Geologic Section and Road Log Across the Idaho Batholith

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Geologic Section and Road Log
Across the Idaho Batholith

by

Rolland R. Reid,[1] Enid Bittner,[1]
William R. Greenwood,[2] Steve Ludington,[2] Karen Lund,[2]
William E. Motzer,[1] and Margo Toth[2]

INTRODUCTION

This field trip to the Idaho batholith is along U. S. Highway 12 across the northern part of the Bitterroot lobe. Geologic data in this report on the eastern part of the trip are less complete than those on the western part. The geology in the northeastern part of the batholith and its environs, seen in part on this trip, has been described in many papers (e.g., Hyndman and Williams, 1976; Chase, 1973). Figure 1 is a generalized geologic map of the Idaho batholith.

The Idaho batholith, broadly of late Cretaceous age, is a large intrusion ranging in composition from quartz diorite to granite. It is cut by several smaller Tertiary batholiths. Much of the material, formerly regarded as border-zone batholith, is now known to be older metamorphic rock of several kinds. The Bitterroot lobe was intruded into metasedimentary rocks that are regarded as Belt-equivalent with varying degrees of certainty (e.g., Hietanen, 1962, 1963a, and 1963b; Nold, 1968). Some or much of the metamorphic rocks may be pre-Belt (Armstrong, 1975). Intrusive gneiss in the border-zone rocks, possibly Precambrian (Reid and others, 1973), may also be of a younger age, possibly Cretaceous, for reasons that are given in the petrology section later in this paper. Rock names used in this paper are based on the Streckeisen (1973) classification.

Structures in the metamorphic wall rocks of the batholith are complex, involving three or more fold sets. At least a part of the deformation relates to the processes of batholithic emplacement. The general disposition of the foliation is variable, ranging from near-vertical, as exemplified by rocks in the field-trip area west of the batholith, to more or less recumbent (neglecting young, mild flexures) as in the Elk City region south of the field-trip area.

The field-trip route (Road Log and Figures 2, 3, 8, 9, and 10), which extends eastward along U. S. Highway

12 from Lowell, Idaho, to a point west of Lolo, Montana, is divided into three sections: (1) the area west of the Idaho batholith (STOPS 1-3), also shown in greater detail in Figures 4-6; (2) the area of the Idaho batholith (STOPS 4-12); and (3) the area east of the Idaho batholith between the stops west of the batholith are described later in the paper.

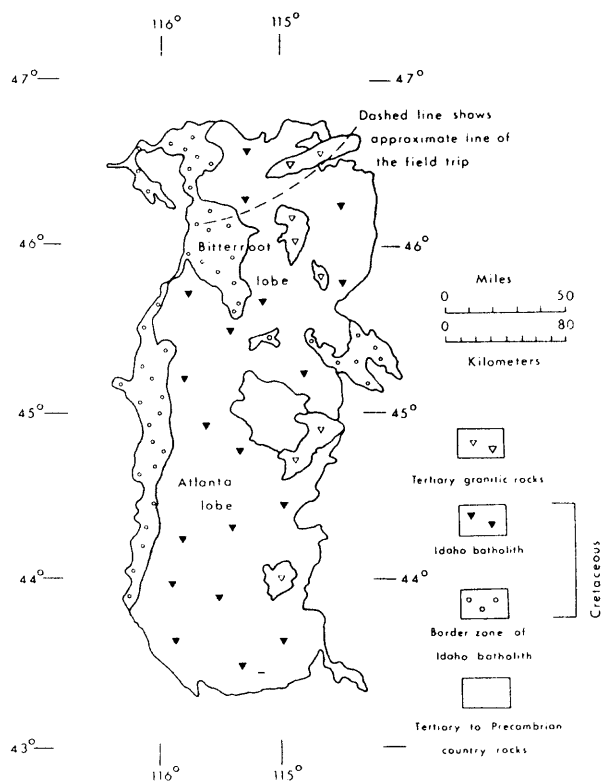Gamma-ray spectroscopy values were obtained with a Geometrics 400 gamma-ray spectrometer to see if they

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Figure 1. Generalized geologic map of the Idaho batholith.

would help with rock correlations. This instrument measures total gamma-ray counts, K^{40}, Bi^{214}, and Tl^{208}. Bi^{214} and Tl^{208} are daughter elements of U^{238} and Th^{232} respectively. These daughter-element measurements are reported as equivalent values of U and Th. Widespread measurements of this type throughout the Idaho batholith by Earl Bennett (written communication) have shown that the Cretaceous plutons that form most of the main batholith have approximately 4,000 to 5,000 total counts over a 30-second counting period, whereas the hypabyssal Tertiary plutons have generally much higher counts (7,000 to 15,000 total counts). The Tertiary dikes throughout the batholith generally have from 6,000 to 10,000 total counts. The lowest values obtained in granitic rocks within the state were from the tonalitic gneisses of this study and were generally less than 4,000 total counts. The radioactive accessory minerals in the tonalitic gneiss and in the granitic phases of the Idaho batholith include thorite, which may contain most of the thorium.

The averages of 4 to 11 values measured for each rock type observed on this field trip are given in the order: total counts, K^{40}, U, and Th. Tonalitic gneiss: 3,300, 300, 75, 35; metasedimentary rocks: 4,800, 400, 120, 80; granodiorites and granites of the Idaho batholith: 4,600, 500, 95, 55; migmatitic screens in the batholith: 5,500, 490, 130, 75; Tertiary(?) granites and dikes: 7,700, 670, 195, 125.

ROCKS WEST OF THE IDAHO BATHOLITH

TONALITIC GNEISS

Tonalitic gneiss, averaging near-vertical dips, makes up the bulk of rocks west of the batholith on this field trip. The gneiss is predominantly biotitic. Between Lowell and Pet King Creek (Figures 2-6), gneiss is exposed for about 3 kilometers along the highway. An additional 3 kilometers of gneiss exposure occurs through
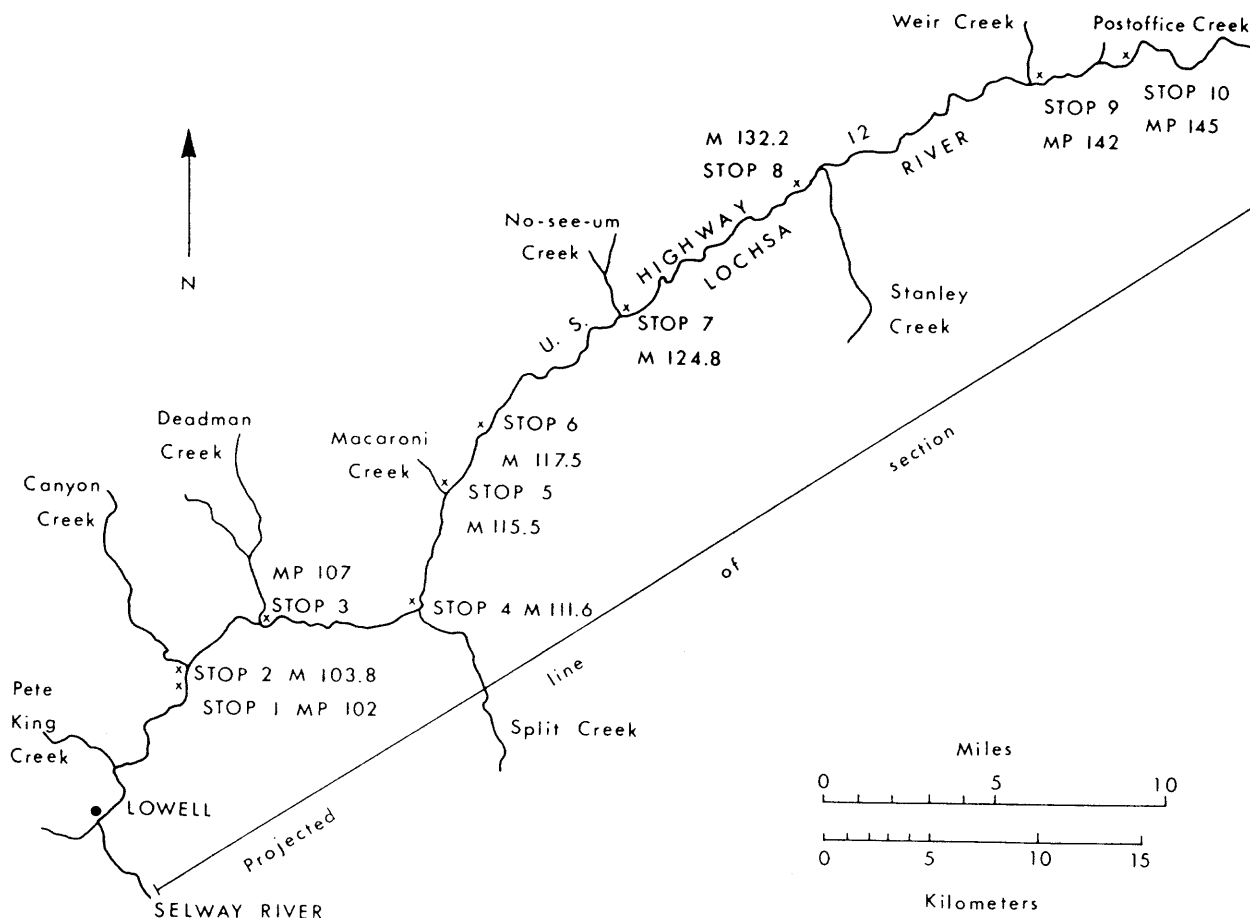

Figure 2. Route of field trip along U. S. Highway 12 between Lowell, Idaho, and a point along Lolo Creek west of Lolo, Montana, showing stops. The route map is continued in Figure 3. MP = milepost. M = mileage at points between mileposts.

the core zone of an antiform extending from Station 009 to near Station 026A (Figures 4-6), and 1 kilometer of gneiss crops out in a synform near Station 030 (STOP 1). Parts of the gneiss are gradational into andesine-biotite quartzite, and the two rocks are not readily distinguishable in the field. All such rocks are called tonalitic gneiss in Figures 4-6. A few thin sheets of amphibolite occur in the gneiss.

A preliminary petrographic study of ten thin sections ·of the tonalitic gneiss near Lowell has revealed many similarities of essential and accessory minerals to those of postkinematic tonalite and quartz diorite of the Idaho batholith. Grain size ranges from 0.5 to 1.0 millimeter. Modes are given in Figure 7.

Plagioclase constitutes about 55 percent of the tonalitic gneiss. It is granoblastic, non-zoned, and locally myrmekitic and ranges from An_{35} to An_{40} in four thin sections. In one thin section, plagioclase is cut by extension fractures filled with quartz, sericite, and opaque grains. The extension fractures, at a high angle to the plane of the thin section, make an angle of about 30 degrees with the schistosity.

Biotite is a strong brownish red and constitutes about 14 percent of the rock. It is partly intergrown with hornblende in two of ten thin sections. In one thin section, biotite flakes are elongated parallel to the lineation in the rocks. Near chlorite-sphene alteration patches, biotite becomes a pale brown.

Quartz constitutes about 27 percent of the gneiss. In some rocks it forms platy grains elongated parallel to the lineation direction. In others, large, platy, granoblastic grains are cut by partly granulated cataclastic shear zones parallel to the schistosity. These early cataclastic zones have partly recovered to form small granoblastic grains which are then further strained; and the grains now show undulatory extinction. Large grains also display undulatory extinction. Accessory minerals include zircon, pyrite, calcite, sphene, apatite, garnet, thorite, rutile, beta-zoisite, and baddeleyite.
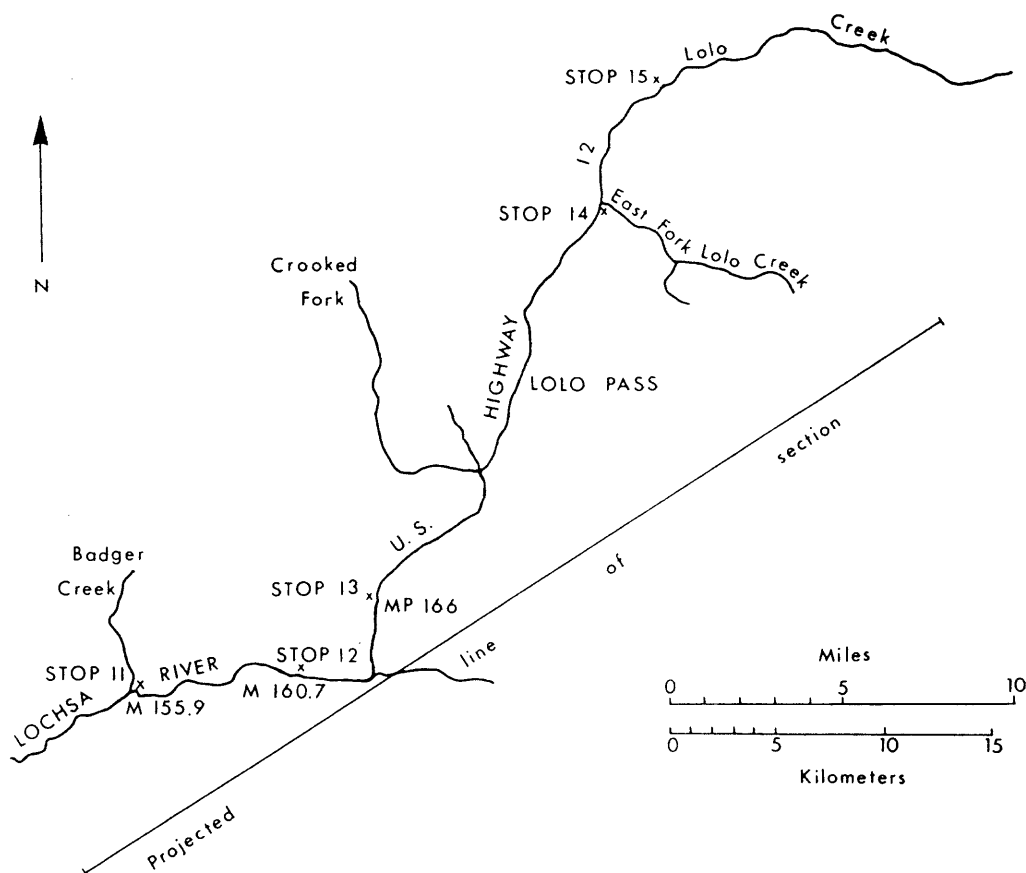

Figure 3. Route of field trip along U. S. Highway 12 between Lowell, Idaho, and a point along Lolo Creek west of Lolo, Montana, showing stops. This route map continues from Figure 2. MP = milepost and M = mileage at points between mileposts.
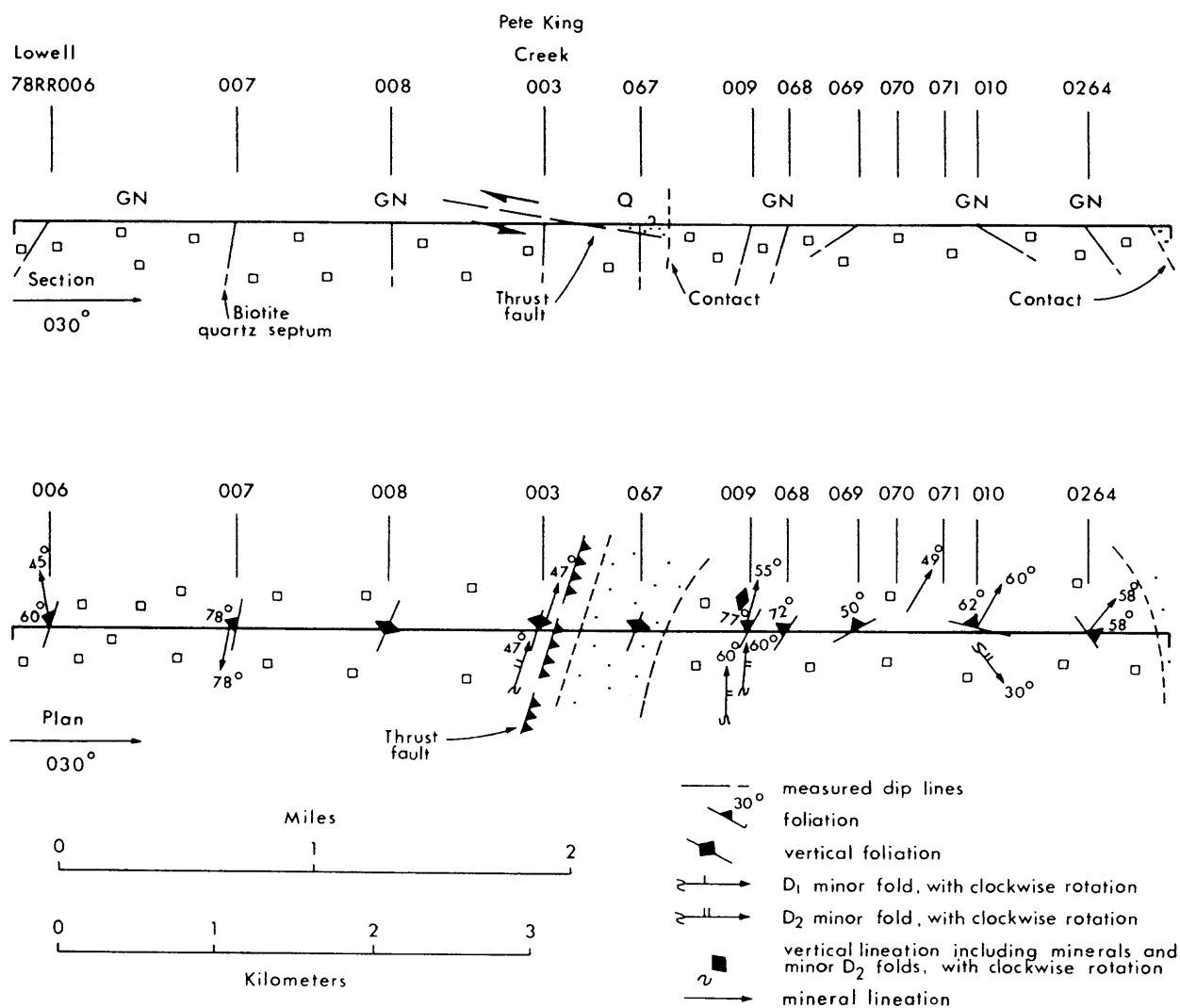
Figure 4. Cross-section and strip geologic map from Lowell, Idaho, to the Idaho batholith, along U. S. Highway 12 (see Figures 2 and 3). Geologic map symbols defined in this figure also apply to Figures 5 and 6. This section is continued in Figure 5. GN = tonalitic gneiss. Q = biotite quartzite. Selected stations are described in *Metamorphic Rocks at Several Stations West of the Idaho Batholith.*

In one oriented sample the minerals have a strong lineation that plunges down the near-vertical dip. This lineation style is common in many of the tonalitic gneiss exposures. Minerals with strong elongation and parallel orientation include blebs of pyrite; grains and grain clusters of biotite, zircon, sphene (which partly rims rutile), rutile, beta-zoisite, apatite, and baddeleyite; blebs and platy grains of quartz; and hornblende. Pyrite partly replaces magnetite and may have inherited its elongate form from that mineral. In two thin sections biotite displays much cataclastic kinking and related alteration to chlorite and sphene.

The history interpreted for the tonalitic gneiss follows: The intrusion into biotite schists and quartzites was accompanied and followed by deformation and metamorphism to produce a strongly foliated biotite-plagioclase-quartz assemblage. A mineral lineation developed in the foliation parallel to the dip direction. At some places, the strain rate perhaps exceeded the recovery rate (e.g., Hatcher, 1978), resulting in cataclastic quartz that was partly annealed in continuing recovery.

Augen gneiss has been included with the tonalitic gneiss in this discussion as it is mostly tonalitic also,

except for a few 2-to 3-meter-thick zones that are granodioritic and have rapakivi rims on the K-feldspar augen. Pegmatites in steep-to shallow-dipping dikes and in concordant sheets are also tonalitic, having bulk compositions much like those of the tonalitic gneisses.

QUARTZITES

Between Stations 026A and 029 (Figures 4-6), the biotite quartzites on the northeast limb of the antiform crop out for about 2 kilometers. Nearly 3 kilometers of biotite quartzite lies in the northeast limb of the synform at STOP 1 from west of Station 072 to near 073. STOP 2 is in this unit, whereas STOP 1 is at a tonalitic gneiss unit in the quartzite. At Station 027, several

quartz lenses occur that probably represent flattened cobbles and boulders of quartzite in a conglomeratic unit. In the southwestern limb of the antiform (Station 067), biotite quartzite is intruded by and partly faulted against tonalitic gneiss and is much thinner (about 0.5 km) than that in the northeast limb. Biotite quartzite generally contains 15 percent or less andesine and is partly gradational toward biotite schist. Small isoclinal folds exist in the quartzites, so that their true stratigraphic thickness is unknown.

Between the calc-silicate gneiss, next to be discussed, and the Idaho batholith, about 1 kilometer of coarsely crystalline white quartzite is exposed.

Figure 5. Cross-section and strip geologic map from Lowell, Idaho, to the Idaho batholith, along U. S. Highway 12 (see Figures 2 and 3). Geologic map symbols used here are defined in Figure 4. This section extends from that given in Figure 4 and continues in Figure 6. GN = tonalitic gneiss. Q = biotite quartzite. AGN = augen gneiss. MP = milepost. M = mileage at points between mileposts. Selected stations are described in *Metamorphic Rocks at Several Stations West of the Idaho Batholith.*
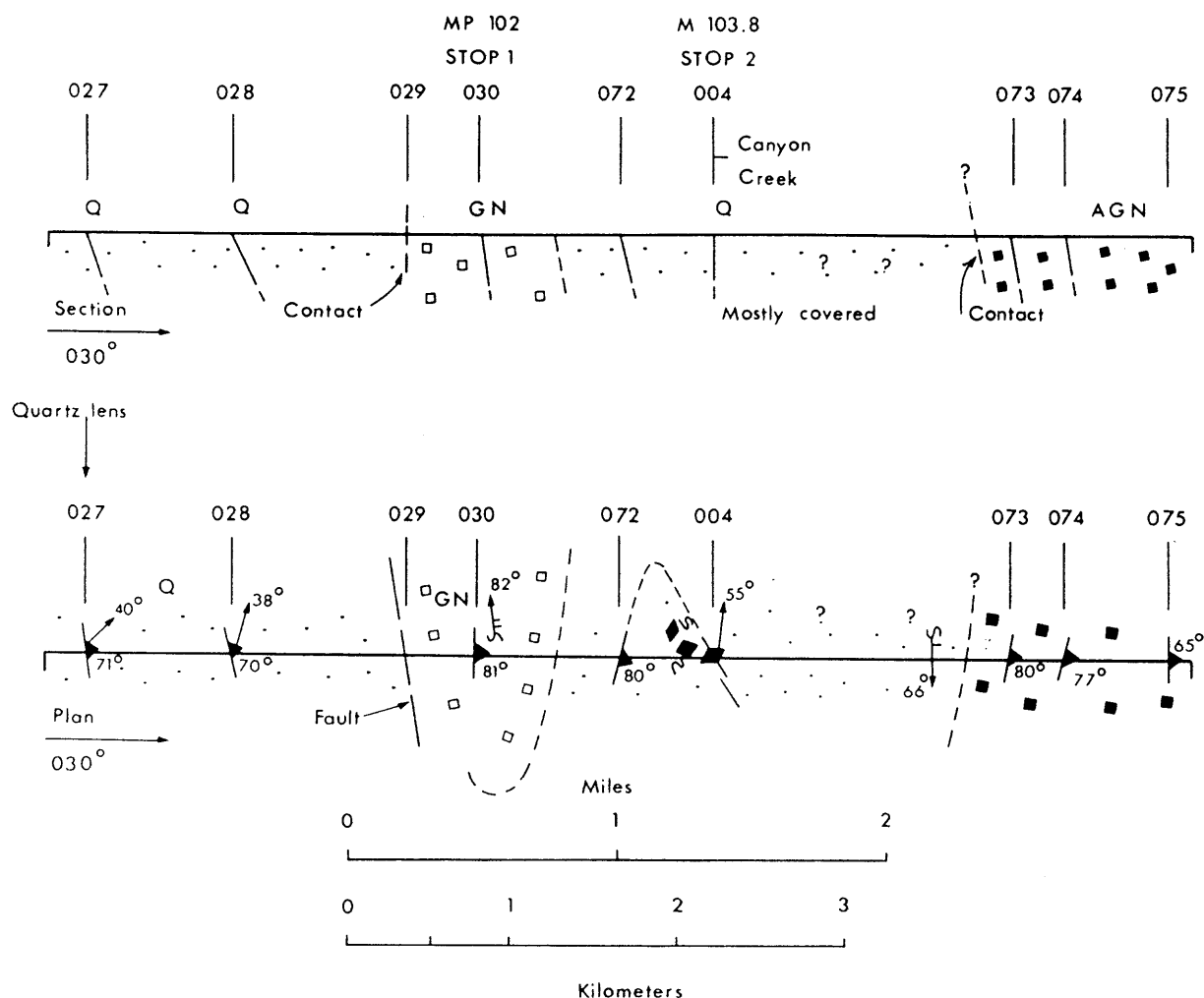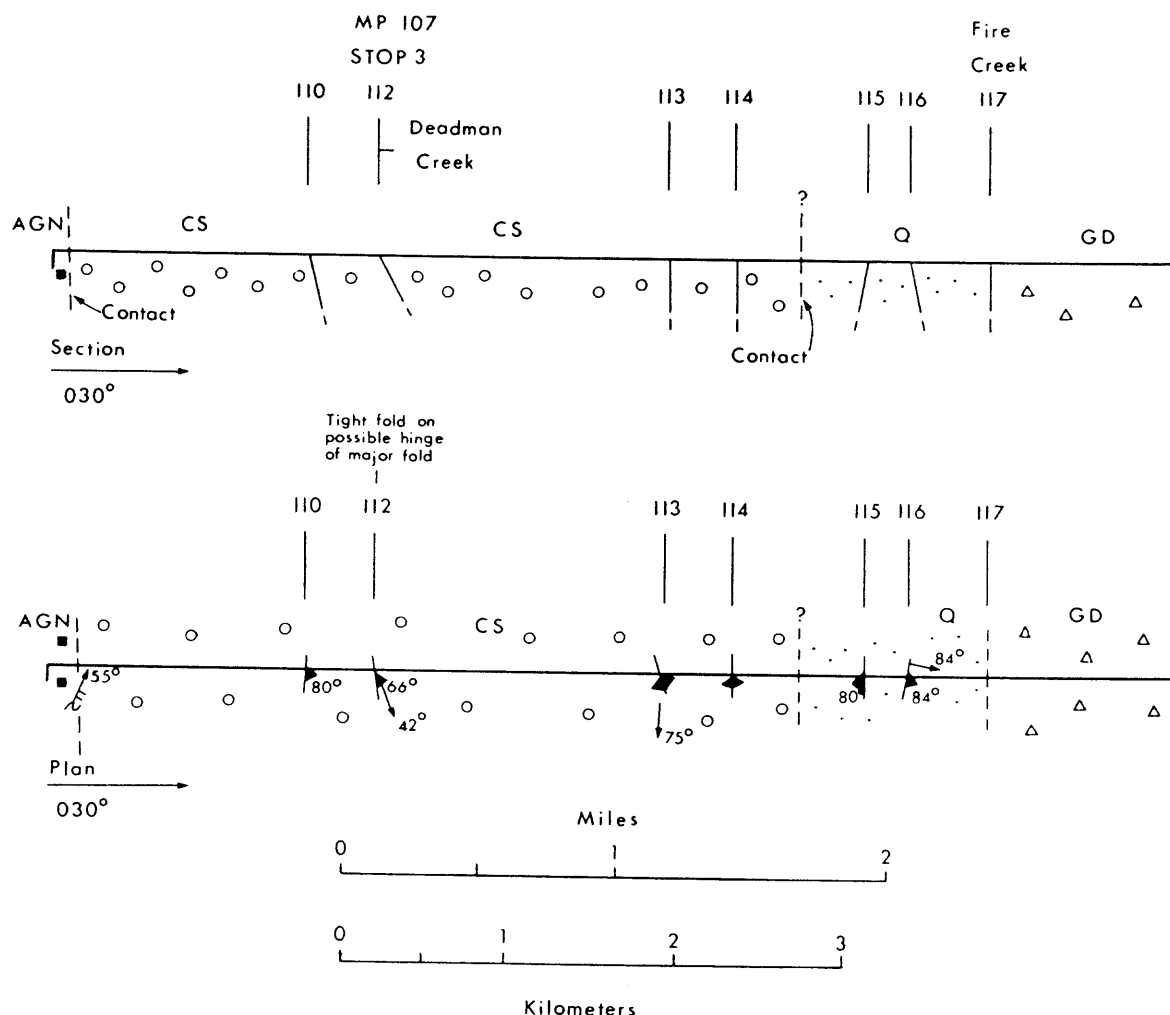
Figure 6. Cross-section and strip geologic map from Lowell, Idaho, to the Idaho batholith along U. S. Highway 12 (see Figures 2 and 3). Geologic map symbols used here are defined in Figure 4. This section continues from that given in Figure 5. AGN = augen gneiss. CS = calc-silicate gneiss. Q = white quartzite. GD = granodiorite of the Idaho batholith. MP = milepost. Selected stations are described in *Metamorphic Rocks at Several Stations West of the Idaho Batholith.*

CALC-SILICATE ROCKS AND AUGEN GNEISSES

About 1.25 kilometers of augen gneiss, mentioned briefly in the section on tonalitic gneiss, is exposed along the highway between Station 073 and the contact with the calc-silicate gneiss east of Station 075 (Figures 4-6). The calc-silicate gneiss is exposed along the highway for about 4.5 kilometers. Small isoclinal folds exist in this unit, so that the true stratigraphic thickness is unknown. STOP 3 is at Station 112 in the calc-silicate gneiss (Figures 4-6).

Quartzites and calc-silicate rocks described herein may be highly metamorphosed equivalents, respectively, of quartzites of the Ravalli Group and dolomite-bearing argillites of the Wallace Formation of the Belt Supergroup, as proposed by Morrison (1968, p. 108).

ROCKS OF THE IDAHO BATHOLITH

INTRODUCTION

Intrusive rocks of the Idaho batholith are more mafic on the west and become progressively more felsic eastward. Quartz diorite dikes and sheets intrude the metasedimentary and metaigneous rocks west of the batholith. A 2-kilometer thick zone of granodiorite along the west edge of the batholith proper grades into granite that makes up the bulk of the batholith to its eastern contact. In the Lochsa River valley, granite occurs directly at the western contact of the batholith;

some of this granite may predate granodiorite inasmuch as a xenolith of granite was found in granodiorite. The descriptions of the batholithic rocks that follow are based mainly on field and hand-specimen observations, but some petrography was done on rocks from near the western margin. Modal compositions are shown on Figure 7.
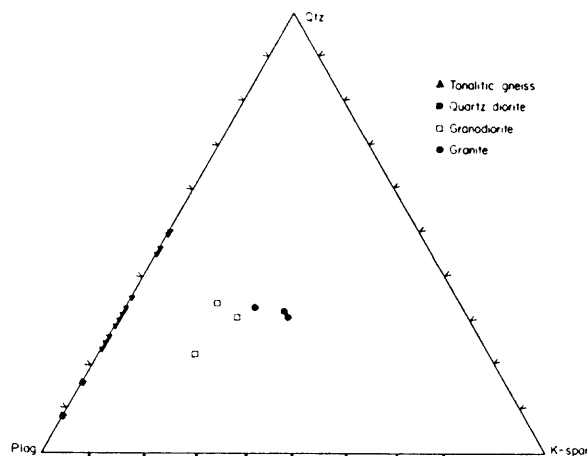

Figure 7. Diagram illustrating the modes of tonalitic gneiss, quartz diorite, granodiorite, and granite in the Lowell area.

The batholith is divided into three broad intervals or facies for purposes of this field trip. The western facies is mostly granodioritic with steeply dipping flow foliation. The central facies is mostly granite, brecciated, and altered, with shallow-dipping flow foliation in places; the eastern facies is mostly granite with steeply dipping flow foliation.

QUARTZ DIORITE DIKES
AND SHEETS WEST
OF THE BATHOLITH

Biotite to hornblende-biotite quartz diorite in dikes and sheets intruding the calc-silicate gneiss west of the batholith has a grain size of 1-2 millimeters. Plagioclase is euhedral with normal zoning: andesine cores to oligoclase rims. Red-brown biotite, moderately aligned in a primary flow foliation, is partly altered to muscovite, chlorite, and sphene. Quartz is anhedral. Accessory minerals include apatite, thorite, zircon, baddeleyite, sphene, epidote, and magnetite.

WESTERN FACIES

The western part of the batholith is characterized by steeply dipping zones of granodiorite with primary flow

foliation (STOP 4, Figure 8) intercalated with zones of massive granodiorite. Screens of migmatite involving lit-par-lit gneisses and metasedimentary material up to 1 kilometer thick parallel the primary flow foliation.

Granodiorite at STOP 4 has a hypidiomorphic granular texture and moderate primary flow foliation together with some more massive granodiorite. Grain size is 1-2 millimeters. Sodic plagioclase (oligoclase) has normal zoning and euhedral grain form. Other minerals include quartz, K-feldspar, and biotite; and some late muscovite occurs. Accessory minerals include zircon, baddeleyite, apatite, magnetite, sphene, and leucoxene.

CENTRAL FACIES

The granite of the central part of the batholith is massive for the most part, but locally shallow-dipping zones display primary flow foliation. The granite is hypidiomorphic granular, and the grain size is 1-2 millimeters. Plagioclase has prismatic form and normal zoning. Other major minerals include K-feldspar, quartz, and biotite. Accessory minerals include apatite, epidote, sphene, allanite, thorite, baddeleyite, zircon, and magnetite.

Certain zones in the central part (STOPS 8, 9; Figures 8-10) are intensely, randomly jointed (Figure 11) and altered. The alteration involves silicification and chloritization and produces a pink coloration perhaps due to the formation of K-feldspar, or the alteration to clay, or the introduction of iron in the existing feldspars.

EASTERN FACIES

Granite in the eastern part of the batholith (STOPS 10, 11; Figures 8-10) is much less intensely brecciated and altered than that in the central part. Northeast-trending joints are somewhat more strongly developed than other joints (Figure 12). Primary flow foliation dips steeply, more or less parallel to migmatite screens.

ROCKS EAST OF THE IDAHO BATHOLITH

East of STOP 12, calc-silicate quartzites (Figure 10) like those at STOP 13 are intruded by granite at the eastern contact of the Idaho batholith. Metasedimentary rocks east of the Idaho batholith are correlated with formations of the Belt Supergroup on the basis of lithologic similarities (Nold, 1968). These rocks are also intruded by Tertiary(?) granite of the Lolo batholith (STOP 14). Quartzitic rocks of the Ravalli Group (STOP 15) are exposed west and east of the Lolo batho-
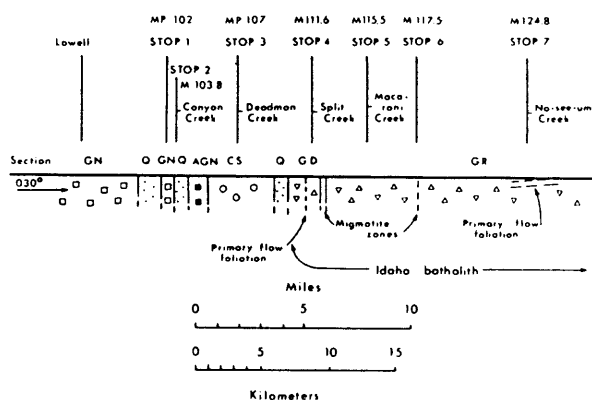
Figure 8. Major rock units and structures along U. S. Highway 12 across the western border and western part of the Bitterroot lobe of the Idaho batholith. This highly generalized section shows only units thicker than a kilometer and emphasizes the vertical character of wall rock structures and contacts. GN = tonalitic gneiss, includes some quartzite. Q = biotite quartzite and white quartzite. AGN = augen gneiss. CS = calc-silicate gneiss. GD = granodiorite. GR = granite. MP = milepost. M = mileage at points between mileposts. This section is continued in Figure 9.
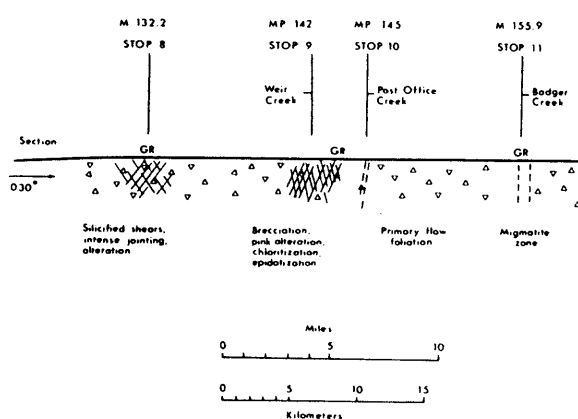

Figure 9. Major structural features and alteration zones in granite along U. S. Highway 12 across the center and eastern part of the Bitterroot lobe of the Idaho batholith. GR = granite. MP = milepost. M = mileage at points between mileposts. This section extends from that shown in Figure 8 and continues in Figure 10.

Figure 10. Major rock units and structural features along U. S. Highway 12 across the eastern border zone of the Bitterroot lobe of the Idaho batholith and across the Lolo batholith. This highly generalized section emphasizes the vertical nature of structures in the contact zone and in the wall rocks. GR = granite. CQ = calcareous quartzite. TG = granite. MP = milepost. M = mileage at points between mileposts. This section continues from that given in Figure 9.

lith along U. S. Highway 12 (Figure 10). Details of the road cuts in the calc-silicate rocks of the Wallace Formation at STOP 13 and of the quartzite of the Ravalli Group at STOP 15 are shown in Figures 18 and 19, respectively.

STRUCTURE AND PETROLOGY
OF THE METAMORPHIC ROCKS
WEST OF THE BATHOLITH

The metaquartzites and calc-silicate gneisses west of the Idaho batholith, described later in this paper, have been correlated with the Belt Supergroup of northern Idaho (Greenwood and Morrison, 1973). The calc-silicate gneiss and the quartzite west of the batholith closely resemble nearby rock units that Hietanen (1962, p. A18) correlated respectively with the Wallace Formation and the underlying Ravalli Group of the Belt Supergroup.

Evidence in minor folds suggests at least two episodes and perhaps three of deformation and associated metamorphism (Greenwood and Morrison, 1973). The minor folds, described in detail later in this paper and shown in Figures 4-6, suggest an early isoclinal folding (D1) which developed an axial-plane schistosity (D1, D2, etc. refer to successive deformations). This folding suggests some repetition in the quartzite and the calc-silicate gneiss units, although the sketchy mapping to

date as well as the heavy forest cover have not made it possible to recognize such repetitions. Later folding (D2) produced small to large folds that deformed the axial-plane schistosity of D1 and that may have increased further the original sedimentary thickness.

About half the section between Lowell and the batholith (Figures 4-6) is occupied by metaigneous rocks including the tonalitic gneiss and the augen gneiss. Included here with tonalitic gneiss are some rocks,

previously mapped as biotite-andesine schist by Morrison (1968), that are probably of metasedimentary origin modified by metasomatism. The metaigneous portion of the tonalitic gneiss unit is so strongly sheared and recrystallized in much of this section that it resembles the metasedimentary biotite-andesine schist in outcrop. Even with close hand-lens study, the distinction may be difficult. However, petrographic study has shown the close mineralogic similarity of the metaigneous gneiss to the postkinematic quartz diorites and tonalites of the Idaho batholith (Figure 7); moreover, dikes of tonalitic gneiss intrude the biotite quartzite at Station 029 (Figures 4-6), and concordant lit-parlit injections are seen at Station 072. The thick tonalitic gneiss bodies also appear to be in part broadly concordant injections from the parallelism of their foliation and contacts to the foliation in the metasedimentary sequence. Therefore, an igneous origin is proposed for the tonalitic gneiss.

Prior work (Greenwood and Morrison, 1973; Reid and others, 1973) has suggested that tonalitic gneisses, including some of those between Lowell and the west contact of the batholith, were emplaced during Precambrian metamorphism. Now it appears equally possible that the Precambrian ages, which were based on isotopic age determinations on zircon, may be the ages of the deep crustal rocks from which at least a part of the tonalitic magma was anatectically derived at some later

time. The mineralogical similarity of the tonalitic gneisses to postkinematic quartz diorites and tonalites of the Idaho batholith leads us to postulate both a chemical and a temporal relation; specifically, we postulate that these gneisses were early phases of Idaho batholith injection into the wall and roof rocks and were metamorphosed by the batholith as it continued to rise into and through its roof and wall rocks.

The timing of petrologic events in the area presents problems. The tonalitic gneiss contains no minor D1 folds; therefore, we believe that the tonalitic gneiss was injected after D1. Coming after D1, the gneiss appears to belong to D2, and the D2 event is considered to have occurred at the time of and as a result of the emplacement of the batholith.

A single metamorphic event is shown by the fabric of both the gneiss and the older metasedimentary rocks. Apparently all the rocks were recrystallized during batholithic emplacement, and any fabric evidence of the older metamorphic and associated folding events was destroyed. Only a few relict grains of garnet and kyanite persist, formed in some earlier metamorphic event or an early stage of batholith emplacement.

It follows that the foliation in the tonalitic gneiss was generated in D2. The largely planar foliation displayed
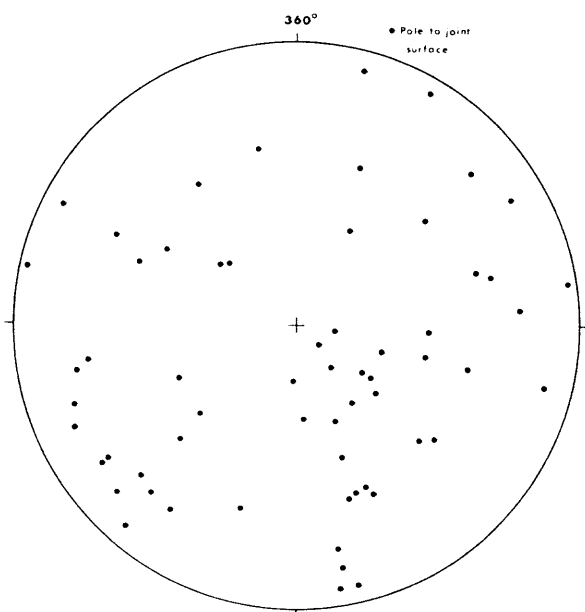

Figure 11. Orientation of 59 joints near STOP 9 in the Greystone Butte quadrangle; poles plotted on the lower hemisphere of the Wulff stereonet.
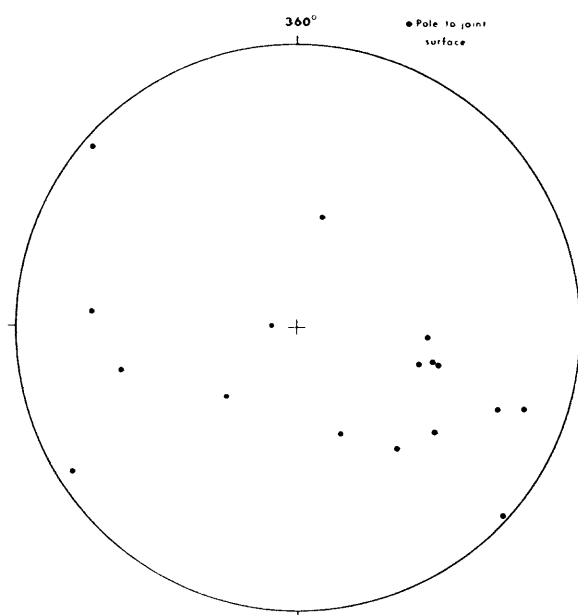
Figure 12. Orientation of 17 joints near STOP 10 in the Bear Mountain quadrangle. Poles plotted on the lower hemisphere of the Wulff stereonet.

by the gneiss is expected in such a single-phase event in which a massive igneous rock is converted to gneiss by penetrative shearing and concomitant metamorphic recrystallization. The few minor folds that occur perhaps represent sites of local, minor stress reorientation, so that the plane of viscous flow shifted slightly, and pre-existing foliation could be deformed. Folded boudins may be understood in much the same way.

The large folds in the gneiss perhaps also represent late stress reorientation in which the early formed foliation was flexed during a late stage of continuing deformation. Some minor folds may be systematic on the large folds, postdating such folds that deform boudins.

Mineral lineations parallel some but not all of the minor D2 fold axes in the gneiss. D1 fold axes in the metasedimentary rocks have no parallel mineral lineation. Furthermore, the existence of "orthogonal" minor folds in the metasedimentary rocks (some axes horizontal and some vertical) is suggestive of an orthorhombic, flattening style of deformation. The same orthorhombic, flattening style is expressed in the tonalitic gneisses by the presence of lozenge-shaped boudins of pegmatite, alaskite, and pegmatitic quartz which bear the same lineation imprint as the rest of the rock. All these data suggest two directions of extension in the foliation plane in the metamorphic sequence. This extension can be understood as the effect of horizontal pressure exerted by the rising batholith, the batholith spreading laterally somewhat as it rose into higher crustal levels.

Pegmatite becomes more abundant in the rocks near to the batholith and seems clearly to be derived from the batholith. Pegmatite-sheet involvement in the deformation further supports the correlation of D2 with the time of batholith emplacement. Pegmatite continued to be injected after deformation ceased, forming nonfolded dikes. If the synkinematic and the post-kinematic dikes are all of a single generation, then the deformation is tied closely to a particular stage of batholith development. Alternatively, some early pegmatites may have been formed from the tonalites and quartz diorites, and the later ones may have been formed from the granites. The shallow-dipping pegmatites were injected into shallow-dipping primary fractures (Balk, 1937, p. 34) developed within the batholith and in its wall rocks within a few kilometers of the contact.

Pegmatite sheets could not be injected along the foliation in the gneiss until that foliation had formed. Then, once the pegmatite had been injected and deformed in lozenge-shaped boudins, they and the enclosing foliated gneiss were wrapped around the hinges of the large folds. This structural sequence further indicates the late character of the large folds.

The large folds seem, however, to have formed in about the same general stress field as that of the earlier, purely orthorhombic stage of folds. As shown in Figure 16, the large folds are of conical symmetry. Mineral lineations throughout the area plunge about parallel to the axes of the large conical folds. The lineations are viewed as lying in kinematic *a*, a near-vertical flow and stretching direction. Seen in this way, the large folds are comparable to the vertical folds in salt piercement structures.

Augen gneiss forms a single unit in the eastern part of the section west of the batholith (Figures 4-6). Rapakivi texture in some layers emphasizes its similarity to other augen gneisses in Idaho (e.g. Reid and others, 1970), whereas its generally tonalitic composition suggests a relation to the other tonalitic gneisses. Its age and timing of emplacement are enigmatic, although the absence of D1 structures may constitute evidence for emplacement during D2. It is clearly of igneous origin, including as it does xenoliths of metamorphic rocks. The augen and their rapakivi rims are of igneous form, where little metamorphosed, and modified to more classical augen shapes, where metamorphic reconstitution has been more intense. The rapakivi rims have a relation to the K-feldspar cores suggestive of an origin by exsolution in a late igneous to early metamorphic stage.

West-directed, shallow, eastward-dipping thrust faults cut all the metamorphic rocks west of the batholith (Figure 15). East-directed, shallow-dipping thrust faults cut the metamorphic rocks east of the batholith (Figure 18). The shear products and their relative age suggest a long period of thrusting. The earlier manifestations of thrusting include shears containing mylonitized quartz and shears containing ultramylonite to pseudotachylite. These thrusts appear to be related to the spreading of the batholith very late in its emplacement. Younger movement on the thrusts has produced gouge, breccia, and clay indicative of low-pressure deformation and suggestive of reactivation at some later time.

Sheared andesite and rhyolite dikes parallel the northwest-striking gneissic foliation (Figure 13), and gouge was produced by later faulting along the foliation. These faults display horizontal slickensides indicative of strike-slip movement. Faults having comparable features in the batholith display extension joints indicative of right-lateral shear, near STOP 8, for example. The faults having horizontal slickensides in
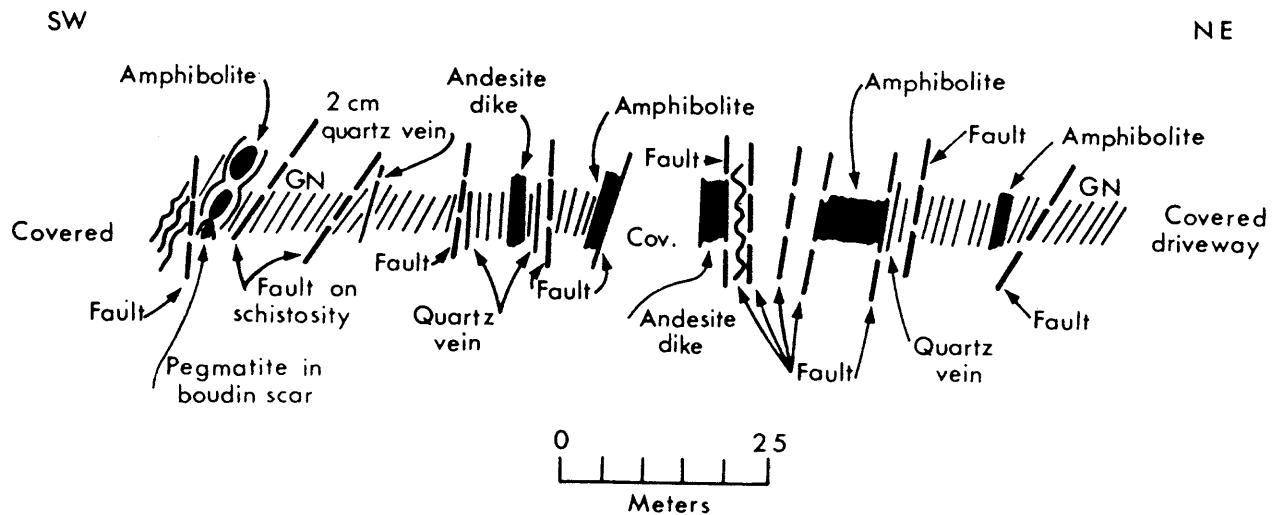
Figure 13. Sketched cross-section at Station 78RR006, near Lowell, Idaho (see Figures 4-6). GN = tonalitic gneiss.

the metamorphic rocks are probably also right-lateral. The earlier thrusts may have been reactivated during this phase of strike-slip faulting. Alternately, reactivation may be due to younger uplift during intrusion by a Tertiary batholith beneath the area.

EMPLACEMENT AND ALTERATION OF THE BATHOLITH

If we assume that the batholith was rising buoyantly in the zone of viscous flow (cf. Ramberg, 1972), we may inquire whether the batholith was generally inducing upward flow in its walls as a result of arching of the country rocks or whether the batholith was inducing downward flow in its walls and beneath it (Ramberg, 1972) to compensate for the volume vacated by the rising batholithic mass. The structural characteristics of the wall rocks are the same in either way: The D2 flow lines would be near vertical; the D2 lineated minerals would be stretched vertically; and the relative sense of shear between the batholith and its walls would be the same.

The age of rock near a batholith compared with the age farther away may give a clue to the direction of flow in the wall rocks. A batholith that has arched its wall and roof rocks will display older rocks near the contact and younger rocks farther away. On the other hand, a batholith that has undergone marginal underflow will display younger rocks near the contact and older rocks farther away.

Some evidence on these points comes from the Sierra Nevada batholith (Hamilton and Myers, 1967, p. C2):

The rocks of the western border belt in the central Sierra dip steeply toward the batholith and consist of long fault blocks of which those nearest the batholith contain the oldest rocks, although in each block the youngest rocks tend to be on the side toward the batholith. The eastern border belt of the central Sierra dips steeply in either direction, but the rock becomes in a gross way younger westward toward the batholith.

The Sierra Nevada batholith may have induced some underflow in its emplacement, although some late arching may have also occurred on the western side.

Nold (1968) shows in the Lolo Pass area northeast of the Idaho batholith that the rocks are younger toward the batholith. The Prichard Formation is exposed farthest away, the Ravalli Group rocks closer, and the Wallace Formation in contact with the batholith. Thus the Idaho batholith may have had underflow at its northeastern margin.

Yet another line of evidence may be considered in the rocks west of the Idaho batholith. Batholithic arching would bend upward any prebatholithic linear structures in the metamorphic rocks that were discordant to the contact. Thus, the plunge of the linears in the metamorphic rocks would steepen to the west as the west contact of the batholith is approached. Alternately, batholithic underflow would bend the linears downward, and the plunge of the linears would steepen to the east as the west contact of the batholith is approached.

To investigate this second line of evidence, the orientation of linear structures in metamorphic rocks west of the Idaho batholith was examined on geologic maps prepared by Hietanen (1962, 1963a, 1963b). The fold axes plunge east at shallow angles farther from the batholith and more steeply as the batholith is approach-
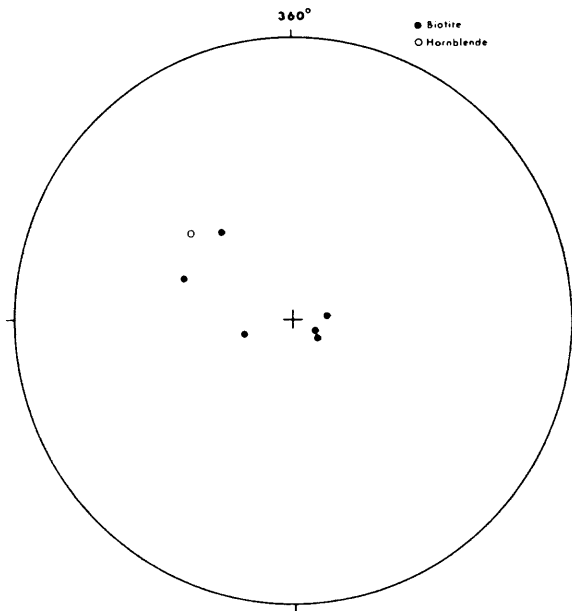
Figure 14. Biotite and hornblende lineations at Stations 78RR006 and 007, near Lowell, Idaho, plotted on the lower hemisphere of the Wulff stereonet.

produced by this mechanism should have monoclinic symmetry, but the structures in the Lowell area have orthorhombic symmetry, which is not consistent with transcurrent shear. The regional down-bending of the lineation in the metamorphic rocks west of the batholith is also inconsistent with transcurrent shear.

More difficult to evaluate is some combination of transcurrent shear and diapirism. The contemporaneity of the batholith and the D2 structures hardly supports such a combined hypothesis, but it cannot be evaluated adequately with data available now.

Morrison (1968) attributed the steep folds of the area to an episode of cross folding; this now seems unlikely. Cross folding would not produce the orthorhombic structures observed.

In a general way, the batholith displays quartz diorite on the west, which grades to granodiorite and then to granite to the east, as has been observed by earlier workers. The existence of granite at the western contact near STOP 4 (Figure 8) and its presence in granodiorite suggests a complex local history that must await further study.

ed. In the Pierce area, the plunge is up to 80 degrees toward the batholith, suggesting a bending down of axes toward the batholith. This plunge also suggests downward flow and possibly underflow.

The granite, granodiorite, quartz diorite, tonalitic gneiss, and metasedimentary rocks all contain similar accessory-mineral suites, suggesting considerable assimilation of the metamorphic wall rocks by the batholithic magma.

In addition, the trans-Idaho discontinuity must be considered, because it, according to Yates (1968), passes through the area. If transcurrent shear had deformed these rocks during their metamorphism, steeply plunging folds could have been generated and mineral lineations would parallel their axes. Structures

Magmatite screens and primary flow foliation suggest a broad general arch hinted at in Figures 8-10 and indicative of a position near the roof of the batholith. Shallow-dipping pegmatite sheets at Station 007 and elsewhere near the western margin of the batholith, both in and out of the batholith, have been injected
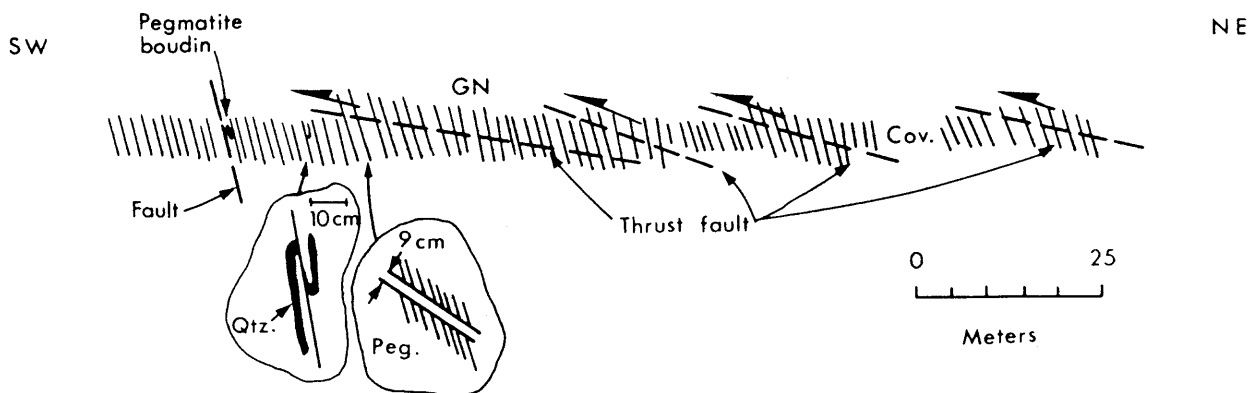

Figure 15. Sketched cross-section at Station 003 near Lowell, Idaho (see Figure 4), exposed in road cuts. GN = tonalitic gneiss.
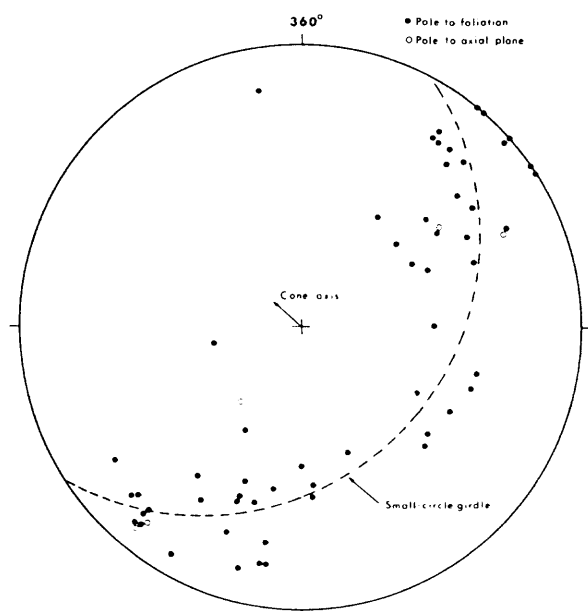
Figure 16. Conical folds in the metamorphic rocks along Lochsa River between Lowell, Idaho, and the Idaho batholith (see Figures 4-6), shown by a small-circle girdle defined by the distribution of poles to foliation. Points are plotted on the lower hemisphere of the Wulff stereonet.
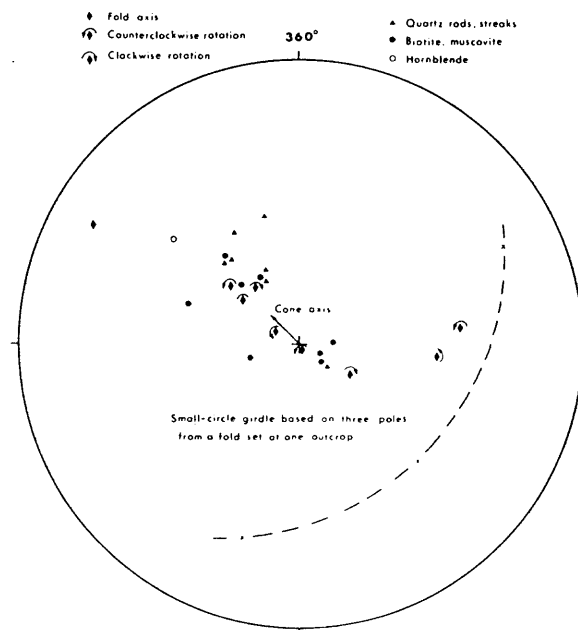

Figure 17. Linear features in the metamorphic rocks along Lochsa River between Lowell, Idaho, and the Idaho batholith (see Figures 4, 5, and 6). Lineations are plotted on the lower hemisphere of the Wulff stereonet.

into primary joints along which some later, minor thrusting has occurred.

From STOP 8 through STOP 12 (central and eastern Bitterroot lobe of the Idaho batholith), the batholith is intensely to moderately jointed and altered within several kilometers of the Lolo batholith of Tertiary(?) age, which lies to the north. We speculate that brittle shattering of the wall rock has occurred during emplacement of the Lolo batholith in shallow crustal levels and that the alteration is due to late hydrothermal solutions emanating from Tertiary(?) granite into the wall rocks, after the emplacement of Tertiary(?) andesite to rhyolite dikes in this part of the Bitterroot lobe. Vertical faults trending 060 degrees are subparallel to the southern margin of the Lolo batholith and may have guided the emplacement or have been formed during the emplacement of that batholith. These faults have the same kind of alteration as that seen in the numerous joints in the central to eastern Bitterroot lobe.

Vertical 325-degree-trending right-lateral and 10-degree-trending left-lateral faults outside this cross-section area show at least some movement postdating the epidote-chlorite-K-feldspar(?) alteration provisionally attributed to the Lolo batholith.

North-directed low-angle thrusts of late-stage Idaho batholithic age lie northeast of the batholith. These thrusts are injected by sheets of contemporaneous pegmatite and mafic rocks.

METAMORPHIC ROCKS AT SEVERAL STATIONS WEST OF THE IDAHO BATHOLITH

At Station 78RR006 near Lowell (Figures 4-6), the rock is primarily tonalitic gneiss with a continuous planar foliation exposed over a distance of 115 meters along the road (Figure 13). Several amphibolitic sheets 1-10 meters thick parallel the foliation and were probably injected after the foliation developed. A steep lineation is present in which biotite and hornblende are both streaked out in a nearly vertical to northwest-plunging array (Figure 14).

Two andesite dikes or sheets, one 25 centimeters thick and the other 3 meters thick, parallel the foliation. Faults parallel to the foliation postdate the andesite dikes and have gouge zones up to 2 meters thick and horizontal mullions and slickensides.

At Station 007 (Figures 4-6), a 30-meter-thick septum of biotite quartzite and biotite schist is enclosed in

tonalitic gneiss that makes up a uniformly steeply dipping section more than 75 meters along the road. A north-south-striking fault dips 15 degrees east and has a gouge zone about 1 meter thick that includes mostly orange clay gouge but also a 15-centimeter pegmatitic quartz vein, which has been mylonitized in the fault zone. The steep faults parallel to foliation previously described do not contain any pegmatitic quartz and may be younger than the thrust faults. Biotite lineation in the gneiss averages a steep plunge to the northwest like that at Station 78RR006 (Figure 14).

Station 003 is at the mouth of Pete King Creek (Figure 15). The gneiss dips nearly vertical over 135 meters of the outcrop. Lozenge-shaped pegmatite boudins occur in the gneiss. Their size generally ranges from 1 to 10 centimeters. A 9-centimeter pegmatite dike cuts across the foliation at a 10-degree angle. Quartz veins in the foliation are shear folded (Figure 15). Biotite and healed quartz streaks and rods form a steeply plunging lineation similar in orientation to that of the biotite and hornblende lineation previously described (Figure 14). Quartz boudins of pegmatitic character (white, massive) are also lozenge-shaped and contain the same streaks of biotite and healed quartz rods that are found in the gneiss.

Several small thrust faults cut the gneiss at Pete King Creek, all with overthrusting toward the west-southwest (Figure 15). These faults all have gouge and breccia of nonmetamorphic character.

Station 009, like the others described, displays a steep homoclinal sequence of tonalitic gneiss. A 130-meter section was studied. As shown in Figures 4-6, this station is on the southwest limb of a steeply plunging antiform in the gneiss. A vein of pegmatitic quartz has first been extended in boudins and subsequently deformed in small passive-flow folds that have bent the boudins. Small folds in this outcrop show both clockwise and counterclockwise rotation. Vertical, 315-degree-trending faults parallel to the foliation have horizontal slickensides. A 4-meter-thick, gouged granophyric dike occurs in one of these faults.

One minor fold with clockwise rotation plunges 60°, 310°. Some biotite lineation streaks parallel this minor fold axis, but others are nearly vertical.

Station 010 displays a steep homoclinal sequence much like those discussed above, except that it is near the hinge of a major, steeply plunging antiform in the gneiss. Some lozenge-shaped boudins of pegmatite lie in the foliation plane, but later-stage muscovite-quartz pegmatite cuts across the foliation as do some still later pegmatitic quartz dikes and veins. Lineation is steeply

oriented much like that described above and consists of stretched muscovite, minor fold axes, crumpled gneiss and associated rodding, and some recrystallized quartz rods.

Station 026A also has a near homoclinal sequence of steeply dipping tonalitic gneisses on the east limb of the antiform. Pegmatite boudins in the plane of the foliation are lozenge shaped. One boudin measured 2 centimeters by 3 centimeters by 5 centimeters, with a horizontal major axis. A 6-meter pegmatite dike and several smaller ones postdate folding.

Minor folds that deform schistosity in the gneiss have a counterclockwise sense of rotation. "Shearing-off" structure is locally developed in that small folds are disrupted by shearing and some layers of gneiss are disrupted and boudinlike in zones of bent folia in the surrounding gneisses. Some minor fold axes plunge 30°, 085°, discordant to the local trend of streaky biotite lineation (plunging 58°, 336°). Other minor folds parallel the mineral lineation.

At Station 027, biotite quartzite to feldspathic biotite quartzite is exposed on the northeast limb of the large antiform described at Station 009 (Figures 4-6). Minor folds (amplitude 1.5 meters, wave-length 0.3 meters) with axial-plane schistosity plunge 22°, 310°, and show clockwise rotation. Streaky quartz lineation plunges 40°, 345°, discordant to the minor folds. A 60-centimeter pegmatite dike that cuts across the schistosity has 5-10-centimeter-thick pegmatitic apophyses that extend along the foliation in lit-par-lit fashion. Quartz lenses here are as long as 60 centimeters in the foliation plane and as thick as 5 centimeters.

Station 028, also in a homoclinal sequence, has more pegmatite, both in lozenge-shaped boudins and in postkinematic dikes, than occurs to the southwest. Some pegmatite is concordant and locally folded, with an internal foliation parallel to the foliation in the enclosing quartzite. Other pegmatite dikes that cut the schistosity at a low angle have an internal flow structure probably of igneous character. Hornblende and biotite lineation in the quartzite parallel approximately the lineations seen earlier (plunge 38°, 315°).

Station 029 is at a fault contact between the quartzite and tonalitic gneiss. Near this fault, tonalitic gneiss dikes inject the quartzite discordantly, different from the generally concordant relations seen elsewhere. The gneiss here contains dark xenoliths.

Station 030 is near the axis of a tight synform in the tonalitic gneiss (Figures 4-6) but shows generally homoclinal foliation in the outcrop. Rare, small folds deform

the foliation in the gneiss and are broadly concordant to the northwest-trending mineral lineation. A 5-meter dacite sheet is injected along the foliation.

Station 072 is in biotite quartzite with so many lit-par-lit injections of tonalitic gneiss that the rock might also be called a migmatite.

At Station 004 (mouth of Canyon Creek, Figures 4-6, a vertically dipping section of quartzite is exposed. Vertically plunging minor folds in the quartzite show both clockwise and counterclockwise rotation, although they are separated by only a few meters. Other minor folds of comparable geometry have horizontal axes. An ultramylonite to pseudotachylite sheet, 10-20 centimeters thick, dips gently east and displays shear movement with the top to the southwest, away from the batholith.

A 30-meter rhyolite sheet at Station 004 parallels the vertical, 90-degree-trending foliation. The one exposed contact is strongly sheared through a 5-meter interval by later faulting. Strong hydrothermal alteration and minor mineralization are associated with this shear zone. Pyrite is predominant, but trace amounts of chalcopyrite, galena, and arsenopyrite were recognized. Pyrite is disseminated in quartzite throughout the outcrop, probably from the hydrothermal event. Pyrite and galena also occur in joints in the ultramylonite.

Stations 073-075 are in augen gneiss of mostly tonalitic to granodioritic composition, which apparently forms a concordant sheet about 1.5 kilometers thick between the quartzite to the west and calc-silicate gneiss to the east (Figures 4-6). The sheet is not continuous over long distances, however; quartzite is in direct contact with calc-silicate gneiss a few kilometers to the southeast in Gedney Creek valley. Foliation in the augen gneiss generally parallels that in the enclosing metamorphic rocks. A small fold (66°, 120°) deforms the foliation of augen gneiss, has counterclockwise rotation, and is discordant to the mineral lineation displayed in other rocks. One xenolith of quartzite was seen in the augen gneiss. Shear intensity is varied, represented both by domains of varied grain size and by zones of sheared-off minor folds.

The augen gneiss is injected both by dikes and by concordant sheets of andesite, is faulted along the foliation of the gneiss, and is cut by a few thrust faults. Shallow-dipping pegmatite dikes cut the foliation. At Station 075, a 3-meter-thick, shallow-dipping dike contains an intrusive breccia consisting of amphibolite fragments in a dioritic matrix. This breccia is injected

by two 1-meter-thick dikes of andesite along or near the opposite walls of the breccia dike.

Calc-silicate gneiss crops out a short distance east of Station 075. Some interbeds of quartzite up to 15 meters thick are present. A 5-meter-thick andesite dike and a 5-meter-thick latite dike cut across steep layering at small angles. The calc-silicate gneisses contain small folds like those in the tonalitic gneiss to the west, which deform schistosity and trend parallel to mineral lineation in the rocks. The small folds display clockwise rotation.

Lozenge-shaped boudins of pegmatite and aplite occur in the calc-silicate gneiss. Concordant sheets of tonalitic gneiss 5-10 meters thick were also injected into the calc-silicate gneiss.

Station 112 (Figures 4-6) displays a zone of very tight folds over 75 meters, which may represent the hinge zone of a major fold in the calc-silicate gneiss unit. The axial plunge is 42°, 105°, which is different from the orientation of the mineral lineations. The geometry of these folds is similar to that of one in the biotite quartzite at Station 027; they may be of the same age.

Station 114 has interbedded calc-silicate gneiss and quartzite cut by a concordant 35-meter-thick sheet of hornblende diorite that is rich in calc-silicate gneiss xenoliths. Shallow-dipping dikes of pegmatite cut the sequence, as do some thrusts dipping gently to the east.

Stations 115 and 116 are in a massive white quartzite, and Station 117, opposite the mouth of Fire Creek, is at the contact between the metamorphic rocks and the Idaho batholith.

A few features of the metamorphic rocks west of the Idaho batholith remain to be described. First is the character of the folded foliation, shown in Figure 16. Sixty poles to the foliation lie in a small-circle girdle. Poles to axial planes of small folds are similarly arrayed, although too few small folds were found for statistical analysis.

Figure 17 shows the mineral lineations and small fold axes in the metamorphic rocks west of the Idaho batholith (Figures 4-6). Although the points are somewhat scattered, their center of gravity is not far from the point representing the axis of the cone that gives rise to the small-circle girdle in Figure 16. An axis generated by the intersection of three planes measured in one of the large folds also lies in the general area of the cone axis; these bedding planes give an indication of the fold style.

ROAD LOG — FIELD-TRIP STOPS ALONG U. S. HIGHWAY 12

STOP 1.   Lowell quadrangle. Milepost 102. Tonalitic gneiss in center of synform (Figures 4-6), fairly constant planar foliation oriented about 330°, 85° NE. Rare, small folds that plunge about 80 degrees deform both the schistosity and conformable alaskitic (trondhjemitic) sheets. Biotite lineation plunges down the dip, more or less parallel to fold axes. Some horizontal joints. A 5-meter-thick dacite sheet lies in the plane of the foliation.

STOP 2.   Lowell quadrangle. Mile 103.8. Turnout just west of Canyon Creek.   Biotite-sillimanite-microcline-albite-chlorite-bearing quartzite or schistose quartzite, perhaps equivalent to the Ravalli Group of the Belt Supergroup, with minor isoclinal, doubly vergent, vertically plunging conical folds (Figures 4-6). The albite and chlorite may be late-stage or retrogressive minerals. Horizontal fold axes in the foliation trend 90 degrees. This rock is cut by a zone of ultramylonite to pseudotachylite dipping gently to the east. A 30-meter rhyolite dike lies at the south end of the outcrop. A faulted contact between the rhyolite and the quartzite is heavily altered and mineralized with pyrite and minor galena and chalcopyrite. Pyrite and galena occur in joints in the quartzite and in the ultramylonite.

STOP 3.   Coolwater Mountain quadrangle. Milepost 107. Just east of Deadman Creek. Zone of intense crumpling and folding in the calc-silicate gneiss unit, perhaps equivalent to the Wallace Formation of the Belt Supergroup. Fold axes plunge 42°, 105°. Low-angle pegmatite sheet oriented 060°, 10° SE. Diorite dikes or sheets, 10-15 centimeters thick, parallel the foliation which is oriented 290°, 65° NE.

STOP 4.   Coolwater Mountain quadrangle. Mile 111.6. First turnout past the bridge at Split Creek trail. Primary gneiss (granodiorite) in the marginal zone of the Bitterroot lobe of the Idaho batholith (Figure 8) has a moderately strong primary flow foliation oriented 305°, 75° NE. A basalt dike intrudes the batholith.

STOP 5.   McLendon Butte quadrangle. Mile 115.5. Macaroni Creek. Massive granite.

STOP 6.   Huckleberry Butte quadrangle. Mile 117.5. Lit-par-lit gneiss in a migmatite screen (similar to several near mile 112.5). See Figure 8. Based on hand-specimen analysis, the gneisses in this screen are tonalitic to granodioritic in composition, resembling to a certain extent the tonalitic gneisses to the west. Some metasedimentary material is included in the migmatite screens. Granite and granodiorite of the batholith, both massive and flow foliated, are exposed through this part of the section, mixed with screens of migmatitic gneiss up to 1 kilometer thick. The internal foliation trend in the migmatite screen averages about 300 degrees and the dip is vertical. The trend of the screen probably parallels that of the

flow foliation, although mapping will be necessary to ascertain this.

STOP 7.   Huckleberry Butte quadrangle. Mile 124.8. No-see-um Creek. Granite. Shallow-dipping primary flow foliation (Figure 8). The rock has widely spaced joints and is relatively unaltered.

STOP 8.   Holly Creek quadrangle. Mile 132.2. About 1.6 kilometers (1 mile) east of Castle Creek. Jointed, altered granite, with silicified shears and intense alteration along the jointing (Figure 9). Near STOP 8, a vertical fault striking 325 degrees has related vertical extension joints striking 360 degrees. The fault surface has horizontal slickensides indicative of strike-slip movement. The joints suggest that the maximum principal stress was oriented 360 degrees and was horizontal. Therefore, the fault had right-lateral motion. Vertical slickensides overprint the horizontal slickensides, suggesting later dip-slip motion.

STOP 9.   Greystone Butte quadrangle. Milepost 142. Just east of Weir Creek. Granite, moderately to intensely jointed, brecciated, and altered to pink rock (rich in K-feldspar?) with associated epidote and chlorite alteration (Figure 9). Some fractures are quartz-filled and contain minor pyrite. Joints have many orientations, but northeast-trending fractures are more abundant than others (Figure 11). This northeast trend is similar to the trend of the more systematic joints to be seen at STOP 10. Andesite and more mafic dikes here are highly sheared, mylonitized, chloritized, and altered to pink along fractures. Pyrite-bearing calcite veins cut the dikes. The brecciation and alteration of the granite clearly postdates dike injection.

STOP 10. Bear Mountain quadrangle. Milepost 145. About 0.8 kilometers (0.5 miles) east of Postoffice Creek. Brecciation and alteration are much less intense than at STOP 9. Trend of primary flow foliation averages 280 degrees, and the dips
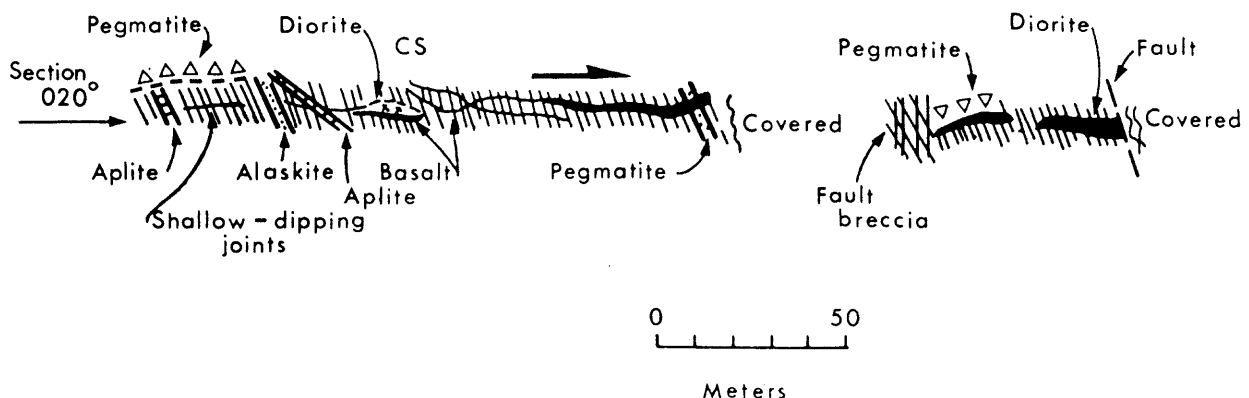

Figure 18. Sketched cross-section showing details of structures in calc-silicate rocks of the Wallace Formation at STOP 13, exposed in road cuts northeast of the Idaho batholith. CS = calc-silicate gneiss.

average 80° SW, in foliated granite. Andesite dikes cut the granite. Joints generally strike north-northeast and show a wide range of dips (Figure 12).

STOP 11.   Cayuse Junction quadrangle. Mile 155.9. Just east of Badger Creek. A migmatite screen (Figure 9) contains coarsely por-phyritic granite and older gneiss. A muscovite lineation trends 275 degrees and plunges 65 degrees.

STOP 12.   Rocky Point quadrangle. Mile 160.7. About 1.9 kilometers (1.15 miles) west of the turnoff to Powell Ranger Station. Granite with 1-10-meter-diameter xenoliths of calc-silicate quartzite near the eastern contact of the batholith with the calc-silicate country rocks (Figure 10). The xenoliths are cut by 2-4-centimeter-thick veins of quartz-rich pegmatite. Quart-zite bedding is little disrupted (025°, 65° NW), and the quartzite may form more of a septum than isolated xenoliths. Some pyrite occurs in the quartzite, the granite, and some basalt dikes. Vertical fault shears trending 310 degrees cut the basalt dikes.

STOP 13.   Rocky Point quadrangle. Milepost 166. Calc-silicate quart-zites of the Wallace Formation are cut by aplite, alaskite, pegmatite, and mafic rocks on shallow-dipping thrusts (Figure 18). These pegmatite bodies, unlike those in the Ter-tiary(?) granite at STOP 14, are free of miarolitic cavities. They resemble pegmatites of the Idaho batholith and are presumably related to that body. The thrust faults are north-east directed and are also partly injected by sheets of basalt and diorite. The mafic sheets cut pegmatite dikes and are themselves cut by pegmatites of the same type (Figure 8). Thus, the thrusting appears to have been under way during
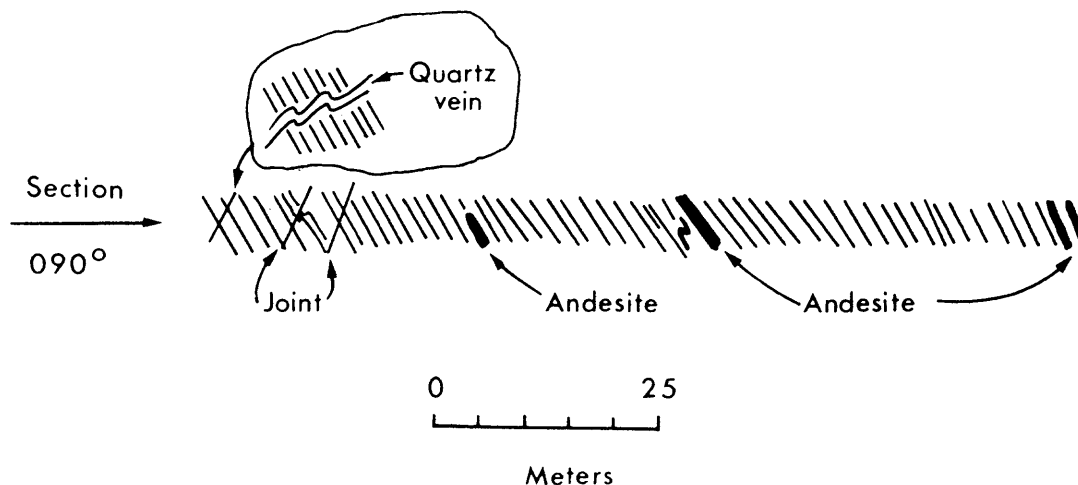

Figure 19. Sketched cross-section showing details of structure in quartzite of the Ravalli Group at STOP 15, exposed in road cuts northeast of the Idaho batholith.

the late stages of batholith emplacement. Bedding is fairly uniform throughout this area, trending 070 degrees and dipping 55° NW.

STOP 14. Lolo Hot Springs quadrangle. At the mouth of the East Fork Lolo Creek. Tertiary(?) granite of the Lolo batholith. The granite contains irregular podiform bodies of pegmatite and aplite, up to 3 meters in diameter, and miarolitic cavities. Shallow-dipping shears are oriented 290°, 12° SW. A dip-slip fault trends 016 degrees and dips 75° NW, with many shear joints parallel to the fault.

STOP 15. Garden Point quadrangle. About 2.4 kilometers (1.5 miles) west of Cedar Run Creek. Quartzite of the Ravalli Group has slaty laminations. Bedding is oriented 300°, 35-50° NE. The quartzite has some cross-bedding and scour features that indicate that the beds are upright. Andesite sills parallel bedding in the quartzite (Figure 19).

ACKNOWLEDGEMENTS

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