Reconnaissance Petrographic Cross Section of the Idaho Batholith in Adams and Valley Counties Idaho

By DWIGHT L. SCHMIDT

CONTRIBUTIONS TO GENERAL GEOLOGY

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RECONNAISSANCE PETROGRAPHIC CROSS SECTION OF THE IDAHO BATHOLITH IN ADAMS AND VALLEY COUNTIES, IDAHO

By Dwight L. Schmidt

ABSTRACT

The rocks of the west-central part of the Idaho batholith grade in structure and composition from highly foliated metasedimentary rocks and migmatitic gneisses on the western border to directionless granitic rocks in the interior. Along a 35-mile section, from west to east, across the western half of the batholith in the latitude of McCall and Donnelly, Idaho, five gradational belts have been recognized: fine-grained migmatitic gneisses and biotite-quartz schists (2-mile width exposed from under a continuous cover of basalt to the west); leucocratic quartz dioritic migmatite (2 to 10 miles wide); quartz dioritic gneiss (6 miles); leucocratic quartz diorite (6 miles); granodiorite (7 miles) and quartz monzonite (more than 12 miles).

Minerals vary systematically across the gradational belts: potassium feldspar, essentially zero to a few percent in the migmatite and quartz dioritic gneiss, increases to nearly 30 percent in the quartz monzonite core area of the batholith; the anorthite content of the plagioclase, averaging An_{30} in the migmatite, increases to An_{40} in the quartz dioritic gneiss and subsequently decreases to An_{25} in the quartz monzonite core area; biotite averages 6 percent in the migmatite, 15 percent in the quartz dioritic gneiss, and decreases eastward to 3 percent in the quartz monzonite; hornblende, averaging as much as 10 percent in the more mafic rock in the quartz dioritic gneiss, decreases both westward and eastward within the quartz dioritic gneiss belt almost to zero. Various combinations of sphene, allanite, epidote, and magnetite characterize the migmatite and quartz dioritic gneiss, whereas various combinations of ilmenite, magnetite, and monazite characterize the granodiorite and quartz monzonite.

The metamorphic grade in the fine-grained gneiss and schist belt is that of the kyanite zone. The sillimanite isograd occurs in the migmatite. An eastward increase in metamorphic grade within the sillimanite zone can be traced into the westernmost part of the granodiorite belt by critical mineral assemblages in relict inclusions of schist and calc-silicate granofels. Inclusions are abundant in the migmatite, but decrease to zero in the granodiorite. Mineral assemblages containing bytownite, spinel, and forsterite typify the highest metamorphic grade.

The schists, gneisses, and migmatites of the border of the batholith were produced by regional synkinematic metamorphism and in part by sodium metasomatism. The process of emplacement of the batholith is not fully understood. Much of the evidence bearing on the origin of the batholith is obscured by endomorphism which caused recrystallization of quartz and potassium feldspar and adjustment of plagioclase under regional postemplacement conditions.

INTRODUCTION

Tracing the source of monazite (thorium-bearing, cerium-earths phosphate) and euxenite (uranium-bearing, yttrium-earths niobate-titanate) in economic placer deposits in Valley County, Idaho, during the summers of 1952 and 1953 made it evident that they are accessory minerals in the granitic rocks of the Idaho batholith. These and other associated heavy minerals, such as magnetite, ilmenite, sphene, and allanite, are distributed in the bedrock in definite zones roughly paralleling the major structural features of the batholith; at Cascade, for example, the zones parallel the west border and foliation trend. A reconnaissance petographic study was undertaken to clarify the relationship of the radioactive heavy minerals to the structure and rock composition of the batholith, and to investigate the ultimate origin of these minerals. The study is a byproduct of an investigation of placer deposits containing radioactive minerals conducted by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission (Mackin and Schmidt, 1956).

This paper describes the granitic rocks of a part of the Idaho batholith in west-central Idaho (fig. 1). Most of the material presented here was originally set forth in greater detail in an earlier report (Schmidt, 1958).

GEOLOGIC SETTING

The oldest rocks in the area studied in Adams and Valley Counties are metasedimentary rocks consisting of biotite schists and minor associated calc-silicate granofels (Goldsmith, 1959). Similar rocks in the Yellow Pine district in the northeastern corner of Valley County are generally referred to the Belt Series (Precambrian), and regarded as roof pendants in the batholith (Ross, 1933, p. 376; White, 1940, p. 252). Younger rocks consisting of a series of metavolcanic and metasedimentary rocks of Permian, Triassic, and Jurassic(?) ages occur west, northwest, and northeast of the area studied but not within it (Livingston, 1925; Kirkham, 1931, p. 565; Ross, 1934b, p. 28; Wagner, 1945, p. 4–5; Anderson and Wagner, 1952, p. 5–6; Mackin, 1953, p. 124–126; Hamilton, 1953; Cook, 1954, p. 3; Leonard, 1957).

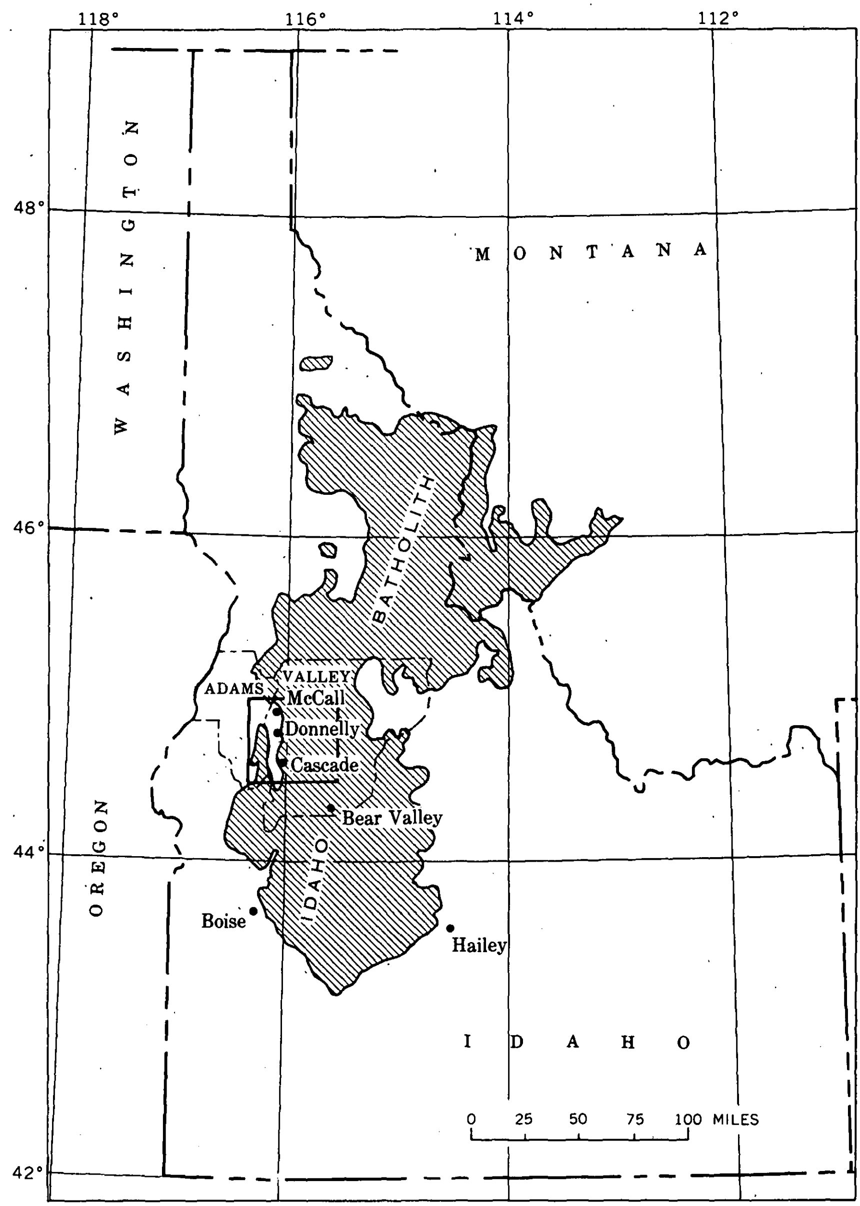

FIGURE 1.—Index map of Idaho showing area studied in Adams and Valley Counties.

The granitic rocks of the batholith have been variously considered to range in age from Jurassic to Paleocene (Ross, 1928, p. 692; Anderson, 1952, p. 261–263). Lead-alpha age determinations made on zircon from 16 rocks ranging from tonalite to muscovite quartz monzonite indicate an early Late Cretaceous age, 108 ± 12 million years for the batholith as a whole (Larsen and others, 1958, p. 51). Four lead-alpha ages made on rocks collected near the area of this study suggest a decreasing age from the quartz diorite to quartz monzonite, but the error of the individual determinations is too large to support any positive conclusion.

Brief local descriptions of the batholithic rocks can be found in many geologic reports describing the many mining districts in the Idaho batholith. In addition, A. L. Anderson and C. P. Ross have discussed the origin of the batholith (Anderson, 1942; Anderson and Wagner, 1952; Ross, 1928, 1933). Anderson (1942, p. 1103) states that in general a quartz dioritic marginal zone encloses a granodioritic-quartz monzonitic interior zone. Locally the marginal rock facies is said to be only a few hundred feet wide but in most places it is a few thousand feet to several miles wide and may constitute half the mass of the batholith. He states that, "because of lack of systematic mapping it is not feasible to show distribution" of the two rock zones. In contrast to Anderson's zones, Larsen and R. G. Schmidt (1958, p. 3) consider the batholith to be made up of individual bodies of granitic rock; they consider the southern half of the batholith with which this paper is concerned, to be "made up of a few huge bodies" of granodioritic and quartz monzonitic rock.

The regionally significant northward-trending "quartz diorite line" (Moore, 1959, p. 199), which systematically divides the Mesozoic batholiths in western United States into western quartz dioritic parts and eastern granodioritic-quartz monzonitic parts, is well defined in the Idaho batholith in Valley County.

A swarm of andesitic to rhyolitic porphyry dikes, making up the Boise Basin porphyry belt and extending northeastward through Bear Valley, intruded the batholith probably during early Miocene (Ross, 1934a, p. 242–249; 1934b, p. 54–68; Anderson, 1947, p. 139–151). The dikes do not cut the batholith in the vicinity of the McCall-Donnelly cross section; they occur south and southeast of the area considered in this report.

Miocene and Pliocene (?) Columbia River Basalt overlies eroded border rocks of the batholith along the entire western boundary of Valley County. The basalt is moderately tilted westward in fault blocks. Several basalt remnants, downfaulted into granitic rocks well inside the batholith, are part of a formerly more extensive cover of basalt (Capps, 1941, p. 5; Anderson, 1941, p. 215).

Quaternary alluvium covers about 10 percent of the area studied in Valley County. Its deposition was controlled in part by block faulting and in part by glacial processes. The placer deposits containing the radioactive minerals monazite and euxenite occur in small parts of the alluvium. The U.S. Bureau of Mines has determined the grade, yardage, and reserves of many deposits (summarized in Eilertson and Lamb, 1956).

METHODS

From several hundred specimens collected over an area of 2,500 square miles, thin sections were made of 50 samples of metasedimentary rock and of 75 samples of granitic rock. About 200 polished thick slices, stained with sodium cobaltinitrite (Gabriel and Cox, 1929), were prepared of the gneissose and directionless granitic rock. Each specimen collected probably is representative of the bedrock at the outcrop from which it came, but it should be recognized that the density of sampling is low, and that the study is of a reconnaissance nature.

Point-count modes were made on 45 polished and stained thick slices of the gneissose and directionless granitic rock samples from the area. The counts were made under a binocular microscope using a mechanical stage and denominator. The grain-size of the granitic rocks is between 30 to 40 on Chayes' *IC* scale which is the "number of major identity changes along a unit length of line" (40 mm) (Chayes, 1956, p. 72).

Using Chayes' precision standard for "reconnaissance work" (p. 84), a minimum area of 2 square inches was counted for each sample. The accuracy of the modal determinations does not warrant recalculation of the modes to weight percentages; that is, the variance and error in the modal analysis is at least several times greater than the conversion factor for changing volume percent to weight percent.

The anorthite content of the plagioclase was determined in each thin section by measuring the extinction angles of several carefully chosen albite-twinned grains in which 100 and 001 were very nearly perpendicular to the section (Goranson curves).

In order to show graphically the fully gradational nature of the granitic rocks across the batholith, the Larsen triangular diagram (Larsen, 1938) as modified by Robertson (1952, p. 37) is used. In this ternary diagram, two sets of coordinates are plotted from the three corners of an equilateral triangle, so that one set is defined by the total mafic, total quartz, and total feldspar (M–Q–F) content and the other by the albite, anorthite, and potassium feldspar (Ab–An–Kf) content. The resulting M–Q–F and Ab–An–Kf points on the diagram when joined by a line become a symbol representing a given rock mode. (See the explanation, pl. 2.)

The subdivision of the granitic rock sequence in Valley County into units or zones, which grade continuously from quartz diorite to quartz monzonite, is in part arbitrary depending upon the classification used. The Brown classification (Brown, 1952) has been used in this report because, in general, it provides a more equal division of common natural occurrences of granitic rock. Figure 2 shows the distribution of quartz diorite, granodiorite, quartz monzonite, and granite, as defined by the Brown classification on the Ab–An–Kf part of the Larsen-Robertson diagram. By definition, these rocks must have more than 10 percent quartz and more than 10 percent mafic minerals when the plagioclase composition is between An_{10} and An_{30}. The granodiorite and quartz monzonite contain less than 10 percent biotite, but for the sake of simplicity the adjective "leucocratic" has been omitted from the rock name.

The division between quartz diorite and granodiorite in the Brown classification differs essentially from that in the Johannsen classification in that Brown uses An_{30} to divide quartz diorite and granodiorite whereas Johannsen (1939, p. 156) uses 5 percent potassium feldspar as the division line.

Although the distribution of monazite in the granitic rocks in Valley County bears directly on the placer study, the distribution and petrographic relations of all the accessory minerals have been studied for their contribution to the petrogenesis of the granitic rock. The quantities of accessory minerals are not satisfactorily determined by modal count because too few grains occur in each thin section. In a few specimens the accessory minerals were quantitatively determined in bromoform cuts of crushed specimens, but most of the accessory mineral abundances and distributions are generalized from heavy-mineral analyses of pan samples of the naturally disintegrated granitic rocks.

ACKNOWLEDGMENTS

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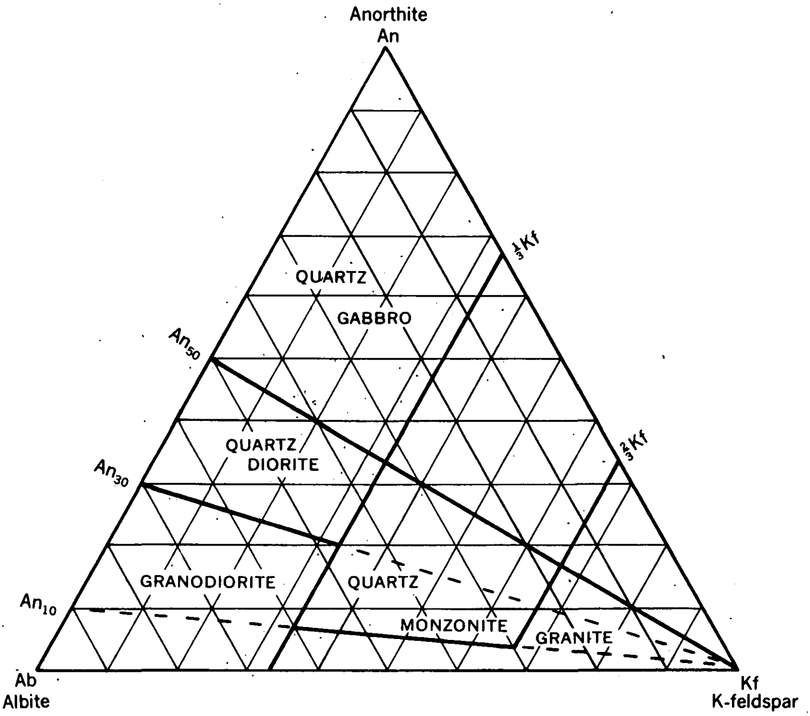

FIGURE 2.—Assignment of rock names on an Ab–An–Kf ternary diagram according to the Brown (1952) classification of igneous rocks. Rocks should contain more than 10 percent quartz.

MAJOR ROCK ZONES

From west to east across the border and interior of the Idaho batholith, the bedrock systematically and gradationally changes from schist and gneiss to directionless granitic rock. For convenience of discussion, the area in Adams and Valley Counties is divided into six major rock zones (pls. 1 and 2) each characterized by a principal rock type, but the change between zones is so gradational that the contacts drawn between the six zones on the map and sections are necessarily arbitrary. Each zone is referred to by its principal rock type and a geographic locality where the rock is typically exposed.

The six major rock zones are the gneiss of Council Mountain, the migmatite of McCall, the quartz dioritic gneiss of Donnelly, the leucocratic quartz diorite of Little Valley, the granodiorite of Gold Fork, and the quartz monzonite of Warm Lake. In this paper the three westernmost zones consisting of migmatite and gneisses are arbitrarily considered part of the border of the batholith and the three inner zones of directionless rocks are considered part of the batholith (pl. 2).

Typical rocks of the three border zones are easily distinguished from each other and from the directionless rocks in the inner zones, but distinction between the directionless rocks of the three inner zones is more difficult. Use of modal analyses, plagioclase composition, textures and structures, and accessory minerals alleviates any doubt as to the classification of any rock. In figure 3 polished thick slices, representing five of the rock types, can be compared with each other.

The modes of individual rocks are given in table 1 and are plotted on Larsen-Robertson ternary diagrams along the cross section in plate 2. In the diagrams the continuous variation of position and orientation of the plotted modal symbols from rocks of one zone to those of another clearly demonstrates the actual natural variations in composition of the different rock units from zone to zone across the batholith. The average modes of the analyzed rocks of each zone are tabulated in table 2 and are plotted on a ternary diagram in figure 4.

The strongly foliated rocks of the border grade into essentially directionless granular rocks inside the batholith. The foliation parallels the border and trends north to northeast with a generally vertical dip. Deviations of as much as 45° in both strike and dip are common whereas deviations in strike as large as 90° are rare (pl. 1).

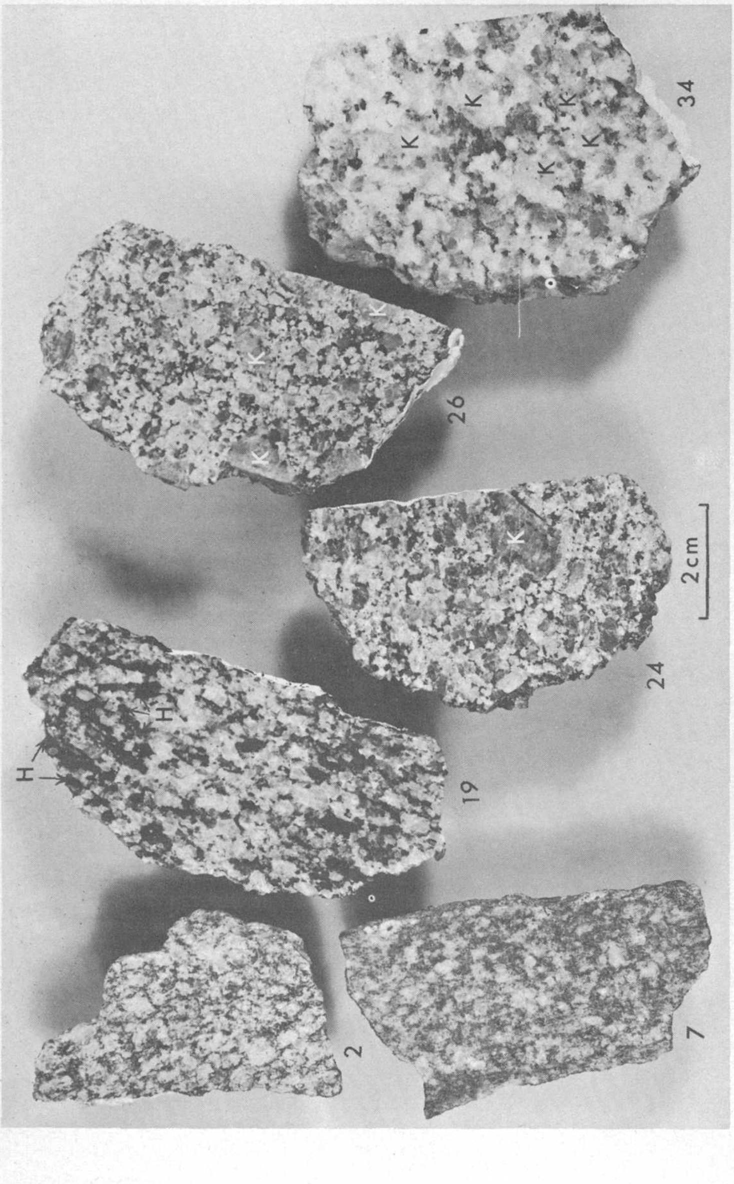

FIGURE 3.—Polished thick slices from the gradational rock sequence across the Idaho batholith; in natural order from border (left) to core (right); migmatite of McCall (samples 2 and 7), quartz dioritic gneiss of Donnelly (19), leucocratic quartz diorite of Little Valley (24), granodiorite of Gold Fork (26), quartz monzonite of Warm Lake (34). Numbers refer to sample numbers used on plate 2. *K*, potassium feldspar, *h*, green hornblende. Natural scale.

TABLE 1.—*Modal analyses, An content of plagioclase, and coordinates for ternary diagrams*

[M, mafics; Q, quartz; F, feldspars; Ab, albite; An, anorthite; Kf, potassium feldspar; Pl, plagioclase. Values in parentheses are estimated. Leaders mean that mineral is not reported]

	Migmatite of McCall															Quartz dioritic gneiss of Donnelly					
	Typical					Atypical						Atypical Brundage Mountain suite				Typical					
	2	5	6	7	8	1	3	4	9	12a	12b	10	11a	11b	11c	14	16	17	18	19	20
Quartz	26	34	31	23	30	19	16	22	41	25	23	34	31	31	25	26	23	28	29	24	23
Potassium feldspar	9.5	5.7	1.5	.4	2.0	0	16	.2	4.7	24	.005	20	23	21	28	.3	.1	1.1	------	2	2.7
Plagioclase	60	50	60	68	58	61	60	54	49	45	51	41	43	45	42	57	54	52	47	49	54
Biotite	3.8	10	7.0	7.7	8.7	12	8	24	3.7	4.7	25	5.3	3.6	3.8	5.1	17	15	16	23	15	13
Hornblende	------	------	------	------	------	4.7	------	------	------	------	.3	------	------		.005?	.1	7.2	4.1	.7	10	5.9
Epidote	------	------	------	------	------	3.3	------	------	------	------	------	------	------	------	------	------	.05	------	------	------	.4
Allanite	.1	.1	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Sphene	.2	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	.3
Opaque blacks	.4	.1	.4	1.0	.2	.2	.3	.1	.8	.3	------	------	.1	------	.2	.05	.3	.1	------	------	.2
Muscovite	------	------	------	------	.4	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Total [1]	100	100	100	100	99	100	100	100	99	99	99	100	101	101	100	100	100	101	100	100	100
An content of plagioclase (avg.)	28±	(32)	(32)	(32)	32±	?	32	?	(30)	32	33	30?	20±	20±	28?	(37)	(40)	(37)	44±	34	39
Coordinates:																					
F	70	56	62	68	60	61	76	54	54	70	51	61	65	65	70	57	55	52	47	51	57
Q	26	34	31	23	31	19	16	22	41	25	24	34	31	31	25	26	23	28	29	24	23
M	4	10	7	9	9	20	8	24	5	5	25	5	4	4	5	17	22	20	24	25	20
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ab	63	60	65	68	65	------	54	------	63	44	67	47	53	54	43	63	60	61	56	63	58
An	24	29	32	32	32	------	25	------	28	22	33	20	12	14	17	37	40	37	44	33	37
Kf	13	11	3	0	3	0	21	0	9	34	0	33	35	32	40	0	0	2	0	4	5
Total	100	100	100	100	100	0	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100
Q	27	38	33	25	33	24	17	29	43	27	31	36	32	32	26	31	30	35	38	32	29
Kf	10	7	2	0	2	0	17	0	5	26	0	21	24	22	30	0	0	1	0	3	4
Pl	63	55	65	75	65	76	66	71	52	47	69	43	44	46	44	69	70	64	62	65	67
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

	Quartz dioritic gneiss of Donnelly—Con.			Leucocratic quartz diorite of Little Valley			Granodiorite of Gold Fork						Quartz monzonite of Warm Lake					
	Atypical			Typical			Typical					Atypical	Typical					
	13	15	21	22	23	24	25	26	27	29	30	28	31	32	33	34	35	36
Quartz	36	25	24	33	32	29	36	34	34	34	39	31	32	32	30	37	30	33
Potassium feldspar	7.7	16	.1	11	17	14	21	11	17	9.7	12	29	20	21	19	27	26	22
Plagioclase	43	46	46	43	45	46	39	47	41	46	41	35	43	40	45	30	39	39
Biotite	13	12	14	12	6.3	11	3.8	7.8	7.4	9.2	7	4.8	3.4	2.2	3.1	4.4	4.3	3.4
Hornblende	.4	.3	15															
Epidote																		
Allanite																		
Sphene				.1														
Opaque blacks	.2	1		.3	.3			.1			.1							
Muscovite				.1	.1	.4	.2	.3	.2	.2	.1	.1	1.9	4.7	2.8	1.3	.6	2.8
Total[1]	100	100	99	100	101	100	100	100	100	99	99	100	100	100	100	100	100	100
An content of plagioclase (avg.)	(35)	35	45	32	35	32		28	25	27	25		27	(25)	27±	25	(25)	25±
Coordinates:																		
F	51	62	47	54	61	60	60	58	58	57	54	64	65	66	67	59	66	64
Q	36	25	24	33	32	29	36	34	34	34	39	31	32	32	30	37	30	33
M	13	13	29	13	7	11	4	8	8	9	7	5	3	2	3	4	4	3
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Ab	55	48	55	54	47	52		59	53	59	58		48	46	49	38	44	45
An	29	26	45	26	25	25		22	18	23	20		18	15	18	13	15	16
Kf	16	26	0	20	28	23		19	29	18	22		34	39	33	49	41	39
Total	100	100	100	100	100	100		100	100	100	100		100	100	100	100	100	100
Q	41	29	34	38	34	33	37	37	37	38	42	33	34	34	32	40	32	35
Kf	9	18	0	13	18	16	22	12	18	11	13	30	21	23	20	28	27	23
Pl	50	53	66	49	48	51	41	51	45	51	45	37	45	43	48	32	41	42
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[1] Rounded to nearest whole number.

NOTE.—In the Ab, An, and Kf calculations, pure feldspars are assumed, and the weight percent is taken to be equal to the volume percent of the modal analysis because the value of the conversion factor is several times less than the measurement error.

TABLE 2.—*Average modal analyses, An content of plagioclase, and coordinates for ternary diagrams of the five rock types typifying the cross section of the Idaho batholith.*

[M, mafics; Q, quartz; F, feldspars; Ab, albite; An, anorthite; Kf, potassium feldspar; Pl, plagioclase. Leaders mean that mineral is not significant in average]

	Magmatite of McCall	Migmatite of McCall Brundage Mountain suite	Quartz dioritic gneiss of Donnelly	Leucocratic quartz diorite of Little Valley	Granodiorite of Gold Fork	Quartz monzonite of Warm Lake
	5	4	6	3	5	6
Volume percent: [1]						
Quartz	30	30	25	31	35	32
Potassium feldspar	4	23	1.5	14	13	23
Plagioclase	60	43	52	45	44	39
Biotite	6	4.5	15	10	8	3
Hornblende	------	------	6	------	------	------
Epidote	------	------	.1	------	------	------
Allanite	------	------	------	------	------	------
Sphene	------	------	.1	------	------	------
Opaque blacks	.4	.1	.2	.2	.005	------
Muscovite	------	------	------	.2	.2	2.3
Total [2]	100	101	100	100	100	99
Weight percent: [3]						
Quartz	30	30	24	30	35	32
Potassium feldspar	3.7	22	1.4	13	12	22
Plagioclase	59	43	51	44	44	39
Biotite	6.7	4.9	16	11	9	3
Hornblende	------	------	7.3	------	------	------
Epidote	------	------	.1	------	------	------
Allanite	------	------	------	------	------	------
Sphene	------	------	.1	------	------	------
Opaque blacks	.7	.2	.4	.4	------	------
Muscovite	------	------	------	.2	.2	2.7
Total [2]	100	100	100	99	100	99
An content of plagioclase (average)	30	25	38	33	26	25
Coordinates:						
F	64	66	54	59	57	64
Q	30	30	25	31	35	33
M	6	4	21	10	8	3
Total	100	100	100	100	100	100
Ab	66	49	61	51	58	48
An	28	16	37	25	19	15
Kf	6	35	2	24	23	37
Total	100	100	100	100	100	100
Q	32	31	32	34	38	34
Kf	4	24	2	16	14	24
Pl	64	45	66	50	48	42
Total	100	100	100	100	100	100

[1] Volume-percent averages are calculated directly from table 1.
[2] Rounded to nearest whole number.
[3] Weight-percent averages are calculated from volume-percent averages of this table.

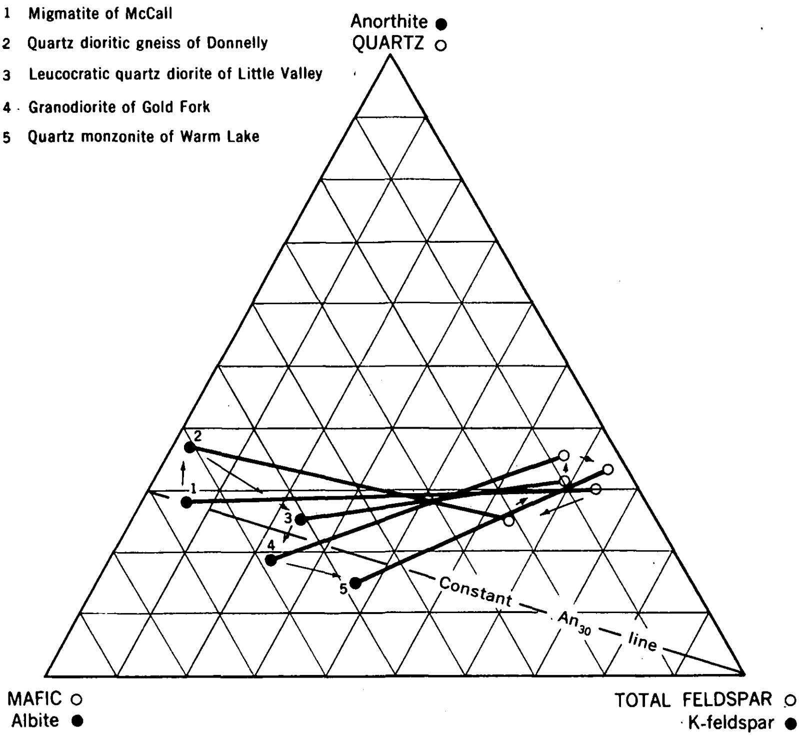

FIGURE 4.—Symbolic representation of the average mode of each of five rock types along the petrographic cross section of the Idaho batholith. Arrows indicate direction of progressive change from migmatite to quartz monzonite. Plot is on a Larsen-Robertson diagram ; modal values are given in table 2.

GNEISS OF COUNCIL MOUNTAIN

The gneiss of Council Mountain is the westernmost exposed rock; it is completely covered to the north, south, and west of the Council Mountain area by Columbia River Basalt. It consists dominantly of variously textured fine-grained biotite gneiss and in lesser abundance of layered fine-grained biotite-quartz gneiss intercalated with a variety of light-colored schists, mostly biotite-quartz-feldspar schists. Smaller amounts of heterogeneous green hornblende gneiss, layered green hornblende gneiss, and amphibolite are intercalated with the biotite gneisses and schists. Resistance to weathering allows the hornblende-rich rocks to be conspicuous in weathered outcrops, soils, and local gravels. Minor amounts of pegmatite, commonly muscovite and garnet bearing, generally occur as layers parallel to the foliation planes (Fryklund, 1951, p. 8–10).

The predominant trend of the structure is north, commonly varying as much as 20° either east or west of north and commonly dipping 70°

712–191 O—64——3

to 90° east, but deviations in strike to as much as N. 45° E. and in dip to 45° maximum, generally east, do occur. In many places the gneisses are schistose, cleaving along biotite-rich layers.

Few thin sections of the gneiss of Council Mountain have been studied. Its mineralogic character has been partly checked in pan concentrates of heavy minerals collected from small streams containing only local bedrock detritus. A metamorphic grade in the kyanite zone is indicated by an abundance of kyanite without sillimanite to the west of the Middle Fork of the Weiser River and of sillimanite without kyanite to the east.

MIGMATITE OF McCALL

The zone of the migmatite of McCall is only 2 to 3 miles wide along the Donnelly section (*BB''*, pl. 2); the rock grades westward into the gneiss of Council Mountain (pl. 1). Fifteen miles to the north, along the McCall section (*AA'*, pl. 2), the migmatite zone is at least 7 miles wide; its western part is covered by basalt.

The migmatite of McCall varies from banded and augen to flaser gneiss. The gneissose structures and textures vary across the foliation planes. The rock is wholly crystalline, with no cataclastic textures, but exhibits textures which imply contemporaneous shearing-deformation and recrystallization. The grain size, which conspicuously ranges from very fine to medium grained in the area of a single thin section, gives the rock a pseudocataclastic texture. A fine grain size, however, is dominant. Gneissic layers, containing very fine-grained material of the order of 0.01 mm in size, may grade into, or be in sharp contact with, fine-grained material, 0.1 to 1 mm in size. There is every gradation from essentially euhedral porphyroblasts to augen forms.

The mineral composition may vary greatly across the foliation, both on a microscopic and megascopic scale. The most conspicuous banding in the gneiss is caused by layers relatively rich in biotite alternating with layers poor in biotite. Where the layering is caused by a textural or compositional difference among only felsic minerals, the banding is less conspicuous. Hornblende is uncommon. In a few place remnant quartz-biotite schists and calc-silicate granofels are interlayered with the banded gneisses.

The gross composition of the migmatite of McCall corresponds with leucocratic quartz diorite; the range is from quartz diorite to quartz monzonite but these extremes are uncommon and are designated "atypical" in table 1. The atypical rocks present uncommon situations in the process of migmatite formation. Two examples of atypical rocks follow; monazite occurs in the rock of the second example and is of particular interest in the placer study.

1. In some places adjacent layers, a few inches wide, consist of leucocratic rock rich in potassium feldspar and melanocratic rock rich in hornblende and biotite (table 1, samples 12a and 12b). Although adjacent dark and light layers of gneiss are characteristic of most of the migmatite of McCall, rarely are the dark layers unusually rich in mafic minerals and rarely are the light layers rich in potassium feldspar. The modes of these two rocks are contrasted in figure 5. The leucocratic layer, which has a plagioclase composition of An_{32}, contains 24 percent potassium feldspar; the melanocratic layer, which has a plagioclase composition of An_{33}, contains no potassium feldspar. The large amount of biotite present in the melanocratic layer suggests that this layer contains about twice as much K_2O as the average migmatite of McCall, whereas the leucocratic layer contains about four times the average.

(2) In several places quartz monzonitic gneiss occurs as lenticular bodies, several feet wide by tens of feet long, which are interlayered

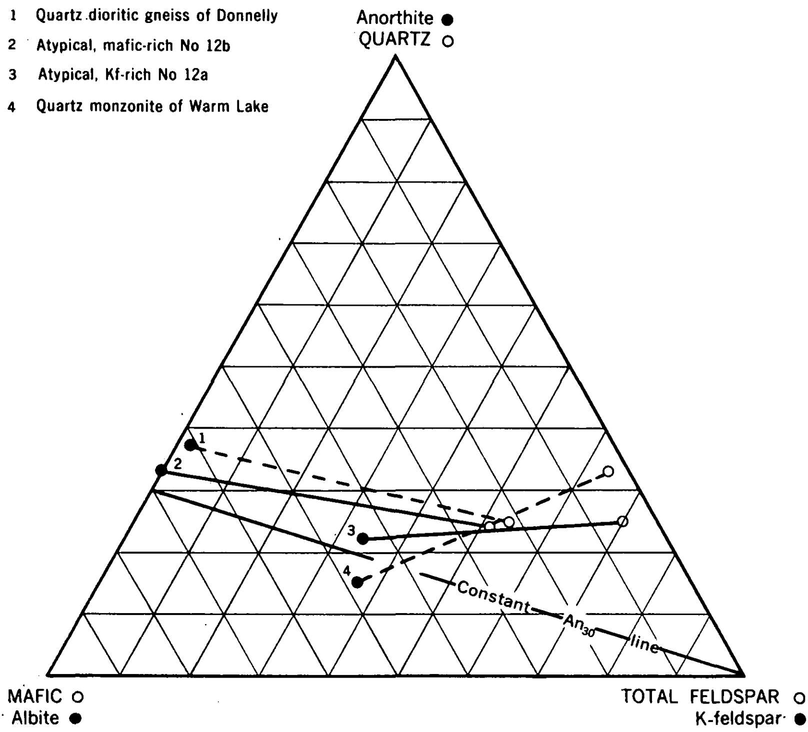

FIGURE 5.—Two adjacent atypical rocks, one melanocratic, rich in biotite and hornblende, and the other leucocratic, rich in potassium feldspar, occurring in the migmatite of McCall. Modal analyses are given in table 1. The average modal compositions of the quartz dioritic gneiss of Donnelly and the quartz monzonite of Warm Lake are plotted for comparison.

in the leucocratic quartz dioritic migmatite of McCall (for example, the atypical Brundage Mountain Suite, table 1, samples 10, 11a, 11b, 11c). The contact between the two rocks is gradational. The quartz monzonitic rock has a well-developed flaser gneissose foliation, though much less pronounced than that of the surrounding, more typical, migmatitic gneiss. Accessory monazite is disseminated in the rock in percentages comparable to the richer occurrences in the granodiorite of Gold Fork; however, the total amount of monazite is small because both the number and volume of the quartz monzonitic lenses are small. The modes of the atypical quartz monzonitic gneiss and the average migmatite of McCall are contrasted in figure 6. The quartz monzonitic gneiss contains 23 percent potassium feldspar and has a plagioclase composition of An_{25} (table 2) in contrast to the average migmatite of McCall with 4 percent potassium feldspar and with a plagioclase composition of An_{30}.

These two examples are of particular interest because they demonstrate extremes of rock composition within the outcrop belt of the

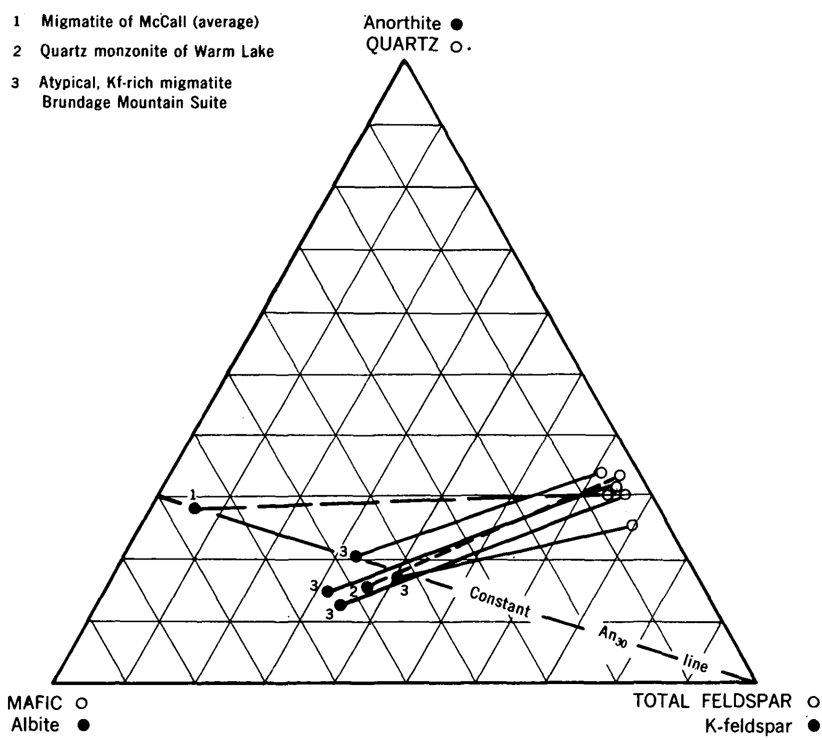

FIGURE 6.—Atypical rock rich in potassium feldspar occurring in the migmatite of McCall. Modal analyses are given in table 1, samples 10, 11a, 11b, and 11c. The modal composition of the rock is compared with the average modal composition of the migmatite of McCall and the quartz monzonite of Warm Lake.

migmatite of McCall. These extremes constitute a small fraction of one percent of the migmatite, yet their compositions are similar to the composition of the average quartz dioritic gneiss of Donnelly and the average quartz monzonite of Warm Lake. It is possible that similar processes of rock evolution acted on a small scale to form these atypical rocks of the migmatite of McCall as acted on a batholithic scale to evolve some of the major rock units of the batholith.

QUARTZ DIORITIC GNEISS OF DONNELLY

The quartz dioritic gneiss of Donnelly forms a zone about 6 miles wide, much of which is covered by alluvium in Long Valley (pl. 1). The rock is exposed along the Donnelly section (*BB''*, pl. 2) in the vicinity of Rock Creek and on the east side of Long Valley northeast of Donnelly. To the west it grades into the migmatite of McCall and to the east into more leucocratic granitic rocks (pl. 2). Along the McCall section (*AA'*, pl. 2) the quartz dioritic gneiss of Donnelly is apparently gradational to the west into the migmatite of McCall; the extent of the gneiss eastward beyond the McCall section has not been determined.

In hand specimen the quartz dioritic gneiss of Donnelly is principally a uniformly textured medium-grained flaser gneiss. In places, however, it is a banded gneiss with darker layers, rich in biotite and green hornblende, alternating with lighter layers rich in quartz and plagioclase. Hornblende lies in the plane of foliation without a conspicuous lineation suggesting that crystallization of hornblende outlasted deformation. Subhedral hornblende crystals are erratically distributed. Large anhedral epidote and large euhedral sphene crystals are commonly conspicuous in hand specimen. On a whole the unit is much darker colored than the other rocks of the section.

The grain size of the gneiss of Donnelly averages 3 mm and ranges from 1 to 5 mm. The microscopic texture is crystalloblastic xenomorphic granular. Pseudocataclastic textures are not common. The microstructure is flaser-gneissose with minor compositional layering.

LEUCOCRATIC QUARTZ DIORITE OF LITTLE VALLEY

The leucocratic quartz diorite of Little Valley underlies an area about 6 miles wide measured along the Donnelly section (*BB''*, pl. 2) in the vicinity of Little Valley (pl. 1). The rock is best exposed in the rock gorge of Gold Fork Creek, east of Long Valley.

The typical Little Valley rock is nearly directionless and uniformly textured, but a faint flaserlike foliation and rare distinct layering mark its gradation into the quartz dioritic gneiss of Donnelly to the west.

Hornblende, commonly as large euhedral porphyroblasts, is conspicuously present in minor quantity; it is sporadic in distribution and does not show a preferred orientation. Sphene, epidote, and even allanite can be easily seen in hand specimens because they are medium-grained, relatively abundant, and contrasted in color in the leucocratic rock.

The grain size ranges from 1 to 4 mm but the average is 2.5 mm. Potassium feldspar porphyroblasts commonly range from 0 to 1 cm in size, rarely to 2 cm. The microscopic texture of the rock is crystalloblastic xenomorphic granular.

GRANODIORITE OF GOLD FORK

The granodiorite of Gold Fork occurs as a northward-trending zone about 7 miles wide along the Donnelly section (*B′–B″*, pl. 2) *in* the drainage area of Big Creek (pl. 1). Westward the unit grades imperceptibly into the leucocratic quartz diorite of Little Valley, and eastward just as imperceptibly into the quartz monzonite of Warm Lake.

The Gold Fork rock is fine- to medium-grained, leucocratic, and granular, and, as a unit, is uniform in appearance. The amount of potassium feldspar in the form of large insets varies in an unsystematic manner from one outcrop to another—in many small outcrops it may be difficult to find the insets, whereas in others they are very conspicuous. In some places there is a suggestion of a foliation, represented by vague lineaments on the rock surface or perhaps by preferred orientation of the crystals, but it is so imperfect or so nebulous that statistical methods are required to map it.

The grain size of the granodiorite of Gold Fork averages 2.5 mm and ranges from 1 to 4 mm. Much of the rock has a porphyritic appearance owing to large potassium feldspar crystals and aggregates of quartz grains. The potassium feldspar insets and quartz aggregates commonly attain a diameter of 1.5 cm, rarely 2 cm. The overall texture has a xenomorphic granular appearance. The structure of the rock is essentially directionless; a faint foliation can rarely be seen in thin section.

Some specimens collected from the granodiorite of Gold Fork are quartz monzonite in composition (for example, sample 28, table 1, and pl. 2). The distribution of the specimens suggests that masses as large as several miles across are quartz monzonite (Schmidt, 1958, p. 25).

In general the quartz monzonite is lighter colored than typical granodiorite. Relative to the bulk composition of the granodiorite of Gold Fork, the quartz monzonite contains an average of 3 percent less biotite, 5 percent less plagioclase, and about twice as much potassium feldspar (20 to 30 percent). The plagioclase has about the same anorthite content as plagioclase in the granodiorite. The grain size and textures of the quartz monzonite are very similar to those of the granodiorite. Quartz is conspicuous in granular aggregates which in hand specimen resemble medium-grained porphyroblasts. The plagioclase grains are commonly anhedral, less commonly subhedral, and impart to the rock a xenomorphic-granular or, rarely, an hypidiomorphic-granular appearance.

The quartz monzonite of Gold Fork resembles the granodiorite of Gold Fork more closely than it does the quartz monzonite of Warm Lake. The plagioclase in the quartz monzonite of Gold Fork is more calcic than the plagioclase in the quartz monzonite of Warm Lake. It is more anhedral, and accessory minerals are much more abundant; specifically, allanite and epidote occur in the quartz monzonite of the western part of Gold Fork but do not occur in the quartz monzonite of Warm Lake.

QUARTZ MONZONITE OF WARM LAKE

The quartz monzonite of Warm Lake underlies what may be called the core area of the Idaho batholith in the latitude of the Donnelly section (pl. 2). It is at least 12 miles wide, the widest zone of the batholith. The eastern part has not been mapped beyond the eastern end of the section. The rock is a leucocratic quartz monzonite, and it can be generally distinguished in the field from the granodiorite of Gold Fork.

The grain size of the quartz monzonite of Warm Lake averages 3 mm and ranges from 2 to 4 mm. Quartz aggregates and potassium feldspar porphyroblasts average 4 to 5 mm although a few euhedral potassium feldspar porphyroblasts are several centimeters long. The overall texture is porphyritic, hypidiomorphic to xenomorphic granular. Granoblastic textures are typically formed between potassium feldspar and quartz owing to late endomorphic crystallization or recrystallization of these minerals.

INCLUSIONS OF SCHIST AND CALC-SILICATE GRANOFELS

OCCURRENCE

Inclusions of schist and calc-silicate granofels make up a small fraction of the migmatite of McCall, and the number decreases eastward through the quartz dioritic gneiss of Donnelly and the leucocratic quartz diorite of Little Valley to zero within the western part of the granodiorite of Gold Fork. No inclusions were observed across a distance of 25 miles to the east, inside the granodiorite of Gold Fork and the quartz monzonite of Warm Lake. Inclusions appear again in the Bear Valley area, east of the core of the batholith (Schmidt, 1958, pl. 5). Specimens from 13 inclusions have been studied: 5 from inclusions in the migmatite of McCall, 4 from the quartz dioritic gneiss of Donnelly, 2 from the leucocratic quartz diorite of Little Valley, and 2 from the westernmost part of the granodiorite of Gold Fork.

Most of the inclusions are small, measuring from several inches to several feet across, and occur in isolated groups. Five of the inclusions are large, tens and hundreds of feet across, and are shown diagrammatically on plate 1. The small inclusions vary in shape from long narrow wisps to round or irregular masses.

The foliation of the inclusions most commonly trends north and dips about vertical; it parallels the structural trend of the enclosing rocks (pl. 1). Broad sinuous deviations of as much as 90° occur on a scale measured in miles, but such deviations parallel similar curvature in the gneissose structure and in the boundaries between the major rock zones. Reversals of 180°, which occur on a scale measured in inches and feet, are commonly observed in outcrops and hand specimens; they represent plunging minor folds, but in general the fold axes of these tight isoclinal folds are nearly horizontal and trend about parallel to the average foliation.

PETROGRAPHY

All the schist and calc-silicate granofels inclusions consist of layers ranging in width from a fraction of a millimeter to several centimeters. The layering in the schists is largely characterized by variation in the amount of dark mica and is emphasized by a strong schistose texture formed by mica and quartz. In the calc-silicate granofels, the variously colored layers, mostly drab greens, browns, and grays, differ in mineral composition. The granoblastic texture of the granofels does not contribute to the layering; however, some variation in grain size from layer to layer does emphasize the layering.

Most of the inclusions consist predominantly of (1) quartz-rich or (2) calc-silicate-rich rock. The quartz-rich rock commonly contains aluminum-rich minerals such as kyanite or sillimanite and biotite and (or) muscovite. The calc-silicate-rich rock commonly contains both mixtures and alternating layers of quartz and calc-silicate minerals, such as diopside, calcic plagioclase, green hornblende, epidote, clinozoisite, zoisite, calcic-scapolite, fosterite, spinel, and grossularite.

METAMORPHISM

Thin-section study suggests that the inclusions are remnants of sedimentary rocks which were isochemically metamorphosed; they probably were derived from varying combinations of calcareous, dolomitic, argillaceous, and quartzose sediments. Local transfer of chemical elements between adjacent layers within the inclusions seems to be of minor importance as is shown, for example, by straight sharp contacts between layers that coincide with bedding layers.

Two stages of regional metamorphism are easily recognized in the remnants of isochemical rocks. They are a progressive synkinematic phase and a retrogressive static phase. The synkinematic metamorphism, which was prior to or contemporaneous with early stages of the formation of the batholith, is recorded by the schistose texture of the inclusions and of the gneisses and schists of the gneiss of Council Mountain. The static metamorphism, which is associated with late stages of the formation of the batholith, caused recrystallization of some minerals and formation of new minerals which have grown across the schistosity formed during the original synkinematic phase. In places the static crystallization obliterated the schistosity, but generally a strong foliation has been maintained by crystallization mimicking the earlier schistosity. The static phase is best developed in the granofels.

ZONATION

The intensity of metamorphism appears to increase systematically eastward across the area, and several metamorphic zones have been distinguished through the study of critical mineral assemblages. Thin sections of 29 specimens from the 13 sample localities were used (individual assemblages and distributions given in Schmidt, 1958, pl. 5). The data are limited by a scarcity of metamorphic inclusions in the gneissic and granitic rocks east of the migmatite of McCall.

The grade of the progressive synkinematic metamorphism of isochemical schists of the Council Mountain area is in the kyanite zone, since kyanite without sillimanite is very abundant in local stream gravels from this area. The assemblage andesine plus epidote (anorthite plus the anorthite-substitute mineral epidote) near locality 1 on plate 1 may be near the upper grade limit of the kyanite zone (Misch, 1949, p. 217; 1954).

The sillimanite isograd is approximately along the contact between the gneiss of Council Mountain and the migmatite of McCall. In the McCall area the sillimanite isograd is apparently between the westernmost known occurrence sillimanite near locality 11 and the andesine-epidote association near locality 1. Sillimanite under proper conditions is an excellent indicator of high metamorphic grade, especially when it takes the place of kyanite in a metamorphic progression (Barrow, 1893; Barth, 1936; Tilley, 1924).

The area of the batholith east of the sillimanite isograd is in the sillimanite zone. Continued eastward increase in grade within the zone is suggested by an increase in anorthite content of plagioclase in critical-mineral assemblages of calc-silicate granofels containing anorthite-substitute minerals (Misch, 1954) and by distinctive calc-silicate minerals or mineral assemblages. Such critical-mineral assemblages include quartz-bytownite-diopside 6 miles east of the sillimanite isograd along the Donnelly section (inclusion near locality 20, pl. 1), quartz-bytownite-diopside-spinel about 9 miles east of the sillimanite isograd (2 miles north of Cascade), and bytownite-diopside-spinel and calicite-diopside-spinel-forsterite 9 miles east of the sillimanite isograd (7 miles south of Cascade).

Spinel and forsterite can crystallize at the same high grade of metamorphism within the sillimanite zone and are considered good indicators of metamorphic grade. In general, under conditions of metamorphism on a batholitihic scale, they characteristically occur in the same metamorphic zone as bytownite and anorthite. Diopside and grossularite occur commonly in the sillimanite zone, but because they also occur in lower-grade zones under some conditions, they are not precise indicators of metamorphic grade. For various examples of correlations between the classical Barrovian zones of pelitic schists and index-mineral assemblages of calc-silicate granofels see Goldschmidt (1915), Eskola (-920), Misch (1949), and Kennedy (1949).

Wollastonite has not been found even though calcite and quartz are found in apparently stable assemblages in the highest-grade inclusions. Calcite and quartz under favorable conditions react to form wollastonite in the highest metamorphic grade; however, the conditions for formation of wollastonite are restricted, so that the occurrence of calcite and quartz well in the high-grade metamorphic zone need not indicate that the wollastonite temperature of formation has not been exceeded (Goldschmidt, 1911; Barth, 1952, p. 287).

On the east side of the core of the batholith, in the Bear Valley area and still inside the sillimanite zone, the metamorphic grade appears to decrease systematically away from the core of the batholith, that is, from west to east (Schmidt, 1958, p. 36 and pl. 5).

The retrogressive static metamorphism of the inclusions of schist and calc-silicate granofels in Adams and Valley Counties has not been resolved into metamorphic mineral zones. Mineral assemblages indicate a broad range of grade from high grade, calcic-scapolite and grossularite, to low grade, actinolite and chlorite. Most of the retrogressive mineral assemblages are various combinations of grossularite, calcic-scapolite, zoisite, epidote, clinozoisite, green hornblende, and andesine, suggesting that much of the retrogressive static metamorphism occurred in the kyanite zone and probably in part in the lowest grade part of the sillimanite zone.

Recognition of the mineral asemblages formed during retrogressive metamorphism is generally easy where only a part of the rock is altered, but where all or nearly all the rock is recrystallized or replaced by later minerals, it is difficult to determine whether the metamorphism was progressive or retrogressive. In some inclusions late crystallization of potassium feldspar and biotite and reconstitution of plagioclase indicate a late metasomatic transfer of alkalies to the included rock from adjacent gneisses or granitic rocks. That this crystallization was late and static is indicated by the crystallization of andesine, potassium feldspar, biotite, and hornblende across relict planes of foliation and by the reconstituted plagioclase which has the same composition as plagioclase in the surrounding granitic rock.

VARIATION OF MINERALS ACROSS THE ROCK ZONES

The modal proportions, chemical composition, optic properties, size, shape, and amount of alteration of all the essential and accessory minerals vary systematically from the border to the core of the batholith. This discussion is based on the rocks studied in detail along the combined McCall-Donnelly sections *A–A′* to *B–B″*, pl. 2) and the variation of the modal contents of these rocks. The plotted control points deviate from smooth curves because of natural variation of the mineral content and because of error inherent in the point-count method of modal analysis.

QUARTZ

The average quartz content in the various rock types is as follows: 30 percent (range, 20 to 40 percent) in the migmatite of McCall, 25 percent in the quartz dioritic gneiss of Donnelly, 30 percent in the leucocratic quartz diorite of Little Valley, 35 percent in the granodiorite of Gold Fork, and 32 percent in the quartz monzonite of Warm Lake (pl. 2).

Large quartz aggregates (5 to 15 mm across), macroscopically resembling quartz porphyroblasts, consist of a mosaic of smaller grains and occur in the directionless rocks. These aggregates are best developed in the quartz monzonitic rocks. In thin section the contact between grains in the quartz aggregates varies from sinuous to extremely sutured.

Quartz not in such aggregates occurs as interstitial grains ranging from 1 to 5 mm across. In the quartz diorite of Little Valley and quartz dioritic gneiss of Donnelly all the quartz is interstitial. In the migmatites some of the quartz is segregated into layers parallel to the foliation. This quartz exhibits good crystallization foliation. Mosaics of fine-grained quartz are commonly seen in the wedge-shaped areas at the ends of the large euhedral potassium feldspar porphyroblasts. The remainder of the quartz in the migmatites is either interstitial or occurs as a very fine grained matrix (grains less than 0.01 mm across) associated with a pseudocataclastic texture.

In the directionless rocks, quartz generally shows slight or moderate undulatory extinction. In the migmatites of the McCall area quartz lacks any pronounced undulatory extinction, but in the migmatites of the Council Mountain area strong undulatory extinction is exhibited. The quartz in all the rock types is uniformly gray.

Quartz occurring as aggregates was the last essential mineral to crystalize, although much of the late quartz crystallized contemporaneously with potassium feldspar. Hence, the texture of the quartz is commonly crystalloblastic with quartz replacing plagioclase and a part of the potassium feldspar.

In places small rounded crystals of accessory minerals such as monazite, zircon, and apatite are included in quartz; these crystals have clearly been partly resorbed during inclusion. "Dust trails" or films commonly containing many tiny crystals of accessory minerals cross many quartz grains. These dust films probably represent replaced biotite which formerly occurred in intergranular positions.

PLAGIOCLASE

The average plagioclase content decreases from 60 percent in the migmatite of McCall, to 53 percent in the quartz dioritic gneiss of Donnelly, 45 percent in the leucocratic quartz diorite of Little Valley, 42 percent in the granodiorite of Gold Fork, and 38 percent in the quartz monzonite of Warm Lake. The gradational change is uniform in its overall aspect but is quite nonsystematic in detail (pl. 2).

The anorthite content of the plagioclase varies systematically from an average of An_{30} in the migmatite of McCall to An_{45} (range An_{35} to An_{45}) in the quartz dioritic gneiss of Donnelly, An_{33} (An_{30} to An_{35}) in the leucocratic quartz diorite of Little Valley, An_{26} (An_{25} to An_{45}) in the quartz dioritic gneiss of Donnelly, An_{33} (An_{30} to in the quartz monzonite of Warm Lake. (See pl. 2.) In rare mottled crystals of plagioclase in the quartz dioritic gneiss of Donnelly, parts of the crystals are as calcic as An_{56} suggesting that at least part of the Donnelly zone was at one time more basic than its average quartz dioritic composition.

The percentage of total anorthite and albite molecules in the average migmatite of McCall, quartz dioritic gneiss of Donnelly, and quartz monzonite of Warm Lake is shown in table 3. As the total albite content decreases from the migmatite of the quartz dioritic gneiss, the total anorthite content remains about the same, and as the total anorthite content decreases from the quartz dioritic gneiss to the quartz

TABLE 3.—*Differences of percent anorthite and albite molecule contained in the type rocks of the border and core of the Idaho batholith in Valley County*

[An, anorthite; Ab, albite. The percentages are calculated from the average modal weight percents given in table 2 assuming pure feldspars. All values in percent.]

	Plagioclase in rock	An content of plagioclase (average)	An in rock		Ab in rock	
			Total	Difference, between rock types	Total	Difference, between rock types
Quartz dioritic migmatite of McCall	60	30	18		42	
				2		12
Quartz dioritic gneiss of Donnelly	50	40	20		30	
				11		1
Quartz monzonite of Warm Lake	38	25	9		29	

monzonite, the total albite content remains about the same. This rather simple relation suggests that regional conditions were uniformly gradational at least late during the genesis of the batholith.

Plagioclase grains average about 3 mm across (range from 1 to 5 mm) in all the rock types except the migmatite of McCall and gneiss of Council Mountain. In the migmatite of McCall the plagioclase grains are decidedly smaller, especially in pseudo-cataclastic parts where they are as small as 0.01 mm across.

Porphyritic or porphyroblastic plagioclase is uncommon in most of the rock types. Plagioclase porphyroblasts are as long as 10 mm in the leucocratic quartz diorite of Little Valley and range from 2 to 5 mm long in the migmatite of McCall.

The large more conspicuous plagioclase grains vary from augenform, common in the migmatite of McCall, to subhedral and uncommonly euhedral in the quartz monzonite of Warm Lake. Smaller plagioclase grains are anhedral in all the rock types, so that despite a few conspicuous subhedral and rarely euhedral grains in the quartz monzonite of Warm Lake, even the quartz monzonite rarely has a hypidiomorphic texture.

The plagioclase is generally a dull milky white, although some grains in the Warm Lake rock have a buff core surrounded by a narrow subhedral white rim. The buff cores are conspicuous in many hand specimens.

Albite polysynthetic twinning is sharpest in plagioclase grains in the quartz dioritic gneiss of Donnelly and tends to become successively less and less sharp in the rock zones to the east; it is least sharp in the quartz monzonite of Warm Lake. Albite twinning is generally not sharp, and is often not developed, in the plagioclase of the migmatite of McCall.

Faint zoning can be seen in some of the plagiclase grains in thin sections of the various directionless rocks. It is best developed in some crystals in the quartz monzonite of Warm Lake where the zoning may be marked by alternating buff and white zones. The two most common varieties of zoning are anhedral simple progressive and subhedral oscillatory. The oscillations are never sharp and they are generally not in the core of the crystals. A maximum of eight faint oscillations has been counted in an exceptional crystal. The change in the composition of the plagioclase from zone to zone is difficult to measure, and seems to be small. The plagioclase of the foliated rocks is generally unzoned, and if any zoning occurs, it is very faint.

A different type of zoning, caused by the presence of a single narrow border zone of albite(?), is common in some plagioclase grains in quartz monzonite of Warm Lake and granodiorite of Gold Fork. These albite(?)-rimmed plagioclase grains are most commonly associated with potassium feldspar; late potassium feldspar and quartz grains may cut the border zone discordantly.

Mottled extinction of plagioclase is best seen in sections of granodiorite of Gold Fork, is less conspicuous in the quartz monzonite of Warm Lake, and is uncommon in the leucocratic quartz diorite of Little Valley. Mottled extinction was not observed in the quartz dioritic gneiss of Donnelly or the migmatite of McCall, except in subordinate, highly calcic plagioclase grains. In any given grain of plagioclase the mottling may appear as simple shadows, as more complex spotty shadows, or as a network of shadowy veinlets. The mottling tends to be most strongly developed in the vicinity of late potassium-feldspar crystals. Calcite may be associated with advanced stages of the veinlet type of mottling. The mottling expresses differences in albite-anorthite composition within individual plagioclase crystals, and at least in part suggests an incomplete decalcification reaction.

Sericite and muscovite are conspicuous alteration products of plagioclase in the quartz monzonite of Warm Lake; they are less well developed in the granodiorite of Gold Fork, and are poorly or not at all developed in the outer rock zones of the batholith. Small ragged clinozoisite(?) grains may occur in the most extensively altered plagioclase. This alteration occurs preferentially along cleavages.

Mutual contact relations indicate that the plagioclase in the directionless rocks is older than most of the quartz and potassium feldspar. In the gneissose rocks the essential minerals are more nearly contemporaneous.

POTASSIUM FELDSPAR

Along the McCall-Donnelly section (pl. 2) the average potassium-feldspar content varies from less than 5 percent in the migmatite of McCall to less than 1 percent in the quartz dioritic gneiss of Donnelly; it increases to 13 percent in the leucocratic quartz diorite of Little Valley, 15 percent in the granodiorite of Gold Fork, and 23 percent in the quartz monzonite of Warm Lake where it reaches a maximum of 27 percent (pl. 2).

To the southeast of the eastern end of the Donnelly section the amount of potassium feldspar decreases; 15 miles farther east in Bear Valley, it decreases to 20 percent. Hence, the maximum of 27 percent potassium feldspar in the quartz monzonite of Warm Lake at the east end of the Donnelly section locates the "core" of the batholith.

For some 60 miles south, from the Donnelly section to the Boise Basin, the amount of potassium feldspar systematically increases to the east similar to the increase demonstrated along the Donnelly section (Schmidt, 1958, pl. 2).

Anomalously larger amounts of potassium feldspar than are typical in any given rock zone are uncommon and involve only small volumes of rock; the quartz monzonite in the granodiorite of Gold Fork is an exception. Examples of atypical samples containing anomalous amounts of potassium feldspar are plotted along section *A–A′* and *B′–B″*, plate 2. In the migmatite of McCall leucocratic atypical rocks containing from 20 to 28 percent potassium feldspar occur in small lenses and layers in the migmatite. In the quartz dioritic gneiss of Donnelly leucocratic rock from two sampled layers contain 8 and 16 percent potassium feldspar respectively (table 1, samples 13 and 15). Scattered throughout the granodiorite of Gold Fork are quartz monzonitic bodies which are generally hundreds of feet across and probably make up more than 10 percent of the Gold Fork zone (see p. G18–G19); a specimen from one of these bodies is designated atypical on plate 2 (sample 28) and contains 28 percent potassium feldspar.

The potassium feldspar in the directionless rocks is commonly grid-twinned microcline; in the gneissose rocks it is rarely grid-twinned. Microperthitic potassium feldspar is neither common nor well developed in any of the main rock types. Most of it occurs in the quartz monzonite of Warm Lake as "film and shadow perthite." Well-developed microperthite is common only in some pegmatites. Many potassium-feldspar crystals exhibit irregular shadowy and mottled extinctions, suggesting additional internal compositional variations.

Potassium-feldspar grains in the quartz monzonite of Warm Lake and the granodiorite of Gold Fork vary from anhedral intergranular crystals 1 to 5 mm across to euhedral porphyroblasts several centimeters long (fig. 3). Anhedral to subhedral porphyroblasts 5 to 10 mm across are most common.

In the leucocratic quartz diorite of Little Valley the potassium feldspar is commonly anhedral and equigranular with the other essential minerals, but some porphyroblasts do occur (fig. 3). In the quartz dioritic gneiss of Donnelly the potassium feldspar occurs as small intergranular crystals. In the migmatite of McCall most of the potassium feldspar forms large porphyroblasts, commonly 5 to 20 mm and occasionally 50 mm long; the shape varies from augen-form to euhedral. Few of the potassium-feldspar porphyroblasts are dragged out along the foliation planes. Little or no potassium feldspar is in the fine-grained pseudocataclastic parts of the migmatite.

In the "atypical" potassium-rich rocks from any of the rock zones, potassium feldspar is associated with the coarse-grained fraction of the rock; this association is especially conspicuous in strained rock slices.

In the field, potassium-feldspar porphyroblasts are the most conspicuous single feature in any of the directionless rocks; the crystals commonly protrude from the weathered rock surface because of greater resistance to weathering. Generally they constitute only a small percentage, perhaps as little as 1 percent, of the volume of a given rock; locally, however, they may amount to as much as 20 to 30 percent of the volume. The porphyroblasts are commonly euhedral with length-to-width ratios of 2:1; exceptional crystals may have ratios near 5:1.

Under crossed nicols many potassium-fledspar porphyroblasts in the directionless rocks exhibit a faint growth (?) zonation which is similar in appearance to the euhedral oscillatory zoning in plagioclase and is probably similarly caused by compositional variations.

Inclusions of plagioclase, quartz, biotite, and accessory minerals occur in the potassium-feldspar porphyroblasts in all rock types. These inclusions constitute as much as 10 or even 20 percent of the porphyroblasts.

In the directionless rocks, plagioclase inclusions in potassium-feldspar porphyroblasts are commonly euhedral, zoned, and oriented parallel to crystallographic directions of the enclosing crystal. Quartz inclusions occur as round blebs which are also generally optically oriented with regard to the crystallographic directions of the potassium feldspar. Ragged grains of biotite and inequidimensional grains of accessory minerals are similarly oriented.

In the gneissose rocks, inclusions of plagioclase, quartz, and biotite in the potassium-feldspar porphyroblasts are generally anhedral and randomly oriented.

Myrmekite is associated in varying amounts with all occurrences of potassium feldspar. It is most abundant in the quartz monzonite of Warm Lake, less abundant in the granodiorite of Gold Fork and leucocratic quartz diorite of Little Valley, and scarce in the quartz dioritic gneiss of Donnelly and migmatite of McCall. It occurs as intergrowths of tiny blebs of quartz and plagioclase within a narrow replacement zone between plagioclase and potassium feldspar. Some of the myrmekite may be included in the potassium-feldspar crystal, indicating that the potassium feldspar replaced plagioclase.

The fact that a large part of the potassium feldspar in the directionless rocks crystallized late in the paragenetic sequence is indicated by mutual granoblastic contact relations between potassium feldspar and associated quartz, plagioclase, and biotite. On the other hand, in the gneissose rocks, potassium feldspar appears to have crystallized contemporaneously with quartz, plagioclase, and biotite. In the quartz dioritic gneiss of Donnelly, for example, the potassium feldspar appears to be interstitial owing to the small amount present and not because it crystallized after the major minerals. In the migmatite of McCall most potassium feldspar, both intergranular grains and porphyroblasts, crystallized at the same time as the last major healing of the kinematically sheared rock and as a result is contemporaneous with the other essential minerals; only a small part of the potassium feldspar is late and is clearly associated with small late shears paralleling foliation planes or with the atypical potassium feldspar-rich leucocratic segregations. (See p. G14–G17.)

BIOTITE

Biotite and hornblende are the essential mafic minerals in the Valley County rocks. Biotite occurs in all the major rock units, whereas hornblende as an essential mineral is restricted to the quartz dioritic gneiss of Donnelly.

Along the McCall-Donnelly section the average content of biotite decreases to the east, toward the core of the batholith, from 15 percent (ranging from 13 to 17 percent) in the Donnelly zone to 10 percent (6 to 12 percent) in the leucocratic quartz diorite of Little Valley, 8 percent (7 to 9 percent) in the granodiorite of Gold Fork, and 3 percent (2 to 4 percent) in the quartz monzonite of Warm Lake (pl. 2). The average content of biotite also decreases to the west of the Donnelly zone to an average of 6 percent (4 to 10 percent) in the migmatite of McCall.

Two relatively mafic-rich samples (samples 4 and 12b) from the migmatite of McCall are labeled atypical on the cross section (pl. 2) and contain 24 and 25 percent, respectively, biotite. Both represent single, narrow, dark layers, several inches or less wide, in the migmatite.

The pleochroism of biotite remains remarkably uniform in all the major rock types of Valley County: X=tannish yellow, Y and Z=opaque or dark brown. Tiny pleochroic halos due to radioactive inclusions in the biotite are uncommon but are relatively more numerous in the migmatite of McCall and the granodiorite of Gold Fork.

In the granodiorite of Gold Fork many of the biotite grains have a greenish hue; the maximum absorption color in these grains is either opaque or dark greenish brown. Many of the other biotite grains in the granodiorite of Gold Fork are altered to an opaque or nearly opaque nonpleochroic mineral.

In the migmatite of McCall the biotite ranges from 0.01 to 1 mm across with an average of 0.05 mm. It occurs as thin ragged wisps which, together with quartz and plagioclase, form a pseudocataclastic fabric. The biotite is commonly alined in the foliation planes. In some places the biotite is segregated into crude mesocratic layers which alternate with more leucocratic layers, and in other places the biotite is more disseminated and emphasizes an augen or flaser structure. In still other places medium-grained biotite has crystallized in a weakly foliated gneiss.

The biotite in the quartz diorite of Donnelly is mostly medium-grained, platy, and anhedral and marks a strong foliation in a dominantly medium-grained flaser-structured rock. Most of the biotite is uniformly dispersed, but some is concentrated into gradational layers which form a weak-layered structure in some of the rock.

The biotite grains in the leucocratic quartz diorite of Little Valley range widely in size and are more equidimensional than the ragged wisps of biotite in the migmatite of McCall. The finer grained biotite is associated with the foliated varieties of the rock, whereas the coarser grained biotite is generally associated with the directionless varieties. The coarser grained biotite, although apparently dispersed in hand specimen, tends to be concentrated along short randomly oriented planes and in clusters when viewed in thin section.

In the granodiorite of Gold Fork and the quartz monzonite of Warm Lake, the biotite ranges from 0.2 to 1 mm across, with an average of 0.5 mm. It is more nearly equidimensional and subhedral than in any of the other rock units but always has conspicuously ragged ends. The biotite tends to lie in short randomly oriented planes and in clusters.

HORNBLENDE

Hornblende ranges from 0 to 10 percent in the quartz dioritic gneiss of Donnelly. It decreases to essentially zero to the west in the migmatite of McCall and also to the east within the leucocratic quartz diorite zone of Little Valley. Hornblende occurs locally in migmatite of McCall and is relatively abundant in some of the gneissic layers of the gneiss of Council Mountain. Local concentrations of hornblende also may be found in the leucocratic quartz diorite of Little Valley. An exceptionally mafic-rich atypical rock in the quartz dioritic gneiss of Donnelly contains 15 percent hornblende, about 10 percent more than normal. However, the amount of biotite (14 percent) in the rock is normal (pl. 2).

The hornblende is pleochroic with X=greenish yellow, Y=deep green, and Z=dark green. In some thin sections Z has a bluish hue. The maximum extinction in the prismatic section is 30°. Some of the hornblende crystals are twinned on (100).

In the quartz dioritic gneiss of Donnelly the hornblende is commonly subhedral and coarse grained, ranging from 1 to 10 mm across. The hornblende crystals commonly lie in the plane of foliation (fig. 3), but many lie across the foliation. The crystals are rarely fragmented or sheared out along foliation planes; they commonly exhibit porphyroblastic, in some places poikiloblastic growth. The hornblende seems to mark a strong crystallization foliation and probably postdates the deformative metamorphism which caused the foliation. In the leucocratic quartz diorite of Little Valley most of the hornblende occurs as prophyroblasts as much as 10 mm long.

Some of the hornblende is replaced by biotite. Pseudomorphs after euhedral hornblende crystals consist of aggregates of biotite, epidote, and relict hornblende, with or without clinozoisite, magnetite, and sphene; late chlorite may be present. All stages of transformation from hornblnde to a biotite and epidote assemblage with late chlorite can be seen in a single thin section or in rocks from different localities.

MUSCOVITE

Three types of white mica are recognized, each related to a particular stage of the making of the batholith.

1. Relatively coarse granular muscovite is conspicuous and intimately associated with essential minerals in thin sections of the quartz monzonite of Warm Lake; its average abundance is 2 percent (ranging from 0.6 to 5 percent). The average amount abruptly decreases in the granodiorite of Gold Fork to 0.2 percent (0.2 to 0.3 percent) and is the same, but ranges from less than 0.1 to 0.4 percent, in the leucocratic quartz diorite of Little Valley. Muscovite is absent to rare in the quartz dioritic gneiss of Donnelly and migmatite of McCall, occurring only in association with some of the more granitic textured parts of these rocks (pl. 2). The muscovite is fine grained to medium grained and is similar to bio-

tite in size, shape, and mode of occurrence; it crystallized late under the same equilibrium conditions which controlled the crystallization of the essential mineral assemblage.

A brown-tinted pleochroic "muscovitelike" mica or minor abundance in one specimen from the migmatite of McCall is similar in occurrence to the muscovite discussed in the preceding paragraph, but because the brown-tinted mica has an optic angle (2*V*) of about 20° in contrast to about 30° for the muscovite, it may be phlogopite or phologopitic muscovite. Its paragenesis is probably the same as that of the muscovite; it simply reflects the more diverse and heterogeneous chemical composition of the migmatite as compared to that of the granitic rock within the batholith. Phlogopite of different association occurs in a Mg-rich calc-silicate inclusion near the Little Valley-Gold Fork contact.

2. A coarse-grained muscovite, crystallized in free-space growth on the walls of a prominent mineral-coated northeastward-trending joint set, is found in all the rock zones, but is far more abundant in the Gold Fork and Warm Lake zones and is best developed in the quartz monzonite of Warm Lake. The muscovite-coated joint also cuts aplite and pegmatite dikes.
3. Fine-grained, sericite is for the most part inconspicuously the alteration product of plagioclase throughout the granitic rocks of the area, but is conspicuous as an alteration product in the walls of the mineral-coated joints in the quartz monzonite of Warm Lake. In general the sericite is later than the coarse-grained muscovite in the joints.

ACCESSORY MINERALS

The accessory minerals observed in thin sections of the gneissic and granitic rocks in Valley County are epidote, allanite, monazite, sphene, apatite, zircon, and various opaque minerals. As stated earlier, the thin-section study was undertaken chiefly to determine the manner of occurrence in the bedrock of heavy accessory minerals that have been observed in about 2,000 pan concentrates of weathered bedrock, soil, and alluvium. Detailed results of the study of the pan concentrates enter into the present discussion only as background information. The approximate distribution and quantities of accessory minerals in the vicinity of the Donnelly section are shown diagrammatically on plate 2; values have not been determined for rocks of the McCall section. The sporadic distribution and scarcity of accessory minerals make the determination of abundances difficult in thin section, but where comparisons can be made, such modal estimations agree favorably with the pan-concentrate data.

EPIDOTE

Epidote increases in abundance from nearly zero in the migmatite of McCall to as much as 0.5 percent in some specimens of the quartz dioritic gneiss of Donnelly. It decreases rapidly eastward in the leucocratic quartz diotrite of Little Valley to an average of 0.003 percent, is scarce (0.001 percent) to absent in the granodiorite of Gold Fork, and is essentially absent in the quartz monzonite of Warm Lake.

The epidote grains range from less than 0.1 to 1 mm across. They are anhedral and ragged; only rarely are subhedral grains observed.

Epidote is most commonly intergrown with hornblende, biotite, and chlorite. When hornblende is not present, epidote is either intergrown with biotite or is closely associated with biotite in mafic clots. This mineral association and areal distribution of epidote and hornblende indicate that the epidote was formed by the biotitization of hornblende, late during the formation of the batholith.

Epidote forms a euhedral optically continuous rim on rounded allanite crystals in places in the leuocratic quartz diorite of Little Valley and the granodiorite of Gold Fork. The epidote rim may make up as much as 10 to 30 percent of the allanite-epidote crystal in the plane of the thin section. The change from allanite to epidote crystallization probably marks the change from available to nonavailable rare-earth constituents at a time when the available rare-earth constituents became fixed in either allanite or monazite.

A completely different form of epidote is derived by the sericitization of plagioclase. It is closely associated with altered parts of plagioclase as a very fine grained aggregate of irregular shape and is markedly different and formed later than the granular epidote.

ALLANITE

Allanite is relatively abundant in the migmatite of McCall and the quartz dioritic gneiss of Donnelly and is much less abundant, about 0.001 percent, in the leucocratic quartz diorite of Little Valley. Allanite is scarce, 0.0001 percent, in the granodiorite of Gold Fork and is absent in the quartz monzonite of Warm Lake.

Allanite crystals are several tenths of a millimeter long, ranging from 0.2 to 1 mm. The crystals, elongated parallel to Y (b), are commonly subhedral or euhedral, but in some samples they are anhedral owing to strong resorption. Narrow euhedral growth zones are characteristic; the zones (of which there are generally many more than 10) are emphasized in delicate shades of blue on slightly weathered crystals. Most allanite crystals are covered or partly covered with a diagnostic, blue to blue-white alteration skin commonly less than 0.01 mm thick. Otherwise, the allanite appears unaltered. Metamictized allanite as characterized by anastomosing microfractures is rare with the exception of allanite associated with accessory euxenite in granodiorite(?) from Bear Valley.

The radioactive-element content of allanite is probably about average for accessory allanite because only several crystals were observed to have faint pleochroic halos in adjoining biotite. Allanite, collected about 36 miles south of the Donnelly section in rock equivalent to leucocratic quartz diorite of Little Valley ("Cascade type granodiorite" of Larsen and Schmidt, 1958), contains 1.2 percent ThO_2 and 0.0036 percent U_3O_8 (Smith and others, 1957, p. 369).

In thin section allanite is commonly twinned on the (100) twin plane. Its pleochroism is: X = dark brown or dark greenish brown, and Z = very dark brown or very dark reddish brown.

Allanite is most commonly associated with biotite-rich layers in the foliated migmatitic rocks and with biotite clusters or clots in the directionless rocks. Less commonly, some of the finer grained allanite is included in quartz, potassium feldspar, and rarely, in plagioclase. Allanite crystallized paragenetically late.

MONAZITE

Monazite is most abundant in the granodiorite of Gold Fork, where the average tenor is 0.001 percent. To the east the amount of monazite decreases to nearly zero in the central part of the quartz monzonite of Warm Lake; it occurs more abundantly again in Bear Valley east of the core area of the batholith. Monazite has not been found in the gneissose rocks west of the granodiorite of Gold Fork with the exception of several very local occurrences in the migmatite of McCall. (See p. G14–G17.) The restriction of monazite, largely to a single "monazite belt" in Valley County, was recognized in the field by pan sampling.

The tenor of richer occurrences of monazite in the Gold Fork zone is of the order of 0.3 pound per cubic yard (0.01 percent). These occurrences are "spotty," involving only several cubic feet or several tens of cubic feet of rock which contains 10 to 100 times more monazite than the adjacent identical-appearing granitic rock. An abundance of these small rich occurrences or "spots" of monazite locally increases the overall tenor of monazite within the monazite belt. Such monazite-rich areas tend to be associated with potassium feldspar-rich varieties of the Gold Fork granitic rock, and the small rich "spots" of monazite-bearing rock are probably segregations of monazite which appear to be independent of the segregation or concentration of any other essential or accessory mineral. These conditions suggest that the monazite was segregated during the transformation of granodiorite to quartz monzonite within the Gold Fork zone. (See p. G18–G19.)

Two distinct types of monazite occur together in the directionless rocks of the batholith: (1) Large euhedral prismatic crystals are typically associated with clots or clusters of essential biotite; the crystals have frosty-textured surfaces, an elongation parallel to the *c* crystallographic axis, and elongation ratio of 2:3, and an average larger size of ½ by 1 mm. (2) Tiny subhedral prismatic crystals are typically included in essential minerals, most commonly in quartz, potassium-feldspar, and biotite, but also in plagioclase; the crystals have smooth shiny surfaces, an elongation parallel to *c*, an elongation ratio of 3:6, and average length of about 0.01 by 0.05 mm. Both types of monazite have large dark pleochroic halos where in contact with biotite.

Monazite from seven placer deposits in the vicinity of the Donnelly section contains an average of 4.20 percent ThO_2 and 0.13 percent U_3O_8 (average of 12 analyses by the U.S. Bureau of Mines), and monazite from the Bear Valley euxenite placer deposits contains 4.60 percent ThO_2 and 0.27 percent U_3O_8 (average of 2 analyses by the U.S. Bureau of Mines). On the premise that the radioactivity of accessory minerals relatively reflects the radioactivity of the host rock, the higher radioactive-element content of monazite from Bear Valley suggests that the host granodiorite(?) in Bear Valley contains more thorium and uranium than the grantic rocks along the Donnelly section; the same relation is indicated by the evidence of more radioactive allanite in the Bear Valley rock.

In a very few places in the migmatite of McCall monazite is disseminated in lenses or pods of leucocratic, potassium-feldspar-rich and moderately gneissose quartz monzonitic rock. The lenses are several feet wide and tens of feet long, and they pinch and swell between foliation planes in the migmatite. The tenor of the monazite in one of the lenses (locality 11, pl. 1) is about 0.3 pound per cubic yard (0.01 percent). The crystals are small, subhedral, tabular after (100), and have rounded edges and such smooth surfaces as to appear highly polished; this is caused by partial resorption.

The crystallation of monazite as an accessory mineral in granitic rock is apparently controlled by a rigid set of conditions. The monazite in both the migmatite and Gold Fork zones is associated with moderately potassium feldspar-rich (granodioritic to quartz monzonitic) and moderately leucocratic (5–10 percent biotite) granitic rocks; monazite does not occur in less potassic and less leucocratic rocks (quartz diorite) and occurs in much less abundance in more leucocratic, more potassic granitic rocks (quartz monzonite).

Interpretation of textural relations suggests that both the tiny included crystals and the large intergranular crystals of monazite are about the same age and that little or no monazite crystallized directly from a granodioritic magma of Gold Fork. It is likely that, during endomorphic recrystallization, when a more homogeneously coarse-grained and potassic feldspar rock was evolving, monazite constituents were released from intergranular positions and from replaced and reconstituted major minerals. These constituents nucleated and crystallized as monazite in intergranular positions. Where the intergranular contact was stable, as at sites of biotite crystallization, the monazite grew to large size, but where the intergranular contact was not stable, as where one essential mineral continued to replace another essential mineral, the monazite crystal growth was stopped and even reversed by partial resorption upon inclusion in the growing essential mineral. In striving for equilibrium among essential minerals, quartz and potassium feldspar commonly replaced plagioclase or smaller quartz and potassium feldspar grains, but in places plagioclase replaced older, chemically less stable, plagioclase or smaller grains of plagioclase, quartz, and potassium feldspar.

In the local, monazite-rich lenses of quartz monzonitic gneiss in the migmatite of McCall, recrystallization and potassium feldspathization released monazite constituents from the older gneissose rock. These constituents nucleated and crystallized with tabular habit in intergranular positions. This particular rock, however, went beyond the conditions of monazite stability—perhaps because potassium feldspathization continued to a quartz monzonitic composition—and resulted in partial resorption of the monazite crystals. Also, it is likely that moderate stress caused the monazite to crystallize with tabular rather than prismatic habit.

SPHENE

Sphene is abundant, 0.3 percent, in the migmatite of McCall and the quartz dioritic gneiss of Donnelly. The amount of sphene decreases rapidly within the leucocratic quartz diorite of Little Valley from 0.1 percent on the west to zero on the east. Sphene is absent in the Gold Fork and Warm Lake zones farther east. On a scale of several tens or several hundereds of feet, the sphene is not uniformly distributed in any given rock type but varies erratically in abundance from place to place.

In thin section the sphene is generally colorless and nonpleochroic, but in the leucocratic quartz diorite of Little Valley some of the sphene is weakly to moderately pleochroic. Sphene in hand specimen varies in color from bright yellow to dark brownish yellow.

Sphene crystals range from 0.1 to 5 mm long and from anhedral to euhedral. An average length is several tenths of a millimeter. Euhedral crystals several millimeters long are conspicuous in hand specimen.

Sphene is associated with mafic layers and clots of either biotite or biotite and hornblende. Only rarely is sphene included in quartz and plagioclase.

APATITE

Apatite is found in all the granitic and gneissic rocks studied. It is most abundant in the migmatite of McCall and is abundant but decreases in quantity to the east: about 0.003 percent in the quartz dioritic gneiss of Donnelly and the leucocratic quartz diorite of Little Valley and about 0.001 percent in the granodiorite of Gold Fork. Relatively small quantities of apatite occur in the quartz monzonite of Warm Lake.

The apatite is colorless in thin section and milk white in reflected light. The grains are subhedral to euhedral and range from 0.1 to 2 mm long. Apatite in the migmatite of McCall is commonly subhedral with rounded edges. In all the rocks the coarser grained apatite is associated with biotite and other accessory minerals in mafic-rich layers and in mafic clots. The crystals less than 0.2 mm long are commonly included in quartz, potassium feldspar, and plagioclase. The apatite in the Warm Lake quartz monzonite is relatively small and euhedral.

At least some of the apatite in the migmatite of McCall formed contemporaneously with shearing deformation (synkinematically); in one thin section a large apatite crystal is broken and dragged out along a foliation plane; the crushed rock matrix is completely recrystallized. Elsewhere the apatite crystals commonly lie in the plane of foliation but are rarely broken.

ZIRCON

Zircon occurs in all the rock types. It is most abundant in the migmatite of McCall and decreases to the east: about 0.003 percent in the quartz dioritic gneiss of Donnelly, 0.001 percent in the leucocratic quartz diorite of Little Valley, and 0.0001 percent in the granodiorite of Gold Fork and quartz monzonite of Warm Lake.

In general, crystals range from 0.02 to 0.2 mm long and are euhedral. The largest crystal, in the migmatite of McCall, is 0.5 millimeter long and subhedral. Smaller crystals are simple tetragonal-dipyramidal prisms with elongation ratios varying from 1 to an exceptional 10; intermediate ratios of 2:5 are most common. Larger crystals commonly have a ditetragonal-dipyramidal form and smaller average elongation ratios. Length to width ratios have not been studied. In the migmatite of McCall the zircon crystals are commonly subhedral with rounded edges and are elongated parallel to the layering of the gneiss; apparently they crystallized under conditions of mild deformative metamorphism, probably late synkinematically.

In all the rocks many of the smaller zircon crystals are included in quartz, potassium feldspar, plagioclase, and biotite. The biotite-enclosed crystals have very faint or invisible pleochroic halos.

OPAQUE MINERALS

The opaque minerals seen in thin section were not identified in the petrographic study. They are most abundant, about 0.4 percent, in the migmatite of McCall, 0.1 percent in the quartz dioritic gneiss of Donnelly, and 0.2 percent in the quartz diorite of Little Valley. They are less abundant, about 0.05 percent, in the granodiorite of Gold Fork and are minor or absent in the quartz monzonite of Warm Lake. The opaque minerals are commonly subhedral and are as much as 2 mm across. They are associated with biotite, hornblende, and nonopaque accessory minerals in mafic-rich layers in the gneissic rocks and in mafic clots in the directionless rocks.

Study of pan-sample concentrates indicates that the opaque minerals are dominantly magnetite and ilmenite, that magnetite is predominant in the migmatite of McCall and quartz dioritic gneiss of Donnelly, that magnetite and ilmenite are the opaque minerals in the granodiorite of Gold Fork and quartz monzonite of Warm Lake, and that as the amount of sphene decreases to zero in the leucocratic quartz diorite of Little Valley, the amount of ilmenite significantly increases so that the ratio of ilmenite to magnetite increases toward the east.

Pyrite is a minor constituent of the opaque minerals. It occurs throughout the rocks of Valley County associated with the mineral-coated joint set which cuts the batholithic rocks.

SUMMARY OF ROCK GRADATION

The progressive gradation of rock composition, structure, and texture across the border and interior of the Idaho batholith in Adams and Valley Counties provides evidence that processes acted on a regional scale before, during, and after the emplacement of the batholith. In summary, the sequence of rocks making up the gradation, taken from the west border zone to the east interior, is the gneiss of Council Mountain, commonly schistose; migmatite (leucocratic quartz dioritic) of McCall, dominantly pseudocataclastic gneissose; quartz dioritic gneiss of Donnelly, medium-grained, more even granular gneissose; leucocratic quartz diorite of Little Valley, uneven, mixed fine- and medium-grained texture, transitional between gneissose and directionless; granodiorite of Gold Fork, medium-grained, mixed to even-granular textured and directionless; and quartz monzonite of Warm Lake, medium-grained, most even-granular textured, most directionless, and most leucocratic.

The megascopic change from strongly gneissose to directionless rock can be seen in figure 3 showing a series of polished thick slices of specimens of each rock type except the gneiss of Council Mountain. The microscopic detail of the progressive decrease in development of foliation from west to east across the various rock belts is even more striking.

Gradation of the average compositions of each rock unit can be compared on the Larsen-Robertson diagram on figure 4. The continuous compositional variation is illustrated by arrows drawn through the respective Ab–An–Kf and M–Q–F points. If the quartz dioritic gneiss of Donnelly is omitted from consideration, the M–Q–F points group in a small area indicating little M–Q–F mineralogic change along the batholithic section. The Ab–An–Kf points, disregarding the quartz dioritic gneiss of Donnelly, however, show a large relative increase, 19 percent, in potassium feldspar content as compared to a large relative decrease, 21 percent, in plagioclase content. The anorthite molecule content, however, decreases only 9 percent whereas the albite molecule content decreases 12 percent, thus changing the anorthite content of the plagioclase from an average of An_{30} in the migmatite to An_{25} in the quartz monzonite.

If the recalculated modes of typical rocks (table 1) along the McCall-Donnelly section are plotted on a ternary diagram with quartz-potassium feldspar-plagioclase coordinates (where plagioclase approximates for albite), a nearly horizontal trend line results (fig. 7) which is sharply contrasted to the diagonal trend line formed by magmatically differentiated rocks as suggested by Bowen (1954, p. 11). In the same manner the McCall-Donnelly trend line differs from the trend lines of typical suites of magmatically differentiated granitic rocks from various batholiths in the western United States (Moore, 1959, p. 205). This suggests that other processes, perhaps in addition to magmatic differentiation, have changed the composition of the rocks along the McCall-Donnelly section or that the McCall-Donnelly rocks were not initially genetically related. In any case, a regional set of conditions has acted across the batholith and border zone in Adams and Valley Counties to produce a gradational sequence of rocks.

The estimated oxide contents, averaged for each rock unit, vary systematically along the McCall-Donnelly section (fig. 8). The oxide contents are calculated from the average weight percent of the modal feldspars, biotite, and hornblende in each rock unit assuming ideal or pure mineral compositions without regard for perthitic, antiperthitic, or mutual solid-solution contaminants.

The estimated Na_2O values decrease from west to east through the migmatite zone and remain essentially constant along the rest of the section. The estimated CaO values, except for an increase in the quartz dioritic gneiss of Donnelly, decrease toward the core of the batholith in contrast to the general increase of estimated K_2O. This general decrease in CaO and increase in K_2O from the migmatite toward the core of the batholith suggests that some unit process of decalcification and potassium feldspathization acted on a batholithic scale.

The estimated Na_2O value (5 percent) in the migmatite of McCall is greater than is common for either sedimentary or igneous rocks, so that sodium metasomatism is suggested. The Precambrian Belt Series, for example, is a possible source rock of the migmatite, but the average

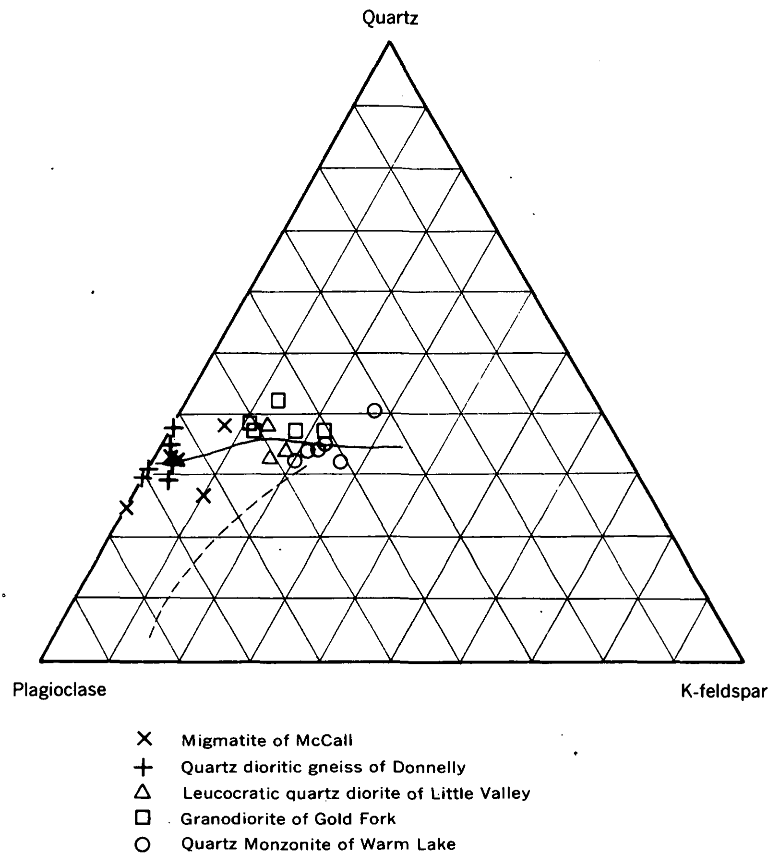

FIGURE 7.—Plot of recalculated modes of typical rocks from each of the five rock zones along the McCall-Donnelly section (table 1) shows a horizontal trend line (solid line) which is contrasted to the diagonal line (dashed) typical of suites of magmatically differentiated rocks from various batholiths in western United States (Moore, 1959, p. 205). The gap between 55 and 62 percent plagioclase is the result of recalculation (Q+Kf+Pl=100) of typically mafic-rich samples of quartz dioritic gneiss of Donnelly; more closely spaced sampling of the gradation between the Donnelly and Little Valley rocks would fill this gap.

Na_2O content of 13 rocks of the Belt Series, mostly argillites from the Coeur d'Alene district, Idaho, is only 1.6 percent (S. W. Hobbs, written communication, 1954).

	Migmatite of McCall	Quartz dioritic gneiss of Donnelly	Leucocratic quartz diorite of Little Valley	Granodiorite of Gold Fork	Quartz monzonite of Warm Lake
Average mode [Weight percent of rock]					
Modal Ab molecule	42	33	30	33	30
Modal An molecule	18	20	15	11	9
Modal Kf molecule	4	1	14	13	23
Modal biotite	7	16	11	9	3
Modal hornblende	------------	7	------------	------------	------------
Total average oxide [Calculated percent of rock]					
Estimated Na_2O	5.0	3.9	3.6	3.9	3.6
Estimated CaO	3.6	[1](4.0+0.4) 4.4	3.0	2.2	1.8
Estimated K_2O	[2](0.9+0.6) 1.5	(0.2+1.5) 1.7	(3.0+1.0) 4.0	(2.8+0.8) 3.6	(5.0+0.3) 5.3

[1] 4.0 percent contributed by An, 0.4 percent contributed by hornblende.
[2] 0.9 percent contributed by Kf, 0.6 percent contributed by biotite.

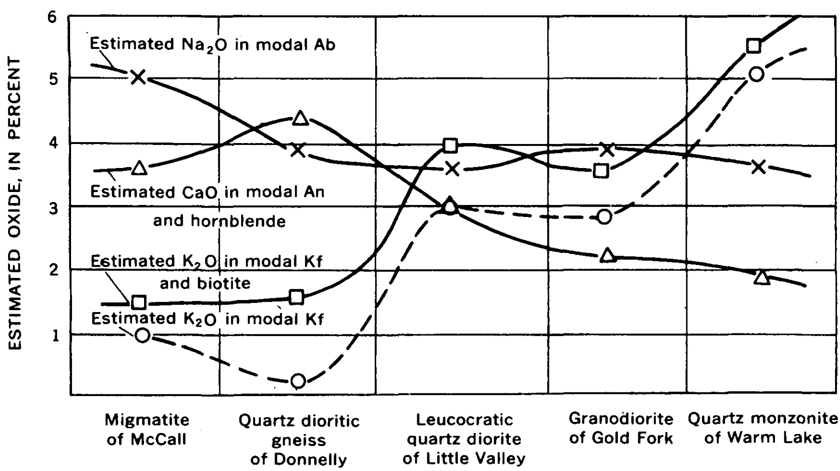

FIGURE 8.—Variation of oxides across the western half of the Idaho batholith in Adams and Valley Counties. The average percent of K_2O, Na_2O, and CaO in each rock type is plotted against the relative positions of the respective rock types. The oxide values were calculated by multiplying the average weight percent of modal feldspar, biotite, and hornblende in each rock type (table 2) by an assumed molecular amount of the respective oxide. The feldspars are taken to be chemically pure; biotite is assumed to contain an average of 9 percent K_2O; and hornblende is assumed to contain an average of 6 percent CaO.

The quartz dioritic gneiss of Donnelly constitutes the only large volume of mafic rock in the border of the batholith and as such seems anomalously located between leucocratic rock units. Its location in the wide transitional zone between migmatitic gneiss to the west and nearly directionless rock to the east strongly suggests that its mafic character is related to the genesis of the directionless rocks.

Various processes of femic enrichment or salic impoverishment have been and can be suggested for different parts of the Idaho batholith but enough data are not available along the McCall-Donnelly section to determine conclusively the mode of origin of the quartz dioritic gneiss of Donnelly. Anatexial processes, tranfers of salic and femic ions both in moving and rest solutions (Hietanen, 1961, p. 163), as well as late endomorphic transfers of femic constituents (Johnson, 1947, p. 504) may be involved. Likewise deep-seated metasomatic processes (Read, 1948, p. 195; Reynolds, 1946, p. 215) or silica-alkali leaching processes (Tuttle and Bowen, 1958, p. 91; Adams [1]) may be applied to various models of rock distribution older than the present distribution. However, the presently available data suggest that the quartz dioritic gneiss of Donnelly does not represent a simple intrusion of quartz dioritic magma or a metamorphosed mafic rock unit inherited from a former stratigraphic sequence. Also, because the migmatite of McCall and the leucocratic quartz diorite of Little Valley have such similar mafic contents, a zone of partially melted migmatite could not separate into a mobile more felsic magma of the composition of the leucocratic quartz diorite of Little Valley and a more mafic solid residuum of the composition of the quartz dioritic gneiss of Donnelly.

No matter what model or process was effective in making the quartz dioritic gneiss of Donnelly, it is apparent that large transfers of added femic or subtracted salic constituents are involved. If, for example, such a transfer is calculated as largely a femic addition to migmatitic gneiss of McCall, then, on the average, an amount of albite molecule would have to be removed from the migmatite to change the plagioclase composition from $Ab_{70}An_{30}$ to $Ab_{62}An_{38}$, which involves a decrease of about 1 percent Na_2O (fig. 8), whereas the CaO (anorthite molecule content) in plagioclase remains about the same (pl. 2 and table 3); CaO, MgO, and FeO would have to be added to make up about 9 percent additional biotite and about 7 percent additional hornblende.

Crystalloblastic textures which are characteristic of all the rock types, are caused by metamorphic crystallization in the border rocks and by endomorphic recrystallization within the batholith (Tuttle,

[1] John B. Adams, 1961, Petrology and structure of the Stehekin-Twisp Pass area, Northern Cascades, Washington: Univ. Washington [Seattle], unpub. Ph.D. thesis, 171 p.

1952). Even in the directionless granodiorite of Gold Fork and quartz monzonite of Warm Lake, the dominantly crystalloblastic texture is broken only by a few subhedral to euhedral crystals of plagioclase. The "most igneous looking rock," selected from seven specimens of typical quartz monzonite of Warm Lake, has a predominantly crystalloblastic texture in thin section.

ORIGIN OF PLACER MINERALS

The specific purpose of the petrographic study of rock specimens from Adams and Valley Counties was to obtain a descriptive knowledge of the bedrock which is the source of the placer minerals. This is one step toward an understanding of the genetic relations between the rock types and the placer minerals. The distribution of the placer minerals in the granitic host rocks is another step and was well established in the field by panning and hand-lens examination as follows: (a) The placer minerals occur in the bedrock in elongate zones or irregularly shaped areas, miles wide, bordered or surrounded by superficially similar rocks in which the minerals are rare or absent; (b) within these zones the distribution of the placer minerals is sporadic in detail—a single cubic foot of granitic rock may contain 10 times the amount of a given valuable mineral as the surrounding rock which seems identical; and (c) variations in placer-mineral content of the rock, grossly and in detail, are not associated with proximity to pegmatite or aplite dikes, veins of any kind, or fractured zones or joints, indicating that the placer minerals were not introduced by hydrothermal solutions. The field relations indicate, on the contrary, that the minerals are integral parts of the rock in which they occur.

The systematic distribution of other heavy accessory minerals across the batholith in Valley County further supplements the suggestion that a unified set of conditions operated on a batholithic scale during crystallization of the accessory minerals. The zones of the various heavy minerals parallel the northerly structural and compositional trends of the bedrock—for example, magnetite is dominant in the quartz dioritic gneiss of Donnelly, magnetite and ilmenite are dominant in the quartz diorite of Little Valley and the granodiorite of Gold Fork, and ilmenite is dominant in the quartz monzonite of Warm Lake. Also, sphene and allanite are abundant in the quartz dioritic gneiss of Donnelly, sphene and allanite without monazite are much less abundant in the quartz diorite of Little Valley, monazite without sphene and allanite occurs in the granodiorite of Gold Fork, and only small amounts of monazite occur sporadically distributed in the quartz monzonite of Warm Lake. The amount of sphene decreases to zero as the amount of ilmenite increases toward the east in the quartz diorite of Little Valley.

Regional zonation of accessory minerals under conditions of metasomatic metamorphism and (or) magmatic intrusion on a regional scale would be expected, especially where retrogressive or endormorphic processes continued to act on a regional scale to account for the regional zonation of paragenetically late accessory minerals. "The monazite belt," for example, corresponds to a zone where physiochemical conditions favored crystallization of monazite from locally derived monazite ingredients during regional reconstitution of the interior part of the batholith by late magmatic or endomorphis processes.

GENESIS OF GRANITIC ROCKS IN ADAMS AND VALLEY COUNTIES

It is evident that the problem of origin of the placer minerals involves the much broader question of origin of the Idaho batholith. The minimum requirements for a worthwhile discussion of the origin of the batholith, even as regards Valley County, are beyond the scope of this investigation—there has been little geologic mapping, no study of patterns of possible flow and fracture structures, and no chemical data to permit a comparison of the composition of rocks older than the batholith with the batholithic rocks in Valley County. The thin-section study reported here provides a preliminary description of the bedrock, and even though the widely spaced sampling does not justify definitive conclusions, a brief review and hypothesization of the origin is in order.

Two prevalent magmatic hypotheses suggest (1) that the batholith was formed by a single intrusion which was differentiated during consolidation to form the more mafic marginal rock and the more felsic core rock (Ross, 1933, p. 374–375); and (2) that the batholith was formed by multiple intrusions, of which a marginal, more mafic facies was early, and an inner, more felsic facies was later (Anderson, 1952, p. 264).

Anderson (1952) has taken into account the widespread occurrence of replacement textures in the rocks of the batholith and proposed multiple intrusion followed by extensive endomorphic alteration by "post-consolidation solutions" which first converted a marginal intrusive dioritic rock to quartz diorite and then changed a later inner intrusive quartz dioritic rock to granodiorite and quartz monzonite.

Replacement growths formed by the late crystallization of quartz, potassium feldspar, and many of the accessory minerals in rocks from many localities have been described by Anderson (1930, p. 30–32), Currier (1935), R. J. Roberts,[2] Anderson and Hammerand (1940), and Johnson (1947). These workers followed earlier ideas of Gillson (1927) who described replacement phenomena in satellitic bodies of granitic rock in northern Idaho (see also Gilluly, 1933). Currier (1935, p. 9) suggested that the late potassium feldspathization formed either by a late magmatic or deuteric process, or a nonmagmatic potassium metasomatism.

Various metamorphic and magmatic phases of the batholith and its border have been more recently discussed by Hietanen (1961) in the northern part near Orofino; Reid (1959 a and b) in the north-central part near Elk City; Hamilton (1953, 1958, and 1960) in the west-central part near Riggins; Leonard (1957) in the central part near Big Creek; and Larsen and Schmidt (1958) for the batholith in general.

Four distinct stages of the genetic history of the Idaho batholith in Adams and Valley Counties are interpreted from the present reconnaissance study.

1. Regional synkinematic metamorphism caused essentially isochemical recrystallization of preexisting dominantly sedimentary rocks during one or more episodes (Reid, 1959 a and b). The intensity of metamorphism increased systematically toward the east causing a mineral zonation which is recorded in inclusions of schist and calc-silicate granofels in the border and in the Little Valley and Gold Fork zones and which provides evidence that the metamorphic rocks may have extended into the present batholithic area.

    The source rock of the gneiss of Council Mountain, migmatite of McCall and displaced and replaced equivalents is not known. The Precambrian Belt Series, consisting of 40,000 to 60,000 feet of dominantly argillaceous, less abundant quartzitic, and minor calcic sedimentary rocks as known in northern Idaho, constitutes a likely source rock on the basis of chemical composition, large volume and thickness, and stratigraphic position. Older schists and gneisses of Precambrian age, as known in eastern Idaho and western Montana, are just as likely a source. On the other hand, the Permian and Mesozoic rocks, consisting of 10,000 to 15,000 feet of dominantly basic volcanics and limestones and prominent cherts and phosphates, are not a likely source rock because they would give rise to abundant para-amphibolite and calc-silicate granofels not common in the metamorphic section in Adams and Valley Counties. For a similar

[2] Roberts, R. J., 1938, The petrography and ore deposits of the Dixie district, Idaho: Univ. Washington [Seattle], unpub. M.S. thesis.

reason, the Paleozoic section is excluded, at least the section of 10,000 to 30,000 feet of limestone, quartzite, and shale known on the east side of the batholith. This does not, however, exclude a possible thick Paleozoic, eugeosynclinal-equivalent section which may have occupied the present batholithic site.

2. Continued regional synkinematic metamorphism caused most of those rocks which reached a metamorphic grade equivalent to that of kyanite zone to be partially converted to migmatitic gneisses, such as the gneiss of Council Mountain, and those which reached a metamorphic grade equivalent to or greater than that of the sillimanite zone to be completely converted to migmatitic gneisses as exemplified by the migmatite of McCall. Sodium metasomatism is likely because large volumes of sedimentary rock with a bulk composition similar to that of the migmatite of McCall do not exist.
3. The emplacement of the batholith may have been by intrusion of magma, by anatexial melting and mobilization, by recrystallization and transformation of migmatite in place, or by some combination of these. The process of emplacement remains unknown; most likely several processes are involved in different parts of the batholith even along the McCall-Donnelly section. Some part of the presently known rock zonation along the Donnelly section must be accounted for during the emplacement of the batholith, but how much was developed in this phase and how much was developed in the next, endomorphic phase is not known. Even the boundary between metamorphic rock in place and mobile batholithic rock is arbitrary at this stage of the study.
4. Endomorphic alteration acted over the entire area of the batholith through a systematically gradational set of physicochemical conditions during a static late-batholithic episode. This final equilibrium adjustment is reflected in the recrystallization chiefly of quartz and potassium feldspar and the reconstitution and replacement of plagioclase in the sense of Anderson (1942). Where the emplacement was magmatic, the endomorphism acted during a late-magmatic and postmagmatic interval (Tuttle, 1952); where the emplacement was metasomatic, the endomorphism was equivalent to a retrogressive interval of regional metamorphism.

That the endomorphic process continued to act late after the formation of the batholith, causing replacement in solid phases, is demonstrated by a dominant northeastward-trending joint set which occurs in all the rocks from migmatite to quartz monzonite but which is most prominent in the directionless rocks and is best developed in the quartz monzonite. The joints cut aplite and pegmatite dikes as well. The joint set is mineral coated with free-space growths of muscovite, quartz, and pyrite indicating that the host rock was solid enough to maintain open cracks at the time of mineral coating. The wall rock in many places is replaced by quartz and potassium feldspar forming a granoblastic mosaic which is continuous with the granular texture of the host rock; in some places porphyroblasts of quartz and potassium feldspar have crystallized across the joint leaving only an included discontinuous line of relict muscovite to mark the former joint.

The endomorphism represented a final adjustment to cooling conditions involving changing pressure, temperature, and compositional factors and acted through reaction, exsolution, reconstitution, recrystallization, and replacement; it involved ion transfer in migrating solutions as well as in rest-liquid media. Readjustment continued at temperatures far below any possible liquid rock phase, and because sufficient time was available, mineral adjustment to equilibrium conditions was nearly complete. As a result, evidence of earlier magmatic or progressive metamorphic phases would be at least partially destroyed. It is not surprising that the evidence for a magmatic origin in contrast to a replacement origin for parts of the batholith in Adams and Valley Counties may be masked by endomorphic, late-stage alteration (Goodspeed, 1959, p. 212, 248).

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