, which in many places is chalcopyrite or tennantite.

Besides differences in the proportions of sulfide minerals, each vein type has characteristic gangue minerals and different amounts or proportions of the precious metals gold and silver. Typically the pyrite veins have a quartz gangue, composite veins a quartz-carbonate gangue, and galena-sphalerite veins a quartz-carbonate-barite or quartz-barite gangue. The quartz in the pyrite veins and in some parts of composite veins is either milky, nearly pure, and little fractured, or is a dull gray because of finely divided pyrite or shearing. The quartz characteristic of the galena-sphalerite veins is finer grain, and, locally, has a chalcedonic appearance. Gold is most abundant in the composite veins and silver in the galena-sphalerite veins; neither gold nor silver is abundant in most pyrite veins. The relative abundance of ore and gangue minerals in the three types of veins is shown graphically on figure 4. A variant of the galena-sphalerite type is a quartz-carbonate type deficient in sulfides, found in the western and northwestern parts of the district. Veins of this subtype are composed chiefly of fine-grained almost chalcedonic silica and iron-bearing carbonates, but locally they contain small amounts of pyrite, galena, or sphalerite.

The classification of veins used here is somewhat similar to the classification used by Bastin and Hill (1917, p. 105–114). We use

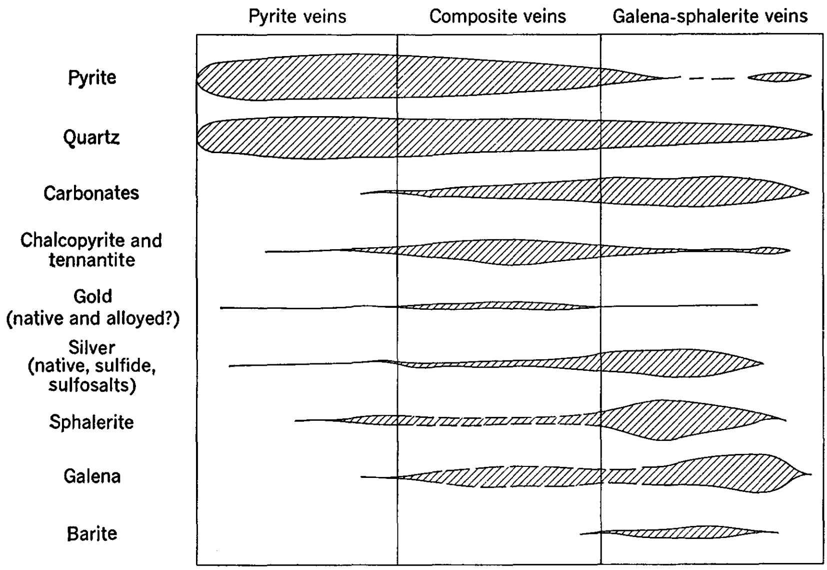

Figure 4.—Relative mineralogic composition of pyrite, composite, and galena-sphalerite veins. Dashed line shows inferred relation.

the term "vein" rather than "ore" in order to classify a vein as a whole rather than its ore shoots and because a vein can have the required mineral assemblage but at no place constitute an ore. We also use the term "composite" in a different sense; Bastin and Hill (1917, p. 112–113) used the term to signify dual states of mineralization, with galena-sphalerite deposition following that of pyrite. As used here, the term means only a mixed mineral assemblage and has no paragenetic connotations.

PYRITE VEINS

The pyrite veins are composed dominantly of pyrite, quartz, and mineralized and altered wallrock, but they also contain small amounts of other ore minerals, chiefly sphalerite, galena, chalcopyrite, and tennantite, which only rarely are visible megascopically. The pyrite occurs as scattered crystals in gangue, commonly either as coarse brassy cubes in white quartz or as fine crystals in dark quartz, and pyrite occurs in massive form in veins and veinlets in altered wallrock. The other metallic minerals are present mainly in microscopic veinlets which cut quartz or pyrite.

The pyrite veins are massive, commonly showing little of the banding found in typical fissure veins. They also commonly have gradational contacts, and in many places consist of minute pyrite veinlets or disseminated crystals evidently formed by replacement in altered rock adjacent to a fracture. Examples of typical pyrite veins are the Berry, Dubuque, and Standard 2 and 4 veins in the Fall River area and the Eagle, Kaverne, and Syndicate veins near Dumont.

Although the pyrite veins are typically low in grade, assays show that both gold and silver are commonly present and that silver exceeds gold in amount but not in value. Representative gold: silver ratios are 1:9 in the lower east tunnel of the Syndicate mine and 1:4 in the Kaverne mine. The ratio in the Syndicate mine was computed from unweighted assays given in Bancroft (1914); gold averages 0.11 oz per ton and silver 1.07 oz per ton. The ratio at the Kaverne mine was determined from production data; gold averaged 0.25 oz per ton and silver 1.00 ounces per ton.

COMPOSITE VEINS

The composite veins contain abundant pyrite and one or more of the minerals chalcopyrite, sphalerite, galena, and tennantite in a quartz gangue or, less commonly, in a carbonate gangue. They locally contain pitchblende and significant concentrations of gold and silver. The gold probably is mainly in native form and the silver in sulfosalt minerals and chalcopyrite. The chalcopyrite, sphalerite, galena, and tennantite occur principally in sharp-walled veins and veinlets that cut silicified and pyritized rocks of the vein zone, but they occur also in intergrowths with pyrite or quartz. Composite veins characterized by copper minerals as the chief nonpyritic component include the Heliotrope, Golden Calf, and Virginia. Veins characterized by copper minerals, galena, and sphalerite as well as pyrite are the Albro, California, Golconda 4, and Pioneer. Veins containing galena and sphalerite in addition to pyrite are the Alexander, Pennsylvania, Saginaw, and Silver King.

The composite veins have been mined principally for gold and secondarily for silver and the base metals copper, lead, and zinc. Much of the output has been in the form of smelting ores of high grade. Ranges in the metal content of smelting ores from representative composite veins, and of concentrates from the California vein, are shown in table 17. The figures do not represent all ore mined, nor necessarily the entire output for the year indicated.

GALENA-SPHALERITE VEINS

Galena-sphalerite veins commonly contain small amounts of pyrite, chalcopyrite, tennantite, and silver minerals, including argentite and

TABLE 17.—*Metal content of some ores from composite veins*

Mine	Years	Crude ore (tons)	Concentrates (tons)	Au (oz per ton)	Ag (oz per ton)	Cu (percent)	Pb (percent)	Zn (percent)
Albro	1914	42	0	1.76	20.1	5.9	7.4	0
	1916	281	0	2.83	13.14	5.9	.02	0
Alexander [1]	1922–26	11.84	0	1.20	72.0	0	5.3	13.7
California vein (Specht tunnel)	1938–39	13,190	1,529	.176	1.43	.58	.047	0
Golconda tunnel [2]	1908	2	0	9.15	68.0	8.1	0	0
	1909	32	0	2.48	22.4	2.0	0	0
	1910	30	0	1.25	9.2	1.1	0	0
Heliotrope	1915–16	22	0	.665	14.0	2.11	.9	0
Pioneer	1910	21	0	.421	9.24	.1	27.4	24.1
	1919	19	0	.55	16.00	2.51	7.00	1.40

[1] Calculated from records of the Idaho Springs sampling works; all others from records of the U.S. Bureau of Mines. All records published with permission.
[2] Vein not known (Bastin and Hill, 1917, p. 316); probably from copper-rich part of No. 4 vein or Golconda vein.

pearceite; more rarely they contain pitchblende and other metallic minerals. The gangue minerals differ from place to place. Quartz-barite gangue occurs in the upper Fall River area, as in the Blazing Star and Clifford veins, and quartz-carbonate-barite gangue occurs in the Lawson area. Gangue predominates in some veins but is sparse in others.

The metal content of galena-sphalerite veins is in general greatest in those which have a quartz-carbonate-barite gangue. Although the veins with quartz-barite gangue are generally rather low in grade, they contain local pockets of high-grade silver ore that have been the source of most of the ore production. Analyses of representative ores from galena-sphalerite veins are given in table 18. The ore from the Almaden mine (Blazing Star vein) represents a vein which has a quartz-barite gangue; the others all have carbonate-bearing gangue. Both smelting and milling ores are represented; for example, the ore from the Jo Reynolds in 1906 was evidently mined selectively and was shipped as direct-smelting ore, but in 1907 and 1908, mining was on a less selective basis and the ore was milled. The metal content reported is that of the crude ore; figures reported do not represent all ore mined.

TABLE 18.—*Metal content of some ores from galena-sphalerite veins*

[Calculated from records of the U.S. Bureau of Mines and of the Idaho Springs sampling works; all records published with permission. Tons in sample represented; not necessarily total production for years listed. N.g., not given]

Mine	Year	Crude ore (tons)	Concentrates (tons)	Au (oz per ton)	Ag (oz per ton)	Cu (percent)	Pb (percent)	Zn (percent)
Almaden (Blazing Star vein)	1904–28	928	0	0.143	48.5	Tr.	2.6	Tr.
Bellevue-Hudson	1912	170	0	.123	27.5	.1	19.4	11.1
	1914	57	0	------	85.37	0	10.2	0
	1918–19	108.48	0	.028	90.3	0	11.3	12.9
Jo Reynolds	1904	808	0	.090	55.0	0	6.2	N.g.
	1906	665	0	.056	47.0	0	5.4	9.6
	1907	6,608	414	.003	3.68	0	.47	.84
	1947	4,158	228	.014	12.25	.07	1.8	1.4
American Sisters	1907	238	0	.049	11.0	1.5	4.0	N.g.
	1909	3,000	260	.009	8.7	0	.25	1.3
Commodore tunnel	1909	73	0	.019	139	0	16.1	9.1
	1910	77	0	.041	49.2	0	18.0	11.0
	1911	29	0	.048	109.7	0	17.4	5.0
	1939	30	0	.025	148.2	Tr.	15.8	3.2
	1942	2,570	257	.003	4.9	.06	4.3	.8
	---------	25	0	.04	33.0	.16	30.3	8.0
Nabob	1949–50	1,570	156	.06	29.03	.34	5.2	N.g.
Murry	1901	30	0	3.0	31.0	0	0	0
	1916–19	63	0	.12	20.6	1.1	8.4	Tr.

HYPOGENE ZONING

REGIONAL PATTERN

Regionally the Lawson-Dumont-Fall River district is on the northwestern side of a large group of zonally arranged deposits (Sims and Barton, 1962, and Sims, Armstrong, and others, 1963, p. 24–26), including those of the Central City and Idaho Springs districts to the east, the Chicago Creek area and Freeland-Lamartine district to the southeast and south, and, possibly, the Georgetown and Silver Plume districts to the southwest (pl. 4). Centrally located areas of pyrite veins are found (1) south of Central City, (2) in the southeastern part of the Lawson-Dumont-Fall River district and adjacent areas, and (3) in the Freeland-Lamartine district about 1¾ miles south of Dumont. For convenience these areas are named the Central City, Clear Creek, and Freeland-Lamartine areas. These areas are alined, and an area containing copper- and gold-bearing pyrite veins (classed as composite veins, pl. 4) near Georgetown lies about on the southwestward projection of the line. Surrounding the pyritic areas are areas containing composite and galena-sphalerite veins, all within a larger area containing nearly barren veins. A large part of the Lawson area contains galena-sphalerite veins.

The three areas containing pyrite veins are possibly surface expressions of a single pyritic zone at depth. The Central City and Clear Creek areas are almost certainly parts of a single pyritic center inasmuch as they are separated on the surface by only a small area of composite veins, and, as noted by Bastin and Hill (1917, p. 16) and Collins (1930, p. 260–261), many composite veins of the Central City area change to pyrite veins with depth. A similar relation possibly holds between the Clear Creek and Freeland-Lamartine areas, inasmuch as Spurr and Garrey (1908, p. 329, 331–332) noted that galena-bearing ores in the upper part of the Freeland mine gave way downward to ores consisting mainly of pyrite and chalcopyrite or cupriferous pyrite.

The regional zonal pattern is not symmetrical with respect either to the larger bodies of Tertiary porphyry or to geologic structural features, although the northern part of the zoned area is approximately bisected by the axis of the Central City anticline (Sims, Armstrong, and others, 1963, p. 25; Sims, 1964). The northeasterly trend of the zoned area parallels the trend of the Idaho Springs-Ralston shear zone, but the shear zone seemingly has no influence on the pattern of metaliferous zoning. It is possible, however, that the area of enargite-bearing veins which transects the main zonal boundaries (pl. 4), may be related in some way to the shear zone or, as also suggested by spatial association, to a group of Tertiary porphyry plutons which crop out near Gilson Gulch and Pleasant Valley (Wells, 1960, pl. 19).

LOCAL PATTERN

Within the Lawson-Dumont-Fall River district, the general zonal pattern is simple in that veins in the southeastern part of the district are mostly of the pyrite type, whereas veins in the northern and western parts of the district are mostly of the galena-sphalerite type (pl. 4). Veins in the far western part of the area are of the nearly barren quartz-carbonate type. An intermediate area separating the pyritic and the galena-sphalerite vein areas contains composite veins. Local exceptions to this relatively simple pattern exist, however. A small area northeast of Dumont within the main area of pyrite veins contains composite veins, and in the eastern part of the district no zone of composite veins separates the zones of pyrite and galena-sphalerite veins.

Transitions from one vein type to another are not directly observable along any single vein, but they can be inferred from relations observed in different mines on the same vein or in groups of subparallel veins. The zonal arrangement of the three main vein types is illustrated in a part of the Fall River area (fig. 5). Pyrite veins

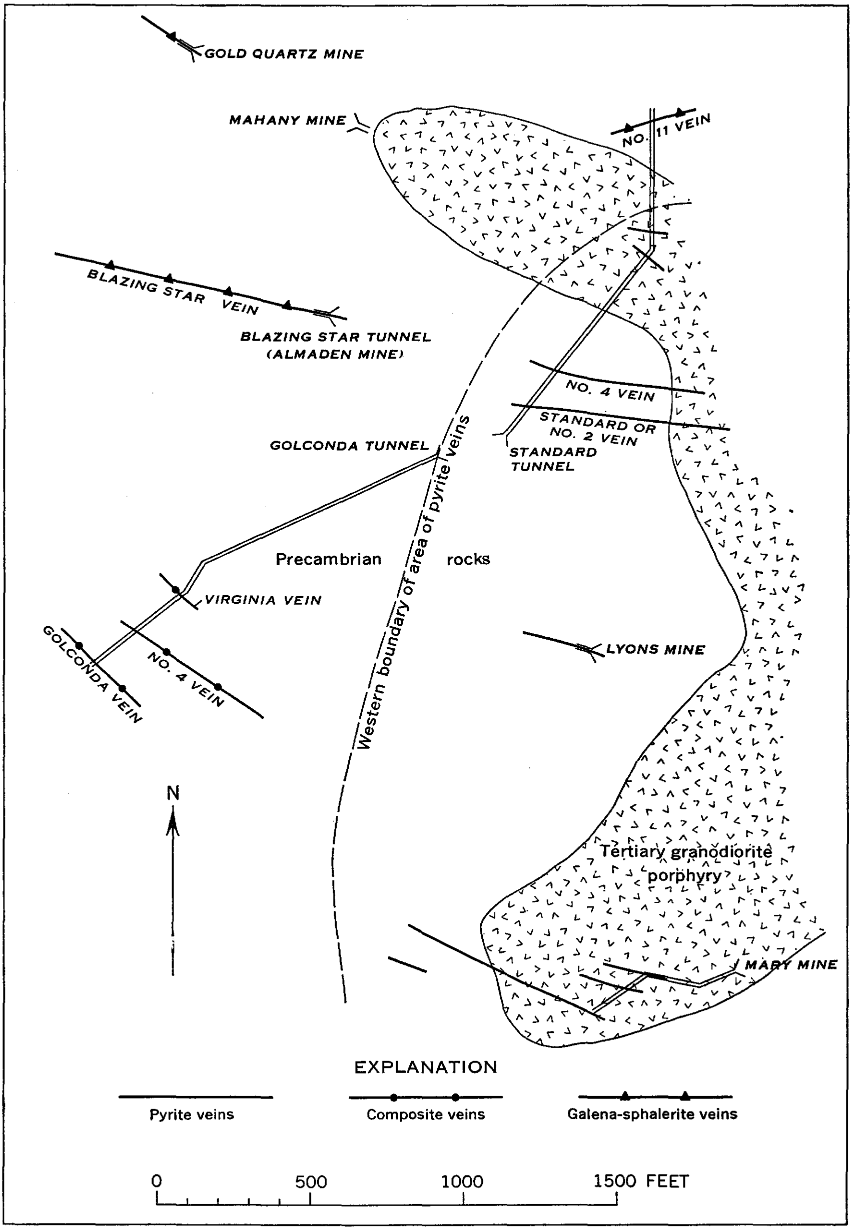

Figure 5.—Distribution of pyrite, composite, and galena-sphalerite veins in part of the Fall River area. In part modified from Bastin and Hill (1917).

occur in the southeast part of the area, whereas galena-sphalerite and composite veins occur in the north and west. As the map suggests, the Blazing Star galena-sphalerite vein may be a continuation of the pyritic No. 4 vein (Standard tunnel), and some of the composite veins of the Golconda tunnel may be continuations of the pyritic veins of the Mary tunnel. The presence of pyritic veins in or bordering the granodiorite stock suggests that the stock influenced mineral zoning, but data are not available to determine whether this relation exists elsewhere in the district.

Zonal arrangement on single veins or on parallel veins can also be inferred in the Dumont area. Galena-sphalerite veins exposed in the Little Superior mine are probable extensions of composite veins such as the Alexander, Golden Hope, and Copenhagen exposed along Mill Creek. In the small area of composite veins northeast of Dumont, the Silver King pyritic galena-sphalerite vein probably is the eastern continuation of the Heliotrope-Caledonia copper-bearing pyritic vein.

Galena-sphalerite veins exposed in the western part of the district probably grade into quartz-carbonate veins; such a relation in the Boulder Nest-Free America vein can be inferred from the description of the Boulder Nest vein in the Commodore tunnel by Bastin and Hill (1917, p. 334–335). A possible zonal change within the galena-sphalerite veins near Lawson is suggested by differences in the abundance of galena and sphalerite. The available data suggest that the Boulder Nest-Free America and the White veins north of Lawson contained relatively more galena than did the Jo Reynolds and American Sisters veins south of Lawson.

The zonal pattern of the veins furnishes a guide to aid exploration for ore in the district. The pyritic veins which occur in most of the southeastern and central part of the district are low in grade; the composite and galena-sphalerite veins, which occur in a local area in the pyritic zone and in the northern and western parts of the district, locally contain gold- and silver-bearing base-metal ore of good grade, and the areas containing veins of these kinds are thus more favorable for prospecting. Mining experience has indicated that quartz-carbonate veins (pl. 4, group 4) are generally unpromising.

PARAGENETIC SEQUENCE

The age sequence of the principal sulfide and sulfosalt minerals is commonly pyrite, sphalerite, chalcopyrite, tennantite or polybasite-pearceite, and galena. This sequence was established both by megascopic observations of veins and by microscopic studies of the ore, principally of veining relations and replacement textures. It is almost identical to that found in nearby areas by Harrison and Wells (1959, p. 42) and by Sims, Drake, and Tooker (1963, p. 41–42). In part, the sequence reflects solid-solution relations, as for example those between sphalerite and chalcopyrite, but in general the sequence probably reflects small differences in the actual time of deposition. The intergrown nature of sphalerite, chalcopyrite, tennantite, and galena, particularly in composite ores, suggests that the time intervals may have been very small.

SULFIDE VEINS

The general sequence of the common ore minerals, as determined megascopically and microscopically, is pyrite, sphalerite, chalcopyrite, tennantite, and galena; this sequence applies to all three of the main vein types despite the differences in proportions of minerals. Of the gangue minerals, quartz occupies about the same position in the paragenetic sequence in all types of veins, but the position of the carbonates differs in the composite and galena-sphalerite veins. In all three types of veins, quartz started to form before the deposition of metallic minerals and probably continued to form throughout the period of mineralization. In contrast, carbonates formed during late stages of, and after, sulfide deposition in composite veins, but formed before, during, and after sulfide deposition in galena-sphalerite veins.

A generalized paragenetic sequence of the vein minerals of the composite and galena-sphalerite veins is summarized in figure 6. The main differences between the two types of veins are the positions of the carbonates, the relative abundances of the minerals, and the rather complex late-stage relations in the galena-sphalerite veins. In composite veins, silver is present mainly in chalcopyrite and probably also in tennantite, and only locally forms discrete silver minerals such as pearceite. In galena-sphalerite veins, silver is more abundant and occurs in several silver minerals as well as in the crystal lattice of other sulfides and sulfosalts. The silver-bearing minerals show rather complex paragenetic relations. Some argentite and pearceite formed before galena and so is definitely hypogene, but some formed with ruby silver after galena where its origin is uncertain. Deposition of silver in definite hypogene and supergene stages, as well as in an inferred late hypogene stage, is indicated in figure 6*B*.

Fracturing or brecciation during the period of ore deposition is shown by cracked and brecciated vein minerals which are veined or

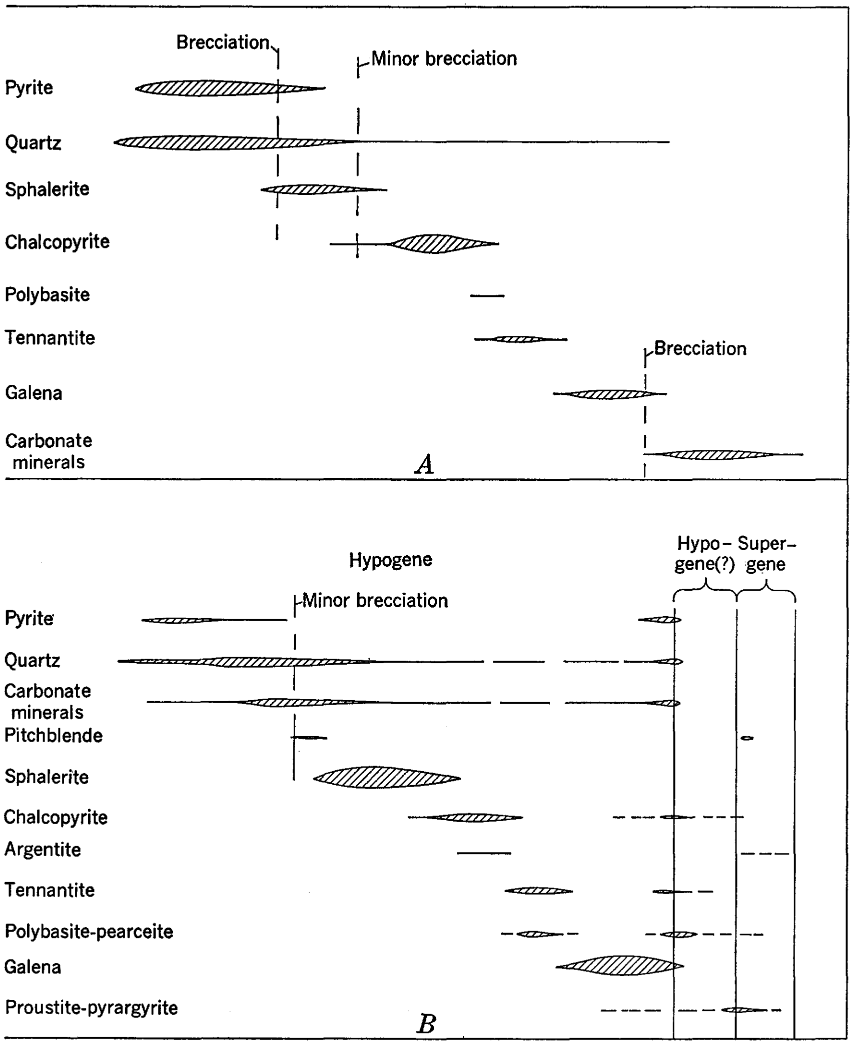

FIGURE 6.—General paragenetic sequence in veins. Dashed lines show inferred relations. *A*, Composite veins. *B*, Galena-sphalerite veins.

cemented by later minerals. In the pyrite and some composite veins, fracturing during quartz-pyrite deposition is shown by alternating layers and lenses of different types of quartz-pyrite vein material. Most typically it is shown by veinlets of white quartz and pyrite alternating with veinlets of gray quartz and fine pyrite. The two kinds of veinlets show no consistent age relation. Brecciation followed the deposition of most of the pyrite and preceded the deposition of most of the other ore minerals as shown especially in the composite veins (fig. 6*A*); these veins also show some brecciation which occurred after the formation of both the sphalerite and the galena.

Exceptions to the general paragenetic sequence occur in some places. Sphalerite deposited after galena was noted in polished sections from the Saginaw(?) vein of the Pennsylvania tunnel, the Ella(?) vein, and, megascopically, in the Jo Reynolds mine where a galena-rich vein is cut by a sphalerite-pyrite vein (in winze below the Elida level). Chalcopyrite, which in most places is older than sulfosalt minerals, is locally younger than sulfosalts and probably younger than galena. Almost simultaneous deposition of pyrite and sphalerite is suggested by the mutual-boundary type of contacts in the Pennsylvania vein, and nearly simultaneous deposition of sphalerite, chalcopyrite, tennantite, and galena is suggested by complex intergrowths of these minerals observed in the Albro and other composite veins.

PITCHBLENDE-BEARING VEINS

Pitchblende occupies two distinctly different positions in the paragenetic sequence. Hard botryoidal pitchblende is old, whereas sooty pitchblende is younger even than the carbonates in the composite veins.

Both sooty and hard pitchblende are found in the Blazing Star vein in the Almaden mine. The hard pitchblende forms sharp-walled veinlets which cut altered garnetiferous gneiss; it is associated at various places in the mine with argentite(?), freibergite, niccolite, and pararammelsbergite(?), as well as with the more common sulfide and sulfosalt minerals. The paragenetic sequence based on polished sections from several parts of the mine is shown in figure 7. The pitchblende is younger than pyrite, which here was formed largely by the sulfidation of iron-bearing minerals in garnetiferous gneiss wallrock. In a pod of ore in the Blazing Star tunnel, the pitchblende forms botryoidal masses which are deposited on the walls of a fracture and around scattered round grains of niccolite. A white nickel-bearing mineral, probably pararammelsbergite, separates the pitchblende and niccolite and apparently replaces both minerals. The central part of the pitchblende vein is partly filled with a fine-grained aggregate of freibergite and tennantite crystals, and this aggregate is cut by veinlets of chalcopyrite and galena. A semiquantitative spectrographic analysis of pitchblende from this locality showed ×.0+ percent silver, which content presumably can be attributed to adhering grains of freibergite. In another pod of ore in the upper adit, pitchblende was deposited after pyrite and before

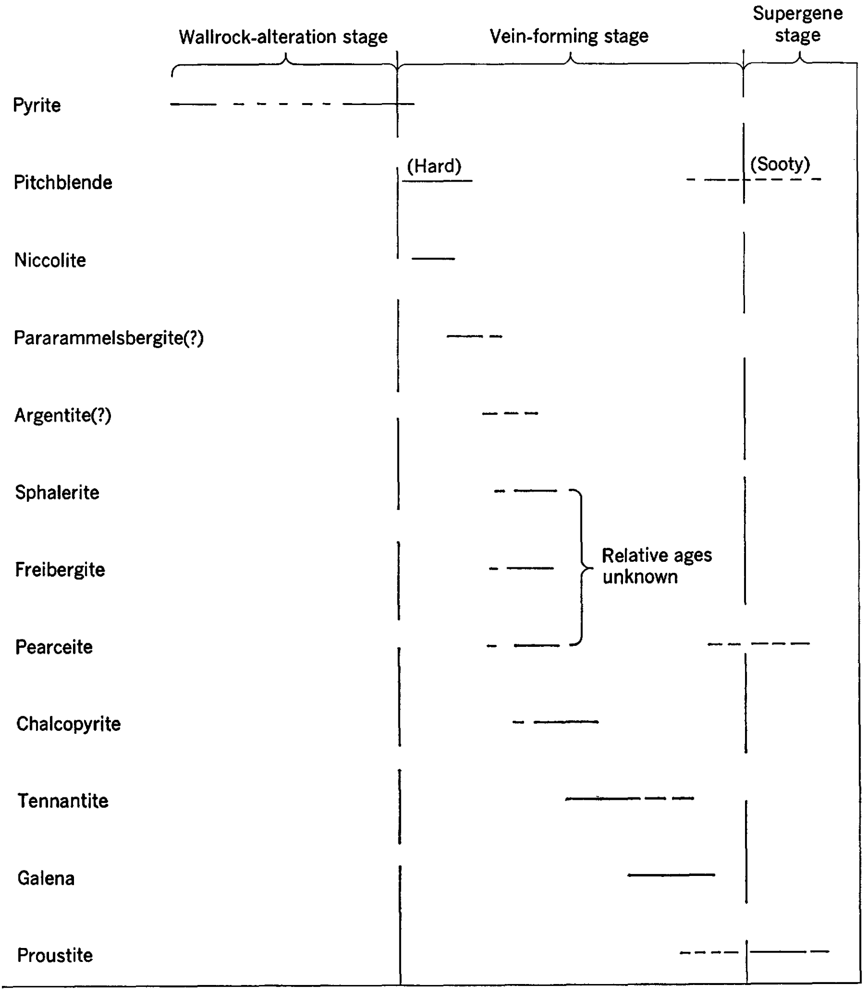

FIGURE 7.—Paragenetic sequence in pitchblende-bearing veins in the Almaden mine. Dashed lines show inferred relations.

argentite(?), pearceite, and chalcopyrite; in a sulfide-bearing part of the same sample, the sequence is pyrite, sphalerite, chalcopyrite, tennantite, and galena. Sooty pitchblende occupies fractures cutting the sulfide or sulfosalt minerals.

Hard pitchblende observed in the Mary and the Jo Reynolds veins and in the surface workings on the Golconda vein also occurs in sharp-walled veinlets next to the vein walls and accordingly is inferred to have formed early in the paragenetic sequence. In one place in the Jo Reynolds mine, botryoidal pitchblende is veined by galena, carbonate minerals, and chalcopyrite and tennantite. In the Mary mine, hard pitchblende formed after pyrite and marcasite and before chalcopyrite and sphalerite.

WALLROCK ALTERATION

The alteration of the wallrock in this and nearby districts has been discussed in detail by Tooker (1963). The discussion here is based primarily on his work and on the megascopic character of the alteration, but also in part on a detailed study of rock alteration along some pitchblende-bearing veins in Fall River.

The chief products of wallrock alteration, in approximate order of decreasing abundance, are clay minerals, sericite, silica (quartz), pyrite, and carbonate minerals. The relative abundance of these products depends on (1) distance from the vein, (2) vein type, and (3) rock type. In general, rocks nearest the vein are silicified, sericitized, and pyritized; rocks somewhat farther from the vein are strongly argillized (altered to clay minerals) and locally pyritized, and rocks still farther from the veins are slightly argillized and grade outward into fresh wallrock. The clay minerals in the intensely argillized zone are principally kaolinite, illite, and montmorillonite; those in the slightly argillized zone are principally illite, montmorillonite, and mixed-layer clays.

Because most wallrock in the district is composed mainly of quartz, feldspar, and mica, it should be expected that alteration halos would be similar in the common rock units, but inasmuch as rock units are not identical in either composition or physical properties, it should not be expected that alteration halos be identical. Rocks rich in biotite and quartz but poor in feldspar, such as the sillimanitic biotite-quartz gneiss, are strongly sericitized but weakly argillized. In the same way, rocks rich iron-bearing minerals such as amphibole or magnetite and poor in feldspar are weakly argillized but strongly pyritized and carbonitized. In general, rocks rich in plagioclase feldspar are strongly argillized, and those poor in plagioclase are only weakly argillized. The chief correlation between alteration and vein type is in the quantity of pyrite and the width of the pyritized zone in the alteration envelope. Pyrite is more abundant in the altered zones, and these zones are wider along pyritic and most composite type veins than along galena-sphalerite veins.

In general, according to Tooker (1963, p. 87), small amounts of potassium, ferrous and total iron, carbon (in carbonates), hydrogen, sulfur, and, locally, aluminum were added to the rocks in the alteration process, and small amounts of silicon, sodium, calcium, ferric iron, and magnesium were subtracted.

The garnetiferous gneiss that typically walls the pitchblende-bearing parts of the veins in the Fall River area contains almost no feldspar but much hornblende and magnetite. As determined from microscopic examination of altered gneiss, clay minerals are sparse, but carbonates and pyrite are abundant; garnet and quartz are not appreciably changed, except immediately adjacent to the veins, but the hornblende is almost completely replaced by carbonate and the magnetite by pyrite. Chemical analysis of unaltered and altered garnetiferous rocks from the Almaden and Golconda mines bear out results of the microscopic study of these rocks (table 19). As compared with fresh rocks, the altered rocks show a small decrease in silica, a marked decrease in ferric iron (reported as Fe_2O_3), magnesia, and lime, a slight increase in alumina, and a marked increase in ferrous iron (reported as FeO) and carbon dioxide. (Work by Tooker (1963, fig. 27, p. 42) suggests that about the same changes can be deduced from comparison of altered and unaltered rock regardless of whether the analyses are compared by weight percent, equal volume, or standard cell.) In contrast, altered biotite gneiss from the Almaden mine shows by comparison with fresh gneiss (table 19) a decrease in lime, iron (FeO and Fe_2O_3), magnesia, and soda and an increase in alumina and potash. Carbon dioxide also increases, but the increase is small relative to that in the garnetiferous gneiss. Hornblendic gneiss from the Almaden mine shows slightly different changes (table 19).

WALLROCK CONTROL OF MINERAL DEPOSITION

Studies in the adjacent Central City district indicate that veins are more likely to be ore bearing in microcline gneiss than in associated biotite gneiss (Sims and others, 1963, p. 50–51), particularly near the crest of the Central City anticline where a thick layer of microcline gneiss rests on a thick layer of biotite gneiss (Sims and others, 1963, fig. 17). The favorability of the microcline gneiss seems obviously due to its greater competency, because the vein fissures pinch down in the biotite gneiss unit. However, competency is relative and ore does occur in biotite gneiss in other parts of the Central City district just as it does in incompetent rocks in many places. Also, as pointed out by Collins (1930), the biotite gneiss may be a favorable host for replacement bodies near the vein fissures.

TABLE 19.—*Analyses of fresh and altered wallrock, Golconda tunnel and Almaden mine*

[Rapid rock analyses by H. F. Phillip, P. L. D. Elmore, P. W. Scott, and K. E. White]

Field sample	Go-51A-55, Go-51B-55	Al-25-55, Al-26-55	Al-27B-55	Al-27A-55	Al-24A-55	Al-24B-55
Laboratory analysis	140577, 140578	140572, 140573	140575	140574	140570	140571
Rock type	Garnetiferous gneiss		Biotite gneiss		Hornblende—biotite calc—silicate gneiss	
	Fresh	Altered	Fresh	Altered	Fresh	Altered
SiO_2	51. 9	51. 3	72. 0	65. 5	58. 1	59. 5
Al_2O_3	8. 8	10. 8	11. 9	17. 7	14. 3	14. 9
Fe_2O_3	11. 3	4. 2	1. 9	1. 3	4. 5	4. 9
FeO	14. 5	16. 7	3. 2	2. 5	5. 4	4. 2
MgO	3. 3	2. 0	1. 5	. 92	3. 0	3. 2
CaO	4. 2	2. 4	1. 7	. 50	5. 2	1. 5
Na_2O	. 10	. 07	2. 6	. 04	1. 2	. 07
K_2O	1. 15	. 26	2. 2	4. 6	2. 6	2. 6
TiO_2	. 42	. 40	. 58	. 85	1. 4	1. 3
P_2O_5	. 65	. 70	. 15	. 06	. 62	. 53
MnO	3. 4	3. 5	. 12	. 17	. 14	. 14
H_2O	. 80	1. 3	1. 0	4. 0	1. 8	5. 6
CO_2	. 19	6. 8	. 64	2. 0	. 70	1. 2
Total	101	100	99	100	99	100
S as S	1. 07	1. 25	. 25	. 09	. 09	. 29
Specific gravity	3. 319	3. 179	--------	2. 708	--------	--------

Golconda tunnel:
Go-51A-55, Go-51B-55. Average of two samples.
Almaden mine:
Al-25-55, Al-26-55. Average of two samples; Blazing Star tunnel.
Al-27B-55. Unaltered.
Al-27A-55. Mainly argillic alteration zone, paired with Al-27B-55.
Al-24A-55. Unaltered.
Al-24B-55. Argillic alteration zone; paired with Al-24A-55.

In the Lawson-Dumont-Fall River district, the data on the control of ore shoots by differences of rock strength are so sparse as to be inconclusive. In the Lawson area, the important mines north of Clear Creek near the Boulder Nest and White veins are in an interlayered sequence containing both microcline gneiss and biotite gneiss. The mines, however, are inaccessible and therefore relations of ore to one unit or the other are unknown. The important Jo Reynolds and American Sisters veins south of Lawson and also the gold mines of the Dumont area are mainly in relatively competent units, namely the biotite-muscovite granite, migmatite, and quartz diorite, but again, knowledge of the ore shoots is insufficient to correlate them with any certain rock.

Only one kind of rock in the district, the garnetiferous gneiss, can be specifically designated a generally favorable host rock for ore deposits of any kind. This rock is a favorable host for uranium deposits and possibly also for copper-rich sulfide deposits. Its favorability is probably due to its chemical and mineralogic composition rather than its physical properties. Thin layers of the gneiss are present northeast of Dumont, but the gneiss is found mainly in the Fall River area where it is exposed underground in the Mary, Golconda, and Almaden mines. Each of the nine main occurrences of uranium minerals in five veins in these mines is in a part of the vein that has garnetiferous gneiss on one or both walls (fig. 8). The control is especially noticeable because other wallrock is more abundant than garnetiferous gneiss and contains veins mineralized with sulfides. Furthermore, the preference of uranium for garnetiferous gneiss is independent of vein type, because the veins of the Mary mine are pyritic, those of the Golconda are composite, and those of the Almaden are of the galena-sphalerite type. Localization of pitchblende in ferruginous or carbonate rocks has been noted elsewhere in the Front Range (Adams and Stugard, 1956; Sims and Sheridan, 1964) and in Canada (Robinson, 1952, p. 205; Allen and others, 1954, p. 70).

Possibly the garnetiferous gneiss also locally influenced the deposition of sulfide or arsenide minerals. The only occurrence of nickel minerals (arsenides) in the district is in the Blazing Star tunnel where they are intimately associated with pitchblende and silver minerals in the Almaden vein. Chalcopyrite is abundant in the Heliotrope vein near Dumont where the vein cuts through extensively sulfidized garnetiferous gneiss. The chalcopyrite occurs in massive slabs frozen to the garnetiferous walls in contrast to its general ocurrence with quartz and pyrite in the vein filling in other wallrock.

RESIDUAL CONCENTRATION AND SUPERGENE ENRICHMENT

Some concentrations of gold and silver and of copper and silver were formed by supergene processes, that is, processes involving downward-moving surface water which rearranged the original or hypogene ores. Gold and silver ores produced by these processes were economically significant during the early days of the mining district when the mines were shallow, but supergene copper ores have been of little economic importance.

The factors that govern near-surface enrichment are in part geologic and chemical as well as physiographic; they include (1) depth and fluctuations of the water table, (2) degree of dissection of the topography, (3) quantities of valuable metals contained in the primary ores, and (4) composition and solubility of the ore and gangue

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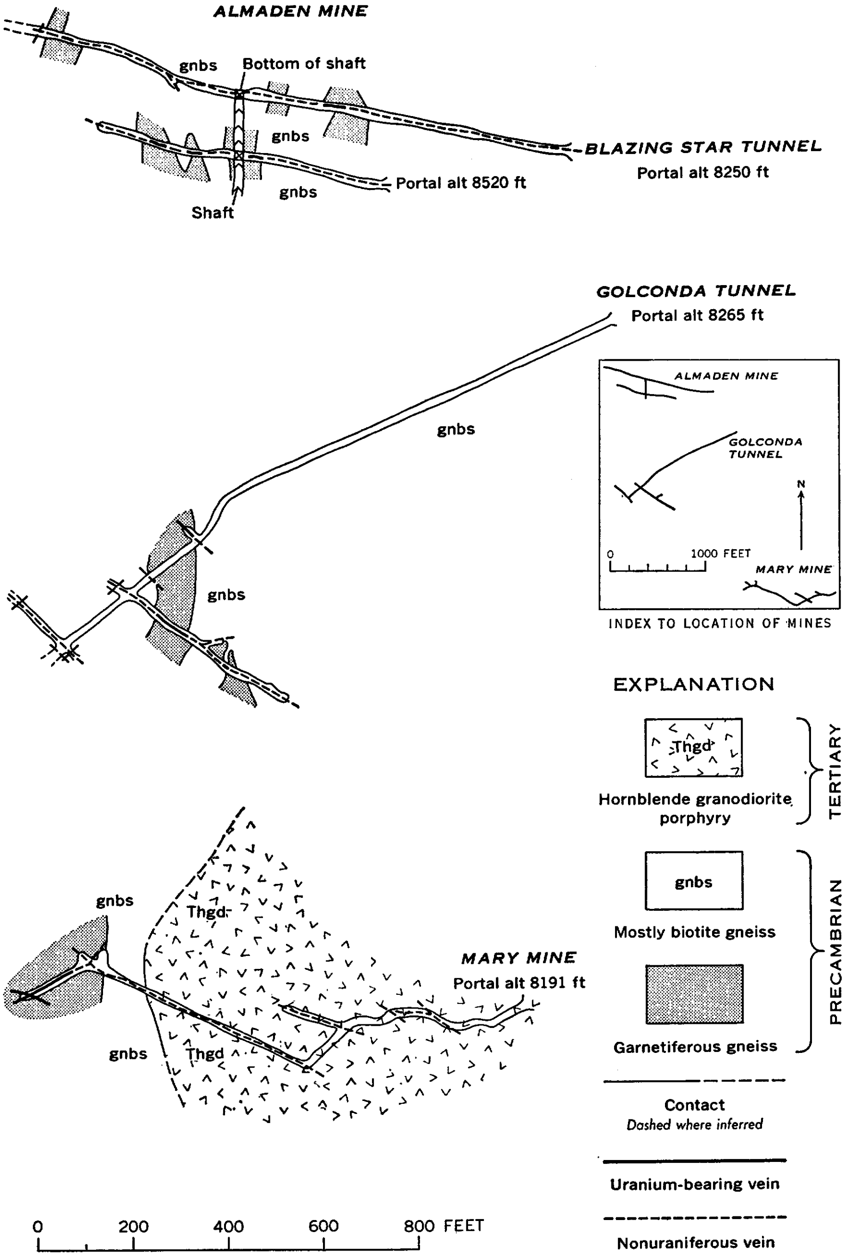

FIGURE 8.—Relation of uranium deposits to garnetiferous gneiss in the Mary, Golconda, and Almaden mines. Workings for U.S. Atomic Energy Commission map, 1953.

minerals. The depth to the water table, or to the bottom of oxidized ore which represents a water table of earlier time, varies from zero in the valleys to about 100 feet. Representative depths are about 65 feet in the Little Giant mine at Lawson, 50 feet in the Albro near Dumont (E. B. Dingle, oral commun., 1955), and 70 feet in the Clifford in the upper Fall River area. These depths are similar to the 50–60-foot depth in the nearby Georgetown-Silver Plume district (Spurr and Garrey 1908, p. 138). No estimates are available for the downward extent of the ground water, but Spurr and Garrey noted that in the Georgetown quadrangle the mines became drier between depths of 500–1,000 feet. The degree of topographic dissection in the district is about intermediate between that in the Central City district, which has generally low relief, and the Georgetown district, which has high relief.

The chemical factors governing supergene enrichment are fairly well known (Emmons, 1917; Garrels, 1954). The reactions of greatest importance are probably the formation of sulfuric acid and ferric sulfate by reaction of oxygen-bearing surface waters with pyrite. The acid solutions thus formed dissolve zinc, copper, and, in places, silver, and remove them from the oxidized zone. They do not generally remove lead or gold which are less soluble, so these substances may be residually concentrated by removal of some of the materials that originally accompanied them. As the metal-bearing acid solutions move downward, they are neutralized and also reduced, and some of their metals are reprecipitated. Zinc, being relatively soluble in neutral and alkaline as well as in acid solutions, generally is carried away, but copper and silver may be reprecipitated. The rate of neutralization depends upon the mineralogy of the primary ore and of the wallrock. According to Emmons (1917, p. 265–66) and Bastin and Hill (1917, p. 142–43), calcite, siderite, enargite, and chalcocite react most rapidly to neutralize the solutions; galena and sphalerite react next most rapidly, and pyrite and chalcopyrite react least rapidly.

RESIDUAL CONCENTRATION

Gold and, to a lesser extent, lead and silver were enriched by residual concentration in the oxidized zone, but very little quantitative information is available on the grade of the enriched ore. Henry deLinde reports (oral commun., 1954) that some of the pyritic veins which crop out in relatively undissected ground west of Bald Mountain assay as much as several ounces of gold per ton at the surface but are nearly barren below a depth of a few feet. Bastin and Hill (1917, p. 139) reported that oxidized ore from the Blue

Ridge vein, a galena-sphalerite vein having low primary gold content, assayed as much as 2.55 oz gold per ton. Several veins east of Dumont, such as the Albro, were extensively mined at the surface, and it seems reasonable to assume that the material that was mined was gold ore of moderately high grade.

In some places, silver apparently was leached from the oxidized zone; for example, Bastin and Hill (1917, p. 341) reported an apparent absence of silver in the Jo Reynolds vein for the first 50 feet below the surface. In other places, however, veins were enriched in silver near the surface. Bastin and Hill (1917, p. 339) mentioned that oxidized ore from the Silver Treasure vein in the Millington mine was rich in native silver and cerargyrite, and, according to Fossett (1880, p. 383), the discovery of the rich Boulder Nest vein was due to the persistence of D. E. Dulany in following oxidized boulder float which assayed as much as several thousand ounces of silver per ton.

Altered galena was noted in the oxidized parts of several veins, and a concentration of cerussite is reported to have been mined from the oxidized part of the Syndicate vein (E. B. Dingle, oral commun., 1954).

ENRICHMENT BELOW THE WATER TABLE

Among the minerals in the veins, those dominantly of supergene origin are proustite, chalcocite(?), covellite, and probably, native silver; minerals locally of supergene origin are argentite, pearceite, chalcopyrite, and sooty pitchblende. A thin zone of supergene copper sulfides typically is formed at the water table, particularly in some of the copper-rich composite veins, but silver was the main component of the ores enriched below the water table.

Silver, in solution as a sulfate, can react in several ways. In one reaction, native silver is formed by reaction with ferrous sulfate (Ravicz, 1915, p. 376):

$$Ag_2SO_4+2FeSO_4=2Ag+Fe_2(SO_4)_3.$$

Other reactions cause precipitation of argentite (where M is a divalent metal):

$$H_2SO_4+MS=H_2S+MSO_4$$

$$2H_2S+2Ag_2SO_4=Ag_2S+2H_2SO_4+S.$$

The sulfate solutions also react with carbonate gangue minerals. In doing so, acid sulfate solutions become neutralized, but carbon dioxide is evolved and some of the silver remains in solution, probably as the bicarbonate (Ravicz, 1915, p. 371–374; Emmons, 1917, p. 266). This reaction may partly explain the deep occurrence of proustite in some veins, particularly in carbonate-rich veins of the Lawson area. Although copper is less soluble than silver in a carbonate solution, the similar occurrence of late chalcopyrite suggests that small amounts of copper may have been transported by a similar mechanism.

Although the highest grade silver ores were dominantly of supergene origin, production records from deep workings in the Jo Reynolds mine, Red Elephant group (Commodore tunnel), and Bellevue-Hudson mine show that ores containing from 50–100 oz silver per ton are common. Considering the changes in mining methods, the grade of many ores mined at depth compare favorably to the ores mined from upper levels.

ORIGIN OF THE ORE DEPOSITS

Although details of ore genesis are speculative, certain generalizations probably are valid. Since early mining days and especially since the work of Spurr and Garrey (1908, p. 67–71, p. 107–110), it has been recognized that the ores of the Front Range mineral belt are related in some way to an episode of Tertiary igneous activity which, in turn, was at least partly coincident with Laramide tectonic activity. The ores were formed late in the episode of igneous activity, and this age relation suggests that rock temperatures probably were elevated. The similarity of rock alteration on all types of veins and the general coincidence of altered areas with areas containing vein deposits indicate that rock alteration and vein deposition are related and took place in one period of hydrothermal activity, although they may not be exactly simultaneous. These generalizations are based primarily on spatial association and known age relations, but others can be partly based on results of recent chemical investigations. The work of Hemley (1953), Barton (1957), and Czamanske (1959), among others, combine to show that the ore metals probably were transported in complexes and not as simple ions, and thus the concentration of complexing components may have been a major control of ore deposition. Evidence from the wallrock alteration and the paragenetic sequence of vein minerals suggests that carbon dioxide and bivalent sulfur, in various forms, were relatively abundant in the altering and ore-forming fluids, and they may have been important complex formers.

SULFIDE VEINS

Although there is a question of whether the rock-altering and ore-depositing solutions were the same or were slightly different, they were closely akin and are discussed together.

Carbon dioxide-, sulfur-rich solutions are postulated because chemical evidence suggests that they are capable of alteration and ore-metal transportation. They are also compatible with the zoning relations observed in the district. The discovery of sulfur-metal complexes that can transport metals such as lead (Hemley, 1953, p. 113–114) at near neutral conditions shows that highly acid or highly alkaline solutions, once deemed important (Garrels, 1944, p. 473–475, 481), are not necessary. Near-neutral ore solutions are also strongly supported by the chemistry of gold solution. According to Krauskopf (1951, p. 863–865), gold can be transported in acid solution only in the presence of an oxidizing agent and a high chloride ion concentration. It may, however, be transported in nearly neutral sulfide colutions where it probably is present as the ion $AuS-$ (Krauskopf, 1951, p. 858, 865–67, 869).

Regardless of the time relations of ore and alteration, the solutions that formed the pyrite veins probably had more sulfur and carbon dioxide than did the ore solutions that formed the composite veins. These constituents probably also were more abundant in solutions that formed composite veins than they were in solutions that formed galena-sphalerite veins. High sulfur concentration of solutions that formed pyrite-type veins is suggested by the abundance of pyrite both in the veins and in the altered wallrock. Pyrite contains more sulfur than any other ore mineral in the district; its presence in the wallrock as a replacement of iron minerals shows that there was not only enough sulfur to combine with iron in solution but also enough to react with iron minerals in the wallrock. In contrast, a low sulfur concentration in solutions that formed galena-sphalerite veins is suggested by the sparsity of pyrite in veins and wallrock and by the dominance of low-sulfur minerals. A relatively low sulfide-ion concentration in the solutions forming galena-sphalerite veins also seems compatible with the presence of the sulfate barite as a primary mineral. As the reduced sulfide species such as S^{-2} become depleted, the Eh of the solution becomes more oxidizing, and the oxygen-bearing ion SO_4^{-2} would tend to become stable. An equilibrium reaction tending to form SO_4^{-2} would probably be favored because of the low solubility of barite:

$$S^{+2}+2O_2 \rightleftharpoons SO_4^{-2} \qquad (1)$$

$$Ba^{+2}+SO_4^{-2} \rightleftharpoons BaSO_4. \qquad (2)$$

That is, the precipitation of barite in equation 2 would tend to cause equation 1 to go to the right.

The argument for decreasing concentration of carbon dioxide in the ore solutions forming, in order, the pyrite, composite, and galena-sphalerite veins is based on an inverse relation, because the carbonate minerals form soluble bicarbonates at high carbon dioxide pressures and so are not precipitated. Carbonate minerals are rarely present within pyrite veins, but they are found in the alteration zones bordering the veins. From this fact we infer that carbon dioxide was present and also that it was present in sufficiently high concentrations in the veins to keep the carbonates in solution in the veins. As the carbon dioxide-rich solutions reacted with the wallrock, carbon dioxide was depleted, bicarbonates became unstable, and so carbonates were precipitated in the altered rocks. Carbonates are present in both the composite and galena-sphalerite veins, and they are more abundant and older paragenetically in galena-sphalerite veins then they are in composite veins. The changes in abundance and paragenetic position suggest a steadily decreasing concentration of carbon dioxide in the solutions which deposited the composite and galena-sphalerite veins.

The source of altering and mineralizing fluids was probably beneath areas of pyritic veins, both because pyrite is the oldest of the vein minerals, and because the veins in the pyritic areas formed at the highest temperatures (Sims and Barton, 1961, 1962). Many workers (Bastin and Hill, 1917; Harrison and Wells, 1959; Tooker, 1963, Sims, Armstrong, and others, 1963) in the Central City-Idaho Springs area have proposed that the hydrothermal fluids spreading out from pyritic centers came in two main surges: (1) an early surge of fluids that altered the rocks along the veins and introduced pyrite, quartz, and very minor quantities of valuable metals into the veins, and (2) a later and possibly overlapping surge of solutions that deposited most of the valuable metals but caused little alteration. Among other features of the deposits, this hypothesis explains the two-stage filling noted in composite veins where sphalerite, chalcopyrite, galena, and other valuable minerals occupy sharp-walled fracture-controlled veins in quartz-pyrite vein material.

An alternative hypothesis somewhat favored by the authors is that alteration and mineralization took place at nearly the same time and that the zonal arrangement of minerals is due to progressive change in space and time of the hydrothermal fluids in the vein system owing largely to reaction of the fluids with the wallrock and the precipitation of vein minerals. This hypothesis is similar to that adopted by Sales and Meyer (1949) in their studies at Butte, Mont. The two-stage filling of typical composite veins was probably due to local fracturing which led to the volatilization of potentially gaseous complexing agents such as carbonic acid, hydrogen sulfide, halogen gases, and the consequent breakdown of soluble metal-bearing complexes. Under this variant of a single-stage hypothesis, the late sulfides were then deposited rapidly in fractures formed in quartz-pyrite vein material. They were deposited sparsely in pyritic areas where complexing agents tended to be abundant and abundantly in the area farther from the source of the fluids, where the complexing agents had already been depleted by wallrock reactions.

A single-stage hypothesis is favored by the authors partly because of an apparent difficulty of the two-stage hypothesis, namely that this latter hypothesis demands nearly simultaneous opening of several fracture sets in order to obtain regular zoning, and this seems rather unlikely. We are also influenced by the chemical effect that the garnetiferous gneiss had on the deposition of pitchblend (p. 78–79) and possibly chalcopyrite (p. 79). Apparently, intense sulfidation and carbonitization of this wallrock had a noticeable influence on vein mineralogy, compatible with contemporaneity of alteration and vein formation.

PITCHBLENDE DEPOSITS

The pitchblende deposits of the district fall into two genetic groups. The deposits of the Fall River area are probably a minor variant of the sulfide ores, but deposits in the Jo Reynolds mine may belong to the early "uranium stage" recognized by Sims, Armstrong, and others (1963).

The well-known pitchblende deposits of the adjacent Central City district are associated with highly radioactive quartz bostonite porphyry (Phair, 1952). They occur in veins of all types and in various kinds of wallrock, and, according to Sims, Armstrong, and others (1963, p. 52–54), were derived from shallow quartz bostonite magmas. Evidence for a direct association of pitchblende with the quartz bostonite is strong, for the deposits not only are closely related spatially to the quartz bostonite porphyry bodies, but like the porphyries have an abnormally high zirconium content.

The pitchblende deposits of the Fall River area, like those in the Central City district, occur in pyrite-, composite-, and galena-sphalerite-type veins, but they differ from those of Central City in not being visibly associated with quartz bostonite and in having a well-defined wallrock control. Moreover, the pitchblende of the Fall River area is intergrown with, and hence contemporaneous with, other metallic minerals, rather than being older, and it is characterized by a high rare earth content rather than high zirconium content.

The wallrock control of the Fall River deposits is of special interest. The major pitchblende deposits of the area—those of the Mary, Golconda, and Almaden mines—occur only in those parts of the veins that intersect the garnetiferous gneiss. This type of gneiss reacted differently than the other wallrock, both to altering solutions and to physical stresses that caused the vein tissues to form. It was more intensely pyritized and carbonatized than the associated altered biotite gneiss and amphibolite, and it formed a vein zone of closely spaced fractures rather than the simple fracture characteristic of less competent rocks. Notwithstanding the difference in fracturing, the primary control of uranium deposition was probably chemical, because other competent rocks, such as pegmatite and microcline gneiss, fractured like the garnetiferous gneiss and are mineralized but do not localize pitchblende deposits.

The occurrence of pitchblende in highly carbonatized wallrock and the existence of soluble uranium carbonate complexes (Garrels and Christ, 1959, p 85–86; McClaine and others, 1956) suggest a relation between carbon dioxide concentration of the ore solution and the precipitation of uranium. A uranous carbonate complex of the type described by McClaine, Bullwinkel, and Huggins (1956, p. 30–32) would decompose as the carbon dioxide concentration of the ore solution was depleted by wallrock reactions, and uranium would be precipitated in the quadrivalent +4 state.

Wallrock control of pitchblende deposition has been noted in the Front Range in sulfide-deficient veins east of the mineral belt (Adams and Stugard, 1956). Hematite occurs in these veins and was formed at about the same time as pitchblende, so Adams and Stugard (1956, p. 202–204, 206–207) proposed that pitchblende was precipitated by the oxidation-reduction reaction of hexavalent uranium U^{+6} with wallrock rich in Fe^{+2}, and by the consequent formation of pitchblende (U^{+4}) and hematite (Fe^{+3}). The veins of the Fall River area contain more sulfides than do those veins described by Adams and Stugard, and they have no hematitic alteration; thus the pitchblende occurrences probably reflect a different precipitation mechanism, possibly as described above.

The occurrence in the Fall River area of pitchblende in several mines and in different types of veins, but only in favorable wallrock, suggests that uranium could have been present in small amounts in many vein-forming solutions but was soluble and only precipitated in notable concentrations under unusual chemical or physical conditions.

The pitchblende deposits of the Jo Reynolds mine are more similar to those of the Central City district (Sims and others, 1963, p. 39–41) and are inferred to belong to an early uranium stage that preceded sulfide deposition. The pitchblende is old paragenetically; it is veined by other minerals including galena. It contains zirconium but no appreciable concentration of rare earths. A large quartz bostonite dike is exposed in the mine, and so a source for the uranium and zirconium in bostonite magma is possible.

Sooty pitchblende found in several of the deposits throughout the district is tentatively classed as both late hypogene and supergene in origin. A late hypogene origin is assigned to the sooty pitchblende of the Golconda tunnel because of its deep occurrence, about 700 feet below the surface. It occurs in carbonate-rich veins and thus is similar to the pitchblende II of Kidd and Haycock (1935, p. 901–904) at Great Bear Lake, Canada, where it is a hypogene alteration product of hard pitchblende. Possibly the sooty pitchblende in the now inaccessible Bellevue-Rochester tunnel is also of hypogene origin because since this occurrence is also deep and, according to Kerr, Anderson, and Hamilton (1951, p. 45–56), is in a vein containing calcite, ankerite, and siderite. In contrast to these occurrences, sooty pitchblende of probable supergene origin occurs in the upper workings of partly oxidized veins, such as the Albro, northeast of Dumont. In part, the uranium is far out of equilibrium; recent oxidation and leaching of the pitchblende is thus suggested.

OCCURRENCES OF URANIUM MINERALS AND ANOMALOUS RADIOACTIVITY

Uranium minerals or anomalous radioactivity have been found in 25 mines in the district. In nine of these occurrences, discrete uranium minerals have been identified; in the remainder the source of the radioactivity is not known, but the radioactivity is associated at several places with either pegmatite or oxidized limonitic vein material. The occurrences are listed and grouped in table 20 according to their content of equivalent uranium. The equivalent uranium content is defined as the amount of uranium a sample would contain if all its radioactivity came from uranium.

Some of the radioactive occurrences in the Dumont and Fall River areas have been reported previously (Wells and Harrison, 1954); detailed information obtained by the present authors on individual deposits is given in the mine descriptions (Hawley and Moore, 1967).

TABLE 20.—*Occurrences of anomalous radioactivity in the Lawson-Dumont-Fall River district*

Mine	Type of vein	Source of radioactivity
Class 1 (>0.1 percent eU)		
Mary	Pyrite	Pitchblende, torbernite(?).
Almaden	Galena-sphalerite	Pitchblende, sparse secondary uranium minerals.
Golconda	Composite	Pitchblende (sooty).
Golden Calf	do	Do.
Bellevue-Hudson	Galena-sphalerite	Pitchblende.
Jo Reynolds	do	Do.
Peabody (Robineau)	do	Pitchblende, dumontite, torbernite.
Class 2 (0.020–0.1 percent eU)		
Albro	Composite	Pitchblende (sooty).
Nabob vein (Lawson area).	Galena-sphalerite	Pitchblende.
Saginaw	Composite	Pegmatite(?).
Gold Chloride	Pyrite	Pegmatite.
Gold Quartz	Galena-sphalerite	(?).
Unknown C5–24 (Black Gulch).	do	Limonite.
Class 3 (0.005–0.020 eU)		
Pennsylvania	Composite	(?).
Standard	Pyrite	(?).
7–40	(?)	(?).
Old Chief	Composite	(?).
Major C. and Little Colonel.	do	(?).
Unknown G452 (Spring Gulch).	Pyrite	(?).
Unknown G643 (Mill Creek).	Composite	(?).
Black	Galena-sphalerite	Unknown mineral in limonite.
Unknown C5–14	Galena-sphalerite(?)	Do.
Unknown C4–10	do	Do.
Unknown C4–3	do	Do.
Keith (shaft)	do	Do.

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