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Disseminated Sulfides

From a Tungsten-bearing

Quartz Lode

Big Creek District

Central Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 594-C



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By B. F. LEONARD, CYNTHIA W. MEAD, *and* NANCY CONKLIN

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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*Study of a low-grade tungsten deposit
whose associated sulfide minerals,
extracted as waste, are rich in
silver and contain some gold*



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SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

SILVER-RICH DISSEMINATED SULFIDES FROM A TUNGSTEN-BEARING QUARTZ LODGE, BIG CREEK DISTRICT, CENTRAL IDAHO

By B. F. LEONARD, CYNTHIA W. MEAD, and NANCY CONKLIN

ABSTRACT

Sulfide concentrates removed as waste from the milling of low-grade tungsten ore at the New Snowbird deposit contain roughly 100–300 troy ounces of silver per ton, 2–4 ounces of gold, and a few percent each of copper, lead, and zinc. Sparsely disseminated sulfides make up only about 0.1 weight percent of the tungsten ore, and not more than 1 ton of sulfide concentrates was accumulated annually during the short life of the mine. The total metal content per ton of ore is comparable to that of some porphyry copper deposits. At the New Snowbird, tungsten proxies for copper, and the precious metals and base metals are potential coproducts. The size of the disseminated sulfide-tungsten deposit is unknown, but its occurrence as a xenothermal replacement within a very large silicified zone coextensive with a major Tertiary dike swarm suggests that the New Snowbird and similar deposits are potentially valuable, though extremely low grade, sources of precious metals.

This report defines the mineralogy of one deposit by microscopic, electron probe, X-ray, spectrochemical, and chemical analyses. Huebnerite, scheelite, and a little stolzite are the main tungsten minerals. Pyrite, chalcopyrite, sphalerite, galena, digenite, and acanthite are the principal sulfides. Elemental gold is present as gold-rich electrum included in pyrite. Elemental silver is present in native silver, electrum, argentopyrite (?), acanthite, argentian tetrahedrite, silver sulfosalts, hesite, argentian digenite, cerargyrite, and perhaps other minerals. Deposition of the complex mineral assemblage within the quartz lode began with huebnerite and scheelite. Pyrite with abundant heterogeneous ore-mineral inclusions was then dumped. Inclusion-rich base-metal sulfides and tetrahedrite followed in weakly ordered sequence, telescoped upon miargyrite (?), acanthite, and late rim-forming copper sulfides. The inferred temperature range for hypogene sulfide mineralization extends from 491°C or less (pyrite-pyrrhotite-arsenopyrite assemblage) to 177°C or less (acanthite formed below the argentite-acanthite inversion temperature). Clay minerals and oxidation products are sparse. The extent of supergene sulfide enrichment is indeterminate but probably slight, though an unknown quantity of supergene alteration products may have been eroded.

INTRODUCTION

Sulfide concentrates accumulated as a waste product during the beneficiation of low-grade huebnerite-scheelite ore from the New Snowbird deposit contain 110–316 troy ounces of silver per ton, 2.7–4.1 ounces of

gold, and a few percent each of copper, lead, and zinc. The sulfides were very sparsely disseminated in the tungsten ore, and the accumulation of “pyrite concentrate” known to contain base metals and silver was roughly 1 ton per year, an amount regarded by the operator as too small to be worth marketing. Nevertheless, milling of the tungsten ore carried out an experiment in concentration that nature apparently failed to perform on a large scale in this district, where bonanzas have not been found. Sulfide concentrates from the New Snowbird mill thus provide the first large sample of a disseminated sulfide deposit from the district, revealing its mineralogy and metal content in a way that conventional sampling and assaying could not have done and suggesting that the extensive, sparsely sulfide-bearing silicified zones of the district may merit attention as potential sources of disseminated metals in bodies reminiscent of the porphyry copper deposits of the Western States.

This report deals mainly with the mineralogy of the sulfide concentrates. The deposit from which they came was, economically, a tungsten ore body in which the value of the other metals probably did not exceed 30–80 cents per ton of crude ore. The sulfide-bearing material itself was not ore; the sulfides were removed merely because a price penalty is imposed for sulfur in tungsten concentrates. Other tungsten deposits of similar type occur in the neighborhood, but this deposit alone has been worked, and no low-grade sulfide deposits have been exploited except the Yellow Pine and Meadow Creek (fig. 1).¹ The intensity of sulfide mineralization

¹The Yellow Pine mine became the Nation's leading producer of tungsten in 1942–44, when it yielded more than 800,000 units of WO₃. Though the ratios of the dollar value of tungsten, antimony, and gold in the ore were approximately 2 : 2 : 1 during the productive life of the mine (1938–52), the ore came from a low-grade pyrite-arsenopyrite-stibnite-quartz lode that contained a large shoot of scheelite ore. Thus, sulfides predominated over scheelite in the ore body as a whole. The Meadow Creek mine produced antimony and gold only, but some scheelite was present in the deposit. Silver was recovered from both deposits, the weight ratio of Ag : Au being 8.2 : 1 at the Yellow Pine mine and 3.4 : 1 at Meadow Creek. For details, see Cooper (1951) and U.S. Bureau of Mines (1938–52).

at the latter deposits was at least one order of magnitude greater than that inferred for the New Snowbird. Thus there is no local standard against which to compare the New Snowbird sulfide assemblage.

Fine grain size and sparse dissemination of the New Snowbird sulfides hamper one's study of the deposit in the field and limit the usefulness of any collection of ore samples numbering less than hundreds. Concentration of the sulfides during beneficiation has largely overcome these drawbacks, probably with little loss of natural detail except in the relation of ore minerals to matrix. Many pyrite grains in the concentrates are euhedral, other sulfide grains are delicately rimmed with soft minerals, and the dust that might be expected from overgrinding is sparse. These features suggest that many sulfide grains simply popped out of the quartz matrix during crushing and wet grinding, with little attendant destruction of the ore-mineral fabric and without development of polymorphic inversions in temperature-sensitive members of the sulfide suite.

Interesting as the mineral assemblage has proved to be, its study might be viewed merely as a prerequisite for understanding the chemical composition of the sulfide concentrates, reported in tables 1 and 2. The data in table 3, analyses of handpicked mineral fractions, represent an unsuccessful shortcut toward that understanding. They illustrate the futility of handpicking apparently homogeneous grains that are complex fine-grained aggregates. These annotated tables will not be discussed in detail, but their interpretation should become plain as the mineralogic study develops. Table 4 shows reasonable agreement between observed and calculated minerals in the most fully analyzed sample of the sulfide concentrates. Table 5 lists the minerals of the deposit. The heavy sprinkling of question marks, either printed or implied there, refers to minerals that make up less than 0.5 volume percent of the deposit. Perusing the five tables before reading the text will be helpful.

Elemental gold in the sulfide concentrates is present mostly as gold-rich electrum included in pyrite. A little pure native gold may also be included in pyrite, but this is an inference based on the rich golden color of the particles. The evidence from fabric studies indicates that the electrum (and native gold, if actually present) is hypogene. If the deposit contains electrum or native gold outside pyrite, we did not find evidence of it in this study. Elemental silver is, in contrast, distributed among many minerals: native silver, electrum, argen-topyrithite(?), acanthite, argentic tetrahedrite, argentic digentite, hessite, inadequately identified silver sulfosalts, cerargyrite, and perhaps other minerals. Acanthite is the most abundant of these. The Ag: Au

TABLE 1.—Assays of concentrates and tailings, McRae Tungsten Corp. mill

[Parts per million, ppm; parts per billion, ppb]

	1	2	3	4	5
Field No.	SN/56/7b	SN/64/1	SN/64/2	SN/56/7a	SN/64/3
Lab. No.	D113983	D115110	D115111	D113982	D100632
Ag. troy oz per ton	316.1	142.62	109.89	0.94	¹ 0.47
Au. do	3.57	4.07	2.73	.02	<.02
Cu. weight percent	4.2	1.21	1.24	.10	² .01
Pb. do	3.40	2.14	1.81	.74	² .01
Zn. do	3.2	1.14	1.40	<.1	² 0
W. do	³ 1	.5	.7	⁴ .45	² .2
As. do	.36	.41	.37	.0090	² 0
Mn. do	³ .3	³ .2	³ .3	4.0	.05
P ₂ O ₅ do	<.01			.12	.02
Total S. do	44.3			<.1	.02
Br. do	(⁵)	(⁵)	(⁵)		(⁵)
Cl. do	(⁵)	(⁵)	(⁵)		(⁵)
Se. ppm	<.5	20	15	.5	<.5
Te. do	15	45	20	90	10
Hg. ppb	1,300	1,200	1,000	180	20

¹ Ag determined by atomic absorption by J. D. Mensik and Claude Huffman is 14 ppm, equivalent to 0.41 oz per ton.

² Semiquantitative spectrographic analysis by Harriet Neiman.

³ Semiquantitative spectrographic analysis by Nancy Conklin.

⁴ Equivalent to 57 percent WO₃. Residues from analysis contained some huebnerite and scheelite.

⁵ Not detected. Less than 0.0005 percent or 5 ppm.

1. Sulfide concentrate collected August 1956 while mill was operating.
2. Sulfide concentrate collected September 1964. Represents upper, more oxidized part of small pile of concentrates remaining at southwest corner of mill floor after mill was dismantled. Screened to remove contaminants—pebbles, twigs, spruce needles.
3. Sulfide concentrate collected September 1964. Represents lower, less oxidized part of the residual pile sampled by 2, above. Screened to remove trash.
4. Huebnerite-scheelite concentrate collected August 1956 while mill was operating.
5. Tailings collected September 1964. Represents upper 8 in. of tailings, sampled on 25-ft centers, over entire tailings pile whose diameter was 100–150 ft. Screened to remove trash.

Ag and Au determined by fire assay by W. D. Goss and O. M. Parker (Nos. 1, 4); by O. M. Parker (Nos. 2, 3, 5).

As and Cu determined colorimetrically by Ardith Bartel and W. D. Goss (Nos. 1, 4); by W. D. Goss (Nos. 2, 3).

Pb and Zn determined volumetrically by W. D. Goss and L. F. Rader (Nos. 1, 4); determined by atomic absorption by Claude Huffman, Jr. (Nos. 2, 3).

W determined colorimetrically by L. F. Rader (Nos. 2, 3); by G. H. Van Sickle (No. 4).

Mn and P₂O₅ determined volumetrically by W. D. Goss and L. F. Rader (No. 4); P₂O₅ in No. 1); by Christel Parker (No. 5) by methods described by Peck (1964).

S determined gravimetrically by L. F. Rader (Nos. 1, 4); by Christel Parker (No. 5) by methods described by Peck (1964).

Br and Cl sought by X-ray fluorescence spectroscopy by Polly J. Dunton.

Se determined nephelometrically by G. T. Burrow.

Te determined by J. B. McHugh by method of Lakin and Thompson (1963).

Hg determined by vapor absorption by W. W. Janes and J. H. McCarthy.

ratio of the sulfide concentrates ranges from 35:1 to 88:1. This high Ag: Au ratio relates the New Snowbird deposit to the epithermal silver-gold class of Nolan (1933, p. 624–625) and Ferguson (1929, p. 134–141), but the assortment of mineralogic, fabric, and structural features that denotes an epithermal origin for the Nevada deposits is not found at the New Snowbird, which is better classed as a xenothermal deposit.

Polished sections of concentrates and crude ore were made in cold-setting plastic mounts cured at room temperature without detectable exothermic reaction. Surfaces were given an adequate polish of low relief by intermediate-speed low-pressure hand-lapping with diamond abrasives on Pellon. Low relief is essential for the detection of native gold and silver in pyrite, and a relatively scratch-free surface is helpful for the positive identification of acanthite by optical means. Low temperature for curing, grinding, and polishing is a nec-

TABLE 2.—*Semiquantitative spectrographic analyses of concentrates and tailings, McRae Tungsten Corp. mill*

[Analyses 1-4 by Nancy Conklin; analysis 5 by Harriet Neiman, M, major; 0, looked for but not detected; ---, not looked for. Other results are reported in weight percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth; these numbers represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time]

	1	2	3	4	5
Field No.....	SN/56/7b	SN/64/1	SN/64/2	SN/56/7a	SN/64/3
Lab. No.....	D113983	D115110	D115111	D113982	D100632
Si.....	0.5	0.7	0.7	5.	-----
Al.....	.2	.3	.3	2.	-----
Fe.....	M	M	M	M	-----
Mg.....	.015	.007	.007	.05	-----
Ca.....	.2	.7	.5	M	-----
Na.....	0	0	0	0	-----
K.....	0	0	0	0	-----
Ti.....	.1	.1	.1	.3	-----
P.....	0	0	0	0	-----
Mn.....	.3	.2	.3	7.	-----
Ag.....	2.	.5	.3	.005	0.001
As.....	.7	.5	.5	0	0
Au.....	.02	.05	.005	0	0
Ba.....	.005	.01	.01	.07	.03
Be.....	0	0	0	.0002	.0002
Bi.....	.007	.003	.002	0	0
Cd.....	.05	.02	.02	0	0
Ce.....	0	0	0	.07	0
Co.....	.002	.0015	.0015	.0015	0
Cr.....	0	.001	.001	.007	.0003
Cu.....	5.	2.	2.	.15	.01
Ga.....	-----	-----	-----	-----	.0007
In.....	0	0	0	0	0
La.....	0	0	0	.05	0
Mo.....	<.003	<.01	<.01	<.003	0
Nb.....	.005	0	0	.07	.003
Ni.....	.0015	.0015	.001	.005	0
Pb.....	5.	2.	1.5	1.	.01
Sb.....	.3	.07	.07	0	0
Se.....	0	0	0	.01	0
Sn.....	0	-----	-----	0	0
Sr.....	.002	.005	.005	.3	.005
V.....	0	0	0	.015	.001
W.....	1.	3.	2.	M	.2
Y.....	0	0	0	.015	0
Yb.....	0	0	0	.002	0
Zn.....	5.	1.5	1.5	0	0
Zr.....	0	0	0	.03	.005

NOTE.—Minor elements looked for, but found to be below the limits of spectrographic detection: B, Ge, Hf, Hg, Li, Pd, Pt, Re, Ta, Te, Th, Tl, U.

1. Sulfide concentrate collected August 1956 while mill was operating.
2. Sulfide concentrate collected September 1964. Represents upper, more oxidized part of small pile of concentrates remaining at southwest corner of mill floor after mill was dismantled. Screened to remove contaminants—pebbles, twigs, spruce needles.
3. Sulfide concentrate collected September 1964. Represents lower, less oxidized part of the residual pile sampled by 2, above. Screened to remove trash.
4. Huebnerite-scheelite concentrate collected August 1956 while mill was operating.
5. Tailings collected September 1964. Represents upper 8 in. of tailings, sampled on 25-ft centers, over entire tailings pile whose diameter was 100-150 ft. Screened to remove trash.

essary precaution against artificially inducing phase transformations in certain sulfides.

Samples used for electron-probe analysis were coated with a thin film of evaporated carbon to make the sample surface electrically conducting. This procedure is particularly important when analyzing disaggregated grains mounted in a nonconducting plastic. For some minerals, the carbon coating enhances the visual contrast between different phases, but for others it obscures the contrast and makes the recognition of a desired grain quite difficult. By confining the electron probe work to qualitative and semiquantitative analysis, we were able to obtain information on a large number of phases.

TABLE 3.—*Semiquantitative spectrographic analyses of handpicked mineral fractions of sulfide concentrates, McRae Tungsten Corp. mill*

[Nancy Conklin, analyst, M, major; 0, looked for but not detected; ---, not looked for. Other results are reported in weight percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth; these numbers represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time]

	1	2	3	4
Field No.....	SN/56/7b.1	SN/56/7b.2	SN/56/7b.3	SN/56/7b.4
Lab. No.....	D113984	D113985	D113986	D113987
Si.....	-----	-----	-----	-----
Al.....	0.5	0.2	<0.007	0.1
Fe.....	M	M	10	M
Mg.....	.005	.005	.0015	.005
Ca.....	.07	.05	.07	.05
Na.....	0	0	-----	-----
K.....	0	0	0	0
Ti.....	.05	.07	.01	.05
P.....	0	0	0	0
Mn.....	.03	.0015	2.	.5
Ag ¹10	.24	2.4	>3.8
As.....	1.	.7	0	0
Au.....	.005	.005	<.005	.005
Ba.....	.005	.003	.0015	.01
Bi.....	0	.003	.03	.15
Cd.....	0	.01	>.46	.5
Co.....	.002	.0015	0	0
Cu.....	.3	M	>4.6	M
Ga.....	-----	-----	0	0
Mo.....	<.003	<.003	<.0015	<.0015
Nb.....	0	.002	0	.002
Ni.....	.001	.001	.0007	.0007
Pb.....	.15	1.5	M	M
Sb.....	0	.02	5.	.3
Sn.....	0	0	0	.002
W.....	.15	.2	.1	.07
Zn.....	.3	1.5	M	M

¹ Quantitative spectrographic analysis.

NOTE.—Minor elements looked for, but found to be below the limits of spectrographic detection: B, Be, Ce, Cr, Ge, Hf, Hg, La, Li, Pd, Pt, Re, Se, Sr, Ta, Te, Th, Tl, U, V, Y, Yb, Zr. Not looked for: In.

1. "Pyrite." Contaminated by inclusions of arsenopyrite, etc.
2. "Chalcopyrite." Contaminated by inclusions and by locked grains, especially pyrite.
3. "Sphalerite." Contaminated by inclusions and by foreign grains, especially argentian tetrahedrite.
4. "Tetrahedrite." Mainly acanthite-rimmed grains of chalcopyrite, copper sulfides, galena, and sphalerite.

However, doing this largely qualitative work required some sacrifice of analytical sensitivity. The electron probe should not be considered an instrument which can detect hundredths of a percent or less of an element but rather an instrument which can detect major elements present in areas of micron size. To obtain maximum sensitivity, which varies with the sample being studied, one must have both a good set of standards and an electron probe set up specifically for the elements of interest. Qualitative analysis has neither of these requirements. In this study, we shall consider that the cut-off point for elements reported as "not detected" is about 1 percent.

TABLE 4.—Approximate mineralogic composition of sulfide fraction of sulfide concentrates, McKae Tungsten Corp. mill¹

	Volume percent (mode) ²	Weight percent		
		Calculated from mode	Calculated from chemical analysis ³	Calculated from chemical analysis ⁴
Pyrite.....	76.5	77.8	76.66	77.73
Arsenopyrite.....			.84	.84
Chalcopyrite.....	10.1	8.6	13.86	12.20
Digenite ⁵	2.8	2.4	1.07	1.62
Sphalerite.....	6.1	5.1	3.44	3.46
Galena.....	2.8	3.8	2.80	2.81
Acanthite.....	1.7	2.3	1.33	1.34
Total.....	100.0	100.0	100.00	100.00

¹ Sample SN/56/7b. Sulfide fraction makes up 97.8 volume percent of the sulfide concentrate. Remainder is huebnerite and gangue.

² Number of points counted (179) is too small, owing to coarse "jumps" on the available counter. Only the major minerals are listed.

³ Assumptions: All Ag is in acanthite; all As is in arsenopyrite; 80 percent of total Cu is in chalcopyrite, 20 percent in digenite; total Fe, not determined in the analysis, is adequate to satisfy total S in pyrite after other sulfides have been calculated.

⁴ Assumptions: Same as (³), except 70 percent of total Cu is in chalcopyrite, 30 percent in digenite.

⁵ Blaubleibender covellite is seen more often, but digenite probably has the greater bulk.

Qualitative analyses were made by comparing the spectrometer traces of unknown minerals with the traces produced by reference minerals, and by displaying the X-ray pulses on an oscilloscope screen on which one can see the distribution of elements of interest in areas whose size ranges from a maximum of about 360 microns square down to a minimum of about 1 micron diameter (pls. 1, 2). Semiquantitative analyses were made for selected elements, such as silver in tetrahedrite. The limiting size of grains suitable for semiquantitative analysis is 1–3 microns. All analyses were carried out with an accelerating voltage of 25 kilovolts and a specimen current of approximately 0.01 microampere.

Cynthia Mead carried out the electron microprobe analyses of the ore minerals. Nancy Conklin made most of the semiquantitative spectrographic analyses. Mrs. Conklin's analyses first indicated the remarkable concentration of precious metals in the sulfide concentrates and led to the present chemical and mineralogic study. X-ray diffraction data not credited to Fred A. Hildebrand, Shirley K. Mosburg, or T. Botinelly are those of Leonard, who is responsible for the study as a whole.

LOCATION AND OPERATION

The New Snowbird deposit is 4.75 miles northwest of Big Creek settlement, Valley County, Idaho, and 1.2 miles northeast of Elk Summit, in the northwest corner of the central ninth of the Big Creek 15-minute quadrangle. (See fig. 1.) The deposit is reached from Big Creek settlement either by the Warren road and Fawn Meadow cutoff or by the Smith Creek road, routes best traveled by four-wheel-drive vehicle. The deposit is on the Tungsten claim of the Snowbird group of seven unpatented mining claims, Big Creek mining district.

The McKae Tungsten Corp. mined the deposit from

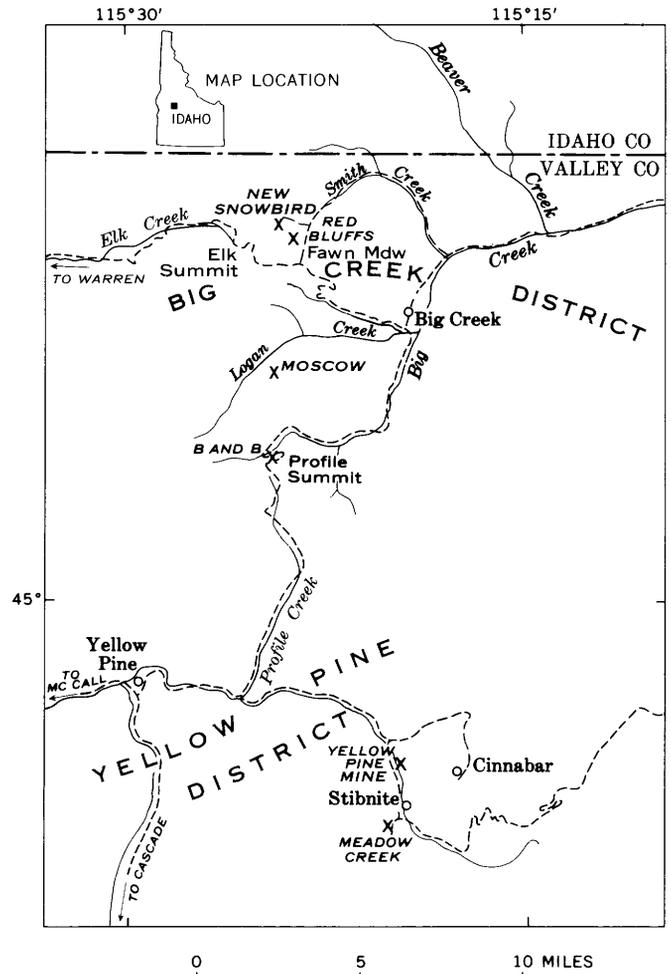


FIGURE 1.—Index map of parts of Big Creek and Yellow Pine districts, Idaho.

1954 to 1957, producing high-grade and low-grade huebnerite-scheelite concentrates whose value exceeded \$90,000. Ore was crushed to 1-inch size, ground to -20 mesh (0.833 mm), classified hydraulically, and separated by tabling supplemented by froth flotation. Sulfides were floated from the huebnerite-scheelite concentrate. The operation was abandoned when removal of the subsidy for domestic tungsten concentrates caused the price to be halved.

GEOLOGY

—The New Snowbird deposit is near the north end of a major system of silicified zones, near the heart of the Idaho batholith. In the Big Creek area, the silicified zones accompany the Profile-Smith Creek dike swarm. (See Shenon and Ross, 1936, fig. 3; Leonard, 1965, p. B24.) Within the swarm, elongate lenticular relics of granitic rock, locally silicified, alternate with dikes and small stocks of Miocene(?) granite porphyry and related rock. The silicified zones at this latitude are in my-

lonitized, sheared, and brecciated felsic granodiorite, alaskite, and aplite of the batholith. Slabby inclusions of metasedimentary rock are sparse and considerably argillized. The whole system of silicified zones is more than 18 miles long and a few hundred feet to several thousand feet wide. It forms a composite, sheared, crackled, and block-faulted unit in which lenticular quartz veins, groups of contiguous veins, and sporadic stockworks alternate with bodies of host rock that contain little or no introduced quartz. Individual quartz bodies range from veinlets a fraction of an inch wide and a few inches long to lodes and masses several hundred feet wide and more than a thousand feet long. Groups of quartz bodies of various shapes and dimensions constitute the silicified zones of the area. The quartz concentrations are partly fissure fillings and stockworks but mostly replacement bodies showing evidence of repeated deformation and reintroduction of quartz.

The quartz-rich intensely silicified zone at the New Snowbird mine is a southward-tapering mass that is shielded from the flanking dikes by a narrow envelope of partly silicified granitic rock. In most places the quartz-rich zone is little more than 100 feet wide. Five hundred feet south of the southernmost workings, the zone narrows to 2 feet and ends abruptly against the granite envelope, which pinches out between dikes less than 200 feet farther south. This quartz-rich zone is the most conspicuous of several subparallel zones, 15–150 feet wide and some hundreds of feet long, each isolated from its neighbor by one or more dikes. North of the mine, the continuity of the complex of dikes and silicified zones is disrupted by the concealed Elk Creek–Middle Fork Smith Creek fault.

The western (hanging-wall) dike at the mine is a brown-weathering gray-green quartz-bearing latite. Its outcrop width is 90 feet. Phenocrysts of hornblende and plagioclase are abundant; those of biotite, K-feldspar, and magnetite are sparse; those of quartz, apatite, and zircon are very sparse and small. The groundmass is mainly turbid alkali feldspar accompanied by some chlorite, sparse quartz and biotite, and sporadic apatite. At the south end of the silicified zone, the western dike is almost devoid of mafic minerals. The eastern dike is pale greenish-gray rhyolite, weathering pink. It is 15 feet wide. Phenocrysts—quartz, sanidine (dominant), sodic plagioclase, and biotite (mostly altered to chlorite and leucoxene)—are rather abundant. The equant, embayed phenocrysts of high-temperature quartz are mantled by spherulitic aggregates of alkali feldspar. Except for a little apatite, zircon, and limonitized pyrite, the minerals of the granular groundmass are the same as the phenocryst minerals. The feldspars are tur-

bid and locally flecked with a little calcite and micaeous stuff. The composition, fabric, and extent of alteration of these dikes vary slightly from specimen to specimen, but in general the dikes look fresh and are representative of the two principal varieties found in this and other dike swarms of the region.

The age relations between the local dikes and the silicified zone are indeterminate. At the Red Bluffs deposit nearby, angular inclusions of sheared, schistose, silicified but unmetallized alaskite gneiss are present in a rhyolite dike. Shearing and granulation occurred after silicification of the granoblastic gneiss but before emplacement of the unsheared, unaltered dike. It is reasonable to suppose that a similar sequence of events took place at the New Snowbird. How metallization relates to these events is debatable. At both deposits, undeformed huebnerite crystals are studded throughout nonschistose, unsheared but locally crackled quartz that replaces older sheared silicified gneiss. Inclusions of this younger quartz (which represents several generations geometrically, if not genetically) have not been found in dikes of the region. This relation suggests that the dikes are older than some relatively coarse, unsheared quartz, but the two might be roughly contemporaneous. A few scheelite specks were found in a thin hanging-wall dike at the New Snowbird (R. J. McRae, oral commun., 1956), but whether these were inclusions, accessory grains, or replacements was indeterminate. Disseminated pyrite is common in many dikes of the region; it seems generally to be a primary accessory mineral, but its origin in some dikes is debatable. We believe that the weight of evidence favors the introduction of some quartz, all the local tungsten minerals, and at least some sulfides after the emplacement of dikes that cut older silicified zones. Metallization is not predike, but it might be either contemporaneous or younger. If the dikes are older than the ore, then a local flattening of the regionally prevailing vertical dip of the western dike at the New Snowbird may have provided a structural trap for the ascending ore solutions; but, as the foregoing account indicates, the dike itself is not everywhere the hanging wall of the ore body. Thus the genetic connection of dikes and ore is as uncertain here as in many other districts.

ORE DEPOSIT

Tungsten ore was mined from a somewhat irregular, crudely tabular lode striking N. 25° E. and dipping 70° W. The footwall of the ore body was partly silicified granitic rock. Locally a selvage of similar material, roughly 5 feet thick, made the hanging wall; locally the hanging wall was the quartz-bearing latite dike. The ore body was 150–170 feet long and generally 4–7 feet

thick. It consisted of a northern, higher grade segment and a southern, lower grade segment; possibly these reflect a crude shoot structure that rakes nearly vertically. Within the segments, scheelite and huebnerite were irregularly distributed, but details of this small-scale variation are not known. The ore body was cut by minor faults of north or north-northeast strike and seemingly slight displacement. The relation between the main body (McRae vein) and an East vein was not determined during exploration of the deposit. Regardless of the possible identity of the veins, they may belong to adjacent blocks separated by a north (?) -striking normal fault.

The tungsten ore was of low grade. Only a small part of the explored body contained ore averaging more than 1 percent WO_3 (Defense Minerals Exploration Admin. field team, unpub. data). Ore mined in 1956, the last year of major operation, averaged 0.65 weight percent WO_3 (U.S. Bur. Mines, 1956, p. 389).

The quantity of disseminated sulfides in the ore was not of interest to the operator and was never determined. From published and unpublished production data we estimate that it was roughly 0.075–0.2 weight percent. The value 0.1 weight percent is a usable approximation. Probably the sulfides were more widely distributed than the tungsten minerals within the silicified zone, for this is a usual pattern in the district. However, the details for the New Snowbird deposit are unknown.

MINERALOGY AND PARAGENETIC SEQUENCE

The minerals of the deposit are divisible into four suites: gangue, tungsten minerals, sulfides and related minerals, and alteration products. This listing represents, with minor exceptions, the order of deposition of the suites. A description of representative ore precedes the discussion of the suites and their complex relations.

TYPICAL ORE

Typical tungsten ore consists of massive milky quartz with sporadic subhedral prisms of huebnerite, small patches of scheelite, and very sparse specks of sulfides. The quartz is fine to medium grained, greasy in luster, and devoid of vugs except where the sulfide specks have weathered from it. The dark-brown huebnerite crystals are mostly less than 1 cm long. Scheelite, looking flesh colored against the quartz, appears in ultraviolet light as brilliant bluish-white patches a few millimeters long,

as trains of minute specks, and as threadlike discontinuous veinlets. Irregular joints are slightly iron stained and locally coated with specks and dendrites of black manganese oxides. Some specimens show small areas of buff clay minerals. With a hand lens, a few additional constituents can be seen: muscovite as small flakes and patches; blue-green copper(?) minerals as granules surrounding specks of limonite and cuprite(?); pyrite, chalcopyrite, and sooty sulfides as minute specks; jarosite(?) as a few small patches. The sulfides are so sparse that one seldom sees more than a few specks in a fist-size piece of ore.

Thin sections add little to knowledge of the ore's mineralogy, but they do reveal its remarkable fabric.

Three kinds of quartz are present:

1. Medium grained (1–3 mm, locally coarser) anhedral to subhedral, mottled at average extinction for a given "individual," turbid from an abundance of fluid inclusions, locally twinned, rarely zoned; most abundant and oldest.
2. Variably grained, inclusion-poor, as narrow replacement veinlets cutting quartz 1 and one another, the individuals always in optical continuity with their host grains; least abundant and seemingly of intermediate age.
3. Fine grained (0.02–0.1 mm, locally much finer), anhedral or rarely subhedral, inclusion-poor, as replacement and dilation veinlets in quartz 1 and 2, and perhaps in small part as narrow granulation zones in quartz 1; common, seemingly youngest, rarely containing a trace of K-feldspar.

Huebnerite, subhedral to euhedral, locally showing darker cores, is mostly confined to medium-grained quartz. Scheelite, anhedral to subhedral, is mostly disseminated through fine-grained quartz or present as thin veinlets collinear with those of fine quartz. Some scheelite veinlets cut across fine quartz veinlets, and some coarser scheelite is found in medium-grained quartz. Scheelite locally replaces huebnerite, rimming and veining the host and forming a cleavage-controlled lattice within it. Some of this "scheelite" may be stolzite, but the distinction cannot be made optically on these fine-grained products. Rarely, huebnerite contains small round inclusions of scheelite. Sulfides—identifiable in thin section only as pyrite cubes and black granules, each rimmed by limonite—seem not to show a preference among the quartz varieties, though the larger pyrite crystals are confined to the coarser quartz.

Limonite locally replaces a little scheelite, huebnerite, and clay minerals, as well as sulfides.

Chlorite, nontronite(?), K-feldspar, malachite(?), and another blue-green secondary mineral (possibly a copper phosphate or arsenate) are very sparingly present.

Fluorite was not found in thin sections, but a colorless variety is present in tungsten concentrates and in the heavy-mineral fraction of tailings. Pale-green and purple fluorite are sparse in the mill products.

GANGUE INDICATED BY MILL PRODUCTS

The tailings pile provides a sample of gangue unequaled for displaying the contents of a silicified zone of the New Snowbird type. Because the ore was of relatively low grade, the tailings are a large proportion of the material milled and consequently are rather closely representative of the whole ore body. Our study of the tailings is only semiquantitative (table 5, col. 1). It

TABLE 5.—Minerals of the New Snowbird deposit

[Arrangement within suites is alphabetical. Minerals forming >1 percent of each suite are starred]

<i>Gangue</i>	*Digenite
Apatite	*Galena
Biotite	Gold
Calcite	Hessite
Chlorite ¹	Idaite(?)
Clay minerals ¹	Ilmenite(?)
Epidote	Marcasite
*Fluorite	Miargyrite(?)
Hornblende	Polybasite(?)
K-feldspar	*Pyrite
*Muscovite	Pyrrhotite
Plagioclase	Silberkies(?) group
*Quartz	Silver
Unidentified minerals	*Sphalerite
	Tetrahedrite
	Unidentified minerals ²
<i>Tungsten minerals</i>	<i>Alteration products</i>
*Huebnerite	Anglesite(?)
*Scheelite	Bianchite(?)
Stolzite	Cerargyrite
Others? ¹	Cerussite
<i>Sulfides and related minerals</i>	Chlorite
*Acanthite	*Clay minerals
Aramayoite(?)	Cuprite(?)
Arsenopyrite	*Goethite
Blaubleibender covellite	Jarosite group
Bornite	Malachite(?)
Chalcocite	Psilomelane
*Chalcopyrite	Pyrolusite
Covellite	Tenorite
Diaphorite(?)	Tungsten alteration products
	Unidentified minerals ³

¹ Alteration products.

² Principal ones are soft white mineral and green-orange unknown.

³ Possibly hydrated sulfates and arsenates.

shows that the body was more complex than one would infer from field study and examination of a modest number of thin sections, but the difference is slight. It lies mainly in the presence of accessory phosphates (apatite and perhaps others) and a few accidental minerals probably derived from small masses of wallrock. Barite, tourmaline, and topaz—minerals that might be expected in a tungsten deposit within a quartz lode—are absent. A few of the constituents are discussed below.

Accidental constituents.—Biotite, muscovite, quartz, K-feldspar, sodic plagioclase, and accessory apatite and zircon are components of sheared granoblastic alaskite gneiss that occurs as relics within the New Snowbird and nearby silicified zones. Small bodies of gneiss, intimately associated with ore, may have been mined and milled here, and part of the mineral assemblage noted in table 5 may thus be extraneous to the quartz veins. However, most of the quartz, muscovite, and apatite and some of the K-feldspar probably belong to the suite of vein minerals proper.

K-feldspar, which is slightly less than 1 percent of the tailings, was investigated on the supposition that it might be adularia. It is not. Both K-feldspar from the tailings and K-feldspar from a granite gneiss inclusion at the neighboring Red Bluffs deposit are intermediate microclines, but their X-ray-diffraction powder patterns are not identical: the New Snowbird microcline has a triclinicity of 0.4; the Red Bluffs microcline has a triclinicity of 0.7. The triclinicity would be zero for monoclinic feldspar, such as orthoclase, and unity for a most highly triclinic microcline. These measurements of degree of symmetry, based on the method of Goldsmith and Laves (1954, p. 3-5), suggest that K-feldspar of the New Snowbird deposit may originally have been xenocrystic, and that it has been partly recrystallized by the vein-forming solutions, becoming more nearly monoclinic and thus more like the adularian K-feldspars found in many veins. A study of other minerals that may have been reworked, such as hornblende, is beyond the scope of this report.

Apatite.—This is a common fluorapatite, but its sharply euhedral habit and abundance exceeding that common to alaskite gneiss of the area strongly suggest that it was brought in or at least concentrated by the quartz-depositing ore fluids.

The presence of at least one additional phosphate as a rare primary(?) accessory is suspected from optical data. However, the impossibility of handpicking the

minute grains for X-ray or chemical confirmation leaves the species in doubt.

Clay minerals are discussed subsequently as alteration products.

A chemical analysis of the tailings (table 6) confirms the results of the mineralogic studies. The gangue of the ore body was chemically as well as mineralogically simple, consisting mainly of quartz with a little muscovite, fluorite, K-feldspar, clay minerals, phosphates, and accidental constituents. In more densely settled parts of the country, mill tailings of this sort have been marketed for use as roofing granules, poultry grit, and concrete aggregate.

TUNGSTEN MINERALS

The chief tungsten mineral of the deposit is *huebnerite*, ranging in color from dark red through dark reddish brown and very dark brown to brownish black. Most of the huebnerite contains about 86 mole percent $MnWO_4$. In the laboratory, it is recoverable at 0.5 amp on a Frantz magnetic separator. Other and less abundant magnetic fractions, recoverable at 0.2–0.9 amp, range in composition from about 84 to 88 mole percent $MnWO_4$. Successive magnetic fractions differ little in appearance, presumably because the color of individual grains depends more on their thickness than on their chemical composition. The estimates of composition were made on representative –150 and +200 mesh fractions by X-ray powder diffraction according to the peak difference method of Sasaki (1959, p. 386–388, 391), to which he ascribed an accuracy of ± 6 mole percent.

TABLE 6.—Chemical analysis of tailings, McRae Tungsten Corp. mill

[Christel L. Parker, analyst. Field No. SN-64-3, Lab. No. D 100632. Tailings collected September 1964. Represents upper 8 in. of tailings, sampled on 25-ft centers, over entire tailings pile whose diameter was 100–150 ft. Screened to remove trash. For semiquantitative spectrographic analysis, see table 2]

Constituent	Weight percent
SiO ₂ -----	90.49
Al ₂ O ₃ -----	4.03
Fe ₂ O ₃ -----	.95
FeO-----	.16
MgO-----	.13
CaO-----	.54
Na ₂ O-----	.24
K ₂ O-----	1.97
H ₂ O +-----	.56
H ₂ O -----	.12
TiO ₂ -----	.08
P ₂ O ₅ -----	.02
MnO-----	.07
CO ₂ -----	.01
Cl-----	.01
F-----	.34
S-----	.02
Subtotal-----	99.74
Less O-----	.14
Total-----	99.60

Scheelite is roughly half as abundant as huebnerite in the mill concentrates. Its low molybdenum content, indicated by bluish-white fluorescence in short-wave ultraviolet light, is borne out by spectrographic analysis (table 2, No. 4). The difficulty of getting pure fractions of huebnerite and scheelite by the usual laboratory separation techniques makes detailed chemical or spectrochemical analysis of these minerals infeasible at present.

Stolzite, tetragonal $PbWO_4$, is sparingly present. It is buff to pale brown, fine grained to exceedingly fine grained, and virtually indistinguishable from slightly brownish scheelite. It is identifiable, even in scheelite-rich mixtures, by its principal reflections in X-ray powder diffractograms: 3.24, 100; 2.72, 28; 2.02, 28; 1.776, 12; 1.653, 24 (d is in angstroms, I is relative intensity; for comparative data, see Berry and Thompson, 1962, p. 228). Because these reflections are close to those of wulfenite, $PbMoO_4$, one X-rayed scheelite-stolzite mixture was qualitatively analyzed by X-ray fluorescence by J. S. Wahlberg, who found Pb and W to be major constituents and Mo to be absent; Ca was not sought (J. S. Wahlberg, oral commun., 1966). Stolzite, rather than wulfenite, is therefore present in the mixture. Stolzite is relatively abundant in the clay-size fraction separated by ultrasonic cleaning of tungsten concentrates and tailings, though some stolzite is also present in cleaned sand-size concentrates. Stolzite accounts for all or most of the Pb in tungsten concentrates and tailings (table 1, Nos. 4 and 5), both of which contain little S. Since Pb is disproportionately higher in the tailings, it seems that a fair part of the tungsten lost in the tailings was in extremely fine grained stolzite.

Other tungsten minerals may be sparingly present as clay-size alteration products mixed with true clays. (See section on "Alteration Products.")

SULFIDES AND RELATED MINERALS

The sulfides, sulfosalts, and native metals are a complex suite, genetically divisible into three groups or stages: (1) early sulfides—pyrite and its included ore minerals; (2) intermediate sulfides and sulfosalts with inclusions of native silver—minerals that, excepting relatives of the ruby silver minerals, do not almost exclusively form crusts—and (3) late sulfides that form conspicuous crusts. For descriptive purposes, this three-fold division is unmanageable, owing to the occurrence of some species in several stages. Therefore, we shall describe the main minerals in order of abundance (table 4) and their associates in alphabetical order. We have tried to present enough information on each species to support our interpretation of the fabric of the whole assemblage and to permit other workers to construct alternative schemes if they wish.

The chemical composition of some less common minerals is shown by formulas taken from Hey (1955), unless another source is cited. Optical properties are listed only for species whose identification here is doubtful.

The term "discrete grains" denotes grains that do not occur as inclusions. Such grains may, however, be locked or composite.

Pyrite, the most abundant sulfide in the deposit, is almost a microcosm of the sulfide assemblage. It contains as inclusions nearly all the sulfides and sulfosalts that subsequently crystallized as discrete grains, as well as eight or nine species not found elsewhere in the assemblage. These included minerals are listed in table 7 and individually described elsewhere in this section. Some pyrite grains show no inclusions, and some contain only arsenopyrite, pyrrhotite, or chalcopyrite, but many of them contain a mixed assemblage of several sulfides with or without native gold, native silver, and gangue minerals (pls. 2, 3, 4A). Pyrite contains, in the form of mineral inclusions, all the elemental gold, a substantial part of the elemental silver, and much of the elemental arsenic found in the sulfide concentrates. Pyrite is partly replaced by several of the intermediate and youngest sulfides. Pyrite has not been found as inclusions in any other mineral unless it is an obvious relic, as in some grains of chalcopyrite and goethite. Thus it seems to have formed first among the sulfides. Its age relations with the tungsten minerals are seldom determinable, though pyrite is the sulfide most often found in contact with these minerals. In one place, an irregular pyrite grain partly replaces the margin of a zoned huebnerite crystal; in another, pyrite envelopes quartz gangue that contains euhedral scheelite; in most places pyrite is molded on euhedral scheelite.

Semiquantitative microprobe analysis of the pyrite shows only the major elements Fe and S. If other elements are present in the pyrite lattice, they are below the limits of detection. Presumably the Co and Ni reported in nearly the same low concentration in spectrographic analyses of sulfide concentrates (table 2, Nos. 1, 2, 3) and of the handpicked pyrite fraction (table 3, No. 1) is accommodated in the pyrite lattice, or in pyrite plus chalcopyrite (table 3, No. 2). Alternatively, the Co and Ni might be concentrated in minute stray inclusions of minerals such as cobaltian loellingite and skutterudite, which could easily go undetected among the arsenopyrite inclusions in pyrite. However, we have looked for these optically and by microprobe but have not found them.

Chalcopyrite is the most abundant base-metal sulfide in the concentrates (table 4). Most of it is present as discrete grains, badly pitted in polished section, containing sporadic inclusions of sphalerite and galena.

Small chalcopyrite blebs are common in pyrite, very abundant in most sphalerite, and sparse in galena and tetrahedrite. Chalcopyrite is molded on some scheelite grains and partly replaces others, but the two minerals are seldom seen in contact. Stubby veinlets of chalcopyrite penetrate pyrite. Rarely, chalcopyrite almost wholly replaces pyrite, leaving relics of chalcopyrite, arsenopyrite, and marcasite. The contacts of chalcopyrite with other base-metal sulfides and sulfosalts are discussed in the section on "Paragenetic Sequence."

The discrete grains of chalcopyrite show a slightly anomalous rose tint, suggesting that the mineral might represent the cubic, high-temperature form recently described by Bud'ko and Kulagov (1963) and by Genkin and others (1966). To check this possibility, powder was drilled from three homogeneous grains and X-rayed by T. Botinelly. Powder photographs of samples from two grains showed the diagnostic 024 reflection of the common tetragonal form; the third photograph was unusable because the powder sample was too small. Thus both X-ray diffraction and electron microprobe analysis (see below) point to ordinary chalcopyrite as the form present here.

Semiquantitative electron microprobe analysis shows Cu, Fe, and S as major constituents of the discrete chalcopyrite grains. No concentration of Ag or Au within the chalcopyrite lattice was detectable. Relict chalcopyrite blebs in pyrite are, under the ore microscope, slightly greener than chalcopyrite that was introduced as veinlets and replacement bodies, but we were unable to make a microprobe comparison of the two varieties.

Sphalerite is the second most abundant base-metal sulfide. Most of it is present as discrete grains, and most of these contain abundant inclusions of chalcopyrite—so many, indeed, that the uncorrected modal value of sphalerite (table 4) becomes too high for the quantity of Zn determined chemically. Acanthite (inverted from argentite), galena, and native silver are very sparingly present as inclusions. A few sphalerite grains contain no inclusions. A little chalcopyrite-bearing sphalerite occurs as small round inclusions in pyrite, chalcopyrite, galena, and tetrahedrite.

Semiquantitative microprobe analysis of several sphalerite grains shows major Zn and S, and minor but appreciable amounts of Fe. Silver, Cu, Mn, and Sb are undetectable. Cadmium, if present, is distinctly minor. This relation differs from one previously inferred from semiquantitative spectrographic analyses of sulfide concentrates and hand-picked fractions (table 2, Nos. 1, 2, 3; table 3, Nos. 3, 4). Those analyses show a Cd-Zn ratio of 0.01–0.013 in the concentrates and a similar or perhaps higher ratio in the hand-picked mixtures.

Either the microprobe analysis of sphalerite grains for Cd was relatively insensitive, or some discrete but still unfound Cd mineral is present in the concentrates, or Cd is bound to some element other than Zn. The first possibility seems most likely.

Microprobe analysis of inclusion-free sphalerite grains shows roughly the same Fe content in them as in the host of the chalcopyrite-rich grains. This relation suggests that low-temperature, Fe-poor sphalerite is either sparse or absent from the assemblage.

Galena makes up several percent of the sulfide concentrates (table 4). Most of it is present as discrete grains, commonly rimmed by later sulfides (pl. 1A). A little is present as round inclusions in pyrite, sphalerite, chalcopyrite, and tetrahedrite, and as rare replacement veinlets in pyrite. Discrete grains of galena infrequently contain sparse round inclusions of sphalerite, chalcopyrite, and tetrahedrite, and minute subhedral inclusions of acanthite(?), aramayoite(?), native silver (rare), and unidentifiable sulfosalts(?). Semiquantitative microprobe analysis of several galena grains yields only the major elements Pb and S, and confirms the optical identification of galena inclusions in other sulfides.

Digenite, cubic $\text{Cu}_{1.8}\text{S}$ (Djurle, 1958) or $\text{Cu}_{9-x}\text{S}_5$ (Morimoto and Kullerud, 1963), seems to be the most abundant copper sulfide in the concentrates, though it is less conspicuous and less frequent than the covellites. Much of the digenite occurs as discrete, equant grains, commonly rimmed by still younger sulfides, but some digenite replaces pyrite, sphalerite, galena, and acanthite. Digenite does not form crusts on older sulfides, but it may be encrusted by younger ones. (See section on "Paragenetic Sequence.") Either bornite or idaite(?) is very sparingly present as an extremely fine grained intergrowth with digenite, generally near the borders of the digenite grains, but bornite and idaite(?) have not been found together within the digenite host. Rarely, a bit of chalcocite is intergrown with digenite.

Semiquantitative electron microprobe analysis of several digenite grains shows Cu and S to be major elements in all grains, Fe minor in some grains, and Te slightly above background in one grain. Silver is sparingly present in some grains. Gold, Bi, Sn, Zn, and probably Se too, are absent. Possibly Fe is due to bornite as extremely fine intergrowths, though the analyzed digenite grains looked homogeneous at very high magnification.

Acanthite, monoclinic Ag_2S , is the most abundant silver mineral in the sulfide concentrates. Typically it occurs as ragged replacement rims on galena (pl. 1A). These rims range in width from about 2 microns to more than 0.1 mm. Many rims are about 20 microns wide. A

few rims engulf all but a minute central speck of galena. Acanthite less commonly forms rims on sphalerite, where acanthite replaces sphalerite preferentially, thereby inheriting the chalcopyrite inclusions of the sphalerite host. Acanthite rims on discrete grains of chalcopyrite are rare. Some acanthite is present as discrete, homogeneous grains, perhaps representing complete replacement of galena. A little acanthite occurs as colloform aggregates interlaminated with an unidentified weakly reflecting mineral. A trace of acanthite probably occurs as rare inclusions in pyrite, sphalerite, galena, and tetrahedrite, though the identification of the included phase is positive in sphalerite only.

In all its forms, the acanthite is an aggregate of very small grains, commonly subhedral. An acicular or thornlike habit is shown by some acanthite crystals that penetrate galena. This habit is diagnostic for the monoclinic, low-temperature Ag_2S polymorph, acanthite. The cross section of one acanthite inclusion in sphalerite resembles that of a slightly distorted octahedron bounded on two sides by sphalerite, on the third side by chalcopyrite, and on the fourth by a sphalerite cleavage pit. This acanthite is indistinctly twinned. Both crystal habit and twinning strongly suggest that this acanthite is pseudomorphous after argentite, the cubic, higher temperature modification of Ag_2S , for which Kracek (1946) reported $177.8 \pm 0.7^\circ\text{C}$ as the temperature of the reversible transformation in the presence of sulfur. A single acanthite inclusion in tetrahedrite shows cleavage that looks cubic, suggesting that this acanthite likewise inverted from argentite. Many other acanthite areas have been examined for evidence of the high-to-low inversion, but without success, possibly because of the extremely fine grain of the mineral, or possibly because all acanthite except the grains included in sphalerite and tetrahedrite developed below the inversion temperature as primary acanthite. The genetic and economic implications of this problem are discussed subsequently.

Rarely, acanthite that rims galena contains minute bright needles of native silver. Acanthite partly altered to cerargyrite is accompanied by pips of native silver. A few grains of acanthite are coated with a thin skin of a hydrated(?) iron arsenate. The relations of acanthite and copper sulfides are discussed in the section on "Paragenetic Sequence."

The optical identification of New Snowbird acanthite was confirmed by semiquantitative electron microprobe analysis of several discrete grains and rims. Analysis showed Ag major, S major (concentration approximately equal to that in galena, or ~13 percent), and Cu barely detectable (perhaps 1 percent as a maximum). Quantitatively, the Ag and S content of the acanthite

is identical with that of an inverted acanthite, USNM R-7560 from Batopilas, Mexico, whose X-ray powder photograph is that of monoclinic Ag_2S (Leonard, from a film prepared by Shirley K. Mosburg).

Aramayoite(?), $6[\text{Ag}(\text{Bi,Sb})\text{S}_2]$, forms minute euhedral inclusions—some lathlike, some diamond-shaped—in galena. The mineral seems to be rare. In air it looks somewhat darker than galena; its estimated reflectivity is about 30 percent; its reflection-pleochroism is distinct, from pale gray (\perp length of laths) to lighter, yellowish gray (\parallel length); its anisotropism is strong; internal reflection is not detectable. In oil the mineral looks much darker than galena, its reflection-pleochroism is slightly increased, and a faint orange internal reflection is visible. These properties are appropriate for several sulfosalts, among which aramayoite is suggested to account for the Bi and Sb found spectrographically in some acanthite-coated galena (the handpicked but impure “tetrahedrite concentrate” of table 3, No. 4). The aramayoite(?) inclusions were found too late to be checked by microprobe.²

Arsenopyrite is confined to pyrite, in which it occurs sparingly as euhedral to subhedral inclusions, singly or clustered, in roughly 8 percent of the grains. These inclusions, seldom detectable at $\times < 340$, are best seen with an oil-immersion objective. Optical identification of the mineral was confirmed by semiquantitative microprobe analysis.

Bornite. See *digenite*.

Chalcocite is rare and extremely fine grained. Bits of it are present as partial rims and replacements of chalcopyrite and galena. A trace of chalcocite occurs in mixtures with one or all of the following: Acanthite(?), covellite and blaubleibender covellite, digenite, and the pinkish-gray unknown.

Covellite and *blaubleibender covellite*³ are widespread and conspicuous but quantitatively negligible, forming peripheral patches or complete rims on other sulfides, or cutting the sulfides as replacement veinlets. The rims and veinlets are narrow, and the individuals that make them up are for the most part very fine grained. The covellite and blaubleibender covellite occur singly or together, with or without chalcocite and digenite. Both “covellites” seem to be young but not necessarily supergene. Blaubleibender covellite, the much more abundant of the two, generally encases covellite, though in places the minerals are randomly in-

tergrown. Covellite and blaubleibender covellite are seen most often on sphalerite, chalcopyrite, galena, and acanthite, though they have also been seen as rims on or veinlets in scheelite, pyrite, tetrahedrite, cerargyrite(?), and gangue minerals. The ragged and embayed inner edges of the covellite and blaubleibender covellite rims indicate at least partial replacement of the host minerals, not merely deposition on them.

Diaphorite(?), $8[\text{Ag}_3\text{Pb}_2\text{Sb}_3\text{S}_8]$, is suspected as elongate inclusions in a small aggregate of miargyrite(?) that also contains an inclusion of native silver. The aggregate has a smooth contact against chalcopyrite. In air, the diaphorite(?) looks white, is distinctly anisotropic, and shows no internal reflection; its polishing hardness is less than that of miargyrite(?); its reflectivity for one position in orange light is equal to that of chalcopyrite, for the other position slightly greater. In oil, the diaphorite(?) shows distinct reflection-pleochroism from white to gray-white with a yellowish tint, is anisotropic, and lacks internal reflection; its reflectivity for one position in orange light is slightly less than that of chalcopyrite, for the other position equal. If the miargyrite(?) is correctly identified, the white inclusions are very likely diaphorite, for few minerals softer than miargyrite have the optical properties listed here.

Gold is mostly and perhaps entirely electrum, the natural variety of Au-Ag alloy. Gold is confined to pyrite, in which it occurs mainly as circular grains 5 microns in diameter (pl. 3). A few reach 12 microns. The largest grain—elongate, with cusped sides—is 17×67 microns. A grain of this size is conspicuous at medium power ($\times 130$), owing to its extreme brightness. With practice, an observer can spot even the 5-micron grains at that magnification. A unique grain shaped like a triskelion occurs at the contact of pyrite and included arsenopyrite, penetrating the latter. All other gold grains are isolated within pyrite, which may or may not contain other inclusions, such as arsenopyrite, pyrrhotite, sphalerite, silver minerals, and quartz (pls. 2, 3). The frequency of gold grains is two to six per polished section containing several hundred pyrite grains. We have never observed more than one gold grain in a single pyrite crystal, possibly because many pyrite crystals have been fragmented but more likely because the gold, unlike silver, seems to have been readily collectable. One might expect to find among goethite pseudomorphs after pyrite a grain or two containing gold, or an isolated gold flake, but we have not found any.

All gold grains checked by semiquantitative microprobe analysis are gold-rich electrum (pl. 2). However, the variable color of the gold, ranging from pale golden yellow to rich golden yellow, indicates a range of com-

² Microprobe analysis subsequently showed Ag, Cu, S, Sb present, Bi absent. Thus the mineral is not aramayoite. This note was added in page proof.

³ Blaubleibender covellite, a distinct species of copper sulfide (Moh, 1964), looks like covellite in polished sections viewed with a single nicol and a dry objective. However, the minerals behave differently when viewed in oil: covellite shows a striking color change to purplish red; blaubleibender covellite (“covellite that remains blue”) merely looks darker and shows more richly the strong blue reflection-pleochroism that was visible in air.

position that may extend nearly to pure gold. There is no correlation between the color of the gold and the abundance of native silver inclusions visible in the pyrite host. Elemental gold as a minor element within the crystal lattice of sulfides was not detected by microprobe.

Clark's (1960, p. 1375, 1379-1381, 1645-1647) experimental observations on the solid solubility of gold in arsenopyrite and in As-rich As-S fluid at and above 660°C are intriguing. In the New Snowbird sulfide concentrates, we found native gold in contact with arsenopyrite in just one place. (See preceding description of gold.) Here and in arsenopyrite-bearing pyrite grains that contain blebs of native gold not in contact with arsenopyrite, the quantity of gold is roughly 20 areal percent that of the arsenopyrite—considerably more than Clark observed as a product of solid diffusion in short experimental runs at and above 660°C. However, the quantity of arsenopyrite lost mechanically or concealed below the surface of our polished sections is unknown. Moreover, it is conceivable that, under natural conditions, time or other variables might compensate for lower temperature, effecting enough diffusion of gold into and out of arsenopyrite to give the quantitative relations we observed. Nevertheless, the total amount of As in the sulfide concentrates (0.36-0.41 weight percent) seems much too low to make Clark's attractive hypothesis of gold diffusion directly applicable to the New Snowbird deposit.

Green-orange unknown.—This mineral seems to be a new species. Characteristically it encrusts and replaces late copper sulfides and is locally encrusted by the pinkish-gray unknown. Where fresh, the unknown mineral is a peculiar greenish orange, optically anisotropic, and rather soft. In a dry climate it tarnishes slowly, becoming orange-pink and then dull pink after a few weeks. Because the color of the freshly polished mineral resembles that of an unripe orange, we refer to this mineral as green-orange unknown. It is essentially a Cu-Fe(?) sulfide. We hope to obtain enough quantitative data to describe this species in a subsequent report.

Hessite, Ag_2Te , was positively identified in one particle only, a broken crystal of pyrite penetrated by stubby veinlets of hessite. Microprobe analysis showed Ag and Te to be major constituents. Gold and other expectable telluride-forming elements were not detected. The electron probe spectrometer trace of this hessite is identical to that of a reference sample of hessite (RTO 267) previously identified by Leonard from an X-ray powder diffraction photograph taken by T. Botinelly.

Idaite(?), Cu_5FeS_6 (Frenzel, 1959), may be present as a trace in some grains of digenite, with which it forms an extremely fine grained and intimate inter-

growth. The idaite(?) is soft, relatively bright, pinkish orange, seemingly anisotropic, and perhaps platy. As the individuals are barely resolvable in oil at $\times 1600$ and the aggregates present too small a target for the electron beam of the microprobe, the identification of this mineral is dubious.

Ilmenite(?).—This mineral was identified by Fred A. Hildebrand in X-ray powder photographs that he took of iron oxide-manganese oxide coatings of huebnerite grains. We have not found ilmenite in the polished section made from these coatings. The Ti content of all samples of concentrates is low, but its higher value in the tungsten concentrates (table 2, No. 4) lends support to the notion that a Ti mineral might be present in them.

Marcasite is sparse. It is confined to pyrite, within which it characteristically forms a delicate grating of prismatic crystals interspersed with small voids. A few pyrite grains contain isolated marcasite euhedra, or clusters of arsenopyrite and marcasite. Isolated marcasite euhedra are seldom distinguishable from arsenopyrite. A few grains consist of stripes of marcasite alternating with slightly wider stripes of chalcopyrite, the later enclosing arsenopyrite crystals and irregular pyrite relics. Evidently chalcopyrite selectively replaced pyrite here. Grains of this sort strongly suggest that at least some, and perhaps all, marcasite is early in this assemblage. Optical identification of marcasite in nets and isolated euhedral inclusions was confirmed by semi-quantitative microprobe analysis, which showed Fe and S as major elements, and As, Co, and Sb to be absent.

The voids between marcasite prisms in the characteristic pseudomorphs occupy about 20-30 percent of the area and thus indicate direct conversion of pyrite to marcasite, rather than volume-for-volume replacement of pyrite by marcasite. Theoretically, the marcasite unit cell has a volume that is 51 percent of the pyrite unit cell; therefore, direct conversion of pyrite to marcasite should produce voids. In area, this change corresponds to a reduction of 18-49 percent, averaging 35 percent, which agrees fairly well with the observed void area of 20-30 percent.

Miargyrite(?), $8[\text{AgSbS}_2]$, is rare. It occurs as a very fine grained aggregate of stubby prisms in smooth contact with chalcopyrite, and as a rim, a few microns wide, consisting of stubby prisms on subhedral grains of argentian tetrahedrite. (See also *diaphorite*, p. C11.) In air, the miargyrite(?) is slightly greenish gray white, has a reflectivity very close to that of tetrahedrite, shows distinct reflection-pleochroism in weakly tinted pale grays, is distinctly anisotropic, and lacks internal reflection. In oil, reflection-pleochroism is distinct, from yellowish gray or brownish gray to green gray to blue gray; anisotropism is distinct; and a faint internal re-

flection in red or orange is visible in places. The optical properties and occurrence are appropriate for miargyrite, but the identification is only tentative.

Pinkish-gray unknown.—An unidentified soft, anisotropic, moderately bright pinkish-gray or brownish-gray mineral is the youngest member of the rim-forming suite. (See "Paragenetic Sequence.") The rims of the unknown are so narrow and the individuals so fine that even the qualitative optical properties are difficult to determine. They do not seem much like those of the Cu-Ag-S minerals stromeyerite, jalpaite, and mckinstryite. (The last is natural β -Cu_{0.8}Ag_{1.2}S, recently described by Skinner and others, 1966.) We did not find large enough areas of the unknown to analyze by microprobe.

Polybasite(?), 16[Ag₁₆Sb₂S₁₁], is very rare. It forms an irregular replacement rim, 4 microns wide, on one grain of galena. The rim is an aggregate of irregular grains accompanied by one small area of a similar but yellower mineral; both sulfosalts(?) are irregularly replaced by a partial rim of acanthite. In air, polybasite(?) looks slightly bluish gray and darker than galena; it looks slightly darker, considerably greener gray, and smoother than acanthite. In oil, polybasite(?) appears darker—distinctly darker than the bright position of acanthite. In air, reflection-pleochroism is rather strong, slightly yellowish gray or slightly greenish gray to bluish gray. In oil, the effects are similar but the yellowish gray position now has a pinkish tint. Anisotropism is strong in both media. In air, purplish-red internal reflection is faint and local; in oil, a suggestion of it is detectable with a single nicol, and with nearly crossed nicols it is red to purplish red but neither strong nor pervasive. Polishing hardness is less than that of galena, greater than that of acanthite. Though the optical properties of the polybasite(?) are very similar to those listed above for miargyrite(?), the habit is not. Whatever these minerals are, they are almost certainly different species.

Pyrrhotite is present as sporadic droplike inclusions in about 5 percent of the pyrite grains. The frequency of pyrrhotite in such grains seldom exceeds one bleb per pyrite grain. The inclusions range in diameter from less than 4 microns to about 80 microns. A few are dumbbell shaped, and some of the larger grains contain a single minute bleb of chalcopyrite. Pyrrhotite has not been found as discrete grains, or as inclusions in any other mineral except chalcopyrite, where it was observed as a minute bleb in one chalcopyrite inclusion in pyrite. The optical identification of pyrrhotite was confirmed by semiquantitative microprobe analysis of several grains, none of which contained Ag, Co, Cu, or Ni.

Silberkies group of Ag-Fe sulfides. Some member of this group, most likely argentopyrite (AgFe₃S₅; Ram-

dohr, 1960, p. 588), is suspected in the form of extremely rare inclusions in pyrite. We have found only two or three such inclusions in successive mounts containing several hundred pyrite grains apiece. The inclusions are round or elliptical, 2–4 microns across, generally unique in the pyrite host, and commonly accompanied by a grain or two of pyrrhotite, chalcopyrite, arsenopyrite, or soft white mineral. The suspected Silberkies mineral is softer than pyrite but harder than pyrrhotite, nearly as bright as pyrite, and distinctly anisotropic. It is paler, yellower, and brighter than pyrrhotite, slightly brighter and less yellow than chalcopyrite. In air, the mineral shows distinct reflection-pleochroism from very pale yellow to brownish or grayish yellow; in oil, pale grayish yellow to pale gray. The optical properties are most like those of argentopyrite as reported by Ramdohr. However, the members of the group are difficult to distinguish from one another, if indeed they are all valid species, and from several commoner sulfides.

Though the New Snowbird argentopyrite(?) can be recognized under the ore microscope without much difficulty, it is indistinguishable from pyrrhotite and chalcopyrite in the carbon-coated specimens viewed through the optical microscope of the electron microanalyzer. All grains hopefully analyzed as argentopyrite(?) proved to be pyrrhotite or chalcopyrite. We think this result demonstrates the rarity of argentopyrite(?) and the impossibility of recognizing it under the carbon coating, not its absence.

The presence of one pyrite cube containing a peculiar intergrowth supports the notion that some mineral of the Silberkies group is or was part of the local assemblage. This pyrite, appearing as a pitted square 0.14 mm on an edge, contains a central square that is 77 microns across. The central square resembles a pegboard in which the board's rectangular system of holes corresponds to minute, nearly equant grains of a soft gray mineral, somewhat darker than pyrite (pl. 4B). A few "holes" are randomly occupied by minute pips of native silver, and a few by pyrrhotite(?). A few areas between the "holes" are argentopyrite(?). The largest gray grains are 4 microns across; the smallest are less than a tenth of that size. In oil, the largest gray grains show distinct reflection-pleochroism from slightly greenish gray to slightly bluish gray. If these grains represent some mineral identified elsewhere in the New Snowbird mineral assemblage, their properties agree best with those of acanthite; and if the gray mineral is now acanthite, its equant habit suggests that it was formerly argentite. The geometric relations and the minerals present, to the extent that one can guess at their identity, suggest that some high-temperature cubic(?) Ag-Fe-S precursor occurred within this pyrite cube; on cooling, this precu-

sor broke down, exsolving argentite and pyrite accompanied by a little native silver and pyrrhotite; the argentite later inverted to acanthite. The barely visible argentopyrite(?) grains might represent a low-temperature polymorph of the cubic (?) Ag-Fe-S precursor, or they might be an exsolution product thereof.

Silver as the native metal is widespread but not abundant. Most of it occurs in pyrite as clusters and strings of minute round or oval blebs (pl. 4A) or very rarely as elongate patches having one edge straight and the other jagged. The blebs are generally less than 2 microns in diameter, evidently diminishing to irresolvable specks. A train or cluster commonly consists of one to five of the larger blebs accompanied by a host of smaller blebs and black specks. Occasionally a single grain of native gold is present, dwarfing the silver blebs with its relatively large diameter of 5 microns. Because the silver blebs are a brilliant yellowish white against the enclosing pyrite, one may see their flash or wink with a medium-power objective, provided the section has just been polished. Even in a dry climate the silver blebs tarnish in a day or two, taking on the appearance of pits locally surrounded by slightly tarnished areas of pyrite host. Only 1 pyrite grain among 50–150 contains recognizable blebs of silver when scanned at high magnification ($\times 336$), but other pyrite grains that show clouds of "dust" are suspected of containing submicroscopic silver particles.

A little native silver also occurs as discrete grains, as small equant inclusions in sphalerite and galena, as slivers in acanthite and the green-orange unknown, and as specks in colloform goethite encrusting chalcopyrite. Of these minor occurrences, silver in sphalerite is the least rare.

Semiquantitative microprobe analyses show Ag as the only element detectable in the native silver inclusions in pyrite and sphalerite.

Jacobsen (1965, p. 12) recently described the occurrence of droplets of native silver in bornite and chalcopyrite from the disseminated copper sulfide deposit at Mangula, Southern Rhodesia.

Soft white mineral.—Minute grains and patches of an unidentified soft white mineral, commonly accompanied by galena, are present in 8 percent of the pyrite grains. The unidentified mineral is bright, white, optically anisotropic, and very soft, having a polishing hardness much less than that of pyrite and slightly greater than that of native silver. In oil, the mineral looks gray against pyrite and shows reflection-pleochroism from gray or slightly bluish gray to yellowish gray or slightly brownish gray; some grains are faintly mottled. Thus the unidentified mineral resembles not only the Pb

sulfosalts and their relatives, but also hessite and matildite (AgBiS_2). However, the Te content of the sulfide concentrates (table 1, Nos. 1, 2, 3) seems too low to account for all the anisotropic white inclusions as hessite, and the lack of Bi in the hand-picked "pyrite" concentrate (table 3, No. 1) eliminates matildite from further consideration. Grains of the unidentified mineral large enough for satisfactory microprobe analysis have not been found.

Tetrahedrite, ideally $8[\text{Cu}_3\text{SbS}_3]$ or $2[\text{Cu}_{12}\text{Sb}_4\text{S}_{13}]$, is rather sparse, probably making up less than 0.5 percent of the sulfide concentrates. It is the argentian variety, freibergite, and is rich in elemental silver. Most of the tetrahedrite is present as discrete grains, some of which contain small inclusions of acanthite (inverted from argentite?), chalcopyrite, galena, and sphalerite, generally as a mixed assemblage. A few of these grains are partly rimmed by miargyrite(?), with or without an outer partial rim of acanthite. A little tetrahedrite occurs as small round inclusions in pyrite and galena.

Optical identification of the tetrahedrite as an argentian variety, based on its yellowish tint, was confirmed by semiquantitative microprobe analysis of several grains. Copper, S, and Sb are major constituents; Ag is always present; Fe, Zn, and either Pb or As are minor elements; Hg is absent. An approximate quantitative determination of Ag indicates that 12–15 percent is present in seven grains and about 8 percent in another grain. Some Ag is definitely present in the tetrahedrite inclusions in pyrite. Attempts to determine As versus Pb by means of the β peak were unsuccessful; the peak was irresolvable, owing to the low concentration of one or both elements.

Tramp iron—stray pieces of partly oxidized steel from mining and milling equipment—is an abundant accessory component of the tungsten concentrates. Obviously malleable and magnetic particles are not likely to be mistaken for minerals, but dust-size particles are sometimes found in the nominally nonmagnetic fractions of these concentrates and in the insoluble residues from incompletely digested samples thereof. Though tramp iron was not seen in polished sections of sulfide concentrates, its presence there or in steel-ground non-flotation samples might lead the unwary into thinking the samples contained a high proportion of native silver grains. Steel and native silver are bright, yellowish white, optically isotropic, and free of scratches in a well-polished section. Tests for magnetism and scratching hardness easily distinguish these substances if the particles are sufficiently large. If they are minute, a measurement of microindentation hardness will quickly tell them apart, as the Vickers hardness at 100-gram load is about 60 for native silver and about 490–575 at

50-gram load for several kinds of steel from the New Snowbird mill.

ALTERATION PRODUCTS

Alteration products make up less than 1 percent of the ore that was mined. The number of these products (table 5) is quite disproportionate to their volume, yet the very presence of oxidized minerals affects one's interpretation of economic features of the deposit, such as expectable extent of supergene enrichment. Presumably the oxides, sulfates, arsenates (?), and halides of the alteration suite are mainly supergene and the clay minerals mainly hypogene, but many of the alteration products are so fine grained and intermixed that evidence of their origin is not to be had. Clay minerals are mentioned first in the following notes, then goethite, then other members of the suite in alphabetical order.

Clay minerals are very sparingly present. The clay-size fraction recovered by ultrasonic cleaning is considerably less than 1 weight percent of the tailings and less than 0.01 weight percent of the tungsten concentrates. No clay-size fraction was recovered from the sulfide concentrates. Argillic minerals in the mill products and in specimens of crude ore are chlorite, illite, kaolinite, montmorillonite (?), muscovite (sericite), nontronite, and palygorskite (?). Kaolinite is the most abundant of these, and illite next. Some chlorite of clay size is intimately mixed with kaolinite in patches in the ore; coarser chlorite is a direct alteration product of biotite. Artificial mixtures of clay-size material always contain additional components—especially jarosites and tungsten minerals—that make more refined studies of the clays virtually impossible.

Goethite is the principal oxidation product of the ore. Most of it has formed from pyrite, but some has formed from chalcopyrite and some from huebnerite. The quantity of goethite in samples of sulfide concentrates ranges from less than 1 to about 5 percent. The distribution of goethite within the ore body itself seems to have been erratic. Since goethite is among the youngest minerals in the assemblage and apparently belongs to a single generation, we suppose it to be wholly supergene. Goethite occurs as replacement veinlets and nets in pyrite and huebnerite; as rims of variable thickness on pyrite and chalcopyrite; as discrete grains representing patchy, cellular, zoned boxwork, or colloform aggregates; and rarely as perfect pseudomorphs after arsenopyrite-bearing pyrite cubes, the diamond shape of the former arsenopyrite inclusions being preserved as well as the cubic shape of the host.

Bianchite (?), $8[(Zn, Fe)SO_4 \cdot 6H_2O]$, or a similar sulfate is suspected in trace amounts. Semiquantitative microprobe analysis of a gray grain whose reflectivity

is distinctly less than 15 percent shows Fe, Zn, and S to be major elements, Cu minor, Ag trace or absent, Cd and Mn absent, O not detectable with the detectors then available.

Cerargyrite.—At least one member of this group occurs very sparingly as a partial replacement of acanthite, of acanthite plus an unidentified ruby silver mineral, or of the pinkish-gray unknown. The cerargyrite and accompanying acanthite contain minute bright specks, presumably of native silver. The low concentration of Br and Cl in sulfide concentrates and tailings (table 1, nos. 1, 2, 3, 5) confirms the results of mineralogical study: cerargyrite is not a major source of elemental silver in the New Snowbird ore.

Cerussite seems to be very sparse. Difficult to identify optically, this gray mineral, which fluoresces white under the electron beam, was suspected of being a tungstate. An uncorrected determination by electron microprobe, using galena as a standard, gave 78.2 weight percent Pb. Eighteen common elements, including As, Bi, Cl, S, Sb, and W, were looked for but not found. Carbon and oxygen could not be determined with the analyzing crystals and detectors available when our work was done. Nevertheless, the determined Pb content and absence of the elements noted, in conjunction with white fluorescence, adequately identify this mineral as cerussite. Anglesite (?) may be intergrown with several cerussite grains that were found after the microprobe study.

Jarosite or natrojarosite, or more likely both minerals, are found in clay-size mixed fractions removed ultrasonically from tungsten concentrates and tailings. The yellow color of clay from the tailings is probably due to one or both of these complex hydrated Fe-bearing sulfates mixed with tungsten alteration products. Plumbojarosite is present in one sample.

The presence of additional hydrated sulfates and one or more arsenates is indicated by fragmental data from optical, X-ray diffraction, and electron microprobe studies. These sparse minerals have not yet been identified.

Psilomelane and *pyrohusite* are rather sparse but common alteration products of huebnerite, which they vein and encase. The manganese oxides are usually accompanied by goethite. Their age relations are indeterminate. The iron and manganese oxides were isolated by Fred A. Hildebrand and identified by him by X-ray powder photography. We did not analyze these minerals by microprobe.

Secondary tungsten minerals of clay size are present, but their identification in X-ray powder diffractograms of mixtures is so unsatisfactory, owing to coincident reflections, that we prefer not to attach names to our

guesses. Stolzite was positively identified (see "Tungsten Minerals"), but there is no way of telling whether the extremely fine grained variety is an alteration product or a primary mineral.

Tenorite, $4[\text{CuO}]$, is very sparse. It occurs as an extremely fine grained platy(?), twinned(?) aggregate in crusts with goethite and unidentified oxidation products.

PARAGENETIC SEQUENCE

A generalized paragenetic sequence for the deposit is: gangue→primary tungsten minerals→pyrite and its inclusions→intermediate sulfides and sulfosalts→rim-forming sulfides and oxidation products.

Arrows are used to indicate sequence from left to right in this and subsequent schemes. Read the arrows as "followed by or replaced by." These schematic representations of paragenetic sequence are useful so long as the reader bears in mind that the relations are necessarily generalized, and that the position inferred for each species reflects more nearly the end of crystallization of the species than its beginning. If two varieties of a mineral are present, such as sphalerite, only the dominant variety is shown in the sequence. If the substance is polymorphic, such as Ag_2S in the acanthite-argentite pair, the observable species is shown in the sequence—acanthite, in this example. Position within a sequence has been determined from (1) crosscutting and encrusting relations, (2) distribution of inclusions, and (3) absence of discrete grains of a species. Fabric features that seem especially significant for age relations are noted below; details are given in the descriptions of individual species.

In searching out and presenting evidence for sequential relations, we hope we have not arrived at a degree of orderliness that was lacking in nature. Evidence for the paragenetic position of some minerals is hard to find; nevertheless, it exists. Perhaps it can be found here only because the natural assemblage has been concentrated roughly a thousandfold by milling. The point is this: we may find order where other workers, dealing with similar but mechanically unconcentrated assemblages, would not. For all but the late and clearly ordered rim-forming sulfides, other workers might see our sequence as their dumped assemblage.

The gross relations of huebnerite to quartz in this deposit suggest that huebnerite generally replaces the host but locally is intergrown with and indented by euhedral milky quartz. The random orientation of disseminated euhedral huebnerite in quartz of several generations is difficult to explain by any process except replacement, perhaps attended by local recrystallization of quartz. The coarser scheelite of the deposit shows similar relations to quartz; the finer scheelite forms replacement veinlets in it.

The veining and replacement of huebnerite by scheelite indicates that some scheelite is younger than huebnerite. However, a few huebnerite prisms contain small round inclusions of scheelite. This suggests either partial contemporaneity of the tungsten minerals, scheelite then continuing to form after huebnerite finished crystallizing, or the existence of two distinct generations of scheelite—one euhedral, coarser, and older(?) and one finer, crosscutting, and definitely younger than huebnerite.

The relations between pyrite and tungsten minerals suggest that pyrite is younger than huebnerite, and either younger than or roughly contemporaneous with scheelite. The scarcity of intergrowths of pyrite and tungsten minerals indicates either that pyrite preferentially replaced quartz, or that it replaced whatever was available in a vein system that contained 100–300 times as much quartz as tungsten minerals.

It is convenient now to discuss the sulfides as if they were a unit set apart from the tungsten minerals. There is no field or laboratory evidence that such a division existed within the deposit, either spatially or temporally.

The paragenetic sequence for the principal sulfides is:

pyrite→sphalerite→chalcopyrite→(galena)→tetrahedrite→acanthite \ (digenite)

The positions of galena and digenite are uncertain. Galena locally replaces pyrite, probably replaces sphalerite, is of indeterminate age relative to chalcopyrite, and is rimmed separately by tetrahedrite or by digenite, as well as by acanthite. Digenite also replaces sulfides that precede and follow galena. It is dealt with in the discussion of rim-forming sulfides.

Smooth, slightly curved or straight contacts prevail among sphalerite, chalcopyrite, and galena, though chalcopyrite locally veins sphalerite. The three sulfides locally replace pyrite; but here too the evidence of age difference, though it exists, is slight. Moreover, all members of the sequence from pyrite through acanthite contain inclusions (table 7, part A). Commonly these are inclusions of one another, pyrite presenting a notable exception. Arsenopyrite, native gold, marcasite, pyrrotite, Silberkies(?) minerals, and the soft white mineral occur only as inclusions in pyrite. Pyrite itself is not included in later sulfides except as an obvious replacement relic. These relations point to pyrite and its inclusions as the first-formed members of the sulfide assemblage.

The distribution of inclusions of the principal metallic minerals among all the intermediate sulfides and sulfosalts of the weakly ordered sequence is brought out in table 7, part B, which shows the inclusion data rearranged horizontally and vertically according to the

TABLE 7.—Distribution of ore-mineral inclusions in discrete grains of the sulfide-sulfosalt-native-element suite¹

A. HOST MINERALS (COLUMN HEADINGS) LEFT TO RIGHT IN PARAGENETIC SEQUENCE; INCLUSIONS (COLUMN CONTENTS) TOP TO BOTTOM IN ALPHABETICAL ORDER

Pyrite	Sphalerite	Chalcopyrite	Galena	Tetrahedrite	Miargyrite(?)	Acanthite	Silver
acanthite(?) arsenopyrite chalcopyrite galena gold marcasite pyrrhotite Silberkies group silver sphalerite tetrahedrite unidentified minerals ²	acanthite chalcopyrite galena silver	 galena sphalerite	acanthite(?) chalcopyrite silver sphalerite tetrahedrite unidentified minerals ³	acanthite(?) chalcopyrite galena sphalerite	 silver diaphorite(?)	 silver	

B. HOST MINERALS LEFT TO RIGHT IN PARAGENETIC SEQUENCE; INCLUSIONS TOP TO BOTTOM IN SAME SEQUENCE AS HOST MINERALS

Pyrite	Sphalerite	Chalcopyrite	Galena	Tetrahedrite	Acanthite	Silver
sphalerite chalcopyrite galena tetrahedrite acanthite(?) silver	 chalcopyrite galena acanthite silver	sphalerite galena	sphalerite chalcopyrite tetrahedrite acanthite(?) silver	sphalerite chalcopyrite galena acanthite(?)	 silver	

¹ Table does not consider minerals "included" by obvious replacement rims.² Mainly soft white mineral.³ Includes mineral tentatively identified as aramayoite.

inferred paragenetic sequence of the host minerals. The unique inclusions in pyrite, the rarely occurring miargyrite(?), and the traces of unidentified sulfosalts in galena and acanthite have been omitted. Eliminating the minor inclusions heightens the impression that the intermediate sulfides and sulfosalts (sphalerite through tetrahedrite) are, like inclusion-rich pyrite, a dumped assemblage. The rearrangement also calls attention to the absence of some expectable inclusions, especially to the absence of tetrahedrite, acanthite, and native silver from chalcopyrite. We attribute this apparent absence to the poor polishing quality of chalcopyrite: the chalcopyrite host is so badly pitted that only the much more abundant sphalerite and galena have been retained as detectable inclusions. Finally, the change from an earlier, inclusion-rich sulfide-sulfosalt assemblage to a later, inclusion-poor one is plainly indicated.

The late, rim-forming sulfides present abundant and clear-cut evidence of sequential deposition. Acanthite, the most abundant rim-former, is a convenient starter for the sequence, which in comprehensive form is:

acanthite→(digenite)→blaubleibender covellite→
green-orange unknown→pinkish-gray unknown
(→cerargyrite)

This comprehensive scheme is inferred from two sets of partial schemes, the first involving mainly acanthite,

the second digenite. Except where otherwise shown, the following sequences are directly observable:

- acanthite→blaubleibender covellite→green-orange unknown (common)
acanthite→digenite (rare)
acanthite→green-orange unknown (rare)
acanthite→pinkish-gray unknown (less rare)
galena→(black crust; pit?)→green-orange unknown→pinkish-gray unknown→cerargyrite (rare)
- digenite→blaubleibender covellite (common)
digenite→green-orange unknown (common)
digenite→blaubleibender corvellite[?]→green-orange unknown (inferred)

Locally, acanthite is deposited on blaubleibender covellite, but the usual sequence is that shown in scheme 1, line 1. In some places, blaubleibender covellite and the green-orange unknown are intimately mixed rather than sequentially related, and the pinkish-gray unknown may be sparingly present in the mixture. In all associations, blaubleibender covellite may be accompanied by a very little covellite, and a little bornite may accompany digenite. Rarely, digenite and blaubleibender covellite form alternating thin crusts on earlier sulfides.

Among minerals that almost surely resulted from

oxidation, cerargyrite alone can be linked to the assemblage of late sulfides.

GEOLOGIC THERMOMETRY

Recent experimental work on sulfide systems provides some clues to the approximate temperatures prevailing during sulfide mineralization. The presence of arsenopyrite fixes an upper limit at 702°C, for arsenopyrite is not stable above that temperature (Clark, 1960, p. 1642). Pyrite and arsenopyrite existing together, and presumably formed in the presence of vapor, indicate that at least one member of the pair crystallized below $491^\circ \pm 12^\circ\text{C}$ (Clark, 1960, p. 1642). Pressure affects the equilibrium only slightly. Therefore, $491^\circ \pm 12^\circ\text{C}$ is the probable upper limit for the formation of most and perhaps all pyrite in the deposit, though some arsenopyrite-free pyrite might have formed above that temperature. The minute size of the arsenopyrite grains precludes a determination of their temperature-sensitive S-As ratio by Morimoto and Clark's (1961) method of X-ray diffraction, and the difficulty of recognizing arsenopyrite under the microscope of the electron micro-analyzer has made direct determination of the ratio infeasible.

Pyrrhotite included within pyrite can be used as another means of estimating the temperature of formation of the pyrite-pyrrhotite-arsenopyrite part of the assemblage. Pyrrhotite is not stable with pyrite and arsenopyrite above $491^\circ \pm 12^\circ\text{C}$, but it is stable with them at and below that temperature (Clark, 1960, p. 1376). Thus if all three minerals formed in equilibrium and in the presence of vapor, $491^\circ \pm 12^\circ\text{C}$ is the maximum temperature for their crystallization.

We hoped to make a closer estimate of the temperature of formation of New Snowbird pyrrhotite by applying the pyrite-hexagonal pyrrhotite equilibrium relations determined by Arnold (1962). To do this, one must know both the composition of the pyrrhotite and its structural form, whether hexagonal or monoclinic. (See, for example, Kullerud and others, 1963.) Attempts to determine these properties of New Snowbird pyrrhotite were disappointing, owing to the very small size of the inclusions. Electron microprobe analysis of three pyrrhotite inclusions in separate pyrite grains gave Fe and S in weight percent as follows: 58.1 and 40.9, 62.5 and 41.9, 53.9 and 34. These are equivalent to 44.9, 46.2, and 47.6 atom percent Fe, or to $\text{Fe}_{0.82}\text{S}$, $\text{Fe}_{0.86}\text{S}$, and $\text{Fe}_{0.91}\text{S}$. The host pyrite, assumed to be stoichiometric FeS_2 , served as an analytical standard. Total Fe plus S in the pyrrhotite is 99 weight percent for the first grain but far from it for the others. The individual variations are presumably due to imprecise analysis of the minute inclusions, not to actual variation

in composition; thus even the mean value of ~ 46 atom percent Fe provides only a rough estimate of the composition of this pyrrhotite. If the pyrrhotite were hexagonal, existed in equilibrium with pyrite, remained unchanged in equilibrium composition during its history, and were relatively free of substituted minor elements, its temperature of formation estimated from the diagram of Arnold (1962, p. 73) would be $\sim 550^\circ\text{C}$. Because of the uncertainty in composition, this estimated temperature merely points toward some high value not exceeding the maximum of $491^\circ \pm 12^\circ\text{C}$ inferred from the phase relations determined by Clark (1960).

The structural form of this pyrrhotite also remains uncertain because the grains are too small to be sampled for X-ray powder diffraction analysis. However, etching with chromic acid (Arnold, 1966, p. 1221) provided an indirect approach to establishing the structural form. Pure samples of this pyrrhotite being unobtainable, etching had to be done on bulk samples of pyrite concentrates in which the position of pyrrhotite inclusions had been carefully determined before etching. Twenty-minute immersion of a polished section in a saturated solution of CrO_3 produced a strong etch on 12 pyrrhotite inclusions out of 17 and a slight or moderate etch on 4. The effect on one grain was indeterminate because of an obscuring water droplet. As Arnold (1966) found that treatment for 1 hour etched monoclinic pyrrhotite but did not affect the hexagonal pyrrhotite intergrown with it, we conclude that the New Snowbird pyrrhotite is homogeneous and probably monoclinic. (The use of an aggregate of grains containing many foreign elements introduces some uncertainty in interpreting the results, but perhaps not much.) This inference of monoclinic form is consistent with the average but equally uncertain composition of the pyrrhotite, $\text{Fe}_{0.86}\text{S}$, which is close to the narrow range of composition— $\text{Fe}_{0.87}\text{S}$ to $\text{Fe}_{0.88}\text{S}$ —shown by the monoclinic pyrrhotites investigated by Kullerud and others (1963) and by Desborough and Carpenter (1965, p. 1436).

Because the New Snowbird pyrrhotite is most likely monoclinic, it is at present unsuitable for direct use as a geologic thermometer, as there seems to be no way of distinguishing a monoclinic pyrrhotite that has always been monoclinic from one that underwent a hexagonal-to-monoclinic transformation during cooling. If the New Snowbird pyrrhotite actually did undergo a hexagonal-to-monoclinic transformation on cooling, its equilibrium temperature estimated from the pyrite-hexagonal pyrrhotite solvus of Arnold (1962) would be $\sim 490^\circ\text{C}$. This value differs from the earlier cited 550°C in the same proportion as the restricted composition of monoclinic pyrrhotite differs from the uncertain average composition of New Snowbird pyrrhotite. The

close agreement between this estimated formation temperature of $\sim 490^{\circ}\text{C}$ and Clark's (1960) maximum stability temperature of $491^{\circ}\pm 12^{\circ}\text{C}$ for the pyrite-arsenopyrite-pyrrhotite assemblage may not be fortuitous. Nevertheless, some indeterminate temperature below $\sim 500^{\circ}\text{C}$ is the best we can infer for crystallization of the pyrrhotite inclusions.

Acanthite included in argentian tetrahedrite must originally have crystallized above 178°C if our interpretation of cubic cleavage as indicative of preexisting argentite is correct, if native silver was absent (it has not been found within the tetrahedrite), and if the system was "condensed" (Kracek, 1946; Skinner, 1966, p. 21). The inversion temperature is lowered only to 176°C in the presence of free silver. Therefore, the tetrahedrite host itself must have begun to form above approximately 177°C .

Acanthite in acicular form, rimming tetrahedrite, must have formed at or below about 177°C . The apparent correlation between the assemblage of included sulfides in pyrite and the paragenetic sequence of discrete-grained minerals, extending through native silver, suggests that at least some late-formed acanthite is hypogene, but we know of no criteria for distinguishing between it and supergene acanthite.

Digenite, bornite(?), and chalcocite in this assemblage cannot be used as geologic thermometers because their polymorphs cannot be determined in these extremely small grains. Covellite is stable through a wide temperature range (Kullerud, 1965). Because it replaces acanthite here, it must have formed below 177°C . Blaubleibender covellite is commonly a supergene mineral (Frenzel, 1959, p. 157), but according to Skinner's (1966, p. 4) interpretation of Moh's (1964) work, it has no true stability field; it occurs metastably(?) with covellite below 157°C (Moh, 1964) and might thus be either hypogene or supergene in the New Snowbird assemblage.

The probable range in crystallization temperature for hypogene sulfides in the deposit is thus from something less than 491° to less than 177°C , a range generally regarded as hypothermal to epithermal. Even if much of the acanthite is supergene, which we doubt, more than 95 percent of the sulfide-sulfosalt-native element assemblage formed above 177°C .

CLASSIFICATION AND ORIGIN OF HYPOGENE MINERALIZATION

We regard the New Snowbird deposit as xenothermal. The characteristics of this class are well summarized by Buddington (1935), who introduced the term, and by Park and MacDiarmid (1964), who provide additional data and examples. The dominant fea-

ture of xenothermal deposits is a misfit assemblage of minerals occurring together and including typically high-temperature minerals and typically low-temperature ones. Buddington interpreted such assemblages as having formed at high temperature and shallow or moderate depth. Regardless of origin, deposits that have this misfit composite assemblage are aptly termed xenothermal.

Most features of the New Snowbird deposit are markedly similar to those listed by Park and MacDiarmid (1964, esp. p. 346-347, 350) for the xenothermal class, but other features are different. The similarities are: complex mineralogy; fine grain size; dumping, or simultaneous precipitation of minerals that are not ordinarily found together (pyrite with its varied inclusions); a recognizable sequence of deposition similar to that usually found in mesothermal base-metal vein deposits (the sequence of sulfides occurring as discrete grains), followed by minerals usually formed at lower temperature (silver sulfosalts, acanthite, blaubleibender covellite, and their associates)—the telescoping of Spurr (1923, p. 292-308), which would embrace the whole New Snowbird assemblage; wide range of temperature indicated by certain geologic thermometers (pyrite-arsenopyrite formed at some temperature below $491^{\circ}\pm 12^{\circ}\text{C}$, but perhaps not much below; acanthite at or below 177°C); gangue minerals including quartz, feldspar, and apatite; a range of argillic and other alteration products; occurrence in a region of hypabyssal intrusives and associated volcanic rocks; repeated penetration of the lode by vein material (multiple generations of quartz).

The principal differences are: occurrence of the ore minerals in massive replacement quartz (many xenothermal deposits are in fissure veins); lack of a pattern of hypogene zoning in nearby ore deposits of the district (the deposits are too poorly known to eliminate the possibility of zoning); lack of evidence that the New Snowbird and broadly similar deposits of the district were deposited at slight depth or have a restricted vertical range.

The vertical range of mineralization at the New Snowbird is unknown. Ore was mined only above the haulage level, and exploration at greater depth was precluded by the fall of the price of tungsten concentrates.

Classifying the deposit is easier than determining its origin. Except for the complexity of the local mineral assemblage and the evident dumping and telescoping, the evolution of the assemblage seems consistent with that of the common ore minerals considered by Holland (1965) in his thermochemical treatment of ore genesis. The hypogene New Snowbird

assemblage may have formed as temperature fell and the fugacity of S_2 and O_2 decreased in a hydrous, mildly alkaline, CO_2 -poor, SiO_2 -rich system. (See Holland, 1965, figs. 37, 27, 17, 5, 8 and table 2.) The stages or groups of ore minerals that we have recognized are merely convenient terms for grouping minerals according to their fabric. These groups are not separated by episodes of deformation or distinguished by radical change in the mineral assemblage, and there is no need to invoke polyascent solutions to explain the groups. Rate of change in pressure, temperature, and fugacity—factors now beyond assessing in detail—may account for the dumped assemblage included in pyrite, and for the weak evidence of depositional order among sphalerite, chalcopyrite, and galena. The process of metallization, though complex, seems to represent a single, uninterrupted episode.

As an alternative hypothesis of origin, hypogene mineralization might represent two principal stages: earlier, high-temperature tungsten mineralization and later, medium- to low-temperature sulfide-precious metal mineralization. Schneider-Scherbina (1962) postulated this sort of superposition for the tin-silver deposits of Bolivia, for which other geologists have inferred a xenothermal or telethermal origin. Schneider-Scherbina related the earlier, generally high-temperature gold-tungsten-tin stages to deep-seated Mesozoic intrusives and the later, lower temperature stage to shallow Tertiary magmatic activity. Though a complete picture of vein mineralization in central Idaho is not at hand, several features suggest that Schneider-Scherbina's hypothesis is not directly applicable to the New Snowbird and broadly similar deposits of the Big Creek and Yellow Pine quadrangles. An episode of intense, deep-seated, but linearly localized metamorphism, yielding granoblastic microcline-bearing alaskite gneiss from the alaskitic facies of the Idaho batholith, occurred after consolidation of the batholith, whose age is commonly regarded as Cretaceous. No lode deposits of tungsten referable to this episode of metamorphism have been found during mapping of this 430-square-mile area, and none were documented by earlier workers. The linear granoblastic zone containing the New Snowbird deposit was silicified and then sheared before Tertiary dikes of the Profile-Smith Creek swarm were emplaced, for a dike at the Red Bluffs deposit locally carries small inclusions of sheared but barren replacement quartz. Tungsten minerals at these two deposits are confined to relatively coarser, not extensively sheared quartz that replaces parts of the zone of earlier silicification and evidently postdates (or perhaps is roughly contemporaneous with) the Tertiary dikes. Elemental

silver is not restricted to relatively late minerals, such as acanthite and most of the native silver; it also occurs in pyrite as minute inclusions of native silver, electrum, inverted acanthite(?), Silberkies(?), minerals, argentian tetrahedrite, and argentian digenite. Some of the pyrite is arsenopyrite-pyrrhotite bearing, and pyrite with its inclusions seems to represent the initial wave of sulfide-precious metal mineralization. The fabric of the whole assemblage strongly suggests initial dumping of the precious-metal-bearing constituents and telescoping of the remaining members. Moreover, the widespread association of typically low-temperature mineral assemblages with tungsten minerals, locally accompanied by molybdenite and tin minerals, in the eastern part of the Soviet Union, in Japan, in the Cordillera of the Americas, in Western Europe, in the Erzgebirge, and elsewhere, suggests a genetic unity that has seldom been demonstrable as an effect of discrete superposed episodes of mineralization. Therefore, an interpretation of the New Snowbird deposit as a xenothermal one resulting from a complex but essentially single episode of tungsten-sulfide-precious metal mineralization seems more reasonable at present.

OXIDATION AND ENRICHMENT

Some oxidation of primary ore is indicated by the presence of small quantities of goethite, much smaller quantities of pyrolusite, psilomelane, jarositic minerals, other sulfates, and tungsten alteration products, and traces of minerals such as tenorite and cerargyrite (table 5). The lack of a gossan, the scarcity or absence of sulfates of Cu, Pb, and Zn, and the very low concentration of Br and Cl suggest either that oxidation has been very slight or that part of a preexisting oxidized zone of unknown metal content has been eroded. The latter possibility is more reasonable because even in this glaciated region highly oxidized base-metal sulfide veins are present within 3 miles of the New Snowbird; the cupriferous scheelite-pyrrhotite deposit at the Springfield mine (U.S. Geol. Survey, 1964, p. A4), 26 miles distant, shows much oxidation to goethite and melanterite; and the mercury-bearing stibnite deposit at the B and B mine is, in places, partly altered to antimony ocher (Leonard, 1965). Among these examples, only the oxidation of the Springfield protore is approximately datable: it is post-Idaho batholith and pre-Wisconsin, for large boulders of the former gossan are scattered throughout fresh glacial debris for 4,000 feet downvalley from the outcropping primary sulfide body. If hypogene mineralization at the New Snowbird were as old as early Tertiary (which seems unlikely), the interval of planation and development of grus on Idaho batholith rocks, preceding deposition of the

Challis Volcanics, would be a likely time for oxidation of the New Snowbird ore body. The Idaho batholith is generally regarded as mid-Cretaceous; the Challis Volcanics, mainly Oligocene, range in age from Eocene(?) to Miocene(?). Thus the interval of pre-Challis weathering of batholithic rocks is roughly limited between Late Cretaceous and perhaps Oligocene time. However, the age of hypogene mineralization at the New Snowbird's neighbor, the Red Bluffs tungsten deposit, is somewhat younger than, or perhaps roughly contemporaneous with, the enclosing swarm of Tertiary dikes. Dikes petrographically identical with those of the swarm cut the Challis Volcanics and are thus presumably Oligocene at the oldest. Ross (1934, p. 67; Shenon and Ross, 1936, p. 12, 19) thought that dikes cutting the Challis and dikes of the major swarms outside the Challis were Miocene, and they are generally regarded as approximately mid-Tertiary. If dikes of the Profile-Smith Creek swarm are Miocene, oxidation of the New Snowbird ore must have occurred between Miocene and Wisconsin time, an interval about which little is known in this area, where upper Tertiary deposits have not been recognized and lower Pleistocene deposits are sparse. The possibility of any but minor oxidation during Recent time is too slight to consider.

Oxidation of the ore is a fact, though the extent and date are unknown. Was oxidation accompanied by appreciable supergene sulfide enrichment? The only evidence now available is mineralogic; it is equivocal, but it bears directly on the attractiveness of disseminated sulfide deposits as targets for exploration. The coatings of covellite, blaubleibender covellite, digenite, unidentified copper minerals, miargyrite(?), and acanthite are late, but their supergene origin is by no means assured. Digenite is usually regarded as hypogene, but the rest are thought to be supergene in many deposits, hypogene in others. (See, for example, Bateman, 1950, p. 285-287; McKinstry, 1948, p. 150-155; Moh, 1964; Ramdohr, 1960, p. 431-434, 441, 613, 629-630.) Part of the New Snowbird acanthite seems to be hypogene; all of it might be. The origin of the rim-forming copper sulfides is utterly enigmatic. Investigating the disseminated sulfides by probing at various depths offers the only solution to the problem.

If there is no bonanza here, are other bonanzas nevertheless present but undiscovered in the region? The possibility exists, but the likelihood seems slight. Most of the region is well exposed, and probably all of it has been searched for bonanzas by two generations of competent prospectors and company scouts. Conceivably some downfaulted block of oxidized or sulfide-enriched ore may be concealed beneath glacial debris and alluvium in valleys athwart the major silicified

zones. Other blocks might be thinly mantled by glacial debris and colluvium on north slopes. Doubtless some hypogene deposits, such as the recently found B and B antimony deposit (Leonard, 1965), have been so concealed. But until there is evidence that supergene alteration of a sparsely disseminated sulfide body has actually yielded rich ore somewhere in this region, the notion of bonanzas, concealed or otherwise, deserves no encouragement.

ECONOMIC CONSIDERATIONS

We have tried to show what the disseminated sulfide assemblage from one deposit is, what and where its metal values are, and what kind of deposit yielded this material. The sulfides with their contained metals are efficiently recoverable by the simple, conventional techniques already used by the McRae Tungsten Corp. The grade of the crude ore is not precisely known, but a fair approximation of it shows that the metal content of the sulfides alone, divorced from the associated tungsten minerals, is not economic at prices prevailing in 1965. Nevertheless, deposits of this sort, provided they are sufficiently large, are a metal source of considerable potential value. The development of such a resource depends on many factors, of which geologic occurrence is only one, but the interplay of demand, price, scientific knowledge, technologic skill, and initiative that have in a few generations led to the exploitation of remarkably low-grade deposits of copper, iron, and uranium should stimulate us to look closely at resources that are not at the moment commercially attractive.

Three factors bearing on the immediate problem deserve comment. These are: local geology, difficulties of sampling disseminated deposits, and relation to porphyry copper deposits.

Our mineralogic study is a byproduct of regional geologic mapping of the Yellow Pine and Big Creek quadrangles. Maps in preparation show the general distribution of major silicified zones in the first quadrangle and their coextension with the Profile-Smith Creek dike swarm in the second. These zones are very large. Commonly though not uniformly they contain sparsely disseminated sulfides. Local concentrations of base and precious metals are present, with or without mercury, antimony, and tungsten minerals. Many of these concentrations have been prospected; a few have been mined. The number of showings of gold-bearing base-metal sulfides greatly exceeds all others. It is geologically reasonable to suppose that some of these, as well as some unexploited tungsten deposits, may be accompanied by disseminated precious-metal-bearing sulfides similar to those of the New Snowbird deposit. Probably not more than one of the gold-bearing base-metal showings has been carefully examined with an

eye to the occurrence of extremely low-grade gold or silver. Yet the old prospectors' dictum (C. P. Ross, oral commun., 1953) that "* * * any quartz vein in the Big Creek country will run a dollar a ton [combined gold and silver?], old price * * *," indicates that very small amounts of gold and silver are present and perhaps widespread in the silicified zones, though the assay value may have been exaggerated by the early prospectors.

Pyrite is sparsely disseminated in some porphyry dikes between the New Snowbird and Red Bluffs deposits and occurs elsewhere in dikes and batholithic rocks of the major silicified zones. Scheelite is present in a very few dikes. The metal content of these rocks may be worth investigating because of their involvement with the silicified zones.

Sampling a disseminated deposit such as the New Snowbird is difficult, especially if the metals sought are bound to fine-grained, brittle pyrite. For example, conventional sampling techniques used in underground exploration of a disseminated pyritic gold deposit near Yellow Pine yielded an occasional high assay value for precious metals but many virtual blanks. More reliable sampling results might be obtained by collecting fewer and larger samples—say 100 pounds—, carefully separating the sulfide fraction by froth flotation in a pilot cell, splitting the concentrate for microscopic study and assay, and assaying the concentrate and tailing separately.

The sulfide-bearing part of the New Snowbird deposit has several characteristics required by Parsons' (1957, p. 8-12) definition of porphyry copper deposits. These are low average metal content, spatial if not genetic association with intrusive porphyry, presence of products of oxidation and sulfide enrichment, and occurrence of protore. It remains to be determined whether the other requirements of convenient mining shape and large size, uniformity of metal distribution, and limitation by assay value of metals are satisfied.

Table 8 shows considerable similarity in the total metal content of New Snowbird ore and ore from the San Manuel porphyry copper deposit. Data for the New Snowbird are only approximate. Nevertheless, the correspondence in magnitude is enough to show that in grade, as well as in some other features, the New Snowbird might be viewed as a sort of porphyry tungsten deposit. San Manuel is used for comparison because the mine was developed rather recently, data on recoverable precious-metal content of the ore are conveniently available, and the mine ranks low among porphyry coppers that yield precious metals. For San Manuel ore, the value of metals listed in table 8 is \$5.20 per ton at September 1965 prices. This is about 10 times

the value of metals in the New Snowbird ore, if tungsten is excluded. The per-ton dollar value of the tungsten ore when sold was, of course, about 10 times the 1965 value of San Manuel ore. But more important resource-wise than the dollar value of the San Manuel ore is the mine's annual production of about 187,000 troy ounces of silver and 12,600 ounces of gold during the period represented in table 8 (data from Creasey, 1965, p. 30). San Manuel is generally one of the 25 top silver producers of the country, as well as one of the 20 top gold producers, though the ore averages only 0.8 ppm (parts per million) Ag and 0.05 ppm Au per ton, equivalent to 0.023 and 0.0015 troy ounces, respectively. The precious-metal content of the New Snowbird ore is higher (table 8). Again, this emphasizes a potential resource value, not a currently assessable dollar value.

TABLE 8.—Metal concentration (recoverable basis) in crude ore, New Snowbird tungsten deposit and San Manuel copper deposit

[Values in ppm]

	New Snowbird ¹	San Manuel ²
Ag-----	7.5	0.8
Au-----	.1	.05
Cu-----	27	5,780
Pb-----	27	-----
Zn-----	22	-----
W-----	4,420	-----
Mo-----	-----	47
Total-----	4,504	5,828

¹ Data for elements except W estimated from approximately known recovery of pyrite concentrate and from weighted assays that include one low-Ag assay not made by U.S. Geological Survey. Data for W based on known recovery of ~ 82 percent.

² Data based on 1956-59 production from San Manuel deposit (Creasey, 1965, p. 30), recalculated by Leonard.

The extraction of gold and silver from deposits whose base-metal content is very low could be temporarily advantageous to the mineral economy because it would not simultaneously stimulate a large production of copper, lead, and zinc—metals whose supply is normally more nearly adequate. (See Kiilsgaard, 1964; Merrill and others, 1965.) At least one of the disseminated sulfide deposits in silicified zones of the Big Creek-Yellow Pine area has this favorable ratio of precious metals to base metals.

Careful examination of the potential resources of the silicified zones of the region seems warranted. The exploration and development of such resources, if the time is ever ripe for it, will be costly, difficult, and time consuming, presumably in some measure as the expected value of the metal content relates to that of the porphyry coppers. The problem is great, but so is the challenge.

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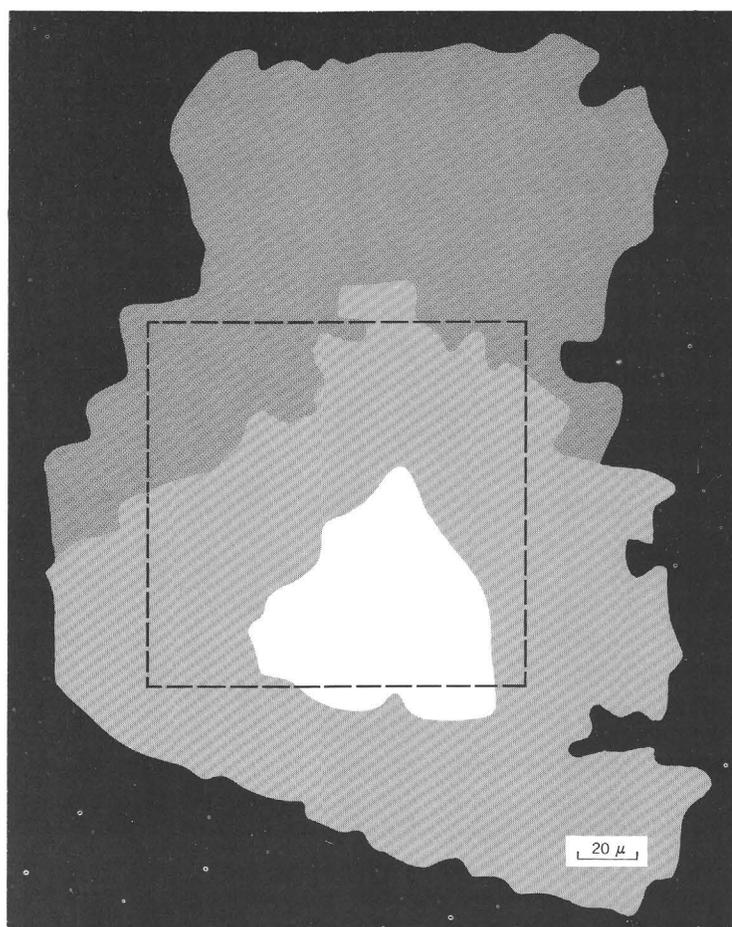
We could not have made this study without the assistance of many people. Robert McRae, president of McRae Tungsten Corp., provided accommodations at the mine and supplied information on the deposit and on extraction of the ore. Paul Desautels, U.S. National Museum, provided a large suite of mineral specimens for comparison. Brian Skinner, formerly of the U.S. Geological Survey, provided polished sections of jalpaite, mckinstryite, and stromeyerite. Detailed geologic mapping by the U.S. Geological Survey Defense Minerals Exploration field team was used to supplement Leonard's fieldwork. Indispensable analytical work was done by Survey colleagues whose contributions are noted in the tables of analyses and in the text. Many of the mineral separations were carried out by William Brennan, George Fairer, Paul Mayrose, and Lee Shropshire. W. N. Sharp took photomicrographs used to locate grains for electron probe analysis. E. P. Krier took the photomicrographs that illustrate this report. Professor J. O. Kalliokoski, Princeton University, called our attention to the paper by Genkin and others (1966). H. R. Cornwall, R. P. Fischer, S. W. Hobbs, R. L. Parker, Ray E. Wilcox, and a seminar at the University of Minnesota improved this report by discussion and comment.

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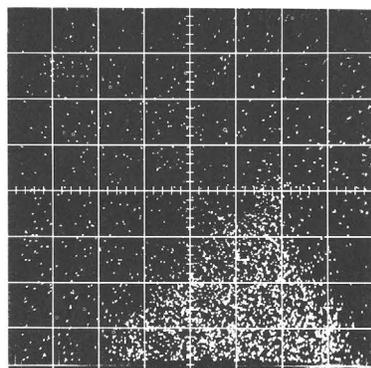
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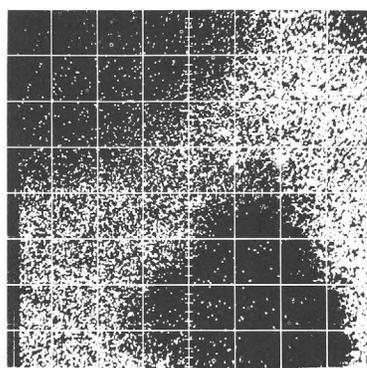
PLATES 1-4



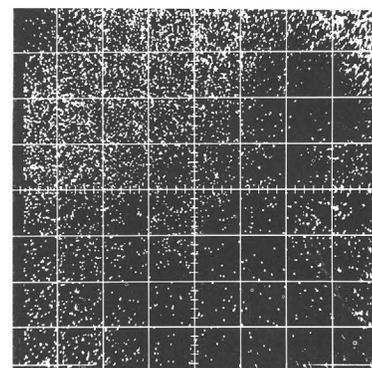
A



B



C



D

ACANTHITE AND COPPER SULFIDES ON GALENA

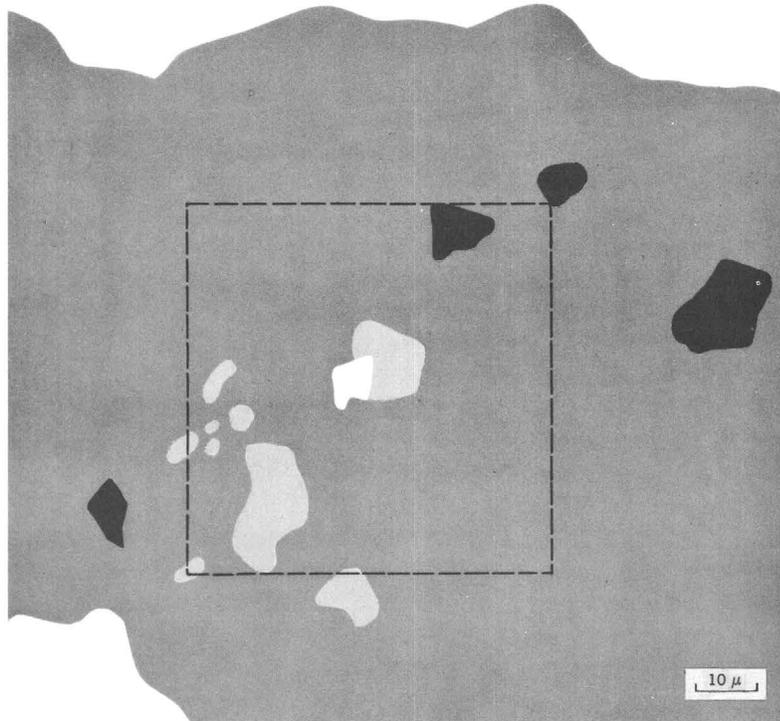
A.—Galena (white) rimmed by acanthite (light gray) and then by unidentified copper minerals (medium gray). Grain mounted in plastic (black). Drawn from a photomicrograph of a polished section. Dashed square represents area scanned by electron beam in B, C, D.

B.—X-ray scanning micrograph (photograph of X-ray pulses displayed on oscilloscope screen). Emitted $PbL\alpha$ radiation.

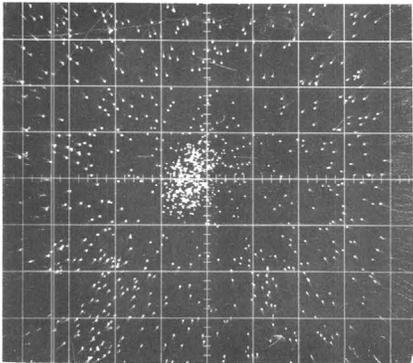
C.—X-ray micrograph, $AgL\alpha$.

D.—X-ray micrograph, $CuK\alpha$.

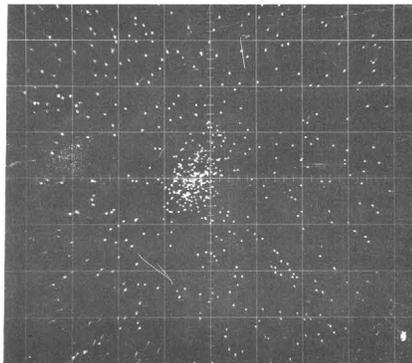
Sparsely distributed bright specks in B, C, and D are due to background radiation recorded during long exposure, not to characteristic X-rays emitted by element present in trace amount.



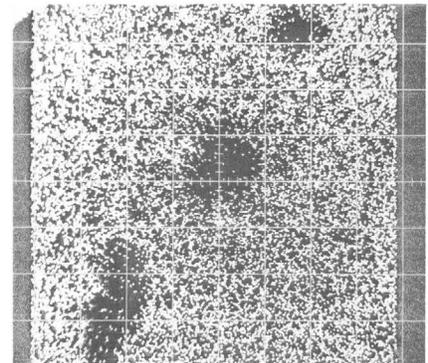
A



B



C



D

ELECTRUM IN PYRITE

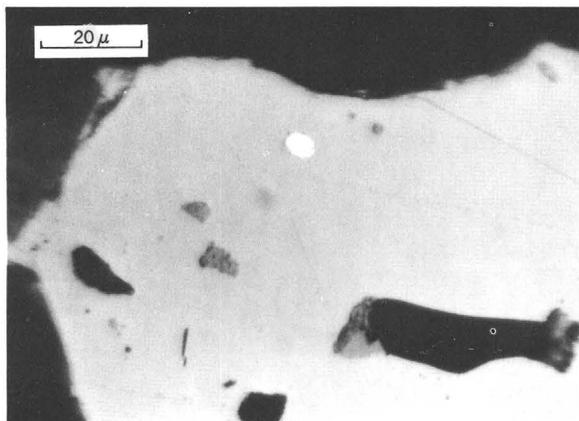
A.—Gold-rich electrum (white) in pyrite (dark gray) that is slightly pitted (black patches). Other inclusions are mainly quartz (light gray). Grain mounted in plastic (white background). Drawn from a photomicrograph of a polished section. Dashed square represents area scanned by electron beam in B, C, D.

B.—X-ray micrograph, AuL α radiation.

C.—X-ray micrograph, AgL α .

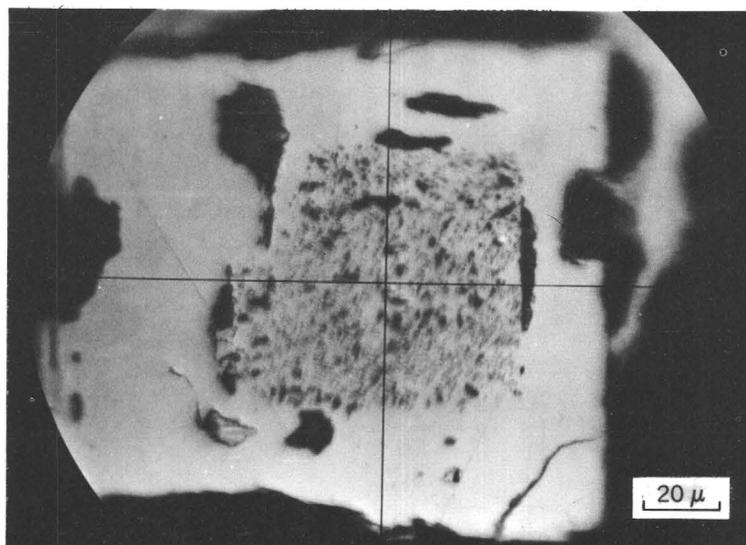
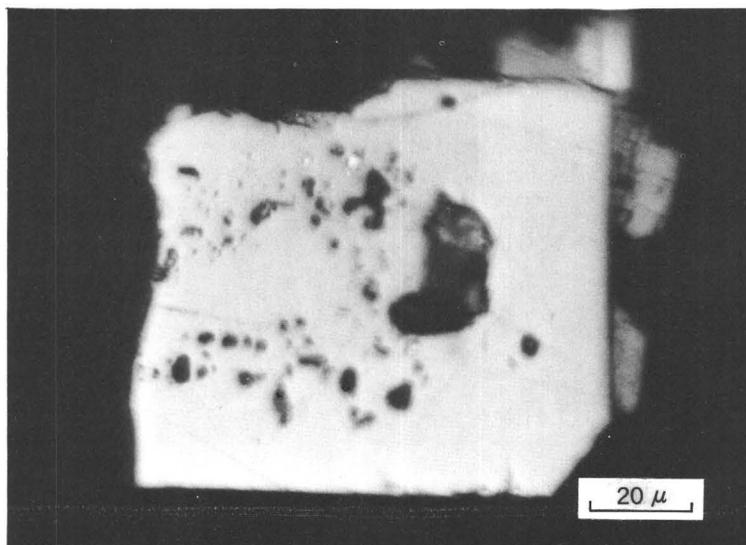
D.—X-ray micrograph, FeK α .

Sparsely distributed bright specks in B, C, and D are due to background radiation recorded during long exposure, not to characteristic X-rays emitted by element present in trace amount.



ELECTRUM IN PYRITE

Photomicrograph of gold-rich electrum (white) in pyrite (light gray). Elongate black grain at lower right is sphalerite with adjoining gray grains of a Silberkies(?) mineral (upper left) and pyrrhotite (lower left). Gray grains left of center are soft white mineral. Black "inclusions" at left and bottom are pits. Euhedral arsenopyrite inclusions, easily seen in the original, are invisible in the photograph because their polishing hardness and reflectivity match those of the pyrite host. Black background is plastic mounting medium. Oil immersion.



SILVER AND INVERTED $Ag-Fe-S$ MINERAL IN PYRITE

- A.—Photomicrograph of blebs of native silver (white) in pitted subhedral pyrite (light gray). Bits of galena (low relief) and pyrite are attached to upper and right edges of the pyrite cube. Embedding medium is plastic (black). Dry objective.
- B.—Photomicrograph of "pegboard" of minute inclusions in slightly corroded pyrite (light gray). Inclusions are mainly acanthite (medium gray) after argentite. Bright specks northeast and west of crosshairs are native silver (white). Inclusions of pyrrhotite(?) and argentopyrite(?) cannot be distinguished in photograph. Inclusions are interpreted as inversion products of a high-temperature cubic(?) $Ag-Fe-S$ precursor, Oil immersion.

