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PLUTONS IN THE EASTERN PART OF THE PIONEER BATHOLITH: FIELD RELATIONS AND PETROGRAPHIC DESCRIPTIONS

by

E-an Zen

U.S. Geological Survey 1/

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1/ Present address: Department of Geology, University of Maryland, College Park, Maryland 20742

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INTRODUCTION

This report summarizes the occurrence, contact relations, petrography, and other directly observable features of the plutonic rocks of the Pioneer batholith as they occur in the east Pioneer Mountains. Two intrusive bodies of uncertain petrogenetic lineage are discussed under "Miscellaneous plutonic rocks" at the end of this report. Table 1 summarizes the characteristics of these plutons for easy comparison and Figure 1 is a location guide. Modal data for these plutons are given in Table 2. For local details, the reader might wish to consult Zen (1988a) and Marvin and others (1983).

The plutons are described in the order of mafic to silicic. Within the east Pioneer Mountains, this order approximates the order of older to younger, based on field relations and/or isotopic dates. Snee (1982) grouped the plutons of the Pioneer batholith into largely time-dominant groups, i.e., "early group", "pre-main group", "main group", and "late group (A and B)", as well as into a few supplementary petrographically-dominant groups, i.e., "porphyry group", "felsic group", and "aplite", and into several individual plutons that defy ready classification. The order used in this paper is generally consistent with Snee's scheme, as is indicated by the inclusion of Snee's (1982) notation between square brackets in the heading of each pluton as well as in Table 1.

All geographic features mentioned in the text are locatable on topographical quadrangle maps. For ease of use, such features, when first mentioned, will be located to the ninth of these quadrangles, e.g. "nw/vp" means the northwest ninth of the Vipond Park quadrangle. Table 3 summarizes these locations in alphabetical order, and also gives the names, scales, and editions of the topographic maps used in preparing this location guide.

ACKNOWLEDGMENTS

I am grateful to the many people, acknowledged on the geological map (Zen, 1988a), for helping me to map the plutons in the east Pioneer Mountains. I benefitted from thoughtful and thorough reviews of this report by Larry Snee and Jane Hammarstrom. The modal data of Table 2 are largely measured by Hammarstrom, who also compiled the data with assistance from Karen Gray. This manuscript was approved for outside publication in 1990. Unavoidable delay followed, but the manuscript has not been revised to include up-to-date for publication in the format of a U.S. Geological Survey Open File Report.

KEOKIRK QUARTZ DIORITE (Kke) [pre-main group]

Occurrence The Keokirk Quartz Diorite (Zen, 1988a) occurs in a circular area a little under 2 km^2 in size, and as dikes in its vicinity each a few meters to a few tens of meters across. On Keokirk Mountain (wc/vp), its type locality, dikes of the Keokirk intrude and have extensively contact-metasomatized the carbonate strata. The map pattern and extent of the Keokirk Quartz Diorite in this area are therefore somewhat simplified. An isolated mafic quartz-diorite dike north of Maurice Mountain (ne/mm) and adjacent to the Clifford Creek Granite could be an outlier of this magma body.

The Keokirk has a K-Ar hornblende date about 80 Ma (Marvin and others, 1983) and a sphene fission track date of 76.5$\pm$7.5 Ma provided by C.H. Naeser (see Zen, 1988a). These are from a single sample of a large dike at the north end of Keokirk Mountain. It is the oldest pluton in the area reported in this study; intrusion of the Keokirk likely overlapped in time the deposition of the upper part of the Upper Cretaceous fluviatile sediments (UKFS) described in Zen (1988a) as part the Colorado Group. By stratigraphic reconstruction, this temporal overlap constrains the depth of intrusion to about 2 km which is the thickness of sedimentary rocks between the Mississippian Madison Group (intruded by the Keokirk) and the top of the UKFS. The Keokirk has an initial strontium ratio (iSr) of 0.7113 which is same as that of the Uphill Creek Granodiorite (Arth and others, 1986).

Description of Rocks In outcrops, the Keokirk Quartz Diorite tends to break into small (a meter or less) pieces along closely spaced vertical and horizontal joints (Ehlen and Zen, 1990). The pluton supports grassy land and is not a cliff former as is the Grayling Lake, the Uphill Creek, and the Trapper plutons. In handspecimen, the rock is typically fine-grained (1 mm or less), dark grey, salt-and-pepper textured, and weathers a dull tan-grey. Laths of plagioclase, as well as prisms of hornblende are readily visible; quartz is commonly absent, as is sphene. Biotite is present, and is conspicuous in some specimens as reddish-brown plates or clusters of plates (Figure 2). Such biotite is found mainly near the younger Grayling Lake pluton, and probably reflects the effect of thermal metamorphism of the pluton by the Grayling Lake intrusion (whether all the biotite is secondary is uncertain), as its K-Ar date (72 Ma; Marvin and others, 1983) is that of the Grayling Lake Granite.

In thin section, the Keokirk is dominated by lath-shaped, simply twinned but rarely gradationally-zoned plagioclase about 1 mm by 0.2 mm; the rare zoned crystals tend to be more equant and are not flow-aligned. Potassic feldspar is readily seen in stained sections; it is irregular to equant, scattered through the rock. Hornblende is equant, from half to two mm across; some have a rim of more greenish pleochroism; twinning is common. Biotite is about equal in abundance to the hornblende and is brownish green, scattered without obvious fabric relations. Some late biotite crystals form large books of rather irregular outline. Sphene is rare and tends to be anhedral. Epidote is rare and resulted from alteration of the mafic minerals. Quartz is generally small, forms clusters in the matrix, and is "anhedral"; some grains do form polygonal junctions and may have been recrystallized, recording the annealing effect of the intrusion of the Grayling Lake Granite. Euhedral apatite is rare; allanite is very rare.

Contact Relations The Keokirk is the oldest known pluton in the northern part of the east Pioneer Mountains, described in Zen (1988a), and is not known to intrude other plutons of the batholith. The Keokirk intrudes the Devonian and Mississippian carbonate units on Keokirk Mountain. Hybridized rocks consist of epidote-rich tonalite-like rocks as well as grossular-epidote-diopside (±actinolite, ±olivine) skarns. Serpentine is found in these skarns as the result of hydration reactions from the intrusion of the Grayling Lake magma.

TRAPPER TONALITE (Kt) [pre-main group]

Occurrence The Trapper Tonalite, mapped and defined by Zen (1988a), is confined to a ca. 6 km^2 circular area east of Granite Mountain (sw/vp) and south of its eponymous Trapper Creek (c/vp). In addition, the border phase of the Grayline Lake Granite at Canyon Lake (wc/vp), Ktcl, might be a fine-grained variety of Kt, but data supporting such a correlation is wanting (see discussion under the Grayling Lake Granite).

The Trapper has a biotite $^{40}Ar/^{39}Ar$ date of 73.5$\pm$1.0 Ma provided by J.F. Sutter (see Zen, 1988a) which agrees with the K-Ar biotite date (74.3$\pm$2.7 Ma) but is nominally older than the hornblende K-Ar date (71.9$\pm$4.3 Ma) (Marvin and others, 1983). The reason for the apparent reversal of hornblende and biotite ages is not understood, but the older date is consistent with the field relation that the rock is intruded by the Grayling Lake Granite. The iSr value of the pluton, 0.7160, is higher than those of all the other plutons (Arth and others, 1986) in the east Pioneers, with the exception of a single leucocratic dike.

Description of Rocks The Trapper Tonalite is a medium-grained (2 mm average crystal size) grey tonalite, and exhibits weak to moderately strong foliation caused by alignment of mafic mineral grains and clusters (Figure 3). The minerals are unaltered and undeformed, and show igneous textures in thin sections, indicating that the foliation is igneous. The Trapper Tonalite is exceptional for the batholith because the hornblende is commonly, if not ubiquitously, cored by pale green augite which is visible with the aid of a handlens. In the vicinity of the older Keokirk Quartz Diorite, these pyroxene-cored amphibole clusters appear as elongate patches, about 1 cm x 2 cm, forming strong lineations within the plane of igneous foliation, giving the rock a peculiar "leopard pattern" appearance (Figure 4). These patches may indicate smearing out of mafic clusters as a highly viscous melt-crystal aggregate was emplaced against a buttress. The origin of the pyroxene in the cores is unknown. The intimate spatial association of the ultramafic rocks (unit "gum" of Zen, 1988a) with the Trapper, described below, including occurrence of the ultramafics as xenoliths, suggests that the pyroxene might be derived from the ultramafics. If so, the ultramafic rocks and the Trapper magma must have interacted long enough to reequilibrate the pyroxene compositions (Jane Hammarstrom, 1990, also written commun.).

In thin section, the plagioclase is more or less equant, generally 1 mm or more, is strongly twinned and zoned, and forms clusters. In shape, complexity of twinning and size, the plagioclase is distinct from that in the Keokirk Quartz Diorite. Some smaller plagioclase euhedra are enclosed in large quartz. Euhedral hornblende dominates over biotite among the mafic minerals; both are 1-2 mm across and are fresh, though some chlorite folia occur in the biotite. The biotite is pleochroic in brownish green whereas the hornblende is weakly colour zoned, the rim tending to be bluish green and possibly actinolitic but the core is brownish green typical of igneous hornblende. Some crystals have ragged edges. Sphene is honey yellow and euhedral; quartz is interstitial. Potassic feldspar is rare and is not visible in hand specimen.

Clusters of magnetite are abundant but epidote occurs only as alteration product. Large allanite euhedra occur with or without thin rims of epidote. Apatite is euhedral and small, enclosed in other minerals.

Contact Relations The contacts of the Trapper Tonalite are against Paleozoic carbonate formations (the Upper Devonian Jefferson Dolomite and the Mississippian Madison Group), against the Keokirk Quartz Diorite, and against the Grayling Lake Granite. An outcrop of siliceous, dark grey to black shale, identical to the lower member of the Middle Cambrian Silver Hill Formation, is found in the area of the pluton, presumably as a xenolith (regional geologic relations indicate these are not in situ roof pendants) east of Cherry Lake (sc/vp) along with massive white coarse marble outcrops interpreted to be xenoliths of the Mission Canyon Limestone.

Carbonate rocks are baked along the contact to marbles locally showing strong ductile shear, and scapolite is formed in the Madison Group. Base-metal mineralization occurs locally as skarn, leading to a string of prospect pits and at least one mine north of the Cherry Creek trail. However, the effect of contact metamorphism does not extend more than a few hundred meters from the exposed contacts, and the contact itself, where control is adequate as along the eastern side of the pluton, is remarkably straight and uncomplicated.

The contact of the Trapper against the Keokirk Quartz Diorite is simplified on the geological map (Zen, 1988a), especially in the vicinity of the large ultramafic xenolith, unit gum, above Granite

Lake (sc/vp), where considerable local metasomatic effects, including hydration and formation of secondary amphibole, are observed. Rocks that are texturally and mineralogically unambiguously the Keokirk Quartz Diorite have no pyroxene cores to the hornblende, so the rafting of the ultramafic xenoliths is interpreted as caused by the Trapper, not by the Keokirk.

The Trapper Tonalite is younger than the Keokirk. In a small gully separating the Trapper from the Keokirk on the cliffs southeast of Trapper Creek, dikes of the Trapper intrude locally sheared Keokirk (Figure 5). These relations are consistent with the isotopic dates. Except for these local effects, intrusion of the Trapper does not appear to have affected the appearance of the Keokirk. The latter, it is true, shows recrystallized biotite which has a much younger apparent age, but that effect is attributed to the Grayling Lake pluton rather than to the Trapper. The lack of extensive hydration of the Keokirk by the Trapper is consistent with the Trapper having been a relatively dry pluton.

ULTRAMAFIC XENOLITHS OF GRANITE LAKE (gum) [early group]

Occurrence The mafic and ultramafic rocks, mapped as unit gum (gabbro and ultramafics) by Zen (1988a), occur in the area west of Granite Lake as variable-sized xenoliths in the Trapper Tonalite (Kt) and possibly in the Keokirk Quartz Diorite (Kke). They are restricted to a large (200 m relief) east-facing cliff above Granite Lake as well as to smaller stepped-back cliffs north of a snow chute on the north side of the large cliff (Figure 6). The xenoliths are possibly as large as 300 m across, though the dimensions on the cliffs have not been measured. Xenoliths of these rocks are found within the Trapper Tonalite as much as several hundred meters away from the contact against the gum unit, but are not known elsewhere within the mapped parts of these plutons.

Description of Rocks The best unaltered samples include coarse (3-10 mm average crystal size) pyroxenite consisting of euhedral crystals of both augite and hypersthene which are in mutual contact, with the interstices filled by plagioclase (Figure 7). The texture indicates a cumulate origin for the rocks. However, minerals in most of the ultramafic rocks have been partially or completely altered to more hydrous assemblages, including talc-chlorite-actinolite. Hand specimens do not always indicate the extent of alteration.

Larger blocks of the gum unit may show apparent layering caused by changes in the proportions of the minerals (Figures 8, 9). Vague suggestions of cross-stratification on the scale of a few decimeters, shown by colour contrast between layers, have been observed.

Contact Relations All the exposures of the gum unit are xenoliths, commonly in the Trapper. Along contacts there are metasomatic selvages including coarse hornblende (several cm across) set in the matrix of typical Trapper Tonalite. At these selvages all vestiges of the original pyroxene of the ultramafic rocks have been destroyed.

GRANITE OF STINE CREEK (Ksc) [other plutons]

Occurrence The Stine Creek pluton (Ksc of Zen, 1988a) was first recognized and mapped by Calbeck (1975); it occurs astride

Stine Creek (nc/sm) but its east end extends beyond the Wise River valley. An outlier below the Grouse Lakes (nw/sm), on the hillside west of Grouse Creek, is similar to the main body of the Stine Creek and is assigned to it. The Stine Creek pluton is about 9.5 km^2 in area, not counting the valley floor of Wise River or the outlier. It has a single iSr value of 0.7139 (Arth and others, 1986), which is virtually identical to that of the porphyritic border phase of the Grayling Lake pluton and suggests magmatic consanguinity. However, the isotopic dates of the pluton, 72.3 ± 2.6 Ma on biotite K-Ar and 74.9 ± 1.6 Ma on biotite $^{40}Ar/^{39}Ar$ provided by J.F. Sutter (see Zen, 1988a), are slightly older than the Grayling Lake magma.

Description of Rocks The bulk of the Stine Creek pluton is a medium-grey, medium-coarse, uniform-textured granite. Quartz, plagioclase and potassic feldspar dominate; biotite is the most important mafic phase. Most samples of the main rock contain tiny, anhedral muscovite that is visible with a handlens.

In thin section, the Stine Creek is a biotite-muscovite granite. Plagioclase is blocky, clustered, twinned and weakly zoned, somewhat saussuritized, 2-3 mm across. Potassic feldspar is subrounded, fresh, 2-3 mm in size, perthitic, shows gridiron twinning, and is generally inclusion-free; myrmekite is rare. Quartz is clear, large, anhedral and granular. Biotite is brownish green and euhedral, about 0.5 mm in size. Muscovite is locally abundant. Some muscovite crystals are in butt-end relation with what appears to be magmatic biotite, thus suggesting its magmatic origin (see Zen, 1988b); however, parts of the Stine Creek pluton, for example in the large bluffs above the highway bridge 6086 (ne/sm) across Wise River, show extensive subsolidus alteration, including growth of epidote and development of greisen (L.W. Snee, 1990, written commun.). Magnetite is abundant, allanite is rare, and sphene is rare and anhedral.

Aside from the typical granite, another important rock type included in the pluton is a fine-grained and dark grey quartz diorite. It occurs as an outcrop over 10 meters in size in the cirque floor at the west end of the body, as an inclusion in the granite, alongside other smaller ($\leq$30 cm) inclusions. Quartz diorite also forms the small body near the Grouse Lakes. The source of these more mafic rocks and their possible genetic relation to the granite are not known.

In thin section, these mafic rocks are fine grained, hornblende-biotite quartz diorite, containing plagioclase in twinned laths, about 0,2 by 0.05 mm across that appear to be flow-oriented. Quartz is very rare and interstitial. Hornblende and biotite are euhedral, 1 mm or smaller, brown-green pleochroic, and are also flow-oriented. The hornblende is zoned and there are many euhedral crystals showing skeletal growth enclosing plagioclase. Magnetite is scattered throughout; sphene is anhedral.

Contact Relations The Stine Creek pluton is entirely within an area of Proterozoic sedimentary rocks of both the Wise River and the Pattengail thrust sheets (Zen, 1988a), but the contact is rarely exposed. The best exposure is on an abandoned roadcut near bridge 6086. Here, the micaceous quartzite of the sequence at Boner Knob (Zen, 1988a) is sharply intruded; mudchips in the country rock are baked into dark grey-green clots, about 1 cm across, consisting of chlorite and muscovite.

One of the few large exposures of the Stine Creek pluton, north of Stine Creek, shows the rock to be riddled with dikes of aplite and some pegmatite, each a few cm wide, in random orientation. These might be dikes exploiting hydrofractures as new magma pulses broke apart the recently consolidated granite, in a manner similar to that suggested below for the granite dikes in the Grayling Lake pluton near Lake Abundance (ne/mm).

UPHILL CREEK GRANODIORITE (Kuc) [main group]

Occurrence The Uphill Creek Granodiorite is the largest, in area of exposure, among the plutons of the Pioneer batholith, but only its northern portion (including its type locality, Uphill Creek (sc/vp) in the east Pioneer Mountains, about 77 km^2, is described here (see Zen, 1988a). The bulk of the pluton can be traced continuously southward for a distance of about 15 km, and westward, across a few faults, for a comparable distance (Snee, 1978, 1982). The distinct petrography of the rock lends credence to the presumption that all rocks mapped as the Uphill Creek are part of the same pluton. The pluton is irregular in shape, but is overall elongate in a west-northwest direction (Snee, 1982, fig. 7), similar to the direction of elongation of the Grayling Lake Granite and is aligned with a major regional tectonic direction in southwestern Montana.

In the vicinity of Rock Creek (sc/vp), the pluton intrudes the Upper Paleozoic Mission Canyon Limestone, Amsden Formation, Quadrant

Quartzite, and Phosphoria Formation, and the Mesozoic Dinwoody Formation, Kootenai Formation, and the UKFS. Farther south, the pluton intrudes Proterozoic sedimentary rocks of the Wise River thrust sheet (Zen, 1988a) that is also cut by the Grayling Lake pluton (Myers, 1952; Snee, 1978; Sharp, 1970).

The Uphill Creek Granodiorite has numerous isotopic dates. These determinations used a variety of techniques: Hornblende and biotite K-Ar, mostly reported by Marvin and others (1983), and both hornblende and biotite $^{40}Ar/^{39}Ar$ provided by J.F. Sutter (see Zen, 1988a) and by Snee (1982). Based on these dates, the age of the pluton is about 72 Ma, same as that of the Grayling Lake Granite, consistent with evidence for magma mixing for the two bodies. The iSr values for the Uphill Creek range from an "end-member" value of 0.7113 to values as high as 0.7121 in the mixing zone (Arth and others, 1986).

Description of Rocks Within the area of my mapping, the Uphill Creek Granodiorite is typically a medium- to coarse-grained grey, massive and homogeneous rock, showing faint igneous foliation. White, euhedral plagioclase about 3 mm long, slightly smoky anhedral quartz a few mm across, and books of biotite and prisms of hornblende 1 mm or less are the major minerals. The proportion of biotite and hornblende varies; in most rocks they are about equal but rare rocks (apparently including all those rocks that show composition banding defined by biotite, described below) exist that have few hornblende crystals. Euhedral, honey-yellow sphene wedges less than 1 mm across are conspicuous and are evenly distributed in the rock. Most exposures of the Uphill Creek Granodiorite are characterized, in addition, by oikicrysts of potassic feldspar. These oikicrysts are colourless, anhedral, and as much as 3 cm across although most are 1-2 cm. They are never euhedral and do not show zonal arrangement of mineral inclusions, in contrast to the potassic feldspar phenocrysts in the Grayling Lake and the Clifford Creek plutons (q.v.). The oikicrysts are always chucked full of inclusions of quartz, plagioclase, hornblende, and biotite, similar in appearance to their counterparts outside of the oikicrysts, so that the oikicrysts are difficult to discern except when light is reflected from the cleavage planes (Figure 10). The oikicrysts then are revealed to be abundant and are in diverse orientations. Mapping of the boundary of the pluton by use of this technique requires sunny days.

The faint igneous foliation is defined by alignment of mafic minerals and more rarely by elongate feldspar. A word of caution is in order. Many outcrops of the rock have closely spaced (ca. 1-2 mm) planes of fracture, especially in areas of concentration of secondary joints that show as hairline fractures (Ehlen and Zen, 1990). Weathering tends to accentuate these fractures. Where the fractures cross large crystals of feldspar these crystals may be splintered into long rods that can mimick igneous alignment of crystals. Topographic saddles commonly are endowed with closely spaced joints and are where these misleading cues most likely lurk.

In thin section, plagioclase is 1-3 mm, euhedral to subhedral, zoned and twinned, with some clustering. Plagioclase enclosed in potassic feldspar oikicrysts tends to be euhedral but smaller and show no clustering. The oikicrysts of potassic feldspar are mostly anhedral microperthite that enclose other minerals, as described. The enclosed minerals tend to be not in mutual contact and are smaller than their counterparts outside. Myrmekite is strongly developed against plagioclase outside of and along the rims of the oikicrysts, but rare among the same phases inside (Figure 11). Sphene is mainly euhedral and locally abundant. Magnetite is euhedral and abundant, and are not all spatially associated with mafic minerals. Both biotite and hornblende are euhedral to subhedral, are brownish green in pleochroism, and are 0.5 to 2 mm. Twinning and optical patchiness is common in the hornblende. Quartz is a fraction of mm to 2 mm in size, interstitial, granular, and without polygonal junctions. Alteration of the mafic minerals into chlorite and epidote is common, though apparently do not affect the grains enclosed in the oikicrysts.

The Uphill Creek Granodiorite contains dark, discoid inclusions as well as recognizable xenoliths of other rock units (Figure 12). In addition, this pluton, alone among those described in this chapter, exhibits mafic coxcomb layering and parallel layering. The parallel layers are horizontal to subhorizontal and are defined chiefly by an abrupt upward increase in the modal content (but not grain size) of biotite (hornblende does not seem to be involved), followed by a gradual decrease (Figure 13, 14). Coxcomb or splayed and disturbed layering, some suggestive of cross-bedding (Figure 15), is much less common. These features are similar in appearance to those described from the Sierra Nevada batholith (Bateman and others, 1963). Unlike the California counterparts, however, those in the Uphill Creek are rarely, if ever, steeply dipping and do not show the grain-size gradation described from the Sierra Nevada batholith by Bateman (1988, p. 61) that requires alternative mechanisms of formation than gravitational settling. Lack of involvement of hornblende suggests that the layering is a late process; if shear flow was the dominant mechanism (Komar, 1976; see Bateman, 1988 for further references), it would be a puzzle why the layers were confined to late stages of crystallization when presumably the magma-crystal mush had much higher effective bulk viscosity.

Within the area of this report, the Uphill Creek contains numerous miarolitic cavities (Figure 16) indicating the presence of a fluid phase during crystallization and thus a shallow level of emplacement; these cavities are commonly filled with coarse crystals of the major phases of the pluton.

Contact Metamorphism Intrusion of the Uphill Creek pluton produced skarn deposits against limy country rock. These skarns are particularly well developed in the Amsden Formation, and consist of marble, fine-grained tactite, and coarse rocks whose mineral assemblage include grossular, idocrase, diopside, epidote, actinolite, and calcite in various combinations or as monomineralic grossular rocks. Pattee (1960), Myers (1952), Geach (1972), but especially Collins (1975, 1977) discussed the skarn at Ivanhoe pit southwest of Browne's Lake (se/vp), where the Uphill Creek and Browne's Lake plutons frame an area of Amsden Formation and produced low-grade scheelite deposits that have been mined. The source of tungsten is not obvious. Instrumental neutron activation analysis of the granodiorite adjacent to the Ivanhoe deposit, as well as various rock types of the Amsden in areas away from any plutonic rocks, produced insignificant values for tungsten. Tungsten deposits and prospects in the Pioneer Mountains are widely associated with the Amsden Formation, and scheelite is especially found as inclusions in large grossular crystals. It is not clear whether the Amsden is the source rock, despite the low concentration observed, or whether some chemical properties of the marly beds of the Amsden were effective in causing scheelite to precipitate along certain stages of growth of grossular.

In the area west of Sugarloaf Mountain (se/vp) south of Browne's Lake, the Paleozoic sedimentary rocks are thermally metamorphosed. Individual quartz grains several mm across characterize the Quadrant Quartzite. The massive chert of the Phosphoria Formation becomes a white rock resembling quartz vein. The Dinwoody Formation is a mixture of marble and limesilicate. The small cap of Kootenai Formation on top of the southern, angular peak of Sugarloaf Mountain, originally a conglomerate, is much deformed and the originally pelitic parts are a cordierite-biotite-andalusite gneiss. Skeletal grossular garnet crystals, with rock matrix remaining in their interstices, occur in the UKFS as far as 1 km from its contact with the Uphill Creek pluton (Haugerud and Zen, 1991).

Evidence for Magma Mixing The northern contact of the Uphill Creek pluton against the Grayling Lake pluton is gradational and represents a zone, about 1 km wide at the present level of erosion, in which the two magmas mixed. Arth and others (1986) gave evidence for this process in terms of the iSr. Rocks of the mixing zone are readily observed in the flat area south of Rock Creek. Field evidence for mixing includes the presence in the Uphill Creek of rare, scattered euhedral pink potassic feldspar phenocrysts characteristic of the Grayling Lake Granite, and conversely the presence in the Grayling Lake of anhedral potassic feldspar oikicrysts of the Uphill Creek Granodiorite. In general, rocks in this zone tend to be more even-grained and contain fewer phenocrysts or oikicrysts than either parent pluton, and have a distinct dull lilac-grey cast.

Immediately above the steep south wall of Rock Creek gorge and within the iSr-defined mixing zone, pegmatites mark the transition and served (Zen, 1988a) to corroborate the boundary of the two plutons. Individual pegmatites are as much as a meter thick, but most are thinner though the number is considerable; these tend to strike parallel to the gradational contact between the two plutons. The pegmatites have typical granitic mineralogy of plagioclase, potassic feldspar, quartz, and biotite; some of the potassic feldspar is pink. The coincidence leads one to suspect a genetic connection between the process of magma mixing and evolution of a H_2O-rich vapour, though the physical chemistry of the process is not clear.

Scattered outcrops of intrusive breccias occur in the mixing zone on the north wall of Rock Creek gorge (and presumably on the Grayling Lake pluton side of the contact; Zen, 1988a). These breccias have a granitic matrix; the blocks, as much as 0.5 meter across, are angular to subangular, and consist of dark diorite, granodiorite, and meta-sedimentary rocks that are now mainly limesilicate skarns and calcareous quartzite (Figure 17).

GRANODIORITE OF DAVID CREEK (Kdc) [late group B]

Occurrence The David Creek pluton occurs as a single body of about 4 km^2 and extending about 4 km in a north-south direction, on the ridge between David Creek (se/mm) and Elkhorn Creek (sc/mm; Zen, 1988a). Similar rocks, mapped as the Torrey Mountain intrusion, are found in the Torrey Mountain and Twin Adams quadrangles immediately to the south (Snee, 1978). Sample "BC" from BM 6420 near the Birch Creek Ranger Station (sw/ta; Zen and others, 1975) has been interpreted as part of the Torrey Mountain intrusion by Snee (1978). The Torrey Mountain and David Creek plutons apparently are separate bodies at the present level of intrusion; the Birch Creek may be also a separate body.

There is no isotopic date for the David Creek pluton; however, it crosscuts the Uphill Creek Granodiorite. A biotite K-Ar date of 70.4 ± 2.4 Ma (Zen and others, 1975; corrected for new constants, Marvin and others, 1983) exists for sample BC, and Snee (1982) reported three biotite $^{40}Ar/^{39}Ar$ plateau dates ranging from 68.2 to 70.3 Ma for the Torrey Mountain pluton. A iSr value of 0.7118 for sample BC (Arth and others, 1986) is nearly identical to that of the Uphill Creek.

Description of Rocks Both the David Creek pluton and the BC outcrop consist of fine-grained granodiorite, with average grain size <1 mm (Figure 18), are weakly porphyritic in some outcrops resulting from feldspar euhedra, and are hornblende-poor to hornblende-free, biotite-bearing rocks. In thin section, plagioclase is stout, twinned and zoned, about 3 mm across, and shows some clustering. Potassic feldspar is oikicrystic in addition to interstitial (as discussed by Snee, 1982, potassic feldspar occurs in his "Late Group B" plutons in different ways, ranging from oikicrystic as in the Uphill Creek to small, interstitial crystals as in BC. The David Creek has both varieties). Quartz is a few mm or smaller and granular. Myrmekite, though not spectacular, is present in all samples. Biotite is 2-3 mm, hornblende is small and rare, though a few 2-3 mm crystals were seen. Euhedral sphene, allanite, apatite, and magnetite are present. Epidote and muscovite are subsolidus phases.

The BC rocks locally show miarolitic cavities demonstrating that it solidified under low enough pressure for a fluid phase to evolve. It has rare myrmekite that may be difficult to locate because the potassic feldspar is fine grained and sparse.

Contact Relations The David Creek and BC plutons are spatially associated with the Uphill Creek, and locally show intrusive contacts against the latter. Such relations can be observed, for example, at the north end of the David Creek body on the cliffs north of David Creek trail (Figure 19), and near the BC locality on roadcut exposures. There is no known contact of the David Creek against nonintrusive rocks.

GRAYLING LAKE GRANITE AND RELATED ROCKS
(Kgl, Kgp, Kgb, Kgm, Ktcl, Kog) [late group A]

Occurrence The Grayling Lake Granite (Kgl) is a large pluton. A number of smaller plutonic bodies (the porphyritic border phase, Kgp, the Browne's Lake pluton, Kgb, the Mono Park outlier, Kgm, the possibly related Osborne Creek outcrop, Kog, and the tonalite Ktcl, of uncertain affinity) are discussed in the same section because of their likely consanguinity with the Grayling Lake.

The main body of the Grayling Lake (sw/vp) pluton is elongate in an east-west direction, is about 14 km long and 5 km wide at the maximum, tapering at both ends. Including the border phases (about 2 km^2 shown with the symbol Kgp), the exposed area is about 44 km^2. Along its southern margin it partly intrudes, and partly forms a gradational contact with the nearly synchronous Uphill Creek Granodiorite, representing a zone of magmatic mixing. Its northern, curved margin is mostly in contact with sedimentary rocks ranging from the Cambrian Black Lion Conglomerate and Silver Hill Formation on the west to the Mississippian Amsden Formation on the east, cutting into and truncating a preexisting anticline. At the extreme west end, its northern contact is against Proterozoic quartzite of the Wise River thrust sheet (Zen, 1988a). Part of the northern contact of the pluton is against earlier, more mafic plutons (the Trapper Tonalite and the Keokirk Quartz Diorite).

The small stock (about 1 km^2) of pink granodiorite-granite exposed around Browne's Lake in Rock Creek gorge (unit Kgb of Zen, 1988a) is in all aspects, including isotopic dates and initial strontium isotope ratios, similar to the main Grayling Lake pluton except for the greater abundance of aplite and pegmatite, probably reflecting the location of the exposed rocks at the roof of the pluton (Figure 20). The stock is in all likelihood a local cupola of the main pluton. It truncates the igneous foliation of the Uphill Creek Granodiorite (Figure 21), thus establishing their relative intrusive ages. This relation does not contradict the interpretation of magma mixing between the Uphill Creek and the Grayling Lake (Arth and others, 1986; Zen, 1988a) because this contact is near the margin of both plutons, which presumably consolidated early, but the area of magma mixing is more interior to both plutons.

The Grayling Lake and related rocks (Kgl, Kgb, Kgm, and Kgp of Zen, 1988a) have numerous K-Ar biotite and hornblende dates as well as a single $^{40}Ar/^{39}Ar$ biotite date determined by J.F. Sutter, summarized in Zen (1988a; see also Marvin and others, 1983). These dates range from 74 Ma to 71 Ma with most of the numbers at about 72 Ma, establishing these rocks as early Maastrichtian -- an important control point as the rocks truncate and metamorphose Proterozoic rocks that have been thrust over middle Campanian to lower Maastrichtian sedimentary rocks of the UKFS (Zen, 1988a; see Zen, 1996). The Grayling Lake and related rocks have iSr of 0.7126 to 0.7137; one sample having a lower value (0.7123) is from the magmatic mixing zone against the Uphill Creek Granodiorite (Arth and others, 1986).

Description of Rocks The Grayling Lake Granite ranges between true granite and granodiorite according to the classification of IUGS (Streckeisen, 1973). It is a medium-coarse rock characterized by pink, subhedral to euhedral potassic feldspar phenocrysts that give the whole rock a pink cast on a fresh surface (Figure 22). These crystals, about 1 cm across, locally contain dark specks of mineral inclusions in zonal arrangement. Plagioclase is 2-3 mm across, white, and typically subhedral to euhedral. Hornblende and biotite are about 0.2-0.5 mm across and euhedral; they range from about equally abundant (typical) to hornblende-free in some samples. Sphene is conspicuous, abundant (as much as 0.5 modal percent), subhedral to euhedral and honey-yellow. Quartz is anhedral to subhedral and is clear to slightly smoky-lilac. Hematite occurs as inclusions in potassic feldspar phenocrysts and as thin rims on magnetite; its paragenesis is not clear, but because it is in potassic feldspar and is always present in fresh rocks, it is considered to be a late magmatic phase and indicates final crystallization with the oxygen fugacity controlled by the hematite-magnetite buffer system.

In thin section, plagioclase is typically subhedral to euhedral, twinned and strongly zoned, and shows much clustering. Rounded cores, possibly restitic, are present. Potassic feldspar is large, anhedral, weakly perthitic. Quartz is anhedral to interstitial and varies from a fraction of mm to a few mm. There is strong development of myrmekite where potassic feldspar, quartz and plagioclase come into contact. Hornblende is typically euhedral, optically patchy and shows rare multiple and common simple zoning, and is pleochroic from green to yellow with brown tinge. Biotite is brownish green and ragged. Sphene, magnetite, and apatite are abundant and ubiquitous. Some alteration epidote and chlorite occur; in addition, some inner zones of plagioclase are saussuritized. Euhedral blades of allanite, with or without epidote rim, are locally spectacular.

Local petrographic variants within the main body of the Grayling Lake include a biotite granite and a biotite-muscovite granite. Both are exceedingly limited in occurrence and probably are products of progressive magmatic differentiation and enrichment in Al_2O_3 as the result of hornblende fractionation (Zen, 1986). In the field these hornblende-free rocks are recognized by their slightly lower colour index and lack of recognizable hornblende in a hand specimen (though recognition of magmatic muscovite relies on careful thin section petrography). The biotite-muscovite rocks are found so far only at four separate localities: On top of Barbour Hill (wc/vp), on the 9600 ft ridge between Canyon Lake and Grayling Lake, on the 10,060 ft peak south of Crescent Lake (ec/mm), and on the 9715 ft peak to its southwest (the last locality is near the intrusive contact against psammitic Proterozoic sedimentary rocks and contamination could have locally increased the peraluminosity of the rock). In each area, hornblende fades out through a zone in which it is rounded and embayed, apparently partially resorbed, and the rock grades from hornblende-biotite to biotite only to biotite-muscovite in butt-end growth, indicating magmatic origin (Figure 23A). The Barbour Hill area was studied in detail and the results, supported by mineral chemistry from microprobe studies provided by J.M. Hammarstrom, were summarized in Zen (1986) as an example of magmatic differentiation and enrichment of alumina through fractional crystallization of hornblende, evolving from a rock having aluminum saturation index, ASI (Zen, 1986) near unity to one that is peraluminous (Table 1) and shows normative corundum as well as modal muscovite. As discussed below, absence of tourmaline in this peraluminous rock probably means that contamination by Proterozoic sedimentary rocks was not a significant factor in its petrogenesis.

Rocks mapped as the porphyritic border phase (Kgp of Zen, 1988a) of the main body of the Grayling Lake Granite are texturally variable. North of Barbour Hill, where most data are collected, the rock is a hornblende- and biotite-bearing granodiorite showing strong igneous flow foliation of feldspar and the mafic minerals, oriented parallel to its contact (Figure 24). It differs mineralogically from the Grayling Lake Granite in its higher colour index (about 20) and rarity and smaller sizes of pink potassic feldspar phenocrysts; however, identical K-Ar date (Marvin and others, 1983) and iSr (Arth and others, 1986), comparable mineral chemistry (Zen and others, 1975; Hammarstrom, 1982, 1990), and close spatial association with the main body of the Grayling Lake pluton indicate their common ancestry (rare inclusions of Kgp are found in the Kgl in the cirque northwest of Granite Mountain). The two rocks, however, show different outcrop characteristics; the Kgp forms slabby outcrops with the slab faces parallel to igneous foliation, whereas the Grayling Lake forms massive, nearly equant blocks. These features largely reflect the jointing properties of the rocks which in turn reflects the internal fabric (one of the dominant joint sets within the massive Kgl is nearly parallel to the faint igneous foliation defined by the orientation of hornblende and biotite). From a distance or on airphotos, the distinction between the two rock types is unmistakable.

Some of the rocks mapped as Kgp (Zen, 1988a) in the area of the ridge north of Grayling Lake are massive, grey, homogeneous granodiorite lacking the strong mineral foliation of Kgp near

Barbour Hill, and having colour index comparable to the main Kgl. Like the Kgp at Barbour Hill, these rocks lack pink potassic feldspar phenocrysts; lack of intrusive contacts with Kgl on the spur where outcrop is nearly continuous suggests that these are not separate intrusions.

In thin sections of Kgp, plagioclase is large (2-3 mm), twinned and weakly zoned. Potassic feldspar is anhedral and interstitial, about 1 mm in size. Quartz is granular. There is no myrmekite. Brownish green biotite is in 2 mm books; hornblende is much smaller (0.5 mm) and euhedral. Euhedral sphene and magnetite are abundant. Allanite occurs with epidote rim. There is a distinct bimodal size distribution, with much finer (0.05 mm to 0.1 mm) quartz and feldspar in the matrix.

A grey, medium-grained, homogeneous, massive tonalite north of Canyon Lake (Ktcl of Zen, 1988a) may be related to Kgp as it appears to grade into the latter, though lack of adequate outcrop or areal extent of Ktcl makes inference uncertain. In thin section of Ktcl, the plagioclase is in wide laths, twinned but rarely zoned; those crystals showing zoning tend to have saussuritized cores. Potassic feldspar is anhedral and about 1-2 mm, forming part of the matrix. Quartz is granular and interstitial. Hornblende is 1 mm or less, pleochroic in brownish green, irregular and possibly embayed, and contains many inclusion of quartz. Biotite is brown, irregular, and full of quartz inclusions. Sphene is abundant and anhedral. Magnetite is rare.

The isolated exposures of granite near Mono Park (sw/mm; Kgm of

Zen, 1988a) contain pink potassic feldspar phenocrysts, hornblende, and biotite, and strongly resemble the main Grayling Lake (with, however, slightly lower iSr of 0.7126). This area is interpreted to have been downdropped by several km along the Fourth of July fault (Zen, 1988a) and so the pluton might be a nearer-roof part of the Grayling Lake, comparable to the position of Browne's Lake stock.

In the cirque floor of Osborne Creek (nw/sm), along the border of the Stine Mountain - Shaw Mountain 7-1/2 minute quadrangles, there is a single, 30-m outcrop of a pink potassic-feldspar phenocryst dominated granite (Kog of Zen, 1988a). The phenocrysts are euhedral, as much as 3 cm long, showing clustering even in hand specimens, in a matrix of medium (2-3 mm) grained white plagioclase, lilac quartz, biotite (1-2 mm), and magnetite. The potassic feldspar is strongly perthitic. There is no hornblende, but muscovite is visible in thin section and shows butt-end relation with biotite to suggest magmatic origin. The mineral assemblage is most reminiscent of the highly-differentiated two-mica granite of Barbour Hill, earlier described; lack of more outcrops, especially contact relations, in the area preclude further inference. Because the Proterozoic quartzite and argillite in the area of Osborne Creek are uniformly metamorphosed so that the argillite shows conspicuous muscovite-biotite-chlorite spots and abundant recrystallized tourmaline, a larger pluton may be concealed below.

The main phase of the Grayling Lake locally contains abundant discoid mafic inclusions that are modally rich in biotite and hornblende but also contain feldspar and quartz; their grain size is much finer than the bulk of the rock. The discoids are as much as

20 cm across, are commonly aligned in parallel to the plutonic border and form minnow-like swarms (Figure 25), and may represent segregations in the magma chamber of early crystals, possibly including thoroughly reworked xenoliths. Rare angular xenoliths are either mafic or, much more rarely, recognizable meta-sedimentary rocks. There is no evidence for contamination of the granitic rocks by these sedimentary xenoliths beyond a selvage of a few mm. The petrogenesis and geochemistry of these discoids have not yet been studied in detail. In contrast to the Uphill Creek pluton, the Grayling Lake does not have compositional layering defined by biotite.

Aplites are found throughout the pluton, but do not constitute a major part of the rock. Pegmatites are rare, commonly no more than a few decimeters thick, and may have aplitic borders. These pegmatites consist of pink potassic feldspar, white plagioclase, quartz, rare biotite, but little else. The area of greatest concentration of pegmatites is near Lake Abundance, discussed below; here the pegmatites are also mineralogically more complex. Abundant pegmatites in the area of magmatic mixing south of Rock Creek were discussed under the Uphill Creek Granodiorite.

Contact Relations and Metamorphism Except for the screen of flow-foliated granodiorite Kgp on the north side of the pluton, and except for the mixing zone against the Uphill Creek Granodiorite, the contact of the Grayling Lake pluton against older rocks is everywhere clean and abrupt. Dikes of the Grayling Lake Granite do intrude its host igneous rock, for example on the ridge and cirques east-northeast of Granite Mountain (Figure 26) though dikes of the

Grayling Lake Granite are notably rare against sedimentary host rocks. With the exception of local concentrations of mafic discoid inclusions, the same mineralogy and texture of the bulk of the pluton persist to within a few cm of the contact, as can be seen, e.g. in the areas of complete exposure in the cirques east of Granite Mountain.

Because of the complex sequence of intrusions in the area of the pluton, observed contact metamorphic effects in the country rocks cannot always be unequivocally attributed to the Grayling Lake Granite. However, the following observations, arranged from west to east along the northern part of the pluton (the southern part, against the coeval Uphill Creek Granodiorite, did not produce notable contact metamorphism) can be reliably attributed to the Grayling Lake Granite and related plutons.

From the south wall of the large, compound cirque that encloses Lake Abundance and Crescent Lake to about 1 km northeast of Lake Abundance, along the contact between the pluton and the Proterozoic quartzite of the Wise River thrust sheet (the sequence at Maurice Mountain of Zen, 1988a), complex, peraluminous pegmatites are abundant. In addition to quartz, two feldspars, and biotite, these pegmatites typically have muscovite, almandine garnet, tourmaline (as individual crystals or in graphic intergrowth with quartz), and rare beryl (Figure 27). Euhedral, pistacite-rich epidote occurs in pegmatites where the host rock is the Jefferson Dolomite, the footwall rock immediately below the quartzite.

The sequence at Maurice Mountain, mostly quartzite, on the west side of the Crescent Lake cirque is recrystallized by the pluton, and contains similar peraluminous pegmatites near the contact. The pelitic mudchips of the quartzite are baked into muscovite-chlorite clots about 1 cm across. The joint surfaces of the massive quartzite are coated with tourmaline. These effects extend over a few hundred meters from contacts against the pluton. In addition, quartz veins in the quartzite locally contain euhedral prisms of pink andalusite as much as 3 mm long in addition to white mica.

As the complex pegmatites occur only at contact with the quartzite or its immediate footwall rock, and as tourmaline is never found in the Grayling Lake Granite or in its pegmatites away from the quartzite (tourmaline probably is a telltale sign of contamination of the magma by the Proterozoic sedimentary rocks), transfer of boron and aluminum from the country rock into the marginal portions of the crystallizing magma chamber can be inferred. Presumably the transfer is by circulation of meteoric water through country rock into the margin of the pluton.

The cirque of Lake Abundance is compound, containing a longitudinal step about 60 meters high. The step is the contact between quartzite and some pegmatite on the west (high) side and the Grayling Lake Granite on the east side, indicating the relative resistance of these rocks to subglacial erosion.

At the west base of Keokirk Mountain above Lion Creek (wc/vp), outcrops of pelitic rocks assigned to the Black Lion Conglomerate and the Silver Hill Formation are altered to tourmaline-rich two-mica schists. Nearby, local quartz-free dolostone of the Hasmark

Dolomite is altered to periclase-spinel-forsterite marble; the periclase has since been pseudomorphed by kink-banded brucite (Figure 28) and the olivine by serpentine. This rock is characterized by a light grey spotting caused by the brucite pseudomorphs.

Spectacular contact metamorphism is observed at a topographic declivity locally called "Keokirk Bench" (Karlstrom, 1948) north of Barbour Hill. Although I cannot be certain that this effect is not partly due to the Keokirk Quartz Diorite, it is conveniently described here. The Lower Mississippian Lodgepole Limestone of the Madison Group, originally a thin (ca. 10 cm)-bedded micritic limestone having intercalated clay-rich layers (Zen, 1988a), was changed such that the limestone became white marble and the clay-rich layers nearly isochemically became grossular-calcite layers (Figure 29). These garnet-rich layers, each a few cm thick, are more resistant to weathering and stand out as ridges about a cm high. The massive limestone of the Mission Canyon Limestone of the Madison Group in the same area was recrystallized to coarse white calcite marble. The grain size of calcite is fairly uniform for any given bed, but varies in different beds, ranging from 1 cm to greater than 10 cm. The coarsest bed has calcite crystals that in two dimensions are blade-shaped and measure about 5 cm by 15 cm. In favourable light, the blades are seen to be oriented with their long direction parallel to the trace of bedding; adjacent blades can be seen in reflected sunlight to form alternating sets. Measurement of the interfacial angles of these sets indicates that they could be calcite twinned on $\{01\bar{1}2\}$ and so the actual crystal size might be considerably larger. Interestingly, this bed is not in direct contact with the Grayling Lake Granite; a bed having average crystal size of 1 cm is interposed. Other minerals in the zone of giant crystals, clearly products of local metasomatism, are almandine garnet (euhedral crystals about 20 cm across), diopside (crystals about 1 cm; some are rims around garnet) and epidote (crystals about 5 cm), adjacent to the bed of truly coarse marble just described.

In the Hecla Mines area (wc/vp) immediately to the northeast of Keokirk Bench, the Cambrian and Devonian sedimentary rocks have been deformed and metamorphosed by more than one episode of metamorphism; these episodes can be tentatively matched with intrusion nearby of the Keokirk and/or Trapper, and of the Grayling Lake plutons (Zen, 1988a). These are described next.

On the east side of the structural dome of the Hecla Mines area, facing the intrusions, pelitic beds in the Silver Hill Formation are (Zen, 1988a, p. 36) andalusite-chlorite-biotite-muscovite-plagioclase-tourmaline schists. The andalusite is pleochroic in red. This mineralogy is attributed to a polymetamorphic origin. Within this schist there is pinitic material which is likely pseudomorphs of cordierite. In addition, weathered surfaces of these rocks exhibit large (about 1-cm) polyhedral nobbins (Zen, 1988a, p. 36). Many of these nobbins are crudely dodecahedral suggesting garnet, but a few rare ones are nearly parallelpipeds possibly after staurolite (Karlstrom, 1948). These crystals are invariably retrograded to mixtures of white mica, chlorite, and quartz; thin sections of dozens of fresh-looking "crystals" failed to reveal original mineral. However, garnet was clearly a major phase in an earlier contact-metamorphic mineral assemblage.

I infer that the early metamorphism occurred under relatively dry conditions and likely was of moderate temperature, though any mineral geothermometer that might have existed has since been destroyed. During this event, the pelitic, lower member of the Silver Hill Formation produced a garnet-andalusite-biotite-plagioclase-quartz, $\pm$cordierite ($\pm$staurolite?) assemblage. Abundant tourmaline probably resulted from recrystallization of material already in the pelite during this episode. Muscovite may have been part of this assemblage, judging by the butt-end intergrowth with biotite; however, the ease of crystallization of muscovite and the likelihood of recrystallization of biotite during the retrograde event suggests need for caution in interpreting the textural evidence especially as clearly late muscovite is present in these same rocks.

Coarse biotite from these rocks gave a K-Ar date of 72 Ma (Zen and others, 1975), same as the K-Ar biotite date of the Grayling Lake pluton nearby and of the late, sheaf-textured, cross-cutting and presumably subsolidus biotite in the Keokirk Quartz Diorite, also nearby (Figure 2; Marvin and others, 1986; Zen, 1988a). Because of this coincidence in dates, I conclude that the K-Ar date on the biotite of the Silver Hill Formation records the thermal effect of contact metamorphism by the Grayling Lake. In terms of the mineral assemblage in the Silver Hill Formation, the main effect of this younger thermal event is the retrogressive hydration of preexisting mineral assemblages, including formation of pinite after cordierite, pseudomorphic formation of muscovite and chlorite after garnet (and staurolite?), growth of some new muscovite and biotite, and possibly the development of rare fibrolite bundles that are texturally independent of the andalusite.

Several samples from the pelitic rocks of the Hecla Mines area, including some deliberately collected from the undersides of overhanging outcrops to avoid possible effects of lightning strike, contain microscopic patches of an orange-coloured isotropic material that may be halloysite formed during a stage of localized argillic alteration that was thermally destroyed when the rock was heated to about 500°C (Zen, 1988a, p. 37).

To summarize, the sequence of mineralogical changes is an early stage of moderate-temperature (about 600°C?), fairly dry, prograde contact metamorphism with local development of a mineral fabric that may be related to ductile shear at the intrusive contact. This stage was followed first by local retrograde argillic alteration, and later by a pervasive second stage of prograde metamorphism during which the preexisting metamorphic assemblage was hydrated (i.e. retrograded), whereas at the same time the argillic alteration was partially destroyed by prograde dehydration. The second stage of metamorphism is associated with the emplacement of the Grayling Lake pluton.

The calcareous upper member of the Silver Hill Formation in the Hecla Mines area developed into diopside-epidote-actinolite-quartz-plagioclase rocks that preserved delicate sedimentary features; the massive dolostones of the Hasmark and Jefferson Dolomites are bleached white and developed large sunbursts of white tremolite. The metamorphic assemblages of these rocks, and how they responded to the multiple intrusive events, have not been studied in detail.

On either side of Cherry Creek (ec/vp) northeast of Brown's Peak (sc/vp), the Lodgepole Limestone shows extensive ductile deformation and the development of scapolite (mizzonite)-tremolite rock. It is not clear whether the metasomatic reaction resulted from the emplacement of the Grayling Lake Granite or from the earlier Trapper Tonalite which occurs nearby. In the same general area but southwest of Storm Peak (sc/vp), the lower beds of the Kootenai Formation formed cordierite-magnetite rocks (Zen, 1988a) well over a km from the exposed contact of the Grayling Lake pluton.

The calcareous country rocks near Browne's Lake have been intensely metamorphosed and metasomatised. Because these rocks are also close to the far larger Uphill Creek Granodiorite, they were discussed under that heading.

The small exposures of plutonic rocks near Mono Park (Kgm) and in Osborne Creek (Kog) do not show contact relations.

A Possible Internal Contact An outcrop of the Grayling Lake Granite on the southwestern shore of Lake Abundance suggests one mode of intrusion. The typical coarse granite contains a xenolith of ductilely deformed quartzite presumably derived from the nearby Proterozoic units. The xenolith, about 1 m long, is segmented by dikes of granite, although the fragments maintain their alignment. The granite dikes are mutually parallel, are each a few (~5-10) cm wide, and are petrographically identical to the "host" granite. The orientation of these dikes is nearly same as that of the dominant joint set in the granite nearby (Ehlen and Zen, 1990). But for the xenolith, the dikes would have been missed. This outcrop suggests two features: first, at least near the border of the pluton, where solidification occurred early and rapidly, one feasible mechanism for intrusion and enlargement of the pluton is by dike addition (something like sheeted dike complexes) having magma of identical composition as the host (and therefore suggesting little time difference). Second, at the time of dike intrusion the host rock was sufficiently crystal-rich to permit fracturing. The common orientations of the dikes and the dominant joints in the rock suggests that the joints are at least in part early cooling joints.

CLIFFORD CREEK GRANITE (TKc) [felsic group]

Calbeck (1975) first used the name Clifford Creek for a pluton centered about Clifford Creek (ec/sm). Zen (1988a) refined its map pattern. This granite is the only major body of magmatic biotite-muscovite granite in the Pioneer batholith and so its genesis is of considerable interest. Two values of the iSr (Arth and others, 1986) are 0.7123 (main phase of granite; 64.6$\pm$2.1 Ma by biotite K-Ar, Marvin and others, 1983; and 65.6$\pm$1.4 by biotite $^{40}Ar/^{39}Ar$ determined by J.F. Sutter, Zen, 1988a) and 0.7116 (porphyritic phase of granite; 64.9$\pm$2.2 Ma biotite K-Ar, Marvin and others, 1983). These values suggest possible magmatic consanguinity with the Uphill Creek Granodiorite; they are lower than the Grayling Lake values away from the mixing zone (Arth and others, 1986).

Occurrence The main body of the Clifford Creek pluton occupies a trapezohedral area, about 19 km^2 in size, on and west of the main divide of the east Pioneer Mountains north of Black Lion Mountain (wc/vp). A porphyritic phase occurs both within this main body and in a 2-km^2 area centered on the 9578 ft peak (wc/vp) to the east, separated from the main body by a narrow septum of sedimentary rocks. The two bodies are no doubt connected at no great depth.

Description of Rocks The main body of the Clifford Creek Granite is a light tannish-grey, massive biotite-muscovite granite. Biotite is conspicuous; muscovite, as much as 1 mm across, can be found with a little search under the handlens. The average grain size is about 2 mm; a locally measurable weak igneous foliation is defined by the alignment of biotite crystals. The porphyritic granite has a matrix identical to the main body, but contains numerous large (1-3 cm) euhedral prisms of potassic feldspar, commonly showing Baveno twinning (Figure 30). These phenocrysts contain a few biotite inclusions; their white colour (instead of pink) on fresh surfaces, large size, and lack of zonal arrangement of the included minerals distinguish them from those in the Grayling Lake Granite. Their euhedral shape, tendency to weather into positive relief, ready visibility, and lack of random inclusion of the groundmass minerals distinguish them from the oikicrysts of the Uphill Creek Granodiorite.

In thin section, the plagioclase is equant to subhedral, twinned, and weakly zoned. The potassic feldspar is variable in size and shape and is microperthitic; many crystals show gridiron twinning and also contain irregular blebs of plagioclase. Quartz is large, euhedral to subhedral, some occur as inclusions in plagioclase, but in contrast to the older granites (e.g. the

Grayling Lake), apparently are not included in potassic feldspar. Rare myrmekite seems to be restricted to plagioclase enclosed in potassic feldspar. Large books of brown-green pleochroic biotite are generally euhedral. Muscovite is much less abundant, some are shreddy, but some butt-end intergrowth with biotite (Figure 23B) indicates its magmatic origin (Zen, 1988b). Magnetite occurs, apatite is rare, and sphene is absent.

Contact relations Actual exposures of the contact of the Clifford Creek Granite are observed at numerous places. The following are notable:

A. East border of the pluton, in the cirque at the head of Sheep Creek (nw/vp) north-northwest of Black Lion Mountain. Here the granite intrudes the Middle and Upper Cambrian Hasmark Dolomite (Zen, 1988a), producing a contact aureole of coarse diopside-epidote-actinolite rock. The cirque is longitudinally divided by a step, about 60 m high; the western, higher ground is underlain by the granite. The relative resistance to subglacial erosion (granite>carbonate) is what would be expected. Above this cirque, on the east flank of the northern ridge of Black Lion Mountain, numerous apophyses of granite, each a few cm wide and a few decimeters long, cut the Black Lion Conglomerate (Figure 31). Because the latter consists mainly of quartz and feldspar, which are stable at low magmatic temperatures, the thermal effect on the conglomerate is confined largely to the interstitial hydrous minerals and to some discolouration of the rock. The effect is not noticeable more than a few decimeters from the main contact.

B. South border of the pluton, on the main ridge crest north of Maurice Mountain, center Section 36, T2S R12W. The smooth, sinuous southern border of the Clifford Creek pluton follows the projected trace of an east-west high angle fault that was mapped in the saddle south of Black Lion Mountain (=Moose Creek fault of Calbeck, 1975). However, apophyses of granite occur in the quartzite south of the main contact; apophyses are also found on the east flank of the same ridge. Thus, the southern boundary of the pluton likely exploited the preexisting fault zone. In this same area, a mafic dike that intrudes the quartzite (Calbeck, 1975; unit Kdm of Zen, 1988a) is abruptly terminated at the granite contact, as is the abundant float of the dike. This relation is taken as evidence that the mafic dike is pre-Clifford Creek and thus pre-Tertiary, possibly related to the dike-rich Keokirk Quartz Diorite.

C. Western border of pluton. The contact is not exposed. This border is a part of the large Fourth of July fault zone, which down-dropped the west side; thus the pluton might have a hidden continuation west of the fault.

D. North border of the pluton on the main divide south of Bobs Lake (wc/vp). Here the interest is to ascertain the relative ages of this pluton and Bobs Lake pluton. Careful search in this area of abundant outcrop showed no Clifford Creek rocks in the Bobs Lake. However, dikes resembling the Bobs Lake do occur within the Clifford Creek, especially on a series of small cliffs dropping off the east side of the ridgeline.

Though both are biotite-muscovite granites, the Clifford Creek and the Stine Creek differ in other petrographic features, in their dates, and in their initial Sr isotope ratios; they are not the same pluton.

GRANODIORITE OF CANNIVAN GULCH (Kcg) [felsic group?]

Occurrence The small Cannivan Gulch pluton is shaped like a Stealth Bomber and occupies only about 1/2 km^2 of area, at the head of Cannivan Gulch (wc/vp) on the divide between the drainages of Sheep Creek and Vipond Creek (nc/vp). The narrow, northern flank of the body is probably a large dike-like offshoot and at its tip are two small isolated blobs of the same rock (Zen, 1988a). The rock is of economic interest because it hosts a significant vein-type molybdenite deposit (Schmidt and Worthington, 1977; Hammitt and Schmidt, 1982). The granodiorite of Cannivan Gulch has a biotite K-Ar date of 66.8 ± 2.5 Ma (Schmidt and others, 1979), which is a minimum age for the intrusion as the real age may have been significantly modified by the extensive mineralization.

Description of Rocks The Cannivan Gulch pluton is a medium-grained, uniform-textured grey rock that shows small euhedral plagioclase and 1-mm rounded quartz set in a fine-grained matrix. Thin section study of the freshest sample available shows the rock to be bimodal in grain size, with larger plagioclase, potassic feldspar, and quartz and smaller biotite and intergrown, possibly magmatic muscovite set in a fine quartzofeldspathic groundmass. The plagioclase is in euhedral, stout, clustered, 2-3 mm twinned laths and are strongly zoned; many of the zones are selectively altered, accentuating the zoning. Potassic feldspar is scattered and some phenocrysts are seen. Quartz is granular, less than 1 mm. Biotite books, 1-2 mm, are highly altered. Sphene is absent. The textural relations of the potassic feldspar and of quartz distinguish the Cannivan Gulch from the Bobs Lake and suggests instead possibly genetic connection with the Clifford Creek. However, virtually all outcrops of the Cannivan Gulch have been extensively hydrothermally altered and shot through with quartz veins many containing specks of molybdenite. Pyrite is abundant in many outcrops; in these pyritiferous rocks especially, biotite is apt to be destroyed or partly replaced by fluorite.

Contact Relations The Cannivan Gulch pluton has extensively altered the rocks it intrudes, especially the carbonate of the Upper Devonian Jefferson Dolomite. Roadcuts and trenches of the exploration works at Cannivan Gulch exposed diopside-forsterite-epidote skarns.

LEUCOCRATIC, HIGH SILICA BODIES

Leucogranite bodies are scattered in the Pioneer batholith and they may not represent the same magma body. Many of these bodies are dikes that range from several meters to a few cm wide, and from quartz-feldspar rocks to strongly peraluminous, two-mica granites. The larger leucogranite plutons in the batholith are younger than the main plutonic events (Snee, 1982; Schmidt and others, 1979; Zen, 1988a).

Leucogranite of Bobs Lake (Tqp) [felsic group]

Occurrence The Bobs Lake pluton (Tqp of Zen, 1988a) rises above the Sheep Creek valley and is restricted to the north end of the ridge that extends northward from Black Lion Mountain. It is less than 2 km^2 in size, and forms a northwest-extending elongate body. The pluton has a K-Ar biotite date of 66.8±2.4 Ma (Marvin and others, 1983) and an initial strontium isotope ratio (iSr) of 0.7112 (Arth and others, 1986).

Description of Rocks The leucogranite at Bobs Lake is a light grey, medium-coarse rock. Quartz is notable as smoky, large (about 1 cm) anhedral to subhedral "phenocrysts" in a fine-grained to medium-grained, pinkish-grey matrix of quartz and feldspar (Figure 32); this textural relation sets the pluton apart from the Clifford Creek Granite. Biotite, as 1-mm books scattered throughout, is the only visible mafic aluminum silicate mineral. Zoned plagioclase euhedra as much as 1 cm across occur, albeit rarely; these are largely free of inclusions. Microscopically, the grain sizes are strongly bimodal, with plagioclase and quartz phenocrysts, and much more rarely potassic feldspar phenocrysts, in a fine matrix of intergrown quartz, potassic feldspar and plagioclase. Myrmekite is absent. Biotite is large, brown-green, and some grains are full of inclusions of sphene and apatite. Some biotite is altered to chlorite, and a few crystals are in butt-end growth relation to rare magmatic muscovite. Sphene is euhedral to subhedral, and occurs either in biotite or in the groundmass. Hornblende is only found as rare inclusions in feldspar phenocrysts. Magnetite and rare euhedral allanite occur in the groundmass, as do euhedral to subhedral apatite.

Contact Relations A grassy, open swale, about 10 meter wide, separates the Bobs Lake pluton at its southern boundary from the Clifford Creek Granite. The swale is underlain by calcareous argillite and by dolostone, respectively typical of and tentatively correlated with the upper member of the Cambrian Silver Hill Formation and the Cambrian Hasmark Dolomite. On a prominent spur northwest of the main north-south ridge underlain by the Clifford Creek Granite, another large outcrop of the calcareous upper member of the Silver Hill Formation (Zen, 1988a) occurs, now a diopside-epidote bearing tactite. However, because the rock is in a septum between two plutons, the agent of the metamorphism is not clear. Many dark inclusions occur in the Bobs Lake pluton, best seen on the large exposures on the ridge crest. These inclusions are biotite rich and may be partially assimilated xenoliths of the Silver Hill Formation. As already described, dikes of leucogranite of the Bobs Lake pluton are found in the Clifford Creek Granite, fixing Bobs Lake as the younger rock despite their isotopic dates.

Leucogranite of Jacobson Meadows (Tqp) [porphyry group]

Occurrence The leucogranite of Jacobson Meadows (also labeled Tqp by Zen, 1988a) occurs west of the Fourth of July fault, and consists of a few isolated outcrops on the north-facing slope south of Jacobson Meadows (sc/mm) and near the mouth of Elkhorn Creek (Pearson and Zen, 1985; Zen, 1988a). This leucogranite intrudes the Uphill Creek pluton and is a coarse leucocratic granite similar to the Bobs Lake pluton. Interest in this pluton arises from the fact that road cuts through the body revealed numerous quartz-molybdenite veins that appear to underlie a larger, northeast-trending geochemical anomaly (Pearson and Berger, 1980; Pearson and others, 1988).

Description of Rocks The leucogranite at Jacobson Meadows is a mottled grey rock that contains rounded smoky quartz phenocrysts as well as white feldspar euhedra. Biotite is conspicuous as rare black spots. In thin section, quartz is partly rounded and embayed by the very fine grained matrix, which is about as abundant as the phenocrysts. An origin of the rock through rapid quenching of a crystal-laden magma seems obvious. The texture of the rock and its occurrence west of the west-side-down Fourth of July fault suggests very shallow, possibly subvolcanic intrusion, perhaps a nearer-roof equivalent of the Bobs Lake pluton, in a setup favourable to hydrothermal vein mineralization of molybdenite. Greisen deposits are found farther southwest at Crystal Park (nc/pl; Pearson and Berger, 1980), again consistent with a subvolcanic environment.

Contact Relations The leucogranite of Jacobson Meadows is restricted to a few isolated outcrops in an area of extensive moraine deposits. The contact relations are not well defined except that it intrudes the Uphill Creek Granodiorite.

Silicic Dikes (TKds, Tda)

Silicic dikes are relatively young and are found in and around the Pioneer batholith. A large dike occurs in the Ivanhoe pit above Browne's Lake within the Uphill Creek Granodiorite, and another occurs across Rock Creek on its steep north wall. These are mapped as TKds in Zen (1988a). Other, similar dikes extend from near Sugarloaf Mountain to west of Storm Peak, always peripheral to the main plutons. Another large dike labeled Tda on Zen (1988a) occurs in the Hecla Mines area and contains abundant magmatic muscovite as well as biotite. This dike has an exceptionally high iSr value of $\geq$0.7304 (Arth and others, 1986, sample 315-1).

The dike on the north wall of Rock Creek gorge has a wholerock K-Ar date of 64.4 ± 2.2 Ma (Marvin and others, 1983) that places it approximately coeval with the Bobs Lake pluton and with the Clifford Creek Granite. In hand specimens, this and the Ivanhoe pit dikes resemble the "pre-Main Stage" quartz-porphyry silicic dikes from the Boulder batholith in the Butte mining district (Brimhall, 1972, 1979) which have a 64 Ma date.

MISCELLANEOUS PLUTONIC ROCKS

Two small plutons occur north of the Sawmill Gulch (ne/vp)-Trusty Gulch (ne/vp) fault system (Figure 1) and they may be satellite plutons of the Boulder batholith rather than part of the Pioneer batholith (Zen, 1988a). These are briefly described below.

Tonalite of Dry Hollow Gulch (Kqd) [pre-main group]

Occurrence A single outcrop, less than 50 meter by less than 10 meters, of igneous rock occurs in Dry Hollow Gulch (ne/vp; Kqd of Zen, 1988a) at the extreme eastern margin of the Vipond Park quadrangle (boundary of Section 17/18, T2S R9W). However, two sections due east of this area (Section 15, T2S R9W), between Shepherd Mountain (wc/mr) and the Big Hole River directly to the east, similar rocks occur more extensively (G.D. Fraser, 1973, written commun.; Ehlen and Zen, 1990, stations 0302 and 0303). Farther south along the west side of U.S. Route 91 about 8 km south of Glen, Montana, a large dike or sill of similar rock occurs (SW1/4 NW1/4 Section 6, T5S R8W). Some data are reported in Ehlen and Zen (1990, Station 0301), but the sill has not been mapped. The age of the sill is unknown.

Description of Rocks The rock of Dry Hollow Gulch is a mottled medium-gray tonalite that has been contaminated by the country rock as evidenced by many small xenoliths. There is a crude foliation defined by alignment of hornblende.

In thin section, the rock shows euhedral, prismatic hornblende, pleochroic in brownish green and as much as 3 mm across. Euhedral plagioclase is 1-2 mm across, twinned and zoned, and some intermediate zones are saussuritized. Quartz is interstitial, and also occurs in the altered matrix which is in part mats of sericite. Biotite, sphene and potassic feldspar are absent. Large crystals of secondary epidote are abundant.

Contact Relations The country rocks around the plug of Kqd are Cretaceous sedimentary rocks encompassing the uppermost limestone beds of the Kootenai Formation, and the base of the overlying UKFS which in this area consists of quartz-pebble conglomerate, siltstone, quartz sandstone, and marly shales. All these beds show contact alteration (not studied in detail) as far as 100 meters from the small plug, suggesting either a larger body below or the passage of voluminous magma through the exposed pipe.

Tonalite of Lime Kiln Gulch (Klk) [pre-main group]

Occurrence The tonalite of Lime Kiln Gulch (Klk of Zen, 1988a) is restricted to a small area near Lime Kiln Gulch (nc/vp), north of the Sawmill Gulch-Trusty Gulch fault system. Judging by its low iSr value (0.7069; Arth and others, 1986), it is a satellite body of the Boulder batholith rather than part of the Pioneer batholith.

Outcrops are limited, and fresh material suitable for study was found only at a single outcrop near the western margin.

Description of Rocks The tonalite of Lime Kiln Gulch is a medium-grained, dark grey (CI ~30), even-textured rock presenting a salt-and-pepper appearance. Biotite and hornblende are about 1 mm or less. Quartz is not visible in the hand specimen. In thin section, plagioclase is in fresh, stubby laths, 1-2 mm long and about half as wide, that are weakly zoned and strongly twinned. They are densely packed, or have quartz as an interstitial late phase. Hornblende and biotite are subhedral to euhedral, and surround larger ($\leq$2 mm) euhedral plagioclase. The hornblende is deep greenish-brown, and partly altered to chlorite. Small, euhedral plagioclase inclusions occur in hornblende; a few colourless pyroxene cores occur also. Dark brown, euhedral and strongly pleochroic biotite is 1-2 mm across. Apatite prisms are abundant and large. Magnetite is scattered throughout. Large allanite crystals are molded around plagioclase. Sphene is absent.

Contact Relations At the northwest side of the outcrop area of the pluton, a small area of the Mississippian Amsden Formation and the Pennsylvanian Quadrant Quartzite occur between the igneous rock and the Mississippian Mission Canyon Limestone. These rocks are not in the same structural orientation as the belt of these rocks to the east (Zen, 1988a), suggesting that these rocks are in a large xenolith. However, no actual contact has been located.

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FIGURE CAPTIONS

Figure 1. Sketch map showing locations of the plutons described; symbols for plutons, as used in the text. Other rock units: PzMzCz: undifferentiated Phanerozoic rocks, mainly sedimentary. Yp, Middle Proterozoic rocks in the Pattengail thrust sheet. Ywr, Middle Proterozoic rocks in the Wise River thrust sheet. Xga, Early Proterozoic metamorphic rocks. The distribution of Ywr west of the Fourth of July fault is generalized. Major high-angle faults are labeled (barbell on downthrown side) but cross faults are not labeled. Thrust faults have teeth on the upper plate. For further information see Zen (1988a). For location of the Birch Creek sample described in the text see Marvin and others (1983).

Figure 2. Keokirk Quartz Diorite, Kke (sample 132-1) showing sheaves of biotite that apparently resulted from thermal metamorphism by the Grayling Lake pluton, superposed on the preexisting igneous texture. 9300 ft level on cliffs south of Trapper Creek.

Figure 3. Trapper Tonalite, Kt. Large scree block at 8190 ft in felsenmeer at base of 30-meter cliffs south of Trapper Creek, sample 547-1.

Figure 4. Trapper Tonalite, Kt. "Leopard rock", showing clusters of mafic minerals elongate in igneous flow direction. Sample 108-1, 9150 ft level north of Green Lake (sc/vp). Slightly weathered part (main face of photograph) shows characteristic positive relief of mafic minerals.

Figure 5. Keokirk Quartz Diorite, Kke, intruded by a dike of Trapper Tonalite. Rock below the light-coloured veins and mylonite, as well as at extreme upper left corner, are the Keokirk, here strongly deformed. Rock below the scale is the Trapper Tonalite. Rock chute at 8620 ft elevation on north-facing cliffs south of Trapper Creek.

Figure 6. Large cliffs west of Granite Lake, underlain by ultramafic xenoliths. Most of the area to the north (right) of the snow chute is ultramafic rock; the main cliff to the left contains a mixture of these rocks and the host Trapper Tonalite. Relief displayed on the cliff is about 100 meters.

Figure 7. Thin section showing cumulate texture of the coarse pyroxenite of the ultramafic rocks. Euhedral augite and hypersthene in crystal-supported fabric; plagioclase is entirely interstitial. Sample 785-5, talus material at base of large cliffs west of Granite Lake. Width of view, 5.5 mm.

Figure 8. Composition layering in the ultramafic rocks on cliffs west of Granite Lake. Sample location is about halfway up the snow chute shown in Figure 6, elevation 9720 ft.

Figure 9. Xenolith of layered ultramafic rock in Trapper Tonalite, near base of cliffs north of snow chute of Figure 6.

Figure 10. Oikicrysts of potassic feldspar in Uphill Creek Granodiorite (Kuc). The stereo pair was taken with optical axis of camera rotated only a few degrees to bring in the cleavage reflection of the feldspar in one view. Roadcut along Willow Creek, BM7181 (ne/tm; Section 18, T4S R10W).

Figure 11. Thin section of oikicryst of Uphill Creek Granodiorite. Note smaller grain size of the included minerals, and development of myrmekite at the margin of the oikicryst but not within the oikicryst. Sample 1279-1, 9680 ft west of Mount Alverson (Peak 10448, sw/vp). Width of view, 1.6 mm.

Figure 12. Xenolith of Keokirk(?) Quartz Diorite in Uphill Creek Granodiorite, southeast of Mount Tahepia (sw/vp). Notice mafic discoid in upper right corner of photograph.

Figure 13. Layering defined by biotite concentration in Uphill Creek Granodiorite (Kuc), rock basin south of Tendoy Lake (sw/vp). Elevation 9350 ft.

Figure 14. Closeup of biotite-defined layering shown in Figure 13. Biotite shows no size gradation from mafic to leucocratic layers.

Figure 15. Contorted, coxcomb layering by biotite concentration, Uphill Creek Granodiorite (Kuc). Cirque floor east of Mount Alverson. Elevation 8930 ft.

Figure 16. Miarolitic cavity filled with euhedral pegmatitic minerals. Uphill Creek Granodiorite. Loose block on slope south of Tendoy Lake.

Figure 17. Intrusive breccia in Grayling Lake Granite within zone of magmatic mixing, north slope of Rock Creek gorge. The blocks are mainly diorite; a block of metamorphosed calcareous sedimentary rocks is to the left, just below center. Elevation 8270 ft.

Figure 18. Granodiorite of David Creek, Kdc. Sample 1357-1, on 8150 ft cliff, end of ridge south of David Creek.

Figure 19. Dike of David Creek pluton (light coloured) cutting the Uphill Creek Granodiorite that shows mafic layering immediately adjacent to the granodiorite of David Creek. Cliff on ridge crest north of David Creek. Elevation 7900 ft.

Figure 20. Roof of Browne's Lake pluton on the north wall of Rock Creek gorge immediately above Browne's Lake, viewed from the Ivanhoe pit. Contact is at the top of the slight ledge in middle of picture, above the top of the large talus cone.

Figure 21. Crosscutting relations between the Browne's Lake pluton (Kgb; left) and the Uphill Creek Granodiorite (Kuc; right). Igneous foliation in Kuc slants steeply to the lower right in the picture and was truncated by Kgb. North slope of Rock Creek gorge. Elevation 7120 ft.

Figure 22. Grayling Lake Granite, Kgl. Sample 1309-1, at 9080-ft level north of 9400 ft pass southeast of Crescent Lake. Notice euhedral potassic feldspar phenocryst near right edge of photograph.

Figure 23. Muscovite in butt-end intergrowth with biotite, interpreted to indicate a magmatic origin. A, Grayling Lake Granite, sample BHS from top of Barbour Hill (see Zen, 1986). Width of view, 0.5 mm. B, Clifford Creek Granite. Sample 500-1 in cirque north of Black Lion Mountain. Width of view, 2.2 mm.

Figure 24. Porphyritic border phase, Kgp, of Grayling Lake pluton. Sample BH9850 from 9850 ft level north of Barbour Hill summit.

Figure 25. Mafic discoid inclusions in swarms paralleling contact between Grayling Lake Granite (Kgl, matrix to the discoids) and the Keokirk Quartz Diorite (Kke). Cirque west of Cherry Lake. Elevation 9720 ft.

Figure 26. Dikes of Grayling Lake Granite (Kgl) cutting the Keokirk Quartz Diorite (Kke). A, cirque northwest of Green Lake and west of Cherry Lake. Field of view tilted due to camera angle; note apparent slant of upright pines. elevation 9610 ft. B, ridge crest northeast of Granite Mountain. Elevation 9450 ft.

Figure 27. Peraluminous pegmatite developed in Grayling Lake Granite near its contact with the Proterozoic sedimentary rocks in thrust sheet. Aquamarine beryl (center, medium grey), black tourmaline (upper center, black), biotite (right, black), and muscovite (lower right, reflecting) are evident, almandine garnet is in pinhead crystals, feldspar and quartz form graphic intergrowth. Just off Gold Creek pack trail (wc/vp) near range divide northwest of Lake Abundance. Elevation 8700 ft.

Figure 28. Thin section showing pseudomorphs of kink-banded brucite after periclase. The assemblage also includes forsterite (partly replaced by serpentine) and spinel. Cambrian Hasmark Dolomite contact-metamorphosed by the Grayling Lake Granite. Sample 644-1, 8520 ft, west base of Keokirk Mountain. Width of view, 0.5 mm.

Figure 29. Metamorphosed Mississippian Lodgepole Limestone at contact of the Keokirk Quartz Diorite. Northeast of Trapper Lake (wc/vp). Elevation 8590 ft.

Figure 30. Euhedral phenocryst of potassic feldspar in the Clifford Creek Granite. North of 9578 ft peak, Vipond Park quadrangle.

Figure 31. Apophysis of Clifford Creek Granite intruding the Cambrian Black Lion Formation. Southwest corner of cirque headwall north of Black Lion Mountain. Note mm scale.

Figure 32. Leucogranite of Bobs Lake, Tqp. Sample 515-4 from ridge crest, 9100 ft, west of Bobs Lake. Note square-shaped, euhedral to subhedral, partly resorbed quartz (medium grey), for example just below sample label in top center.

TABLE CAPTIONS

Table 1. Principal data and characteristics of plutons in the east Pioneer Mountains.

Table 2. Modal mineralogy of plutons of the Pioneer batholith described in this chapter

Table 3. Locations mentioned in the text.

TABLE 1 PRINCIPAL DATA AND CHARACTERISTICS OF PLUTONS IN THE EAST PIONEER MOUNTAINS

Pluton (map unit)	Size km^2	Snee (1983) grouping	Isotopic date, Ma[a]	iSr	SiO_2	ASI[b]	Mafic Mineralogy	Distinctive Features
Keokirk Quartz Diorite (Kke)	2	pre-main group	~80	0.7113	52	0.85	Hb	Medium-fine grained; dark, no phenocrysts or visible quartz; sheaves of secondary bronze biotite.
Trapper Tonalite (Kt)	6	pre-main group	72-74	0.7160	61	0.95	Hb+Bt	Pyroxene cores to many hornblende. Medium-coarse grained; dark bluish-grey, homogeneous to "leopard rock" texture to mafic minerals
Ultramafic xenoliths (gum)	<1 km	early group	--	--	--	--	Opx + cpx	Euhedra of pyroxene and interstitial plagioclase; most samples strongly hydrated and altered
Granite of Stine Creek (Ksc)	9.5	"other plutons"	72-75	0.7140	71-76	1.05-1.07	Bt+Mu	Medium grained, grey; no sphene

TABLE 1 (Continued)

Pluton (map unit)	Size km^2	Snee (1983) grouping	Isotopic date, Ma[a]/	iSr	SiO_2	ASI[b]/	AFM Mineralogy	Distinctive Features
Uphill Creek Granodiorite (Kuc)	77	main group	70-73	0.7113	65-69	0.95-1.05	Hb+Bt	Massive, grey, potassic feldspar as anhedral oikicrysts full of inclusions of matrix minerals. Abundant euhedral sphene Local compositional layering defined by biotite concentration.
Granodiorite of David Creek (Kdc)	4	late group B	?	?	--	--	Bt+Hb	Light grey, fine grained, massive, rare sphene
Grayling Lake Granite (Kgl)	44	late group A	72-74	0.7123-0.7137	68-73	0.99-1.21	Hb+Bt to Bt+Mu	Massive, homogeneous, pink euhedral K-feldspar with solid inclusions in zonal arrangement; euhedral sphene Discoid mafic inclusions abundant; no compositional layering.
Granite of Browne's Lake (Kgb)	1	late group A	71-73	0.7131	72	1.03	Hb+Bt	Same as Kgl
Granite of Mono Park (Kgm)	?	late group A	73	0.7126	68	0.96	Hb+Bt	Same as Kgl
Clifford Creek Granite (TKc)	21	felsic group	65-66	0.7116 0.7123	72-75	1.06-1.09	Bt+Mu	2-mica; white potassic feldspar phenocrysts; coarse grained

TABLE 1 (Continued)

Pluton (map unit)	Size km^2	Snee (1983) grouping	Isotopic date, Ma[a]	iSr	SiO_2	ASI[b]	AFM Mineralogy	Distinctive Features
Granodiorite of Cannivan Gulch (Kcg)	~1/2	felsic group(?)	67	--	--	--	Bt	Medium to fine grained
Leucogranite of Bobs Lake (Tqp)	1.8	felsic group	67	0.7112	71	1.03	Bt+Mu	Round qtz eyes
Leucogranite of Jacobson Meadows (Tqp)	small dikes	porphyry group	--	--	--	--	Bt	Round qtz eyes Phenocrysts and much finer groundmass
Silicic dikes (TKds and Tda)	each a few meters thick	--	64[c]	$\geq$0.7304	74	1.12	Mu+Bt	Leucocratic; sugary and fine grained
Tonalite of Dry Hollow Gulch (Kqd)	<500 m^2	pre-main group	?	?	--	--	Hb	Mottled gray, no visible qtz, no bt or sphene
Tonalite of Lime Kiln Gulch (Klk)	~0.5	pre-main group	~81	0.7069	57	0.90	Hb+Bt	Dark, "salt-and-pepper" texture, medium-coarse grained. No visible qtz or sphene

[a] For sources of isotopic date data, see descriptions of individual plutons.

[b] Aluminum saturation index, ASI = moles Al_2O_3/(moles CaO + moles Na_2O + moles K_2O)

[c] Age determination on sample 741-1 from north wall of Rock Creek Gorge; other data from sample 315-1, a large 2-mica dike south of Sappington Creek, labeled Tda on Zen (1988a).

Table 2. MODAL MINERALOGY OF PLUTONS OF THE PIONEER BATHOLITH DESCRIBED IN THIS CHAPTER

[Kf, potassium feldspar; Pg, plagioclase; Qz, quartz; Mf, mafic minerals; Op, opaque minerals; Bt, biotite; Mu, muscovite; Hb, hornblende; Ti, titanite; Others, includes apatite, zircon, allanite, epidote, myrmekite, and chlorite; ---, not determined]

Keokirk Quartz Diorite

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
0120	112 57 10	45 35 50	8.6	26.2	27.7	37.5	---
313-1	112 56 52	45 38 58	1.5	43.8	13.4	39.7	1.6
BH9800	112 56 54	45 35 19	19.5	36.6	35.8	7.2	0.8

B. Thin section modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Bt	Mu	Hb	Ti	Other
313-1	112 56 52	45 38 58	0.0	64.9	4.3	7.7	0.0	17.2	0.4	5.6

Trapper Tonalite

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
0111	112 53 50	45 36 45	5.9	42.0	21.7	30.4	---
0130	112 53 5	45 36 5	8.0	39.2	21.5	31.3	---
0130	112 53 6	45 35 10	8.0	39.2	21.5	31.3	---
0131	112 53 9	45 35 7	7.1	41.5	23.5	27.9	---
0131	112 53 5	45 35 5	7.1	41.5	23.5	27.9	---
547-1	112 53 55	45 35 43	5.8	50.6	19.6	23.7	0.3

Uphill Creek Granodiorite

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
0101	112 50 55	45 27 20	22.9	37.3	21.9	17.9	---
0117	112 53 10	45 29 0	17.4	41.6	25.3	15.7	---
0122/23	112 54 40	45 25 40	26.8	28.4	25.0	19.8	---
0132	112 54 5	45 25 45	21.4	29.8	28.0	20.8	---
121-1	112 57 23	45 31 10	18.6	45.6	24.7	10.6	0.4
342-1	112 58 25	45 30 40	14.9	44.3	28.7	11.1	1.0
704-1	112 58 15	45 32 37	19.3	39.6	29.5	11.4	0.2
807-1	112 51 45	45 29 36	13.0	53.3	23.0	9.5	1.2
881-1	112 56 8	45 31 41	17.7	45.0	28.7	8.4	0.2
1272-1	112 58 40	45 32 36	16.1	45.9	27.3	10.5	0.1
1272-2	112 58 36	45 32 42	16.1	45.9	27.3	10.3	0.3
FG	112 49 21	45 23 58	13.4	51.8	20.7	13.9	0.2
IVP	112 50 38	45 31 21	13.2	49.6	23.7	12.3	1.2

B. Thin section modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Bt	Hb	Ti	Op	Other
121-1-78	112 57 23	45 31 10	24.3	30.0	37.1	4.0	2.7	0.3	1.2	0.8
122-1	112 58 25	45 30 48	32.8	30.1	30.9	2.3	2.3	0.3	0.9	0.3
122-2	112 58 29	45 31 9	24.0	36.8	33.7	3.1	0.0	0.6	0.7	1.1
881-1-78	112 56 8	45 31 41	18.5	44.7	23.9	5.8	4.3	0.2	0.9	1.5
IVP(1)	112 50 38	45 31 21	4.3	51.0	26.0	7.8	4.3	0.8	---	5.9
IVP(2)	112 50 38	45 31 21	8.5	48.8	26.9	7.4	5.2	0.4	1.8	1.0

Grayling Lake Granite and related rocks

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
0107	112 59 0	45 34 30	22.7	33.5	18.8	25.0	---
0109	112 56 5	45 35 5	27.3	31.9	18.0	22.8	---
0110	112 56 10	45 34 35	22.8	32.7	20.9	23.6	---
0115	112 53 20	45 33 45	25.0	32.4	29.6	13.0	---
0121	112 56 60	45 35 15	19.4	35.9	29.7	15.0	---
0133	112 55 25	45 34 50	24.5	29.8	17.6	28.1	---
0134	112 55 25	45 34 50	21.8	33.6	22.3	22.3	---
0135	112 55 30	45 34 50	18.9	28.4	28.8	23.9	---
0136	112 58 55	45 34 40	16.8	29.6	23.5	30.1	---
0137	112 58 50	45 34 40	19.9	31.0	25.8	23.3	---
0138	112 0 15	45 34 35	24.7	35.8	25.4	14.1	---
0139	113 59 55	45 34 40	23.9	33.5	28.8	13.8	---
578-1	112 53 37	45 33 26	16.3	44.9	24.1	14.2	0.5
585-1	112 54 57	45 34 9	13.3	42.5	28.9	14.6	0.7
604-1	112 59 3	45 34 50	17.8	38.8	35.0	7.9	0.5
606-1	112 58 33	45 34 50	10.4	43.5	29.3	16.1	0.9
700-1	112 53 20	45 33 4	12.5	41.5	30.3	14.8	0.8
1120-1	112 59 29	45 34 48	26.2	35.2	34.5	4.0	0.1
1228-1	112 58 34	45 33 4	15.4	46.6	27.9	10.3	0.1
1293-1	112 55 41	45 34 42	13.3	45.9	28.2	12.4	0.2
1293-2	112 55 39	45 34 43	14.1	42.7	31.4	11.6	0.1
BHS	112 56 58	45 35 13	18.9	38.7	36.9	5.2	0.3
744-2	112 50 8	45 31 33	16.8	41.6	34.4	6.7	0.3
0124/25	112 50 0	45 31 35	26.2	23.1	23.1	27.6	---
1298-2	113 5 24	45 31 29	14.0	40.6	31.6	12.7	0.3
Mono Ck	113	45	14.7	40.6	31.6	12.7	0.3
BH9850	112 56 54	45 35 18	12.5	47.1	21.2	18.5	0.5

Table 2.--Continued

Grayling Lake Granite and related rocks

B. Thin section modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Bt	Mu	Hb	Ti	Op	Other
BHS	112 56 58	45 35 13	29.0	31.5	34.1	4.3	0.0	0.0	0.0	---	1.1
98-2	112 56 58	45 35 13	20.5	47.5	23.1	8.2	0.1	0.0	0.4	0.2	0.0
101-1	112 56 56	45 35 39	7.9	37.9	41.6	8.5	0.0	2.7	0.0	1.3	0.1
104-1	112 55 50	45 34 1	18.9	20.0	49.0	8.2	0.0	2.7	0.1	0.5	0.6
1293-1	112 55 41	45 34 42	15.0	37.2	32.0	8.7	0.0	4.2	0.2	1.0	1.7
1293-2	112 55 39	45 34 43	24.5	56.1	10.4	4.6	Tr	0.9	0.4	0.5	2.4
BH9850	112 56 54	45 35 18	17.9	39.9	22.8	15.4	---	2.3	0.6	---	1.4
98-1	112 56 54	45 35 17	14.4	47.7	26.0	10.6	0.0	0.2	0.7	0.4	0.0

Table 2.--Continued

Tonalite of Torrey Mountain

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
0118	112 51 15	45 25 5	0.0	19.0	68.4	12.6	---
0119	112 51 15	45 25 0	9.7	24.8	55.7	9.8	---
0127	112 52 25	45 27 50	30.3	32.0	23.5	14.2	---
0128	112 52 25	45 27 55	30.4	31.7	23.5	14.4	---
0129	112 52 35	45 26 50	25.6	24.2	44.5	5.7	---
BC	112 51 14	45 25 3	7.4	49.4	30.4	12.7	0.0

B. Thin section modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Bt	Mu	Hb	Ti	Op	Other
BC(1)	112 51 14	45 25 3	17.3	47.1	28.5	4.5	---	0.3	0.3	---	2.0
BC(2)	112 51 14	45 25 3	10.4	51.5	31.6	4.3	0.0	0.2	0.1	1.3	0.4

Table 2.--Continued

Clifford Creek Granite and other Tertiary granites

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
0102	112 58 50	45 38 40	39.5	30.9	28.0	1.6	---
0103	112 50 15	45 26 50	28.6	35.2	21.3	14.9	---
0104	112 50 15	45 26 50	22.7	34.1	20.8	22.	---
0105	112 58 10	45 31 5	22.5	34.4	20.7	22.4	---
0106	112 57 35	45 31 15	18.8	37.1	20.9	23.2	---
500-1	112 59 47	45 38 54	21.9	34.3	34.8	8.8	0.2
BLM9800	112 59 32	45 38 19	19.5	36.7	35.8	7.2	0.8
32-1	112 58 50	45 38 39	20.2	47.2	27.5	4.9	0.2
516-1	112 59 58	45 39 50	15.2	57.8	21.3	5.5	0.1

B. Thin section modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Bt	Mu	Hb	Ti	Op	Other
500-2-78	112 59 47	45 38 54	36.2	34.3	23.6	3.2	2.3	0.0	0.0	0.2	0.2
32-1	112 58 50	45 38 39	9.9	56.7	28.9	1.7	2.2	0.0	0.0	0.2	0.4

Satellite bodies of the Boulder batholith

A. Slab modes

Sample	Longitude	Latitude	Kf	Pg	Qz	Mf	Other
DCQMZ	112 59 26	45 51 34	0.0	57.4	12.2	29.6	0.8
984-1	112 52 29	45 44 40	0.1	51.0	9.6	37.8	1.4
984-2	112 52 31	45 44 41	3.5	56.3	9.8	29.7	0.7

Table 3. LOCATIONS MENTIONED IN THE TEXT

Quadrangles: Vipond Park (vp), scale 1:62,500, edition of 1958
Polaris (pl), scale 1:62,500, edition of 1959
Stine Mountain (sm), scale 1:24,000, edition of 1978
Maurice Mountain (mm), scale 1:24,000, edition of 1978
Torrey Mountain (tm), scale 1:24,000, edition of 1952
Twin Adams (ta), scale 1:24,000, edition of 1952
Melrose (mr), scale 1:24,000, edition of 1961

9578 ft peak (wc/vp)
Barbour Hill (wc/vp)
Birch Creek Guard Station (sw/ta)
Black Lion Mountain (wc/vp)
BM 7181 (ne/tm)
Bob's Lake (wc/vp)
Bridge 6086 (ne/sm)
Brown's Peak (sc/vp)
Browne's Lake (se/vp)
Cannivan Gulch (wc/vp)
Canyon Lake (wc/vp)
Cherry Creek (ec/vp)
Cherry Lake (sc/vp)
Clifford Creek (ec/sm)
Crescent Lake (ec/mm)
Crystal Park (nc/pl)
David Creek (se/mm)
Dry Hollow Gulch (ne/vp)
Elkhorn Creek (sc/mm)
Gold Creek pack trail (wc/vp)
Granite Lake (sc/vp)
Granite Mountain (sw/vp)
Grayling Lake (sw/vp)
Green Lake (sc/vp)
Grouse Lakes (nw/sm)
Hecla Mines (wc/vp)
Jacobson Meadows (sc/mm)
Keokirk Mountain (wc/vp)
Lake Abundance (ne/mm)
Lime Kiln Gulch (nc/vp)
Lion Creek (wc/vp)
Maurice Mountain (ne/mm)
Mono Park (sw/mm)
Mount Alverson (10448 ft) (sw/vp)
Mount Tahepia (sw/vp)
Osborne Creek (nw/sm)
Rock Creek (sc/vp)
Sawmill Gulch (ne/vp)
Sheep Creek (nw/vp)
Shepherd Mountain (wc/mr)
Stine Creek (nc/sm)
Storm Peak (sc/vp)
Sugarloaf Mountain (se/vp)
Tendoy Lake (sw/vp)
Trapper Creek (c/vp)
Trapper Lake (wc/vp)
Trusty Gulch (ne/vp)
Vipond Creek (nc/vp)

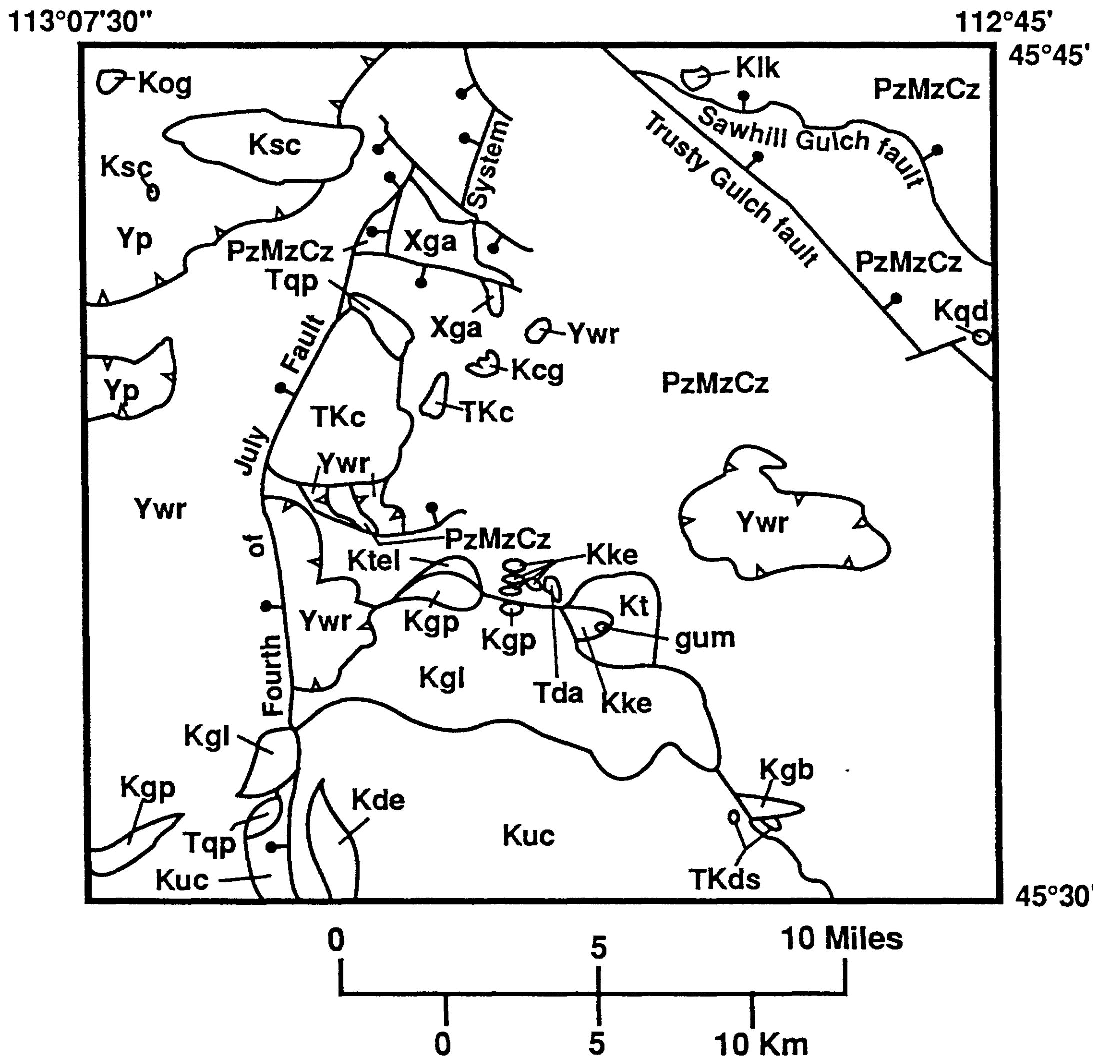

Figure 1. Sketch map showing locations of the plutons described in this chapter. Symbols for plutons are same as used and discussed in the text. Other rock units: PzMzCz: undifferentiated phanerozoic rocks, mainly sedimentary. Yp, Middle Proterozoic rocks in the Pattengail thrust sheet. Ywr, Middle Proterozoic rocks in the Wise River thrust sheet. Xga, Early Proterozoic metamorphic rocks. The distribution of Ywr west of the Fourth of July fault is generalized. Major high-angle faults are labeled (barbell on downthrown side) but cross faults are not labeled. Thrust faults have teeth on the upper plate. For further information see Zen (1988a).

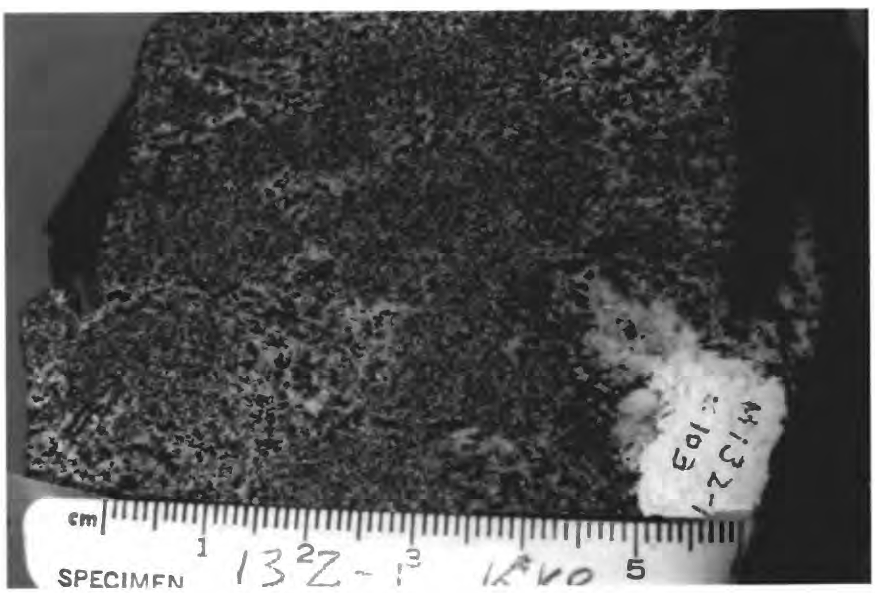

Figure 2. Keokirk Quartz Diorite, Kke (sample 132-1) showing sheaves of biotite that apparently resulted from thermal metamorphism by the Grayling Lake pluton, superposed on the preexisting igneous texture. 9300 ft level on cliffs south of Trapper Creek.

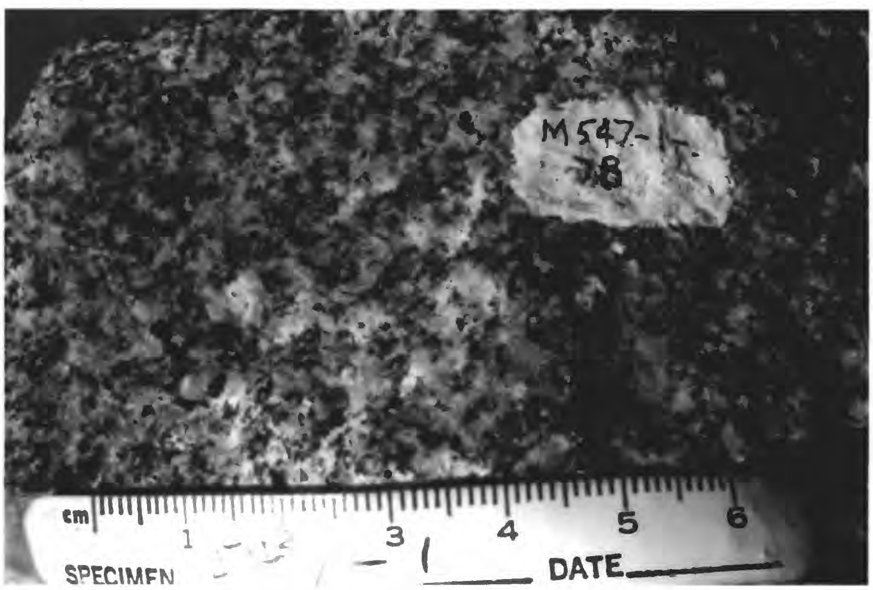

Figure 3. Trapper Tonalite, Kt. Large scree block at 8190 ft in felsenmeer at base of 30-meter cliffs south of Trapper Creek, sample 547-1.

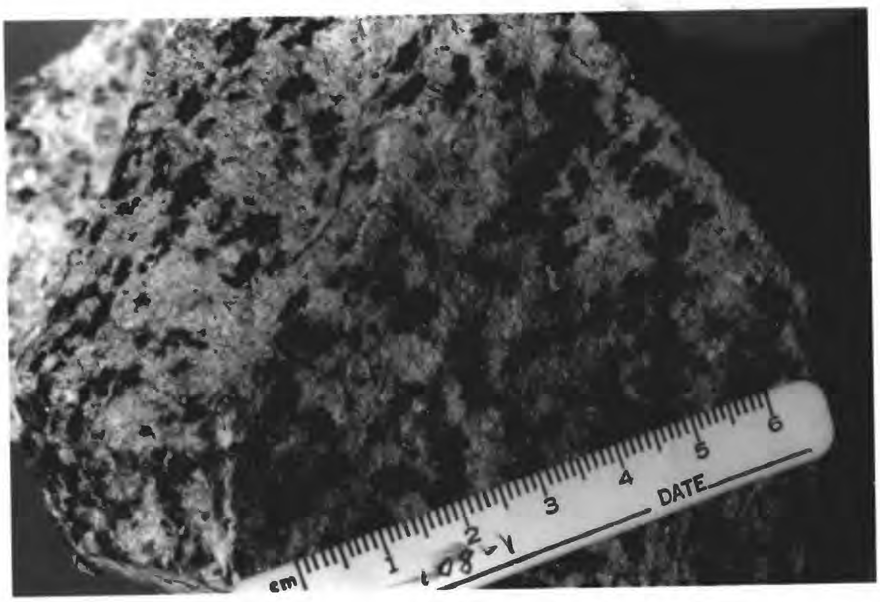

Figure 4. Trapper Tonalite, Kt. "Leopard rock", showing clusters of mafic minerals elongate in igneous flow direction. Sample 108-1, 9150 ft level north of Green Lake (sc/vp). Slightly weathered part (main face of photograph) shows characteristic positive relief of mafic minerals.

Figure 5. Keokirk Quartz Diorite, Kke, intruded by a dike of Trapper Tonalite. Rock below the light-coloured veins and mylonite, as well as at extreme upper left corner, are the Keokirk, here strongly deformed. Rock below the scale is the Trapper Tonalite. Rock chute at 8620 ft elevation on north-facing cliffs south of Trapper Creek.

Figure 6. Large cliffs west of Granite Lake, underlain by ultramafic xenoliths. Most of the area to the north (right) of the snow chute is ultramafic rock; the main cliff to the left contains a mixture of these rocks and the host Trapper Tonalite. Relief displayed on the cliff is about 100 meters.

Figure 7. Thin section showing cumulate texture of the coarse pyroxenite of the ultramafic rocks. Euhedral augite and hypersthene in crystal-supported fabric; plagioclase is entirely interstitial. Sample 785-5, talus material at base of large cliffs west of Granite Lake. Width of view, 5.5 mm.

Figure 8. Composition layering in the ultramafic rocks on cliffs west of Granite Lake. Sample location is about halfway up the snow chute shown in Figure 6, elevation 9720 ft.

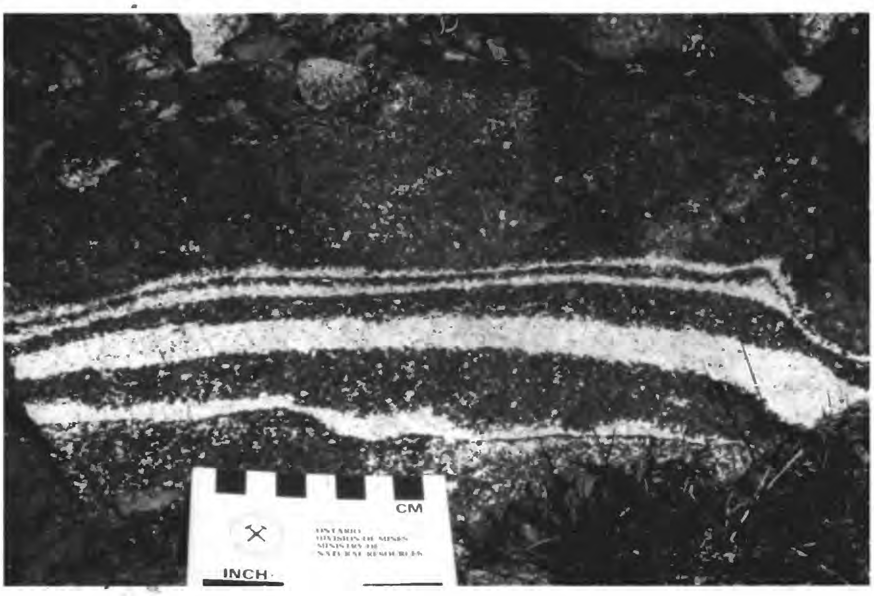

Figure 9. Xenolith of layered ultramafic rock in Trapper Tonalite, near base of cliffs north of snow chute of Figure 6.

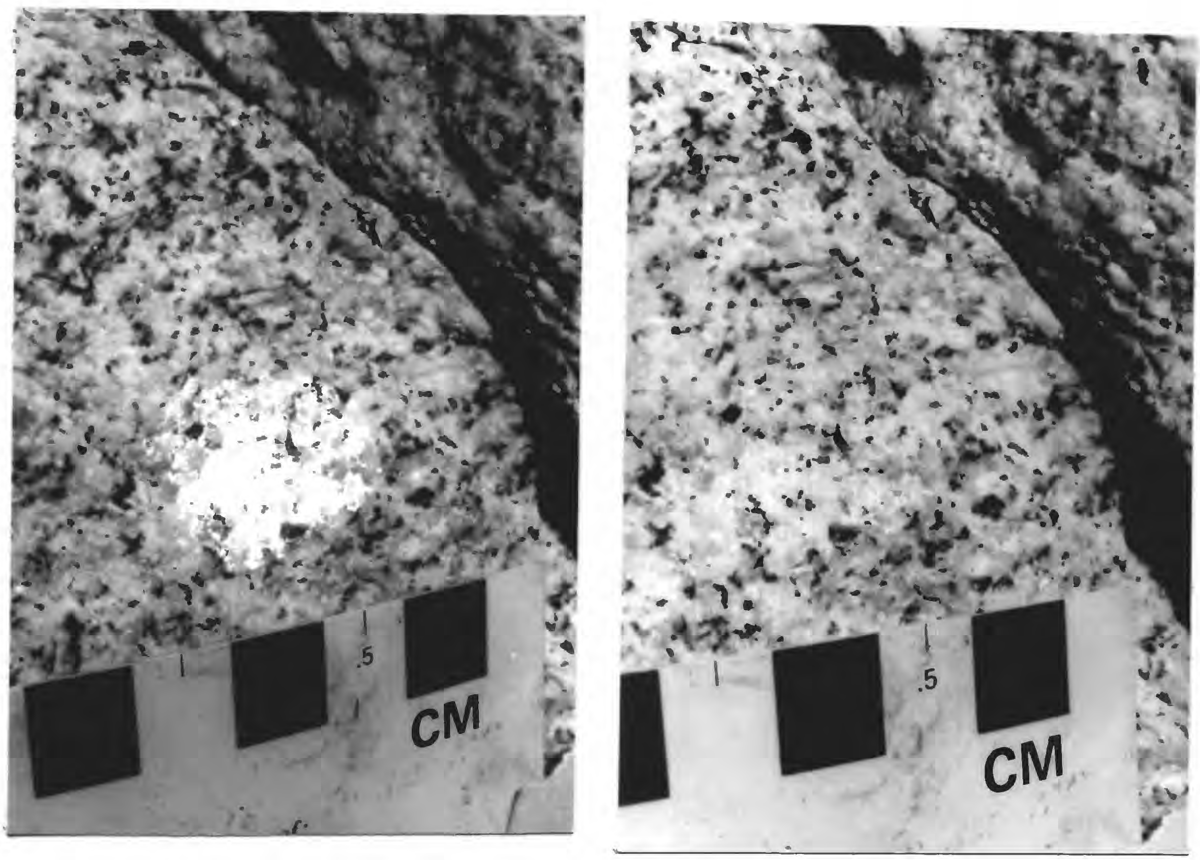

Figure 10. Oikicrysts of potassic feldspar in Uphill Creek Granodiorite (Kuc). The stereo pair was taken with optical axis of camera rotated only a few degrees to bring in the cleavage reflection of the feldspar in one view. Roadcut along Willow Creek, BM7181 (ne/tm; Section 18, T4S R10W).

Figure 11. Thin section of oikicryst of Uphill Creek Granodiorite. Note smaller grain size of the included minerals, and development of myrmekite at the margin of the oikicryst but not within the oikicryst. Sample 1279-1, 9680 ft west of Mount Alverson (Peak 10448, sw/vp). Width of view, 1.6 mm.

Figure 12. Xenolith of Keokirk(?) Quartz Diorite in Uphill Creek Granodiorite, southeast of Mount Tahepia (sw/vp). Notice mafic discoid in upper right corner of photograph.

X B

Figure 13. Layering defined by biotite concentration in Uphill Creek Granodiorite (Kuc), rock basin south of Tendoy Lake (sw/vp). Elevation 9350 ft.

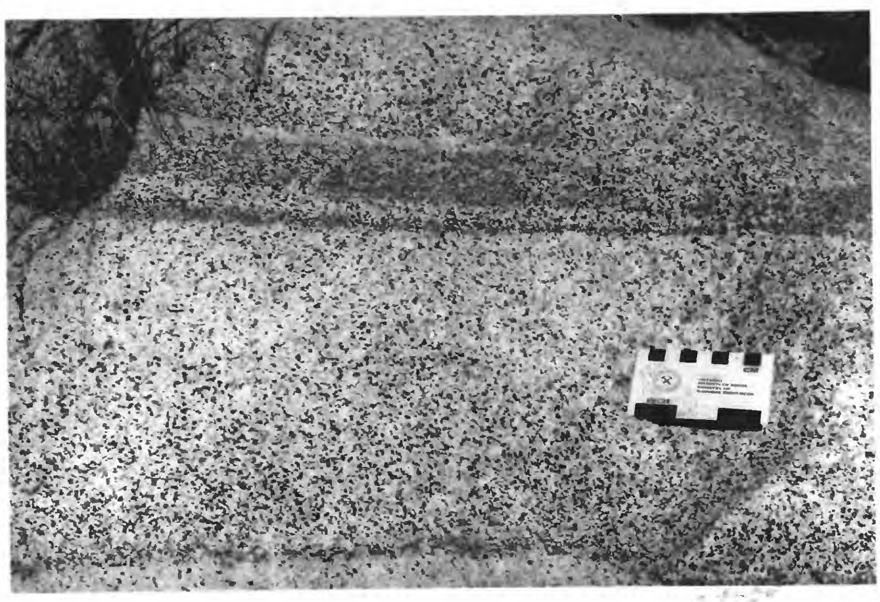

Figure 14. Closeup of biotite-defined layering shown in Figure 13. Biotite shows no size gradation from mafic to leucocratic layers.

Figure 15. Contorted, coxcomb layering by biotite concentration, Uphill Creek Granodiorite (Kuc). Cirque floor east of Mount Alverson. Elevation 8930 ft.

Figure 16. Miarolitic cavity filled with euhedral pegmatitic minerals. Uphill Creek Granodiorite. Loose block on slope south of Tendoy Lake.

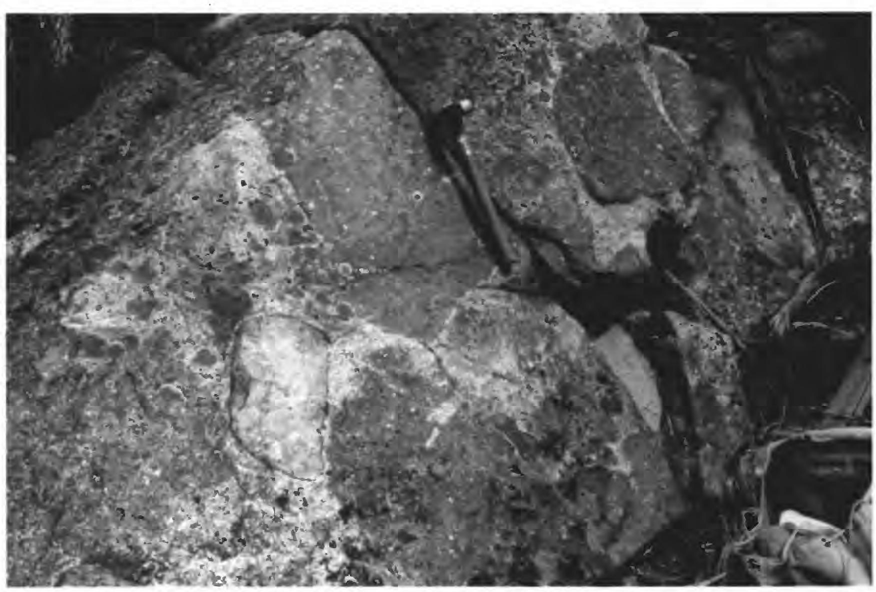

Figure 17. Intrusive breccia in Grayling Lake Granite within zone of magmatic mixing, north slope of Rock Creek gorge. The blocks are mainly diorite; a block of metamorphosed calcareous sedimentary rocks is to the left, just below center. Elevation 8270 ft.

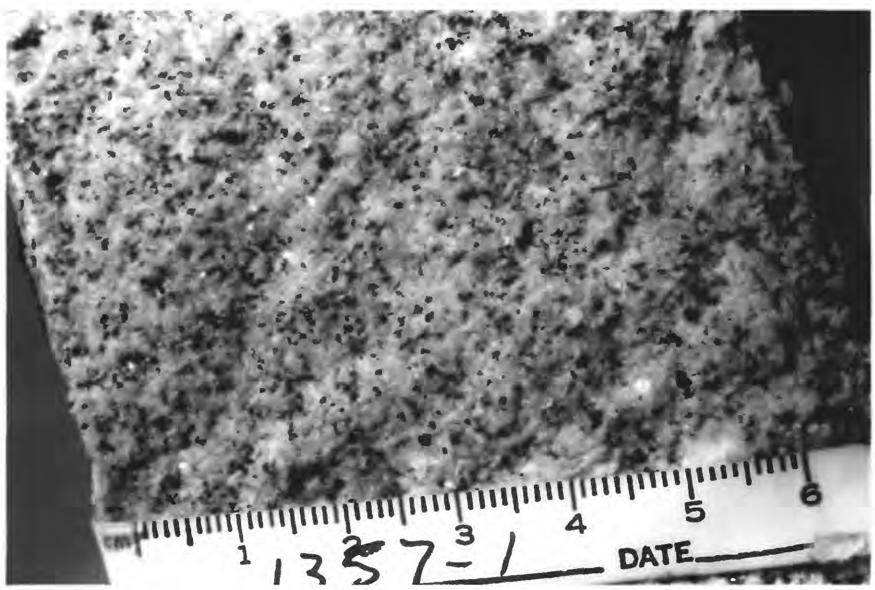

Figure 18. Granodiorite of David Creek, Kdc. Sample 1357-1, on 8150 ft cliff, end of ridge south of David Creek.

Figure 19. Dike of David Creek pluton (light coloured) cutting the Uphill Creek Granodiorite that shows mafic layering immediately adjacent to the granodiorite of David Creek. Cliff on ridge crest north of David Creek. Elevation 7900 ft.

Figure 20. Roof of Browne's Lake pluton on the north wall of Rock Creek gorge immediately above Browne's Lake, viewed from the Ivanhoe pit. Contact is at the top of the slight ledge in middle of picture, above the top of the large talus cone.

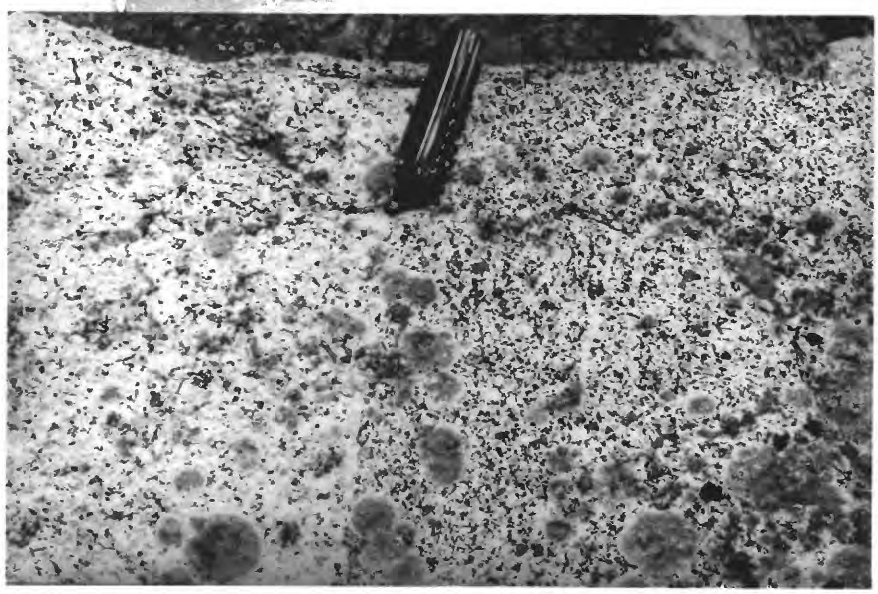

Figure 21. Crosscutting relations between the Browne's Lake pluton (Kgb; left) and the Uphill Creek Granodiorite (Kuc; right). Igneous foliation in Kuc slants steeply to the lower right in the picture and was truncated by Kgb. North slope of Rock Creek gorge. Elevation 7120 ft.

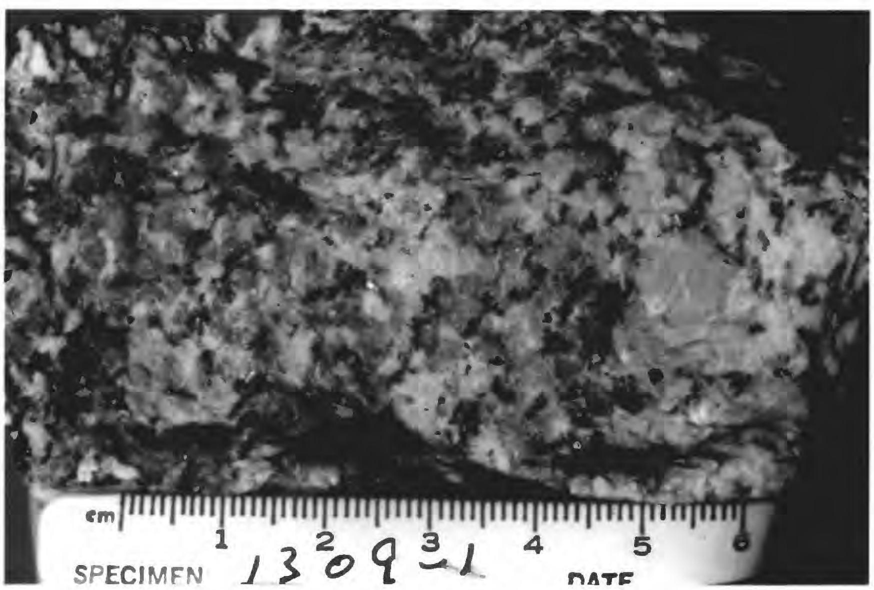

Figure 22. Grayling Lake Granite, Kgl. Sample 1309-1, at 9080-ft level north of 9400 ft pass southeast of Crescent Lake. Notice euhedral potassic feldspar phenocryst near right edge of photograph.

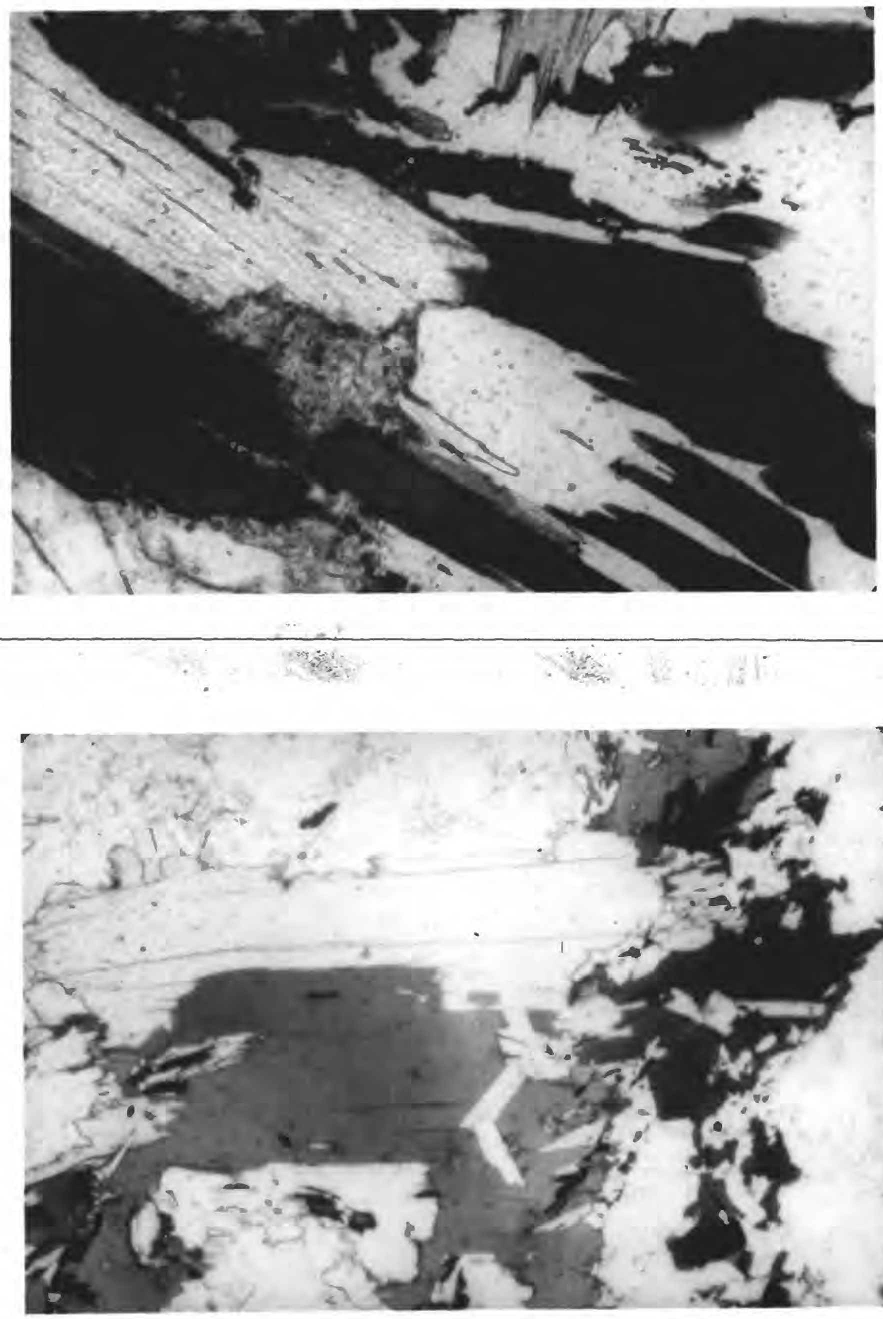

Figure 23. Muscovite in butt-end intergrowth with biotite, interpreted to indicate a magmatic origin. A, Grayling Lake Granite, sample BHS from top of Barbour Hill (see Zen, 1986). Width of view, 0.5 mm. B, Clifford Creek Granite. Sample 500-1 in cirque north of Black Lion Mountain. Width of view, 2.2 mm.

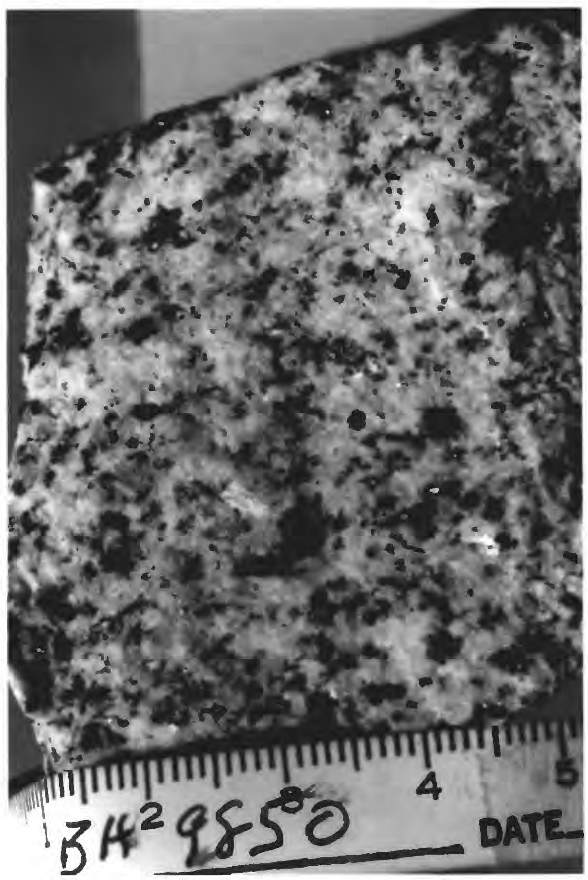

Figure 24. Porphyritic border phase, Kgp, of Grayling Lake pluton. Sample BH9850 from 9850 ft level north of Barbour Hill summit.

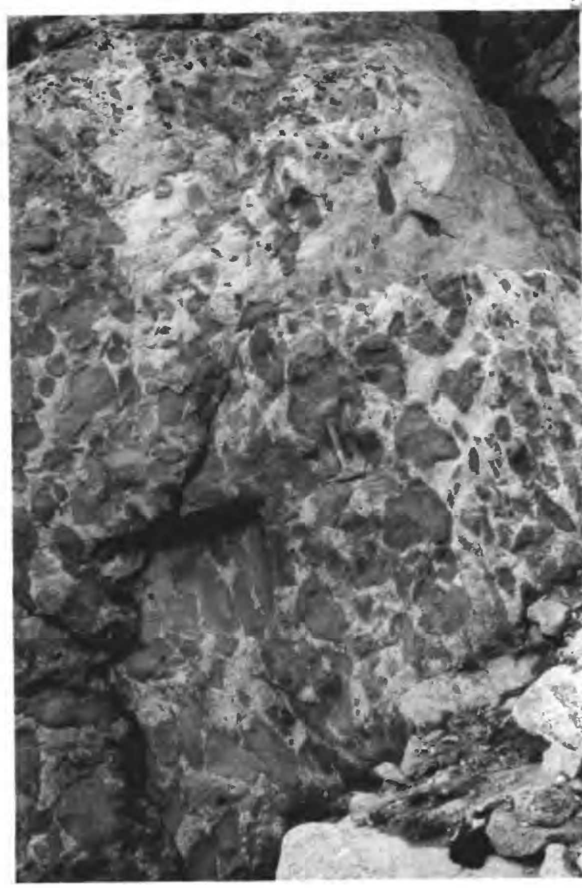

Figure 25. Mafic discoid inclusions in swarms paralleling contact between Grayling Lake Granite (Kgl, matrix to the discoids) and the Keokirk Quartz Diorite (Kke). Cirque west of Cherry Lake. Elevation 9720 ft.

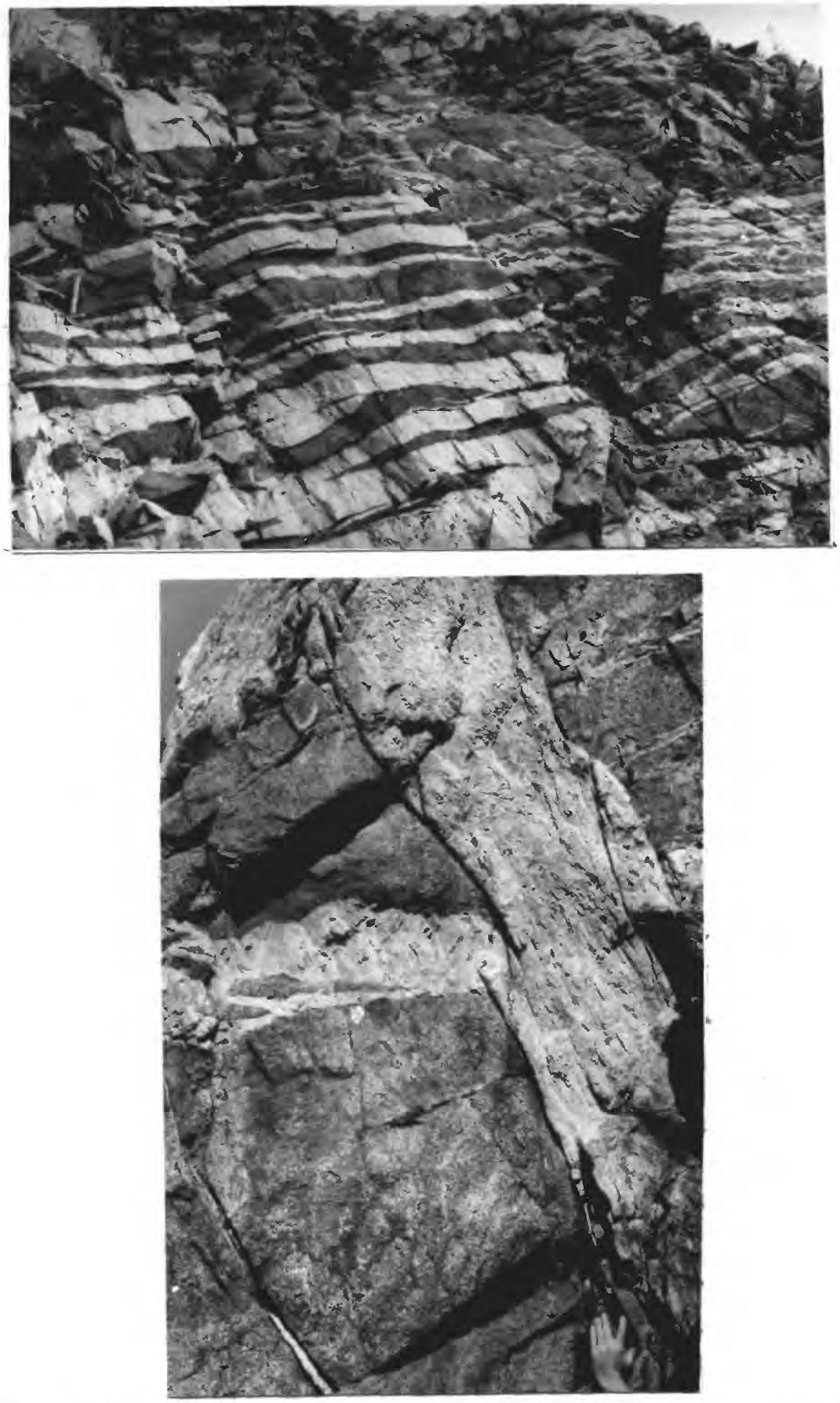

Figure 26. Dikes of Grayling Lake Granite (Kgl) cutting the Keokirk Quartz Diorite (Kke). A, cirque northwest of Green Lake and west of Cherry Lake. Field of view tilted due to camera angle; note apparent slant of upright pines. elevation 9610 ft. B, ridge crest northeast of Granite Mountain. Elevation 9450 ft.

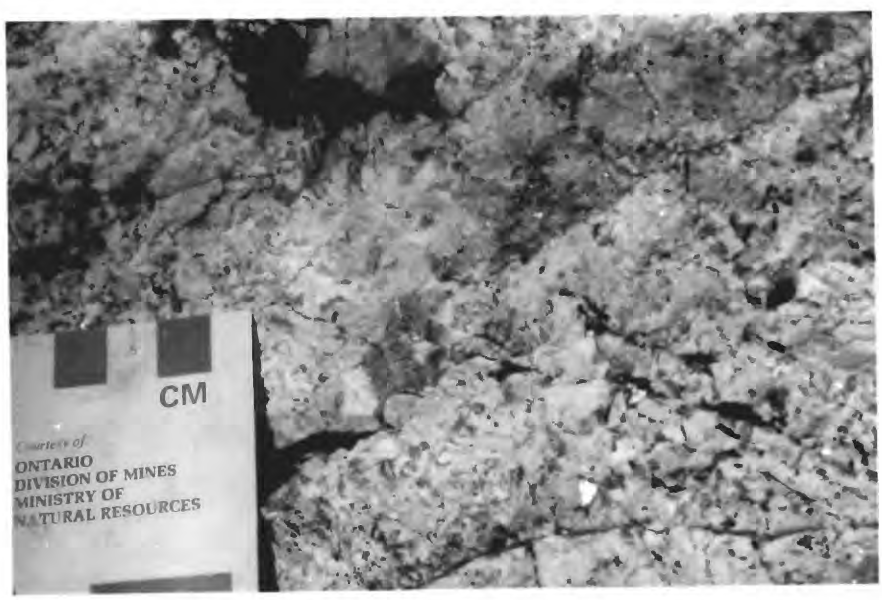

Figure 27. Peraluminous pegmatite developed in Grayling Lake Granite near its contact with the Proterozoic sedimentary rocks in thrust sheet. Aquamarine beryl (center, medium grey), black tourmaline (upper center, black), biotite (right, black), and muscovite (lower right, reflecting) are evident, almandine garnet is in pinhead crystals, feldspar and quartz form graphic intergrowth. Just off Gold Creek pack trail (wc/vp) near range divide northwest of Lake Abundance. Elevation 8700 ft.

Figure 28. Thin section showing pseudomorphs of kink-banded brucite after periclase. The assemblage also includes forsterite (partly replaced by serpentine) and spinel. Cambrian Hasmark Dolomite contact-metamorphosed by the Grayling Lake Granite. Sample 644-1, 8520 ft, west base of Keokirk Mountain. Width of view, 0.5 mm.

Figure 29. Metamorphosed Mississippian Lodgepole Limestone at contact of the Keokirk Quartz Diorite. Northeast of Trapper Lake (wc/vp). Elevation 8590 ft.

Figure 30. Euhedral phenocryst of potassic feldspar in the Clifford Creek Granite. North of 9578 ft peak, Vipond Park quadrangle.

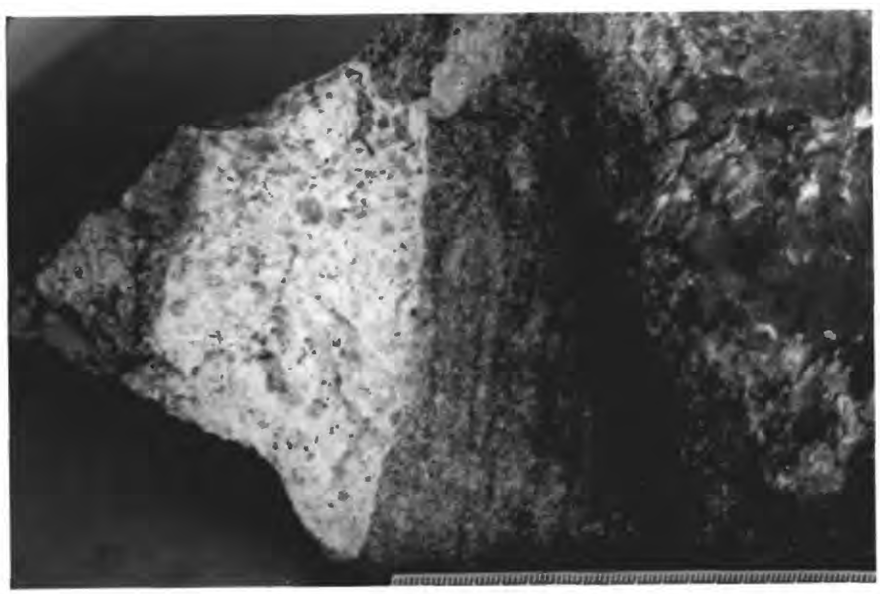

Figure 31. Apophysis of Clifford Creek Granite intruding the Cambrian Black Lion Formation. Southwest corner of cirque headwall north of Black Lion Mountain. Note mm scale.

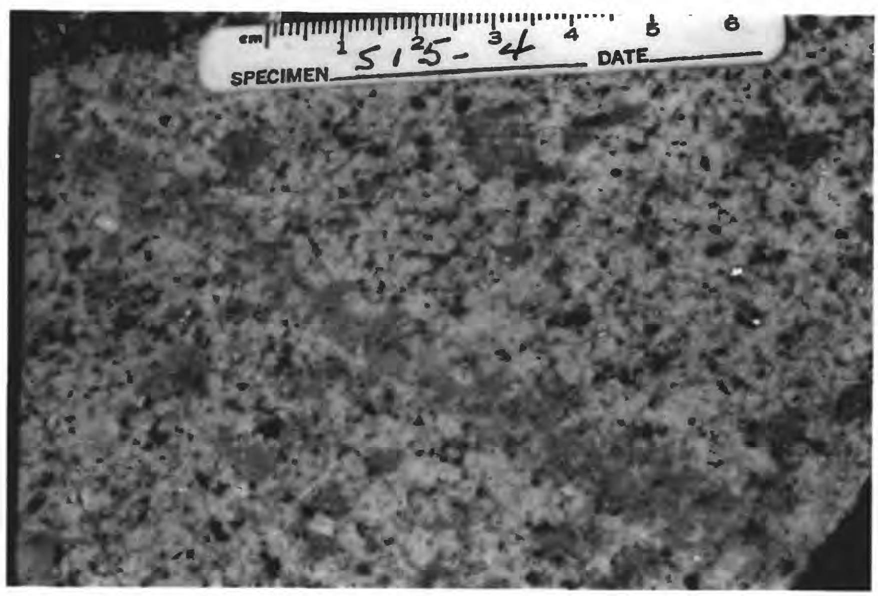

Figure 32. Leucogranite of Bobs Lake, Tqp. Sample 515-4 from ridge crest, 9100 ft, west of Bobs Lake. Note square-shaped, euhedral to subhedral, partly resorbed quartz (medium grey), for example just below sample label in top center.