Geology of Part of the Alder Creek Mining District Custer County, Idaho

GEOLOGICAL SURVEY BULLETIN 1252-A

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By W. H. NELSON *and* C. P. ROSS

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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Discusses the relationships between the ore deposits and the intrusive and metamorphic rocks of the Alder Creek mining district

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGY OF PART OF THE ALDER CREEK MINING DISTRICT, CUSTER COUNTY, IDAHO

By W. H. NELSON and C. P. ROSS

ABSTRACT

In the Alder Creek mining district, stocks of quartz monzonite, granite, leucogranite porphyry and related dikes, and volcanic rocks, all of early Tertiary age, seem to be differentiates of a single parent magma. The stocks have metamorphosed sedimentary rocks of the Copper Basin Formation and the White Knob Limestone, both from Early Mississippian to Early Permian in age; limestones have been in part isochemically metamorphosed to marble, and in part metasomatized to skarn. Valuable concentrations of copper, lead, and zinc minerals occur in the skarn, and mostly within skarn at the contact between the leucogranite porphyry and limestone.

Glacial deposits of two ages and alluvial deposits of two ages occur in the report area.

INTRODUCTION

Metamorphic rocks at the contact between sedimentary and intrusive rocks are magnificiently exposed in the cliffs, ridges, and cirques of the Alder Creek mining district. The sedimentary rocks are limestone, siltstone, and quartzite, and some mixed argillaceous silty and limy rocks. The intrusive rocks are a variety of compositions—all possibly differentiates of a single parent magma. Of the metamorphic rocks, skarn is of greatest interest because it contains most of the copper, lead, and zinc ores that are found in the district. Most of the concentrations of ore minerals are confined to skarn that is adjacent to the leucogranite porphyry, one of the varieties of intrusive rock.

The present summary of data on the Alder Creek mining district is a product of the observations by the authors plus those of T. H. Kiilsgaard, and published data cited below. Nelson constructed the detailed areal map (pl. 1) of most of the productive part of the district, made observations and formulated ideas as to the origin of the ore deposits during the summer of 1958. The mines were inactive during the summer of 1958, and Nelson did not visit the underground workings; control

for the parts of the cross sections through the Empire mine on plate 1 was obtained from detailed mine maps made by Farwell and Full (1944). Nelson did the petrography of the igneous rocks and wrote most of the text. T. H. Kiilsgaard studied the mines briefly in 1961, and ideas he gained at that time have been incorporated here. Ross visited the district at intervals from 1929 through 1961 and saw large parts of the mine workings.

Plate 1 covers about 45 square miles of the Alder Creek mining district, west of the town of Mackay, Custer County, Idaho. The district extends locally somewhat more than a mile south of the area shown. The location of the area of this report is shown in figure 1.

SEDIMENTARY ROCKS

COPPER BASIN FORMATION

The name Copper Basin Formation was introduced by Ross (1962) for the thick assemblage of dominantly noncarbonate clastic rocks in the southern part of the Copper Basin depression. In the area shown on plate 1 the rocks of the Copper Basin Formation range from shale to conglomerate, but most of them are argillaceous siltstone and fine-grained quartzite which are medium gray to very dark gray on fresh surfaces. Much of the dark color of these rocks is due to disseminated carbon; where the rocks are weathered, the color is mostly brown because of included iron oxide.

The Copper Basin Formation and the White Knob Limestone occupy about the same stratigraphic interval; and the Copper Basin Formation, which makes up most of this interval to the west, and the White Knob Limestone, which makes up most of the interval to the east, interfinger in the vicinity of the area of this report. The alternation of rocks that are assigned to these two formations east of the Middle Fork of Navarro Creek is part of this interfingering. Ross (1960, 1962) described the regional relations of these formations, and Skipp (1961) has described interfingering between the various rocks in an area 2 miles west of that shown on plate 1.

Fossils are not abundant enough in the Copper Basin Formation to establish its age range. The formation interfingers with, and therefore is, in part at least, the same age as the White Knob Limestone, which ranges from Early Mississippian to Early Permian in age (Ross, 1962).

WHITE KNOB LIMESTONE

Ross (1962) introduced the name White Knob Limestone for the rocks that had previously been called Brazer in the vicinity of the area shown on plate 1. The name is taken from the White Knob Mountains, which include the mountains in the area of this report.

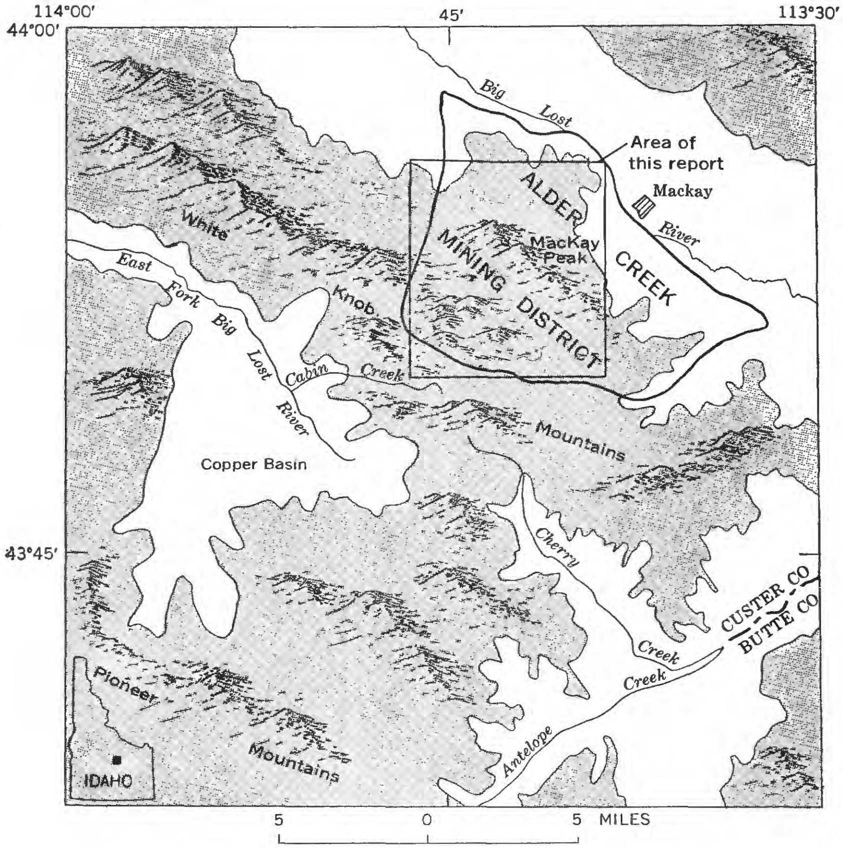

FIGURE 1.—The location of the area of this report.

Most of the White Knob Limestone is very pure limestone. It is light gray to dark gray and is in beds that range from a few inches to about 10 feet in thickness. A thin veneer of clay is common on bedding planes, and at a few places there are shaly beds several inches thick. Locally chert, in the form of nodules and beds an inch or two thick, makes up as much as 15–20 percent of the rock. Chemical analyses of two specimens typical of the limestone are given in table 1. Umpleby (1917, p. 59) presented four analyses of limestone, one of which contains 12.72 percent magnesium oxide. The magnesium content indicates that locally the limestone is dolomitic; however, Umpleby's specimens came from mine workings, and the magnesium could have been introduced locally during metamorphism instead of being a component of the original carbonate beds.

TABLE 1.—*Chemical and normative analyses of rocks of the area*

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Quartz monzonite	Quartz monzonite	Porphyritic rhyolite	Porphyritic rhyolite	Mackay Granite	Mackay Granite	Mackay Granite	Leucogranite porphyry	Leucogranite porphyry	Rhyolite	Challis Volcanics	Limestone	Limestone
	Full 1	Full 2	58 N. 85	58 N. 76	58 N. 14	Full 3	58 N. 4	58 N. 87	58 N. 32	58 N. 71	CPR 648	59 N. 1	59 N. 2

Chemical analyses

[Analyses 1, 2, and 6 by Norman Davidson; 3-5, 7-10, 12, and 13 by Margaret C. Lemon; 11 by Faye H. Neuerburg]

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	58.09	61.85	65.99	67.14	72.49	72.57	74.42	70.16	70.41	76.49	64.43	4.77	5.47
Al_2O_3	15.14	16.06	14.73	14.68	13.86	13.31	12.97	14.73	14.56	12.52	16.85	.17	.12
Fe_2O_3	1.87	1.08	1.44	.85	.90	.99	.80	.21	.24	.70	1.99	.03	.09
FeO	3.84	4.07	1.96	2.13	.99	1.55	1.11	.64	.63	.32	1.22	.06	.03
MgO	3.90	1.99	1.42	1.38	.45	.62	.30	.72	.80	.06	.82	.48	.39
CaO	5.74	4.70	2.73	2.88	1.35	1.74	.78	3.68	3.46	.43	3.27	52.58	52.34
Na_2O	5.00	3.54	3.87	3.31	4.25	4.90	3.73	3.31	3.29	4.08	4.20	.01	.02
K_2O	2.88	3.52	3.98	4.34	4.64	2.90	4.93	5.45	5.41	4.58	3.05	.03	.02
H_2O+	1.37	1.25	1.67	1.24	.35	.53	.28	.22	.26	.38	1.38	.05	.11
H_2O-	.24	.24	.41	.31	.09	.09	.12	.09	.23	.11	.40	.04	.02
TiO_2	.90	.83	.53	.45	.24	.26	.19	.34	.36	.04	.45	.01	.01
P_2O_5	.38	.13	.19	.20	.07	.11	.05	.14	.14	.03	.22	.04	.03
MnO	.15	.20	.07	.03	.04	.09	.08	.04	.04	.04	.07	.02	.01
CO_2	.04	.74	1.13	.75	.01	.10	.02	.02	.01	.16	1.28	41.53	41.31
Cl			.01	.03	.06		.09	.09	.04	.01		.00	.00
F		.05	.07	.06	.14	.08	.07	.05	.04	.09		.01	.01
Subtotal		100.25	100.20	99.78	99.93	99.84	99.94	99.89	99.92	100.04		99.83	99.98
Less O		.02	.03	.04	.07	.03	.05	.04	.03	.04		.00	.00
Total	99.54	100.23	100.17	99.74	99.86	99.81	99.89	99.85	99.89	100.00	99.63	99.83	99.98

C.I.P.W. norm

[Calculated by Burroughs B220 computer]

q	2.445	14.759	23.413	24.848	27.092	28.566	32.075	23.499	23.984	35.085	24.236
or	17.015	20.796	23.514	25.641	27.413	17.133	29.127	32.199	31.963	27.059	18.020
ab	42.286	29.938	32.655	27.771	35.499	41.440	30.880	27.328	27.528	34.431	35.520
an	10.372	17.461	4.707	7.864	5.173	5.768	2.920	9.599	9.147	.277	6.692
c		.030	2.348	1.701	.040		.560			.767	4.190
hl			.016	.049	.099		.148	.148	.066	.016	
wo	6.415					.401		3.045	2.835		
en	9.709	4.954	3.535	3.436	1.120	1.544	.747	1.792	1.992	.149	2.041
fs	4.298	5.582	1.664	2.521	.752	1.766	1.212	.515	.438	.018	
mt	2.711	1.566	2.088	1.232	1.305	1.435	1.160	.304	.348	1.015	2.856
hm											.020
il	1.709	1.576	1.007	.855	.456	.494	.361	.646	.684	.076	.855
ap	.900	.308	.450	.474	.166	.261	.118	.332	.332	.071	.521
fr		.091	.126	.105	.281	.154	.139	.090	.069	.182	
cc	.091	1.683	2.570	1.706	.023	.227	.045	.045	.023	.364	2.911
Total	97.951	98.744	98.093	98.203	99.419	99.189	99.492	99.542	99.409	99.510	97.862

Molecular norm

Q	2.25	13.59	22.00	23.23	24.86	26.67	29.61	21.46	22.24	32.37	23.12
Or	17.15	21.15	24.00	26.25	27.70	17.30	29.55	32.50	32.25	27.35	18.40
Ab	45.30	32.30	35.40	30.40	38.55	44.45	34.00	30.00	29.85	37.05	38.40
An	10.45	17.80	5.25	8.45	5.10	5.85	3.35	8.40	9.15	.95	6.25
C			2.48	1.69			.32			.57	4.89
Wo	6.22	.52			.44	.58		3.36	2.90		
En	10.86	5.58	4.00	3.90	1.26	1.74	.84	2.00	2.22	.16	2.30
Fs	3.64	4.76	1.22	2.18	.64	1.48	1.02	.41	.38	.52	
Mt	1.97	1.16	1.63	.90	.95	1.04	.84	.23	.26	.75	2.10
Hm											.02
Il	1.26	1.18	.75	.62	.34	.38	.28	.48	.50	.04	.64
Ap	.80	.28	.40	.43	.16	.24	.14	.16	.29	.06	.48
Cc	.10	1.48	2.92	1.94	.02	.26	.06	.06	.02	.40	3.52
Total	100.00	99.80	100.05	99.99	100.02	99.99	100.01	99.06	100.06	100.22	100.12

See end of table for description of localities.

297-548—68——2

TABLE 1.—*Chemical and normative analyses of rocks of the area*—Continued

	1	2	3	4	5	6	7	8	9	10	11	12	13
	Quartz monzonite	Quartz monzonite	Porphyritic rhyolite	Porphyritic rhyolite	Mackay Granite	Mackay Granite	Mackay Granite	Leucogranite porphyry	Leucogranite porphyry	Rhyolite	Challis Volcanics	Limestone	Limestone
	Full 1	Full 2	58 N. 85	58 N. 76	58 N. 14	Full 3	58 N. 4	58 N. 87	58 N. 32	58 N. 71	CPR 648	59 N. 1	59 N. 2

Semiquantitative spectrographic analyses

[Determined spectrographically by Paul R. Barnett. Looked for but not detected: Ag, As, Au, B, Bi, Cd, Ge, In, Pt, Sb, Ta, Th, Tl, U, W, and Zn. Data have an overall accuracy of ±15 percent except that they are less accurate near limits of detection, where only one digit is reported]

	1	2	3	4	5	6	7	8	9	10	11	12	13
Cu			0.0008	0.0001	0.0003	---	0.0006	0.004	0.018	0.0001	---	<0.0002	<0.0002
Pb			.004	.004	.004	---	.009	.005	.005	.004	---	<.002	<.002
Mo			<.0002	<.0002	<.0003	---	<.0003	.0006	.0012	<.0002	---	<.0004	<.0004
Ba			.12	.15	.073	---	.042	.14	.070	.002	---	.004	.003
Be			.0005	.0004	.0007	---	.0006	.0004	.0005	.0020	---	<.0004	<.0004
Co			.0005	.0004	<.0003	---	<.0003	<.0003	<.0003	<.0002	---	<.0004	<.0004
Cr			.0022	.0036	.0006	---	.0005	.0012	.0014	<.0001	---	.0010	.0010
Ga			.0016	.0014	.0016	---	.0014	.0014	.0012	.0017	---	<.001	<.001
La			.007	.006	<.008	---	<.008	<.008	<.008	<.005	---	<.01	<.01
Nb			.003	.002	.006	---	.008	.004	.004	.007	---	<.003	<.003
Ni			.0010	.0010	<.0003	---	<.0003	.0005	.0006	<.0002	---	<.0004	<.0004
Sc			.0008	.0008	<.0008	---	<.0008	<.0008	<.0008	<.0005	---	<.001	<.001
Sn			<.0003	.0007	<.0005	---	<.0008	<.0005	.0014	.0008	---	<.0006	<.0006
Sr			.030	.050	.022	---	.014	.036	.038	.005	---	.07	.05
V			.0046	.0041	.0018	---	.0011	.0034	.0031	<.0005	---	<.001	<.001
Y			.002	.002	.004	---	.003	.002	.002	.004	---	<.003	<.003
Yb			.0002	.0002	.0004	---	.0004	.0001	.0002	.0005	---	<.0002	<.0002
Zr			.019	.020	.032	---	.028	.026	.032	.0094	---	<.004	<.004

1. Ridge north of Horseshoe mine.
2. Empire mine, 1,600-ft level.
3. 3,000 ft N. 18° W. of Grand Prize mine.
4. 2,800 ft N. 38° W. of Horseshoe mine.
5. 2,900 ft S. 17° W. of the top of White Knob.
6. Mackay Peak,
7. 1,800 ft N. 45° E. of the top of Mackay Peak.
8. 2,800 ft N. 18° W. of Grand Prize mine.
9. 2,800 ft N. 10° W. of Grand Prize mine.
10. 5,650 ft S. 6° E. of the top of White Knob.
11. 88,500 ft S. 78° W. of the top of Mackay Peak.
12. 2,750 ft N. 49° E. of Grand Prize mine.
13. 750 ft S. 56° E. of Blue Bird mine.

The noncarbonate sedimentary rocks within the White Knob range from shale to conglomerate, but most of them are argillaceous siltstone and fine-grained quartzite. These rocks are medium gray to very dark gray on fresh surfaces. Much of the dark color of these rocks is due to disseminated carbon; where weathered, much of the rock is brown because of included iron oxide.

Small masses of siltstone, quartzite, shale, and conglomerate similar to the rocks that make up the Copper Basin Formation occur in the White Knob Limestone. As noted, the Copper Basin Formation and White Knob Limestone interfinger in this area, and these bodies of siltstone, quartzite, shale, and conglomerate are believed to be either detached pods and lenses of rocks, such as those that make up the Copper Basin Formation, or parts of thin wedges of the Copper Basin Formation that extend eastward into the White Knob Limestone.

Fossil evidence indicate that the White Knob Limestone ranges from Early Mississippian to Early Permian in age (Ross, 1962, p. 385).

INTRUSIVE ROCKS

All of the intrusive rocks and perhaps some of the extrusive rocks may have been derived by differentiation from a single parent magma. There is no direct evidence of the existence or composition of such a parent magma; however, the variation diagram (fig. 2), coupled with what can be deduced from field relationships about the relative ages of the various intrusive rocks, suggests that the magma tended to become more acidic with time. It will be noted on the variation diagram (fig. 2) that the order of the leucogranite porphyry and the Mackay Granite based on their silica content is reversed from their deduced order of emplacement based on field evidence. This should not be surprising because suites of igneous rocks that are believed to have been derived from a single differentiating magma commonly depart from theoretical differentiation curves for a number of reasons.

Table 1 gives the compositions of the igneous rocks. The intrusive rocks, except for the dikes, are described below in their probable order of emplacement. The dikes, some of which seem to have been intruded over a considerable span of time, are described after the other intrusive rocks.

The granitic rocks are clearly intrusive. Their relationship to the enclosing sedimentary rocks is especially evident in the vicinity of White Knob where the contact locally follows bedding; also at numerous places, dikes of granite rock extend out into cracks in the sedimentary rocks.

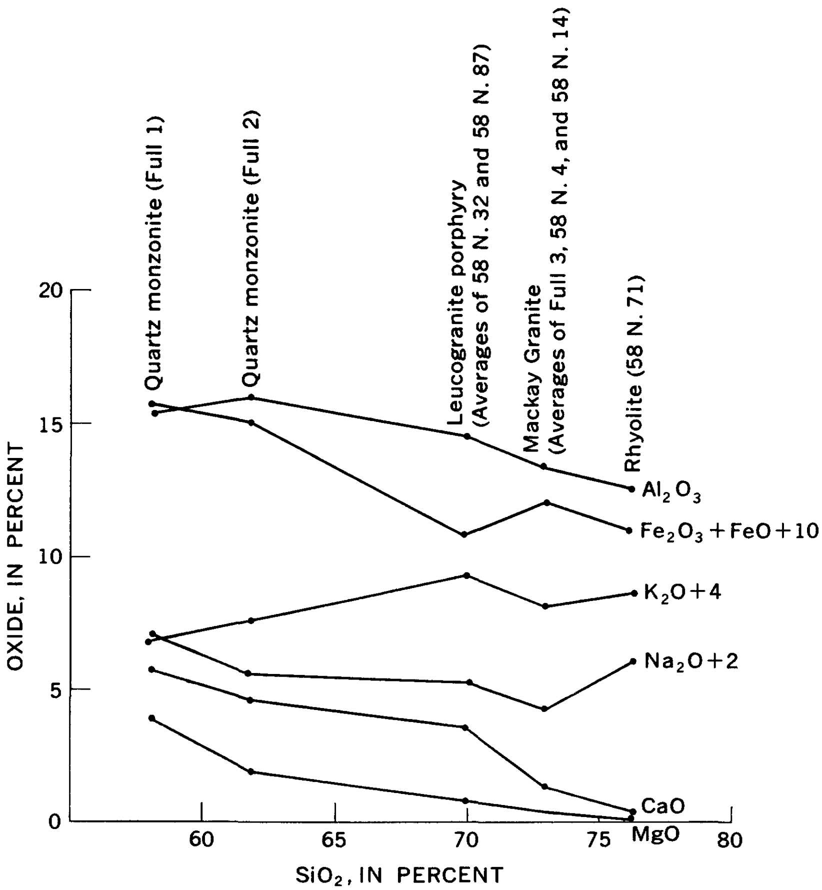

FIGURE 2.—Variation of selected oxides compared to variation in silica. Data from table 1.

QUARTZ MONZONITE

The rock termed quartz monzonite in this report is exposed in three small areas north of the Mackay Granite and in some of the workings of the Empire mine. It has a wider range of composition and appearance than the other intrusive rocks of the area, with the exception of the dikes. That the most common rock types, as well as the range of rock types, seems to be about the same in all these bodies suggests a close relationship between the rocks in the various quartz monzonite bodies. An additional reason for believing that each and perhaps all of these bodies of quartz monzonite are the result of a single episode of intrusion is the gradation of various textures and compositions within these bodies.

The description that follows applies specifically to the stock that is in contact with the Mackay Granite on the northeast side of Mackay Peak. But as noted, above, the rocks of all the quartz monzonite stocks seem to be comparable.

The quartz monzonite ranges from light gray to medium gray and is, on the average, somewhat darker and finer grained than the Mackay Granite to be described below. Most of the groundmass, which makes up from 40 to 50 percent of the quartz monzonite, is fine grained, but at a few places it is medium grained; it consists of a mixture of orthoclase, quartz, and a little oligoclase; the orthoclase is slightly more abundant than the quartz. In most of the stock the quartz is confined to the groundmass, but locally as much as one-fourth of it is in phenocrysts, which are slightly larger than the grains of the groundmass, but considerably smaller than the feldspar phenocrysts. These small quartz phenocrysts are inconspicuous in hand specimens; they are rounded and embayed. Orthoclase is confined to the groundmass of most of these rocks, but in a few places it occurs as phenocrysts. Oligoclase phenocrysts make up about 25 percent of these rocks and are as much as 1.5 mm in length. Mafic minerals contribute 10–20 percent to the volume of the rock and include diopside, green hornblende, and biotite either singly or in combination. The hornblende is commonly associated with and in part rims the diopside. The biotite commonly includes magnetite, and, in some specimens is partly altered to chlorite. Accessory minerals are apatite, sphene, and magnetite.

Farwell and Full (1944, p. 7) called these rocks diorite, and they undoubtedly range from diorite through quartz monzonite; however, most of them cannot be classified as diorite because the ratio of orthoclase to oligoclase is too great. We believe most of the rocks contain enough quartz to be classified as quartz monzonite rather than monzonite. Table 1 includes a chemical and a normative analysis of one of the less silicic of these rocks.

A horizontal thickness of at least 370 feet of quartz monzonite occurs in the Empire mine on the 1,600-foot level (Farwell and Full, 1944, pl. 23). This level was not accessible during the present study, but a few specimens collected by Farwell and Full were available for study. Although these specimens are coarser grained and contain more quartz than most of the quartz monzonite exposed at the surface, they resemble the surface rocks sufficiently in mineralogy and position relative to the Mackay Granite to suggest that they are related to the surface rocks. The amount of quartz in these specimens is within the range observed in the quartz monzonite bodies at the surface. The grains in these specimens range from 0.2 to 10 mm; the

most common size is a little more than 1 mm. Locally some of the feldspar crystals are enough larger than the rest of the mineral grains to be termed phenocrysts. These specimens are composed of 10–15 percent quartz, about 45 percent orthoclase, 30 percent oligoclase, and about 10 percent mafic minerals, mostly green hornblende. Chemical and normative analyses of a specimen of the quartz monzonite from the 1,600-foot level of the Empire mine are included in table 1.

There is little evidence to indicate the age of the quartz monzonite relative to the other intrusive rocks of the area. Along the ridge south of the Horseshoe mine, rocks that are devoid of megascopically identifiable quartz are in abrupt contact with rocks that contain numerous quartz phenocrysts. The former rocks seem to be part of a quartz monzonite body, and the latter seem to be dikes that extend out from the Mackay Granite. These relationships suggest that the quartz monzonite is older than the Mackay Granite.

MACKAY GRANITE

The largest of the intrusive bodies in the area of this report (pl. 1) is here named the Mackay Granite after excellent exposures at its type locality, Mackay Peak (SW¼ sec. 35, T. 7 N., R. 23 E.). This name is a local term which has long been informally applied to this intrusive mass. Although the local name is adopted in this report, it should be noted that the rock is actually granite porphyry. It is exposed over an area of about 11½-square miles. This granite is fairly uniform in texture throughout most of its exposed extent, but shows local variations which seem to be related to the distance from the outer edge of the mass at the time of emplacement.

Most of the Mackay Granite is somewhat weathered and is pinkish gray; less weathered granite, which has been exposed by glacial scouring, is commonly a faintly greenish gray. The bulk of the rock is a porphyry made up of phenocrysts of orthoclase and quartz in a fine-grained groundmass. The orthoclase phenocrysts make up 25–35 percent of the granite; they are as much as 10 mm in diameter, subhedral to euhedral, and pinkish gray in hand specimen. In thin section many of them are seen to enclose small rounded anhedral quartz inclusions. The quartz phenocrysts make up 5–15 percent of the rock, are medium dark gray in hand specimen, as large as 5 mm in size, rounded, and are embayed by and contain rounded inclusions of groundmass material. The groundmass is a mosaic of nearly equidimensional anhedral grains of quartz, orthoclase, and plagioclase. The orthoclase and the quartz of the groundmass each make up 20–30 percent of the rock, and the grains range from about 0.05 to 0.3 mm in size. The plagioclase is albite-oligoclase in composition and makes up 10–15 percent of the granite. Biotite and hornblende each occur in amounts of 1 or 2 per-

cent and are locally altered to chlorite; magnetite, apatite, zircon, and rutile are present in amounts of less than 1 percent. Three chemical analyses of typical Mackay Granite are given in table 1.

A specimen of the Mackay Granite collected by Farwell and Full from the 1,600-foot level (about 7,010 ft above sea level) of the Empire mine has phenocrysts similar to the typical granite and has the same composition, but the grains of the groundmass are larger and range from 0.15 to 1.5 mm in size.

Locally, especially along the ridges northeast of the head of Corral Creek and north of the head of Steward Canyon, some of the Mackay Granite has a finer grained groundmass and a deeper greenish color than the rest of the Mackay Granite. This rock is believed to be a chilled phase of the granite, which is more deeply colored because more hornblende and biotite have been altered to chlorite than in the typical granite.

T. W. Stern (written commun., Sept. 21, 1959) reported that two specimens of Mackay Granite have ages of 40±10 million years as determined by the lead-alpha method, using zircons. Thus the age of the Mackay Granite is considered to be early Tertiary.

LEUCOGRANITE PORPHYRY

The leucogranite porphyry is confined to an irregular area along the northeast side of the Mackay Granite and is in contact with the granite. The rocks of this mass are very light gray and porphyritic. The groundmass is composed of grains so small that the proportions of minerals in it are very difficult to estimate. Chemical analyses of this rock (table 1) show that it can appropriately be termed granite, or more specifically, because of its very light color and porphyritic texture, leucogranite porphyry.

From one-third to two-thirds of the leucogranite porphyry is groundmass made up of fine-grained quartz and feldspar; most of the feldspar is orthoclase. This groundmass is commonly a mosaic of almost equidimensional grains, but locally it has a randomly oriented fibrous texture. The groundmass grains range from 0.007 to 0.06 mm in size, but the full range of size is not present in any one specimen. Orthoclase and quartz phenocrysts occur in about equal amounts, and each is usually somewhat more abundant than oligoclase phenocrysts. Orthoclase phenocrysts are as large as 20 mm, oligoclase phenocrysts as large as 4 mm, and quartz phenocrysts as large as 8 mm in size. The phenocrysts are euhedral to subhedral, and the quartz phenocrysts commonly have rounded corners and are embayed by and contain rounded inclusions of groundmass material. Diopside is the only significant mafic mineral in these rocks, it contributes only 3–5

percent to the volume of the rock and occurs as widely scattered small anhedral grains and in aggregates, which also contain orthoclase. The diopside in these aggregates occurs either as randomly oriented, nearly equidimensional anhedral grains or as rectangular or rodlike grains, which in a single aggregate have a common orientation and seem to be skeletal crystals. The orthoclase in these aggregates occurs as nearly equidimensional, randomly oriented anhedral grains. In some specimens calcite and sphene also make up a small part of the volume of these diopside-bearing aggregates. Table 1 includes chemical and normative analyses of two typical specimens of the leucogranite porphyry.

Umpleby (1917, p. 60) reported various stages of replacement of hornblende and biotite by diopside in granitic rocks associated with skarn. We did not observe similar features in the leucogranite porphyry, and it is difficult to evaluate the significance of these observations by Umpleby because he was not explicit about their extent or location.

Evidence of the age of the leucogranite porphyry relative to the Mackay Granite is equivocal. Exposed contacts between these rocks are scarce, and most are in mine workings. Where the contracts are exposed, rocks resembling the Mackay Granite have various relationships with rocks resembling the leucogranite porphyry. Interpretation of these relationships is complicated by difficulty in positively identifying the rocks of the various plutons and dikes in small exposures.

We believe that the leucogranite porphyry is younger than the Mackay Granite because it resembles the rhyolite dikes which cut the Mackay Granite. At several places, notably in the area a short distance south of the White Knob mine, the leucogranite porphyry grades at its margins into rhyolite which seems to be identical with rhyolite in the dikes that cut the Mackay Granite. A diligent search did not reveal any rhyolite dikes within the leucogranite porphyry, and this, along with the fact that the leucogranite porphyry is athwart the dike zone, tends to confirm the interpretation that the rhyolite dikes are related to and were emplaced at the same time as the leucogranite porphyry.

Minor variations of composition and texture within the leucogranite porphyry masses, especially variations in the abundance of quartz phenocrysts, suggest that the leucogranite porphyry may have been emplaced during several episodes of intrusion, but even so it seems likely that all the leucogranite porphyry was emplaced during a fairly brief time interval.

Relations which suggest the opposite order of emplacement were observed by T. H. Kiilsgaard (written commun., Jan. 19, 1962) on the ridge about 2,200 feet northeast of Mackay Peak. At that place a small

dike that seems to be an apophysis of the Mackay Granite intrudes a leucocratic granitic rock. Because the quantity of quartz phenocrysts in this leucocratic rock is at the lower limit of the range of quartz phenocrysts in the leucogranite porphyry, this leucocratic rock may not be directly related to the greater part of the leucogranite porphyry.

T. W. Stern (written commun., Sept. 21, 1959) determined a specimen of the leucogranite to be 50±10 million years old by the lead-alpha method, using zircons. These figures overlap the age range determined by Stern for the Mackay Granite and therefore do not conclusively establish the relative ages of the two rocks.

Umpleby (1917, p. 44, 94) considered the rocks we call leucogranite porphyry to be merely a border phase of the Mackay Granite, which he called granite porphyry. We believe, however, that the differences between the leucogranite porphyry and the Mackay Granite are too consistent and the contact between them too abrupt for Umpleby's interpretation to be valid.

Kemp and Gunther (1908, p. 275) believed that their quartz porphyry, which seems to be equivalent to our leucogranite porphyry, was formed later than the main mass of granite, the Mackay Granite of the present report.

QUARTZ LATITE

Quartz latite ranges from light greenish gray to dark greenish gray and occurs as dikes. Locally some of it weathers to a light to very light yellowish gray similar to the color of most of the rhyolite described below, but it can be distinguished from the rhyolite by the absence of quartz grains large enough to be seen in hand specimens. The dikes of quartz latite are much more heterogeneous in color and texture than the rhyolite dikes; however, all the quartz latite dikes and the similarly heterogeneous quartz monzonite bodies are believed to be related because they all lack quartz phenocrysts and many of the quartz latite dikes originate from and grade into the quartz monzonite stocks. These rocks are called quartz latite on the basis of their assumed relationship with the quartz monzonite.

A very fine grained groundmass makes up more than three-quarters of the volume of all the quartz latite. The groundmass consists of orthoclase, oligoclase, and quartz. Orthoclase is more abundant than oligoclase, and quartz is much less abundant than either. Most of the feldspar grains are elongated prisms, which are commonly arranged in radiating clusters. The quartz occurs as small isolated grains interspersed among the feldspar grains. Small phenocrysts of altered oligoclase make up a small part of the volume of all these rocks, and small patches of chlorite mixed with calcite, magnetite or limonite, and commonly a little quartz, attest to the former presence of small mafic

297-548—68——3

phenocrysts. Locally a little pyroxene, amphibole, or biotite remains.

The quartz latite dikes that originate from and grade into the quartz monzonite stocks are the same age as the quartz monzonite, which is probably the oldest intrusive rock in the area. Locally, quartz latite dikes are crossed by rhyolite dikes (northeastern part of pl. 1), and this tends to confirm the interpretation that the quartz latite is among the oldest igneous rocks in the area.

RHYOLITE

Rhyolite ranges from very light gray to medium gray; most of it has a faint yellowish tint, but some of it is greenish. All of it contains euhedral to subhedral dipyramid phenocrysts of high temperature quartz, and in many specimens some of the quartz is smoky. Oligoclase and orthoclase together or individually are common as phenocrysts. Most of the phenocrysts do not exceed 5 mm in size. Brownish patches 2–5 mm across occur in most of the rhyolite; these patches consist of mixtures of chlorite, limonite, cryptocrystalline quartz(?), and locally biotite. Biotite occurs as isolated fresh grains in a few specimens, but more commonly it is partly or completely altered to chlorite. Calcite occurs as an alteration product in oligoclase and is locally scattered through the groundmass. A very fine grained groundmass makes up more than 75 percent of all the rhyolite, and appears to consist dominantly of a mixture of quartz and feldspar. Table 1 gives the chemical composition of a typical rhyolite. As previously noted, we believe that the rhyolite, which occurs as dikes, is related to the leucogranite porphyry, and therefore is the same age. Section A–A′, plate 1, shows our interpretation of the relationship of the rhyolite dikes to the leucogranite porphyry.

In the area north of the Blue Bird mine, many of the rhyolite dikes are locally thicker than elsewhere in the area, and these thicker parts of the dikes contain large feldspar phenocrysts similar to those in dikes that are called porphyritic rhyolite in this report. In general the groundmass of the thicker rhyolite dikes that contain large feldspar phenocrysts is lighter colored than the groundmass of the porphyritic rhyolite. At least locally where porphyritic rhyolite dikes cut rhyolite dikes the porphyritic rhyolite is younger than the rhyolite.

PORPHYRITIC RHYOLITE

Porphyritic rhyolite, which occurs only as dikes, differs from most of the other dike rocks of the area in that it contains abundant large feldspar phenocrysts. Three-quarters or more of the volume of all the porphyritic rhyolite is fine-grained gray or greenish-gray groundmass consisting dominantly of orthoclase with shreds of chlorite and

scattered quartz grains. Enclosed within the groundmass are phenocrysts of feldspar, quartz, completely altered mafic minerals, and locally, rare flakes of biotite. White euhedral phenocrysts of oligoclase occur in all the porphyritic rhyolite, and orthoclase phenocrysts occur in most of it in somewhat lesser abundance. Commonly the orthoclase is rimmed by oligoclase to form rapakivi-type phenocrysts; the rim of oligoclase may be from $1/10$ to $8/10$ of the radius of the phenocrysts. The phenocrysts of orthoclase are commonly 15 mm long, and a few are 25 mm long; very few oligoclase phenocrysts exceed about 10 mm in length. Quartz phenocrysts are rounded and embayed and have a maximum diameter of about 10 mm, but are commonly not conspicuous in hand specimens. The former presence of mafic minerals is attested to by prismatic patches of chlorite intergrown with epidote, calcite, or partly altered biotite. Table 1 gives chemical and normative analyses of two samples of the porphyritic rhyolite. Farwell and Full (1944, p. 8) used the term porphyritic granodiorite to refer to these rocks.

Dark fine-grained dikes which are similar to the groundmass of the porphyritic rhyolite occur near and most commonly at the borders of a few of the porphyritic rhyolite dikes. These dark fine-grained rocks may be a chilled phase of the porphyritic rhyolite, but the large phenocrysts in the porphyritic rhyolite may be of intertelluric origin and, if so, would be present even in a chilled phase. The fact that the abundance and size of phenocrysts varies widely in the porphyritic rhyolite suggests that the magmas for the dark dikes as well as for the porphyritic rhyolite, were derived from the magma reservoir during different stage of partial crystallization. Another possibility is that the dark fine-grained dikes are the result of the porphyritic rhyolite magma having been forced through cracks that were so narrow that the larger phenocrysts could not pass through.

The differences between the porphyritic rhyolite and the other intrusive rocks of the area are almost surely due to differences in cooling history; the porphyritic rhyolite probably remained at a temperature that was optimum for the formation of feldspars longer than the other intrusive rocks of the area.

The rounded and embayed quartz phenocrysts in the porphyritic rhyolite are identical in form to those in the Mackay Granite and the leucogranite porphyry, and therefore these three types of intrusive rocks are probably rather closely related differentiation products of a single parent magma.

The amount of variation in the porphyritic rhyolite dikes suggests that they may have been intruded over a significantly long time interval. Some of these dikes seem to be identical with chilled borders of

the Mackay Granite, and therefore these dikes may be about the same age as the Mackay Granite. Some, which cut the Mackay Granite, must be younger than that part of the Mackay Granite that they cut. A few of the porphyritic rhyolite dikes cut and hence must be younger than the leucogranite porphyry. In sec. 27, T. 7 N., R. 23 E., a dike containing large feldspar phenocrysts seems to be cut by a dike without quartz or large feldspar phenocrysts, which shows that some of the porphyritic rhyolite dikes are older than some of the quartz monzonite dikes.

EXTRUSIVE ROCKS

CHALLIS VOLCANICS

In the area shown on plate 1, volcanic rocks—the Challis Volcanics—are everywhere in contact with sedimentary rocks of late Paleozoic age. In a small part of the northeast corner of the area shown on plate 1, the volcanic rocks lie on an irregular surface on limestone. In the northwestern part of the area the contact between the volcanic and sedimentary rocks lies along the base of an escarpment that is probably in part the result of faulting. The uppermost volcanic rocks here are believed to be younger than most of this faulting because they extend a short distance southward across this fault. The contact in the eastern part of the area is a fault that is locally the locus for jasperoidization.

The Challis Volcanics in the map area seems to correspond in composition to the latite-andesite member of this formation in adjacent areas (Ross, 1937, p. 51–53, and 1947, p. 1120–1121). The rocks consist of massive layers which probably include flows, ordinary indurated tuffs, and welded tuffs, as well as tuff breccias. Most of the layers are rather somber shades of brown, reddish brown, greenish gray, and gray; browns and reddish browns are most common. Locally a few of the layers are light tan. These rocks probably range from andesite to rhyolite, and rocks of latitic composition seem to be most common. Phenocrysts as much as 1 mm in length make up from about 5–35 percent of the rocks. Oligoclase makes up more than half of the phenocrysts. Augite and biotite are the most common mafic minerals in the phenocrysts, but a little hornblende is present in some of the flows. Quartz is present in some of the flows, and in a few it is as abundant as the oligoclase. Locally some of the quartz is rounded and resorbed. The groundmass is commonly an aphanitic mass that is probably dominantly feldspar. Table 1 includes a chemical analysis of one specimen of Challis Volcanics.

Rounded rock fragments are included in the Challis Volcanics just west of the road on the ridge west of Tuscarora Gulch 1,400 feet north

of the south edge of the area shown on plate 1. Farwell and Full (1944, p. 9) interpreted these to be granite and concluded that the enclosing volcanic rocks were extruded after the granite was emplaced.

These rounded inclusions are composed of phenocrysts of plagioclase and biotite and locally a little quartz and sanidine in a glassy groundmass. Most of the quartz and feldspar phenocrysts are rather intensely broken, and some of the quartz is rounded and resorbed. The groundmass of these rocks is glassy, and some of it includes laminated glass fragments which look like pumice. Some of these inclusions may be xenoliths of plutonic rocks which have had their groundmasses melted and locally inflated, or as is more likely, they may all be fragments of volcanic rock derived from nearby flows. If any are xenoliths of plutonic rock, then their presence shows that the plutonic bodies from which they were derived had crystallized below the surface before the enclosing volcanic rocks were extruded.

A more definite indication of the relative age of the volcanic rocks is provided by the fact that a rhyolite dike cuts the Challis Volcanics in the northeast corner of the area shown on plate 1. The rhyolite dikes are among the youngest of the intrusive rocks of the area; so, this indication that they are younger then the volcanic rocks does not necessarily conflict with the possible presence of xenoliths of intrusive rocks in the volcanic rocks elsewhere in the area. In any case the extrusive and intrusive rocks in the area are about the same age and composition and, hence, may be genetically related.

Ross (1961, p. C179) concluded that the Challis Volcanics may range in age from Eocene to, at most, early Miocene and that probably most of the formation is Oligocene.

METAMORPHIC ROCKS

Metamorphic rocks occur near the contacts of all the larger intrusive masses in the area and along the contact between limestone and Challis Volcanics. Adjacent to the quartz monzonite and the granite the metamorphism has been dominantly isochemical; that is, recrystallization and rearrangement of chemical constituents of the rocks have taken place, under the influence of elevated temperature, without any appreciable transport of material. Adjacent to the leucogranite porphyry, on the other hand, there has been rather large-scale metasomatism, that is, introduction and removal of some of the components of the rocks, to form skarn. At the contact between the Challis Volcanics and limestone some of the rock has been metasomatized to form jasperoid.

ISOCHEMICAL METAMORPHOSED ROCKS

Isochemical metamorphosed rocks are not shown on plate 1; they form a zone several hundred feet thick at most places near the contacts of the larger intrusive masses. The zone attains its maximum width on the ridge northeast of White Knob, where marble extends about 1,000 feet to the east of the limestone-granite contact. At this place, the contact seems to follow bedding, which is nearly vertical at the surface, but the contact may dip under the limestone so that the surface exposure of marbleized limestone may be wider than the true thickness.

As previously noted the limestone is composed of relatively pure calcite, and the effect of isochemical contact metamorphism simply has been to recrystallize the calcite into larger grains. Locally the limestone contains thin shaley interbeds and beds and nodules of chert. The silica and clay minerals in these beds and nodules have reacted with the enclosing calcite to form lime silicate minerals, which occupy the same positions in the rock and have the same shape as the beds and nodules from which they formed. The lime silicate minerals are, separately or in combination, wollastonite, scapolite, diopside, tremolite, and grossularite.

At the western edge of the area shown on plate 1 the Mackay Granite intruded sandstone and siltstone rather than limestone. In these clastic rocks the effects of the contact metamorphism are much less obvious than in the limestone. The quartz grains have grown together to form mosaics, and the argillaceous components have reacted with one another and quartz to form muscovite and biotite. Near where the Mackay Granite cuts the contact between limestone and clastic rocks, on the ridge east of Corral Creek, some of the metamorphosed siltstone contains considerable diopside, which suggests that the rocks there originally contained some carbonate minerals.

SKARN

Skarn is restricted to and occurs locally at or near the contacts between limestone and all the larger intrusive masses shown on plate 1. The skarn is commonly only a few feet or less in thickness at the margins of the Mackay Granite and the quartz monzonite. All the thicker masses of skarn seem to be associated with the contact between limestone and leucogranite porphyry, especially with the margins of limestone that are partly or completely surrounded by leucogranite porphyry. A mass of skarn several tens of feet thick, between quartz monzonite and limestone on the 1,600-foot level of the Empire mine, is shown on section *B–B′*, plate 1. This is one of several pods of skarn on this level of the mine that have about the same relationship to

quartz monzonite. One of the pods, shown on section *C–C′*, is in part between quartz monzonite and limestone and in part between leucogranite porphyry and limestone; and we believe all these pods may be more closely related to nearby leucogranite porphyry than to the quartz monzonite. Some patches of skarn within the leucogranite porphyry are not now associated with limestone, and these, we believe, are all that remains of engulfed blocks, septum, and roof pendants of metasomatized limestone. The cross sections, plate 1, illustrate these relationships.

These patches of skarn within the leucogranite porphyry seem to be the basis for the statement by Kemp and Gunther (1908, p. 269, 270) "that while the deposits are associated in a general way with the contact of an eruptive rock with limestone * * * the garnetization has taken place not in the limestone, as is usually the case, but in the igneous rock itself." Umpleby (1917, p. 56, 57) also noted that the "most striking and noteworthy feature of the distribution of the garnet rock is that all the larger areas lie within the main granite porphyry mass."

The widely scattered relict bedding and the fossils within the skarn clearly show that much of the skarn has originated by metasomatism of limestone. Umpleby (1917, p. 17) noted that, "Locally the lime silicate rock has inherited in part the pattern of the igneous rock and elsewhere it shows the bedding structure of the limestone." Ross (1930, p. 15) and Farwell and Full (1944, p. 9) concurred with this view that skarn formed mostly from limestone, but also in part from the intrusive rock.

Umpleby (1917, p. 71) concluded that the skarn was formed with little or no change of volume, and we have found no evidence of volume changes that can be attributed to formation of the skarn.

Locally veins of skarn extend into the granitic rocks as much as 100 feet; the dikelike body of skarn shown on plate 1 in the cirque at the head of Mammoth Canyon is probably such a body.

The contacts between the skarn and the limestone or intrusive rocks are generally quite sharp. These contacts are best exposed in several areas where the skarn is too thin to be shown on plate 1. One such place is on the ridge 3,200 feet northeast of the junction of Mammoth and Stewart Creeks, where domical protuberances of the upper surface of granite just reach or just fail to reach the ridge crest. The relationships bteween skarn, limestone, and granite are also well exposed around the small cupola of granite 3,200 feet west-northwest of the Horseshoe mine.

The skarn consists dominantly of garnet mixed with significant quantities of pyroxene, along with subordinate amounts of magnetite,

hematite, actinolite, scapolite, wollastonite, epidote, and fluorite. The garnet makes up more than three-quarters of the volume of most of the skarn. Most of the garnet is brown; chemical analyses presented by Umpleby (1917, p. 63) show that it is composed of somewhat more than half andradite molecules and that the remainder is mostly grossularite. A less abundant kind of garnet is dominantly grossularite mixed with subordinate andradite; this variety of garnet usually has a yellowish hue and is lighter colored than the more common variety. Although this lighter colored garnet is scattered throughout the skarn, it is most common near the contact between skarn and limestone. Most of the garnet is anhedral, but it commonly has crystal faces where it is adjacent to calcite. The pyroxene is greenish gray, and analyses presented by Umpleby (1917, p. 64) show it to be diopside that contains considerable magnesium and a little iron. Locally the skarn consists almost entirely of a mixture of magnetite and hematite, and attempts have been made to exploit a large mass of iron-rich skarn about 1,000 feet northwest of the Grand Prize mine.

To evaluate the changes that occurred during the metasomatism of limestone and intrusive rock to skarn, it is necessary to compare the composition of the rocks before and after metasomatism. Comparison of table 2, which includes analyses of several of the more common types of skarn, with the analyses of limestone and leucogranite porphyry shown in table 1, shows that to form skarn from limestone without change of volume, large amounts of calcium oxide and carbon dioxide must be removed and large amounts of silicon, iron, and aluminum oxides, in decreasing order of abundance, must be added. On the other hand, the principal changes that would be necessary to transform the intrusive rocks to skarn would be the substitution of calcium and a little iron for part of the intrusive rock, principally silica.

The proximity of all the skarn to intrusive rocks suggests that the material which was added to the limestone to form the skarn was related to and may have come from the intrusive rocks or the magma from which they were derived. Furthermore, the fact that all the larger masses of skarn are near leucogranite porphyry suggests that the leucogranite porphyry may have provided more material than the other intrusive rocks. Because all the intrusive rocks seem to be related, a comparison between the composition of the leucogranite porphyry and the other intrusive rocks, especially the Mackay Granite, which is believed to be older than the leucogranite porphyry, might indcate whether or not the leucogranite or the magma from which it was derived has lost any significant amount of material. Inspection of the analyses, table 1, and of the variation diagram, figure 2, does not

TABLE 2.—*Chemical analyses of common types of skarn*

[From Umpleby (1917, p. 63–64). Analysts: Chase Palmer, 7, 8, 6; T. T. Read, 12, 13; Cyril Knight, 9]

	7 Normal massive garnet	12 Massive garnet	8 Dark-amber garnet, distinct crystals	9 Light-amber garnet	6 Massive pyroxene rock	13 Dark pyroxene rock
SiO_2	36. 92	37. 79	36. 57	37. 07	51. 55	45. 85
Al_2O_3	8. 75	11. 97	7. 56	17. 42	4. 00	12. 21
Fe_2O_3	16. 85	15. 77	20. 34	10. 81	1. 02	2. 15
FeO	. 50	1. 31	1. 24	. 68	6. 65	2. 49
MgO	. 17	. 37	2. 10	. 51	11. 38	8. 70
CaO	33. 71	32. 57	30. 20	32. 77	24. 33	28. 54
Na_2O	. 31				. 38	
K_2O	. 31				. 18	
H_2O+	. 39		. 54	. 39	. 25	
H_2O-	. 21	. 09	. 30	. 14	. 14	
TiO_2	. 26		. 20		. 32	
P_2O_5	. 30		. 23		. 24	
MnO	. 67	. 31	. 60		. 30	
CO_2	. 95					
Total	100. 20	100. 18	99. 88	99. 79	100. 64	99. 94

reveal any systematic impoverishment of the leucogranite porphyry in the three principal elements needed to convert limestone to skarn. It may be significant that the leucogranite porphyry contains somewhat less silicon and iron than the Mackay Granite. Aluminum, which is the third element that is needed to convert limestone to skarn, however, is more abundant in the leucogranite porphyry than in the Mackay Granite.

The texture of the diopside in the leucogranite porphyry also suggests that some of the constituent that makes up the skarn may have come from the leucogranite porphyry. As already noted, diopside is the only mafic mineral that we observed in any appreciable quantity in the leucogranite porphyry, and it occurs as skeletal crystals and aggregates of grains, which seem to be relicts of some other mafic minerals, perhaps biotite and hornblende. Alteration of biotite and hornblende to diopside would result in release of aluminum, iron, and perhaps some magnesium, which might then be available to combine with limestone to form skarn. We have found no variation in composition within the leucogranite porphyry however, that could be attributed to differential loss of material from that rock.

Alternatively, the nearness of all the thick skarn to the contact between the leucogranite porphyry and the limestone suggests that this contact may have served as an avenue for movement of fluids that carried material to and from the rocks to form skarn. That this contact is a complex surface that encompasses roof pendants and engulfed

blocks of limestone leads us to believe that introduction and removal of material from the rocks along the contact by transient fluids was probably less important than exchange of material across the contact.

JASPEROID

The jasperoid consists of somewhat ferruginous fine-grained quartz, which is commonly brecciated and recemented with fine-grained quartz.

All the larger masses of jasperoid in the area occur along the contact between limestone and the Challis Volcanics, and most of the jasperoid seems to have resulted from replacement of limestone by silica-bearing material.

Most of the jasperoid occurs along faults, which were probably the avenues for the movement of the fluids that caused the jasperoidization. The origin of the silica in these fluids is not clear; it probably came from igneous rocks, but whether these rocks were intrusive or extrusive, and whether the silica was derived from the igneous rocks prior to, during, or even after the rocks had solidified cannot be determined in most places.

Jasperoid a few feet thick is common where the Challis Volcanics has been deposited on limestone, and this jasperoid seems clearly to have been formed by silicification of limestone by fluids from the overlying volcanic rocks. The resulting jasperoid is somewhat more resistant to erosion than the enclosing rocks, and it commonly remains for some time after the overlying volcanic rocks have been eroded away. The jasperoid that is shown on plate 1 in the SE¼ sec. 19, and some of it in sec. 30, T. 7 N., R. 24 E., probably were formed in this manner. Some of the jasperoid elsewhere in sec. 19, T. 7 N., R. 24 E., sec. 31, T. 7 N., R. 24 E., and sec. 24, T. 7 N., R. 23 E., may have also been formed in this way.

SURFICIAL DEPOSITS

GLACIAL DEPOSITS

Patches of boulders and gravel, including fragments of Mackay Granite, occur on two ridges of volcanic rock in the southeastern part of the area These deposits, mapped as older glacial deposits on plate 1, seem to be material that was transported by glaciers or glacial streams that were related to topography that subsequently has been considerably modified.

During the latter part of Pleistocene time the mountains in and near the area of this report were occupied by alpine glaciers, which sculptured the cirques now prominent in the mountains. Deposits of

sand, gravel, and silt that are only slightly modified and that are probably of Wisconsin age, designated younger glacial deposits on plate 1, are found in many of the cirques and along many of the streams in the area.

ALLUVIUM

Alluvium of two ages is present in the area shown on plate 1. The older is more extensive and occurs as fans which have been locally dissected by the present streams. The younger is confined to the flood plains along streams.

STRUCTURE

The Paleozoic rocks are rather tightly folded in folds with axes which have a general northwesterly trend. The limestone is locally folded in an intricate and nonsystematic manner, which is characteristic of limestones. Ross (1947, p. 1129–1132) has described these folds in nearby areas, and little discussion is warranted here. Section A–A′, plate 1, illustrates some of the larger folds that occur in the Paleozoic rocks.

The Challis Volcanics lie on a major unconformity on the Paleozoic rocks and are folded in gentle nonsystematic undulations.

The geologic map, plate 1, shows two lines which are believed to be due to faulting; both are near boundaries between the Challis Volcanics and Paleozoic rocks, mostly limestone; one trends north-northeastward along the eastern edge of the area, and the other trends northeastward through the northwestern part of the area.

The presence of jasperoid, especially of brecciated jasperoid, along the first of these lines is strong evidence of faulting, although some of the jasperoid along this line may be due to silicification of limestone caused by fluids from volcanic rocks that once overlay the limestone.

The evidence for faulting along the second line consists almost solely of the straightness of the escarpment near the line. It seems likely that this escarpment has retreated southward from the fault, and that some of the uppermost volcanic rocks here have been deposited across the fault subsequent to most, if not all, of the movement on the fault.

Movement on both these faults probably began before or early during the eruption of the Challis Volcanics and may have continued after the volcanic rocks had been extruded.

The dike zone which trends northeastward through the area is evidence of fracturing and perhaps faulting. The fractures in this zone must have developed between the time of emplacement of the Mackay Granite and the time of emplacement of the dikes.

ORE DEPOSITS

Virtually all the mineralization in the Alder Creek mining district is intimately associated with metamorphic rocks, especially skarn, which in turn are confined to contacts between limestone and intrusive rocks. As previously noted, all the thicker masses of skarn seem to be associated with leucogranite porphyry. Nearly 50 properties, mostly on separate lodes, have been worked at one time or another, but most of the production has come from the Empire, Horseshoe, White Knob, Blue Bird, and Champion mines, especially the Empire, which is a copper mine. The Horseshoe and some of the other relatively small mines in the area were developed mainly for their lead-silver content. The map, plate 1, shows the location of the major mines in the district, but it does not adequately indicate the extent to which the hillsides are peppered with prospects, adits, shafts, and pits.

The Empire mine has open-pit and underground workings in a north-trending arcuate zone (Farwell and Full, 1944, p. 12) about 3,500 feet long and as much as 400 feet wide. The horizontal workings have an aggregate length of more than 60,000 feet on more than nine levels, scattered through a vertical range of over 1,500 feet. The lowest exploration is in the 1,600-foot level, or Cossack tunnel, at about 7,010 feet above sea level. The main part of the mine is at the 700-foot level, which is also the longest level. Most of the ore so far mined came from stopes above this level through a vertical range of roughly 500 feet, but ore was mined long ago from stopes extending 300 feet below the 700–foot level.

In 1956 an adit, corresponding approximately to the 1,100–foot level, was driven more than 1,500 feet; during the drilling of this adit, a sulphide ore body was discovered. Exploration has continued intermittenly since then, and in 1960 ore was reported to have been shipped from this adit. In 1961 a mill was constructed at the portal. Sections *B–B′* and *C–C′*, plate 1, indicate the extent of the workings of the Empire mine. Section *B–B′* passes lengthwise through the most intensively developed part of the mine, and section *C–C′* extends across this part of the mine. As previously noted, the control for these cross sections came from detailed maps and cross section of the Empire mine by Farwell and Full. More information on the location of the workings and rocks of the mine can be found in the report of Farwell and Full (1944).

The main haulageways in the Empire mine parallel a segment of the arc within which nearly all the productive mines occur. Most of the ore stopes occur along crosscuts which are approximately radial to the haulageways. These crosscuts follow zones of shearing which cut both the igneous rock and the skarn. These zones, according to Mr. Ray

Webber, who was long the manager of the mine, have proved to be of much value as guides to ore. Many dikes are approximately parallel to this shearing. In most of the stopes visited during an inspection in 1929 (Ross, 1930), the ore was seen to be bounded by fairly definite walls along which there were indications of movement. Some of these walls corresponded to bedding, others to faults.

Valuable concentrations of ore minerals in the Empire mine occur as irregular pipelike bodies (Farwell and Full, 1944, p. 10) that are commonly elliptical in plan, with their long axes in various attitudes but usually steeply plunging. The major axes of the elliptical cross-sections are 15–200 feet long, and the short axes are 5–55 feet long. One pipe has been mined almost continuously through a vertical distance of 600 feet, but most are less persistent. Most pipes pitch northeast, east, or southeast in a direction nearly at right angles to their strikes. Some branch upward; a few downward. A few, mostly at the contact between skarn and marble, are tabular. The ore bodies commonly occur along the contact between skarn and limestone; some are entirely within skarn; and others are at the contact between skarn and instrusive rocks. According to Farwell and Full (1944, p. 13) the ore-bearing skarn is commonly coarser grained and contains more calcite than does the skarn without valuable concentrations of ore minerals. They concluded from this that calcite-rich portions of the skarn were favorable sites for ore deposition. They noted that the concentration of ore minerals diminishes gradually into barren skarn but ends abruptly where the ore-bearing skarn is in contact with limestone.

Chalcopyrite is the principal hypogene mineral in the Empire mine and pyrite, pyrrhotite, calcite, quartz, magnetite, fluorite, scheelite, molybdenite, sphalerite, specularite, and rare bornite are less widely distributed (Farwell and Full, 1944, p. 11). Chrysocolla, accompanied by malachite, tenorite, azurite, and sparse copper sulfate minerals, is the supergene mineral of principal economic importance.

The relative distribution of supergene and hypogene minerals is erratic and not well known. Unoxidized sulfides remain within 50 feet of the surface in a few places, but oxidized ore minerals have been found along sheared zones as deep as the 1,000-foot level although they are more common above the 600-foot level. The Empire mine is developed in a steep mountainside that has over 2,000 feet of local relief, and the mine lies entirely above the foot of the mountain. Throughout this mine, oxidation has occurred wherever the rock has been suitably sheared, but no stable zone seems to have been established wherein secondary enrichment could take place. Only trivial amounts of chalcocite and covellite have been noted.

Umpleby (1917, p. 45–49) gave descriptions and sketches of ore bodies that were accessible to him. The sketches, especially, suggest that the ore bodies are localized and their form influenced by faults and joints. Faults are not shown on Farwell and Full's (1944) surface maps nor on plate 1 of the present report. They are, however, shown on Farwell and Full's underground maps, but everywhere without displacement irrespective of the rocks traversed by the faults. Farwell and Full take cognizance of this fact by noting that displacement along these faults seems to be small. Faults trending northeastward and dipping southeastward are said to persist from level to level, and they are marked by gouge consisting of decomposed intrusive rock, clay, and limonite with some calcite, pyrite, and crushed garnet in zones 2 inches to 6 feet in width (Farwell and Full, 1944, p. 12–14). Some dikes seem to have been intruded after the ore bodies were formed.

Kiilsgaard (in U.S. Geological Survey, 1962) found that in the lower levels of the Empire mine, steeply plunging, irregular, pipelike bodies of primary ore formed where northeast-trending premineralization faults cut the skarn. He reasoned that jointed and fractured skarn was more permeable to mineralizing solutions ascending along the faults than were the limestones and intrusive rocks. Kiilsgaard's conclusions, in part, support the earlier conclusions of Umpleby (1917, p. 45–49) and those of Ross (1930, p. 15, 17), which are less clearly expressed in Ross' brief early paper than in the present report. These conclusions imply that the ore deposition was later than the formation of the skarn, even though there probably is a genetic relationship. This suggests that the ore may persist to a greater depth than might otherwise be possible.

Much of the contact zone between the leucogranite porphyry and limestone has not been located and explored. We suggest that locating this contact zone and searching along it for skarn, followed by systematic exploration of any skarn discovered is likely to reveal additional ore, Farwell and Full (1944, p. 44) made similar recommendations and, in addition, suggested that further exploration of known skarn bodies may locate additional ore and that undiscovered masses of skarn may occur within the leucogranite porphyry wherever it has not been explored.

The mineral deposits on either side of the Empire mine differ in several respects from those in that mine. The Champion mine, at the southern end of the arc delineated by mines, is mostly in limestone, but the workings extend into granitic rock. Some skarn is present in the area, but that reported by Umpleby (1917, p. 101–102) is roughly 1,500 feet from the main workings, which are reached through west-

trending adits. There are various small dikes on the property. Apparently most of the lead ore so far found came from one or more crushed or sheared zones in limestone, presumably of westerly trend. The Grand Prize, White Knob, and Blue Bird properties appear to have been worked mainly for lead, but little information about them is on record.

The Horseshoe mine has been explored on six levels, of which the deepest is the 350-foot level. When visited in 1929 (Ross, 1930, p. 15–16), most of the stopes were filled and the lower levels were full of water. Apparently little has been done since that time. The principal workings trend about N. 30° W., and the main ore bodies are along these workings instead of at large angles to them as in the Empire mine. Some of the numerous minor mineralized slips at various angles to the main ore bodies are approximately perpendicular to the general trend; their direction corresponds to the radiate shearing in the Empire mine. Ore deposition has been effected mainly by replacement rather than by fissure fillings, but the shearing that preceded the mineralization was stronger than that found in the Empire mine and was concentrated mainly along the arcuate trend of the district rather than on radial lines. Furthermore, much of the limestone country rock has been recrystallized to marble rather than converted to skarn. Shipments from this mine have been mainly of lead carbonate ore although bodies of sulfide containing pyrite, sphalerite (or more properly marmatite), galena, and chalcopyrite are known. The high iron content of the sphalerite makes it difficult to market. Oxidized material extends below the 200-foot level although there is some sulfide above this level. Most of the production has come from above the 100-foot level.

Several of the lodes in this part of the district contain tungsten (Cook, 1956, p. 27–29). These include the Empire mine, the Phoenix property near the head of Mammoth Canyon in which powellite and scheelite occur in skarn, the Vaught property close to Cliff Creek on which these same two minerals have been found, the Hanni mine near the head of Cliff Creek from which 11 tons of ore assaying 1.60 percent WO_3 were shipped in November 1953, and the Copper Queen workings at the head of the East Fork of Navarro Creek where scheelite has been reported to occur in skarn.

PRODUCTION

Prospecting was carried on in the Alder Creek mining district in the early 1880's, and the first recorded production from the Empire mine was in 1902, although some ore probably was mined earlier. The

Empire mine produced continuously from 1902 through 1930, first under the White Knob Copper Co., and later under the Empire Copper Co., the Idaho Metals Co., the Mackay Metals Co. (Ross, 1930, p. 8–9), the Mackay Exploration Co., and finally, the Lost River Mines Inc. Umpleby (1917, p. 94) estimated the production through 1913 at $2,500,000, mainly in copper, and Ross (1930, p. 8–9) presented production figures from the beginning of 1914 through April 1929 that total over $6,000,000 in large part from leasing operations. Table 3 gives production figures for the period from 1901 through 1942. These records, which were obtained by Farwell and Full (1944, p. 5) from the Metal Economics Division of the Bureau of Mines, are, except for a few years, larger than those which Ross (1930, p. 8–9) obtained from the Mackay Metals Co., and presumably they include production not on record in the company files. Figures on production subsequent to 1942 are not readily available.

Much of the ore shipped from the Empire mine was oxidized material that could not be concentrated by methods then available; this ore is reported to have contained 4–5 percent copper. In addition, concentrates of sulfide ore averaging about half this amount of copper were shipped (Ross, 1930, p. 15). Some early shipments were sulfide ore containing as much as 6 percent copper (Umpleby, 1917, p. 49). At least one carload of tungsten ore containing 2.08 percent WO_3 was shipped from below the 1,000-foot level of the Empire in 1942 (Farwell and Full, 1944, p. 1, 11). During the most active part of the history of the Empire, only fairly rich copper ore or material easily concentrated by gravity methods could be profitably mined, even though a mill and smelter were built at that time. Presumably much copper-bearing material that could be profitably mined and processed, using more modern techniques, remains in the mine. Some may be already mined and on the dumps.

Production from the Horseshoe mine from 1916 through 1928, as presented by Farwell and Full (1944, p. 6), is summarized in table 4. The mine closed in 1930.

The Champion mine, discovered in 1895, is estimated (J. L. Ausich, written commun., 1961) to have yielded about 4,500 tons of ore through 1960.

Other mines and prospects in the vicinity were in operation until about 1930.

TABLE 3.—*Production of recovered metals at the Empire mine, 1901–42*

These statistics have been furnished by the Metal Economics Division of the Bureau of Mines. Comparison with company records indicate that the crude ore figures include only ore shipped or smelted and not crude ore concentrated]

Year	Crude ore (dry tons)	Concentrates (dry tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)
1901	None				
1902	1, 721		14. 40	607	14, 966
1903	15, 681		240. 95	12, 658	441, 286
1904	67, 850		85.	3, 500	2, 700, 000
1905	13, 000		384. 74	22, 065	684, 134
1906	40, 838		1, 842.	71, 854	2, 807, 926
1907	37, 141	3, 430	1, 823. 33	70, 222	2, 895, 881
1908	382		15. 89	673	38, 698
1909	1, 436		27. 73	2, 236	90, 347
1910	7, 206		265. 24	28, 754	919, 492
1911	11, 057		663.	40, 900	1, 415, 314
1912	26, 227		1, 766.	69, 942	2, 854, 281
1913	35, 950		1, 891. 61	106, 463	3, 962, 125
1914	17, 801		970. 99	59, 243	2, 106, 441
1915	54, 295		3, 155. 06	125, 134	4, 702, 119
1916	69, 907		2, 874. 60	123, 453	5, 006, 291
1917	66, 808		2, 530.	74, 645	4, 208, 401
1918	53, 211		2, 476. 41	56, 014	3, 404, 161
1919	12, 904		672. 80	31, 833	1, 300, 518
1920	15, 755		1, 369.	29, 888	1, 480, 678
1921	9, 992		1, 236.	23, 354	1, 088, 148
1922	16, 717		2, 019.	33, 988	1, 843, 200
1923	15, 791		1, 458.	25, 908	1, 449, 838
1924	11, 775	319	1, 244. 92	18, 808	1, 137, 771
1925	29, 753	4, 760	2, 096. 43	35, 439	2, 352, 306
1926	3, 635	255	234. 38	6, 453	239, 785
1927	13, 627	1, 297	761. 22	9, 734	684, 154
1928	11, 532	1, 053	495.	9, 776	514, 697
1929	66, 573	4, 273	2, 282. 45	60, 883	2, 824, 032
1930	26, 214	2, 379	754. 51	22, 925	1, 121, 586
1931	None				
1932	None				
1933	None				
1934	None				
1935	190		10. 10	1, 510	26, 518
1936	173		8. 83	639	18, 897
1937	22		1. 00	306	3, 876
1938	None				
1939	996		207.	2, 465	175, 940
1940	4, 484		526.	11, 300	632, 217
1941	3, 169		381.	7, 013	380, 469
1942	1, 274		141.	1, 874	104, 000
Total [1]	765, 087	17, 766	36, 925. 59	1, 202, 459	55, 630, 493

[1] In addition a small tonnage of tungsten ore has been produced.

TABLE 4.—*Production of the Horseshoe mine, 1916–28*

[From records of the U.S. Bureau of Mines]

Year	Crude ore (tons)	Concentrates (tons)	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
1916	196		0.88	1,468	3,093	55,587	
1917	1,462		6.99	17,293	2,997	678,074	
1918	1,087		8.64	11,440	1,522	446,628	
1919	1,128		4.76	12,011	2,333	361,937	
1920	2,319		5.96	21,165	2,021	386,352	
1921	116		2.25	1,811	376	55,902	
1922	651		7.61	9,297	902	246,659	
1923	660		6.98	5,014	1,603	169,872	
1924	79		4.33	1,012	287	36,538	
1925	75		1.50	1,776	348	59,310	
1926	865	32	11.72	10,236	3,198	332,597	18,942
1927	182	53	1.52	2,275	495	58,256	18,163
1928	49	5	.43	123	1,159	791	2,366
Total	8,869	90	63.57	94,917	20,334	2,888,503	39,471

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