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A study of the mafic rocks along the eastern flank of the Flint Creek Range western Montana

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A STUDY OF THE MAFIC ROCKS ALONG THE EASTERN FLANK OF THE FLINT CREEK RANGE, WESTERN MONTANA

by

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The mafic rocks along the eastern flank of the Flint Creek Range were studied to determine their relationship to the granitic plutons which form the core of the range, and to determine the significance of their position between and bounded by the granitic plutons on the west and faults to the east. This project helped clarify the structural interpretation of this complex area, and added a new phase to the ongoing study of the igneous history of the Flint Creek Range.

Field work, textural studies and whole rock chemistry lead to development of the new hypothesis that the diorites outcropping in Racetrack and Dempsey Creeks are all part of the same pluton, named the Racetrack pluton. The whole-rock oxide weight percents for the Racetrack pluton fall along the curve previously plotted for the granitic plutons to the west, supporting the hypothesis that all the plutons in the Flint Creek Range are comagmatic. Textural differences between the two major outcrop areas developed when shearing affected the bottom and southern part of the pluton more than other portions. Mineralogical differences were caused by diffusion of fluids from the younger Mount Powell magma through the more porous, sheared portion of the Racetrack pluton.

As a result of this field work and compilation of previous studies in the eastern Flint Creek Range, the Olson Gulch thrust fault has been extended 12-15 km. north from its outcrop in Chinaman Gulch. This fault delineates the eastern boundary of the Sapphire Plate, the recently recognized structural block which contains the Flint Creek Range.

ACKNOWLEDGEMENTS

I would like to thank Dr. Donald Hyndman for giving freely of his resources, for accompanying me in the field, and for constructive criticism and support throughout this and other projects. Drs. James Talbot and Keith Osterheld also read and helped improve the manuscript. Mike Woods was an indispensible help with the chemical analyses. Dick Benoit, my husband, field companion and sounding block introduced me to the mafic rocks and was patient while the work went on. I especially thank all my friends and companions in the Geology Department for keeping life interesting.

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CHAPTER 1

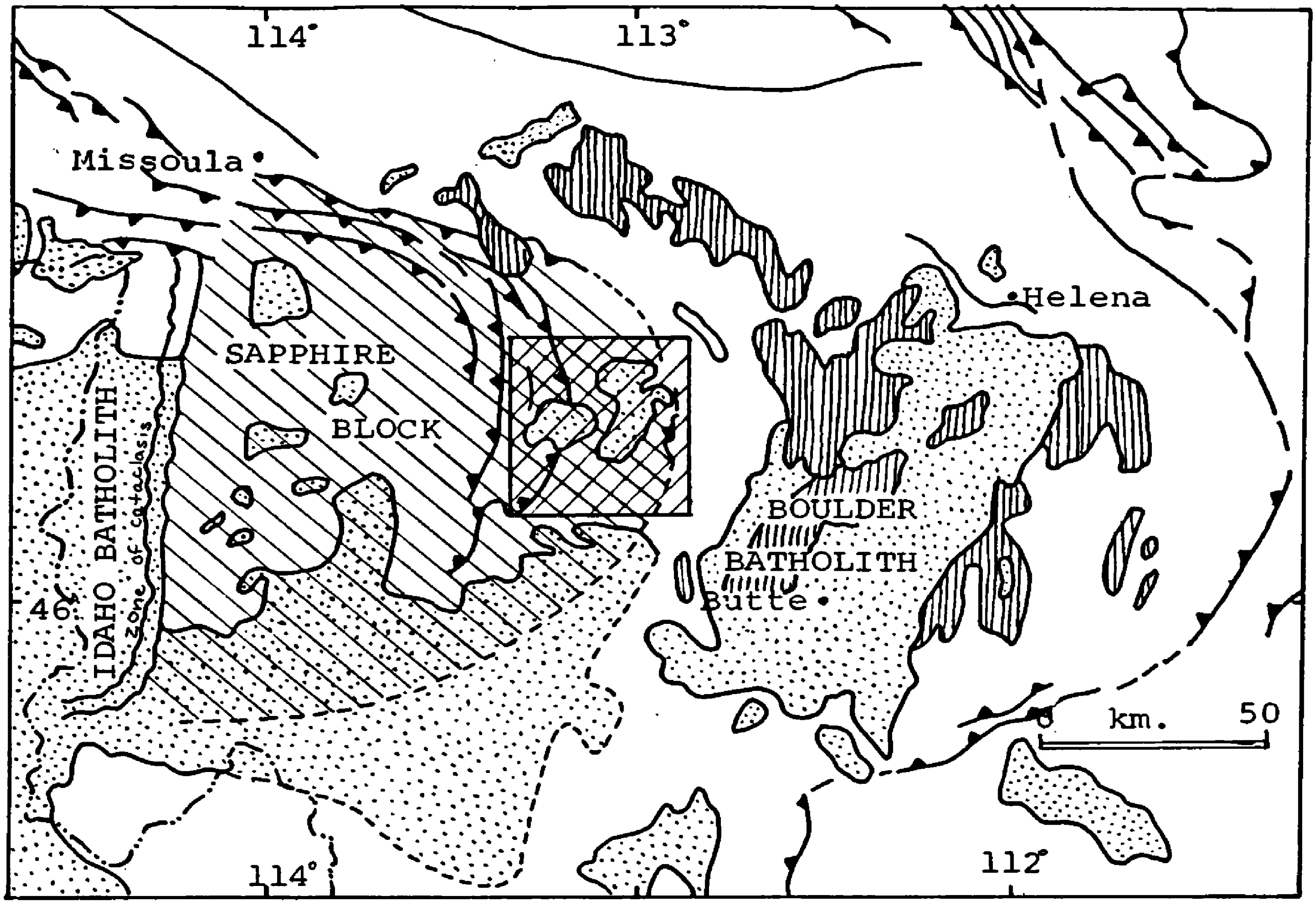
INTRODUCTION

The mafic rocks of the Racetrack "pluton" comprise the only one of several igneous bodies in the Flint Creek Range which has not previously been studied in detail. To complete the igneous history of the range, a detailed study of this body has been undertaken. The purposes were a) to determine the relationship of the mafic-rich Racetrack pluton to the more felsic plutons which form the core of the range, and b) to determine the significance of its structural position, which in turn will help to clarify the structural interpretation of this complex area.

Regional geology

The geology of the area shown in Figure 1 has long been recognized as distinctive from that found along the rest of the North American cordillera. In this area Cretaceous batholiths extend much farther east than anywhere else along the cordillera, and there appear to be two zones of thrusting separated by the Boulder batholith.

The Flint Creek Range lies on the eastern part of the Sapphire Plate, between the Boulder and Idaho batholiths



Granitic rocks

Sapphire Block

Idaho-Montana border

Volcanic rocks

Area of Figure 2
(Flint Creek plutons)

Thrust fault

Figure 1 Regional geology
(modified from Hyndman, Talbot and Chase, ms.)

(see Fig. 1). The Sapphire Plate has moved eastward from the rising Idaho batholith and contains several large thrust faults, as well as numerous igneous intrusives (Hyndman, Talbot and Chase, ms.). The intrusive rocks are compositionally similar to the granitic rocks of the Idaho and Boulder batholiths. Rocks of the Precambrian Ravalli, Wallace and Missoula Group formations are involved in the thrusting.

Previous work

The Flint Creek Range was first studied by Emmons and Calkins (1913, 1915), whose remarkably accurate work remains valuable. Eastern parts of the range were mapped by Csejtey (1963), Mutch (1960) and Allen (1962), who also added detail to the structural interpretations. More recently, the felsic plutons which form the core of the range have been studied in detail under an NSF-funded project (Hyndman and others, ms.). Theses resulting from this work are relatively limited in scope and do not discuss the mafic rocks to the east of the batholiths (Winegar, 1970; Ehinger, 1972; Benoit, 1972; Wold, 1972; Baty, 1973).

Geology of the Flint Creek Range

The core of the Flint Creek Range contains the intrusive rocks of the Philipsburg and Mount Powell batholiths and the Bimetallic and Royal stocks (see Fig. 2). The structural geology is dominated by a group of thrust faults derived from the west, the Philipsburg, Georgetown, Olson Gulch and Thornton Creek thrusts (Emmons and Calkins, 1913; Csejtey, 1963). Precambrian and lower Cambrian rocks are thrust onto Paleozoic and younger formations. To the east of the thrusts are apparently autochthonous Cretaceous and post-deformational Tertiary sedimentary rocks.

During and after the multiple thrusting episodes, the thrust faults have been gently folded into north-plunging synclines and anticlines and erosion and block faulting have obscured relationships among the thrusts (Mutch, 1960; Csejtey, 1963). Forceful intrusion of the igneous bodies caused local overturning and reorientation of folds parallel to pluton margins (Mutch, 1960; Hyndman and others, ms.). The most recent structural activity has been minor block faulting throughout the range.

Hyndman, Talbot and Chase (ms.) have presented a structural interpretation for the area including the Flint Creek Range, extending from the Idaho batholith to the Lombard Thrust Zone. They believe that the thrusting as far east as the eastern side of the Flint Creek Range was caused by spreading away from the Idaho batholith, and that some of

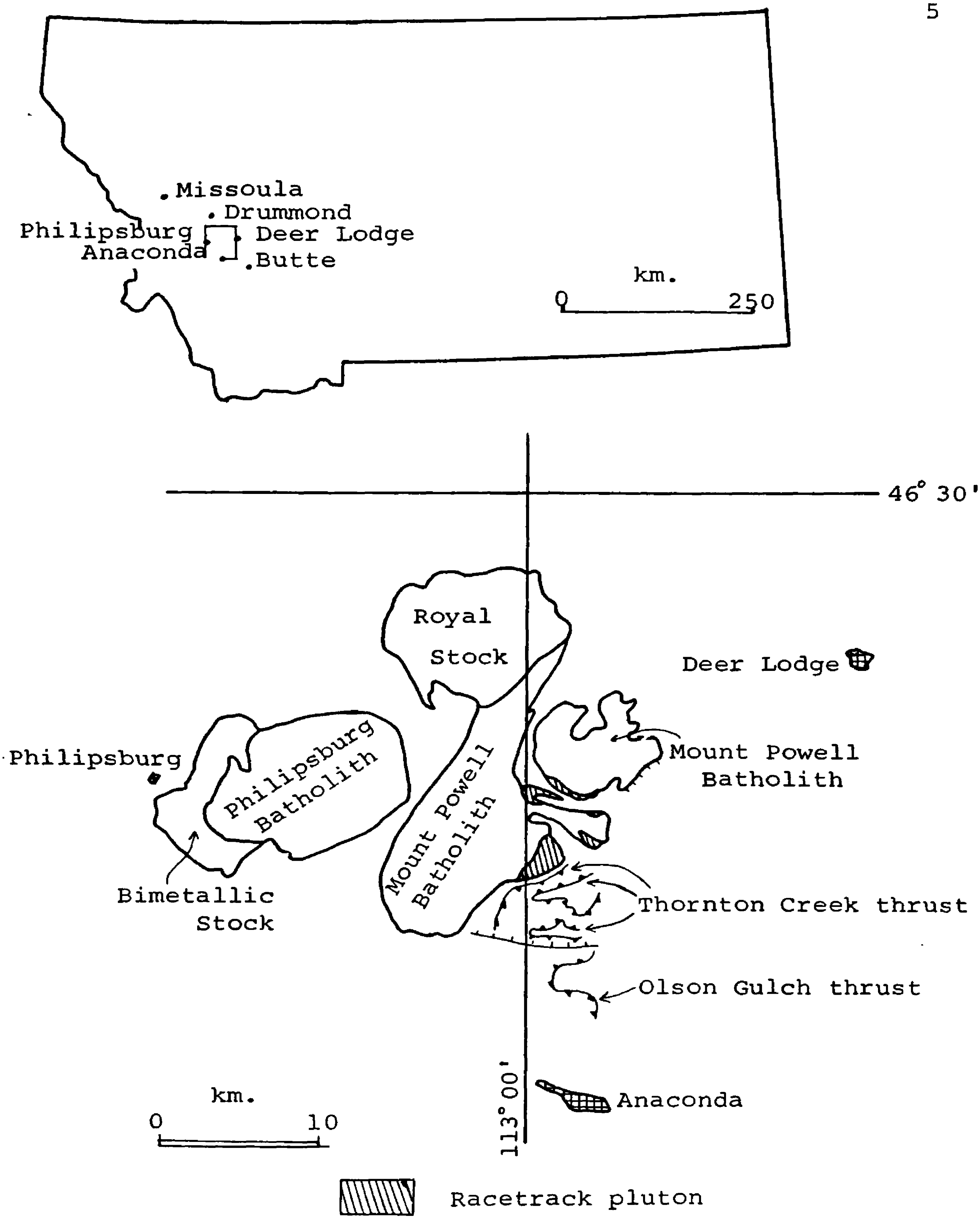


Figure 2 Map of the Flint Creek pluton locations

the plutons in the range intruded along those thrusts.

Emmons' and Calkins' work was primarily observational though they did suggest that the porphyritic biotite granite of Thornton Ridge was probably younger than the Cambrian sediments. They related the foliation developed in the mafic rocks to the thrust faulting present in the area (Emmons and Calkins, 1913, p. 91).

In his study of the structure and petrology of the Royal stock and the Mount Powell batholith, Allen (1962) briefly described and discussed the origin of the "Racetrack Creek hornblende granodiorite". Allen recognized that the hornblende granodiorite was older than the Mount Powell batholith, and believed on the basis of comparitive mineralogy that it was as old as or older than the Royal stock (Allen, 1962, p. 43). His criteria for the greater age were a) the plagioclase of the hornblende granodiorite (An_{33-35}) was slightly higher than that of the Royal stock (An_{26-35}) and b) the Racetrack body contains both hornblende and biotite whereas the Royal stock contains only biotite (p. 43). Furthermore, on the basis of similarity of mineralogy, chemistry and texture to that of the Racetrack body, he believed theRacetrack body, the Royal stock and the Mount Powell batholith were comagmatic and differentiated in that order (Allen, 1962, p. 43, p. 96 ff). Allen interpreted the mafic rocks of Dempsey Creek and Ryan Lake cirque as Precambrian sills in the Missoula Group and Newland Formations (Allen, 1962, Pl. I). He did not describe or discuss them in his text.

Mutch (1960, p. 32) presented only a very brief description of the Racetrack body, but provided somewhat more detail in his discussion of the mafic rocks of Dempsey Creek and Ryan Lake cirque. He also believed they were part of a diabase sill, partly metamorphosed, of Precambrian age, intruding the Newland (Wallace) formation (Mutch, 1960, p. 28). He based his age interpretation on petrographic similarities of this sill to others contained in Proterozoic sedimentary rocks of British Columbia, Idaho, and western Montana. He believed this "sill" correllates with the Purcell sills of British Columbia and northwestern Montana (p. 29).

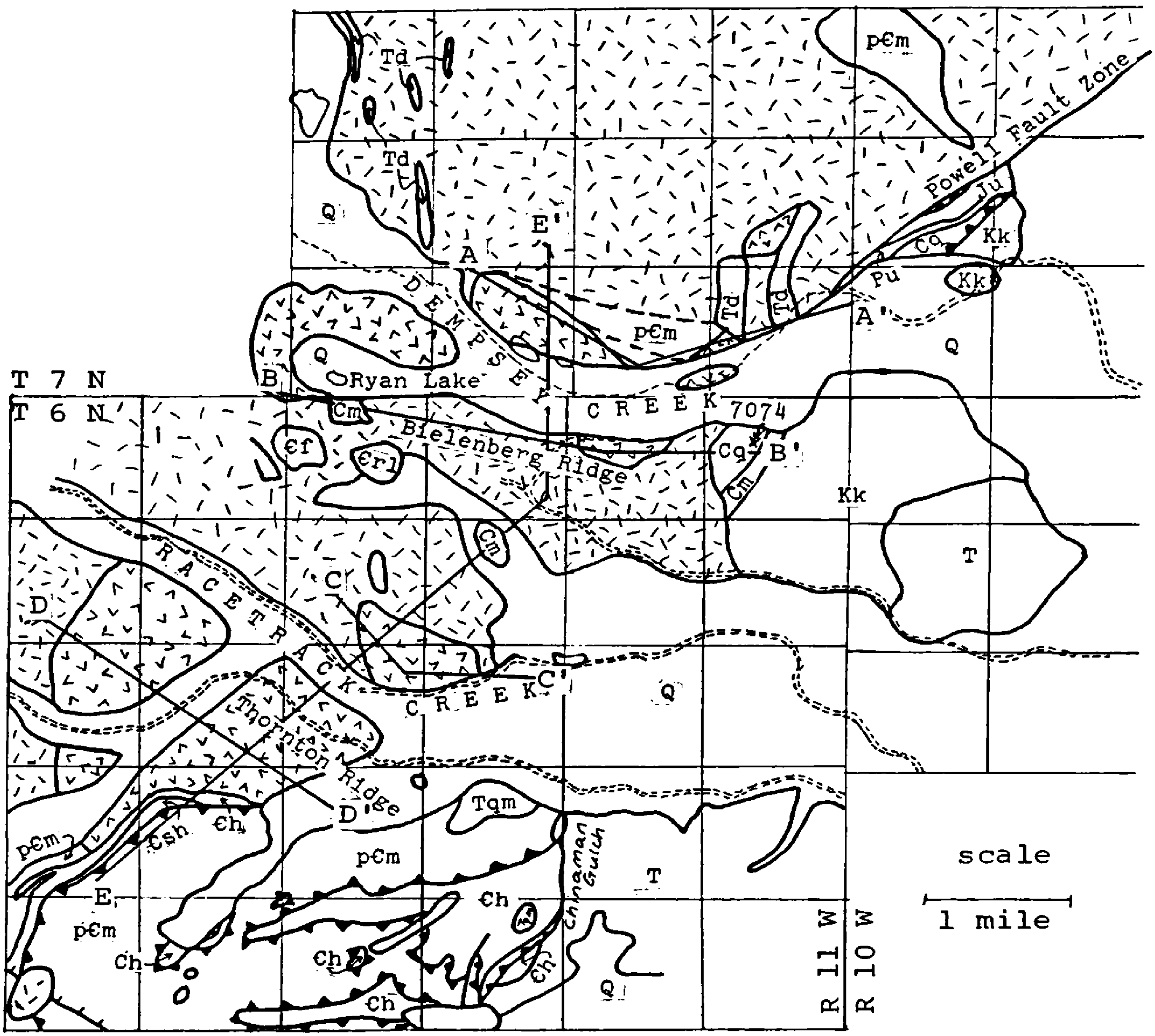
CHAPTER II

FIELD RELATIONSHIPS

Introduction

Mafic rocks are well-exposed in the cliffs on the north side of Dempsey Creek, in the cirque wall above Ryan Lake, on the north side of Racetrack Creek and on the ridges south of Racetrack Creek (Fig. 3). No rocks outcrop on the high grasslands and wooded areas between most drainages.

The rocks of the Dempsey Creek -- Ryan Lake area and those immediately north and south of Racetrack Creek have not previously been discussed or interpreted as a single unit (Mutch, 1960; Allen, 1962). On the basis of the spatial relationships described in this chapter, the textural discussion in Chapter III, and the chemical trends described in Chapter IV, it is presently believed that all the mafic rocks of the Racetrack and Dempsey Creek areas are part of a single body. Variations in texture and chemistry are believed to be caused by a) regional deformation during and subsequent to intrusion of the mafic magma and b) movement of fluids outward from the younger Mount Powell batholith.



Q Quaternary (glacial and alluvial)
T Tertiary sediments
Td Tertiary dikes
Tqm Tertiary quartz monzonite
Kk Kootenai formation
Ju Jurassic undifferentiated
Pu Permian undifferentiated
Cq Quadrant quartzite
Cm Madison limestone
Єh Hasmark dolomite
Єsh Silver Hill shale
Єf Flathead sandstone
pЄm Missoula Group argillites
Racetrack pluton
Mount Powell batholith

(modified from Csejtey, 1963; Mutch, 1960)

Figure 3 Geologic Map of the Racetrack pluton field area

Description of the mafic rocks in outcrop

The mafic rocks are easily recognized from a distance by their very dark color in contrast to the white porphyritic granite of the Mount Powell batholith. The rocks have been pervasively injected with aplite, pegmatite and granitic dikes derived from magmas of the batholith (Pl. 1). The major dikes range from 3 to 35 m. thick and everywhere dip toward the Mount Powell batholith at an average of 35^{o}W. They are characteristically rhythmically layered with layers alternating in any order. Layers include muscovite-rich coarse-grained pegmatites, fine-grained homogeneous aplite, narrow pink garnet-rich layers and quartz-rich layers. Layering is not symmetrical. The smaller dikes and fractures strike and dip in all directions and are primarily aplitic or less commonly, granitic. Fracture and joint surfaces are commonly coated with epidote.

Spatial relationships between the mafic rocks and the sedimentary rocks above, below and to the east of them are not as clear as the contact with the Mount Powell batholith. Deformation at the time of the intrusion of the Mount Powell batholith and related or more recent local block faulting make it difficult to tell whether the contact is intrusive of tectonic. Fine-grained shear zones 3 to 10 cm. thick are commonly found along and near the mafic-rock -- sediment contact. Where these shear zones are found they obscure the original contact characteristics.

On the north side of Dempsey Creek the mafic rocks intrude limestones, quartzites and argillites which were at the time undergoing plastic deformation. The sediments are completely recrystallized and in several areas contain small scale isoclinal folds. Some small veinlets of the mafic rock have been folded with the sediments. Although the mafic rock in many cases becomes finer grained toward a sedimentary contact, nowhere does one see sharp contacts with well-defined chilled margins. This is probably an indication that the magma was not intruding cold sedimentary rock. In a few areas skarn zones have developed along contacts.

Upward through the intrusive exposed in the cliffs, there is a noticeable increase in inclusions of undeformed greenish metamorphosed argillite which are generally surrounded by a coarse-grained rim of hornblende varying in thickness from a few crystals to slightly over 2 cm. The inclusions are larger closer to the contact with the meta-sedimentary rocks.

Inclusions are ubiquitous in the mafic rock, even where it has been metamorphosed and developed a foliation. In

Racetrack Creek the inclusions are dark gray and have been stretched in the direction of the foliation. They have been recrystallized to a fine-grained biotite-quartz rock, suggesting a sedimentary origin rather than an origin as a finer-grained part of the intrusive. These inclusions are postulated to be fragments of a Precambrian pelitic schist underlying the Racetrack pluton, and within the Sapphire Plate. This would account for the compositional difference between these inclusions and those found in the Dempsey Creek outcrops. South of Dempsey Creek and west of the intrusive areas on Thornton Ridge, is an outcrop substantiating the intrusive relationship described above. At sample location PR-4 (NW¼ Sec. 17, T6N, R11W) a block of metasediment 3 m. high was found. Smaller blocks of metasediment float were found nearby. In handspecimen the metasediment is indistinguishable from the argillite found in Dempsey Creek. The size of the block suggests that it is probably in place, but in any case, it has not been transported any great distance. Some roof remnants have been mapped nearby by Csejtey and this outcrop could easily be part of another roof remnant. Its presence 400 m. above the Racetrack drainage and 4.5 km. south of the Dempsey Creek outcrops strongly suggests the origin of all the mafic rocks should be considered together.

Field relationships

By comparing cross-sections drawn WNW-ESE, parallel to and along the ridges on both sides of Racetrack and Dempsey Creeks, one can relate the structure of the four areas, and compile a north-south section. Csejtey (1963) and Mutch (1960) were unable to develop the overall relationships shown in Figures 4 A-E, because each of them studied only half the area of this report.

Figure 4-D is modified from Csejtey (1963, sec. C-C'). Green argillite of the Missoula Group is found south and east of Thornton Ridge. The white crystalline meta-dolomite of the Cambrian Hasmark Formation outcrops at the crest of the ridge, but lower into the Thornton Creek drainage is a rapid transition to the foliated mafic hornblende granodiorite of the Racetrack pluton.

Two thrusts are involved in the section. The older Olson Gulch Thrust plate is evident only through windows into the Hasmark between Thornton Ridge and Chinaman Gulch. The thin, younger Thornton Creek thrust caps the area with Missoula Group argillites. Both thrusts have been folded subsequent to thrusting. East of the Olson Gulch thrust, and hypothetically underlying it, Csejtey has mapped the autochthonous Cretaceous Kootenai and Colorado Formations.

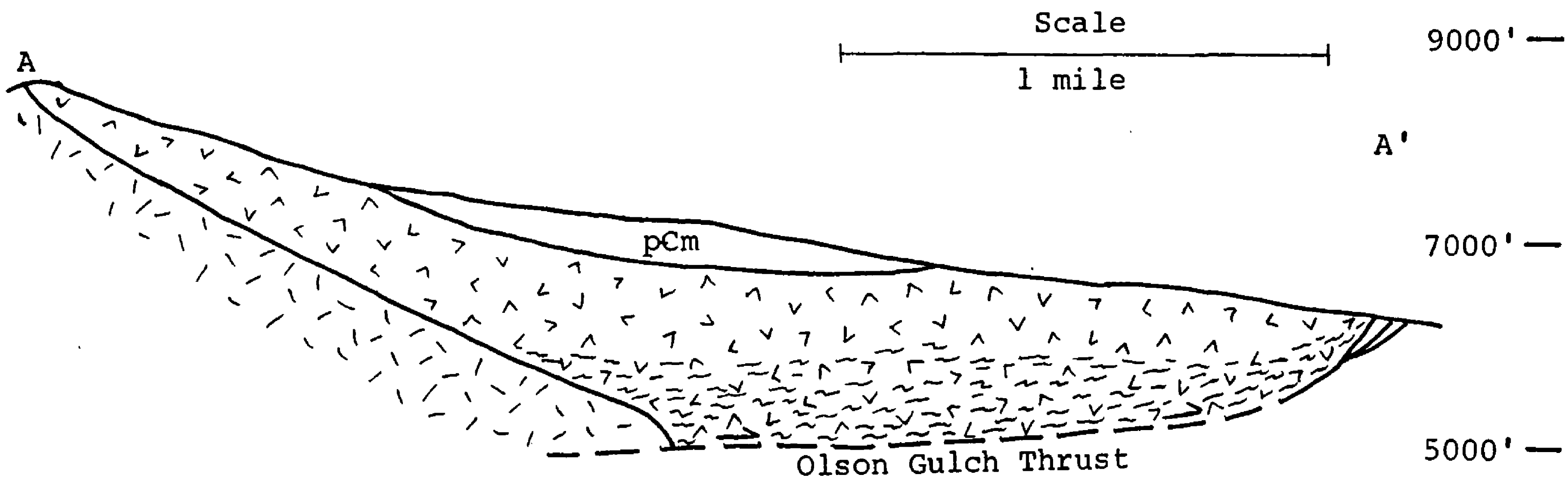


Figure 4-A   Geologic cross-section of the north side of Dempsey Creek

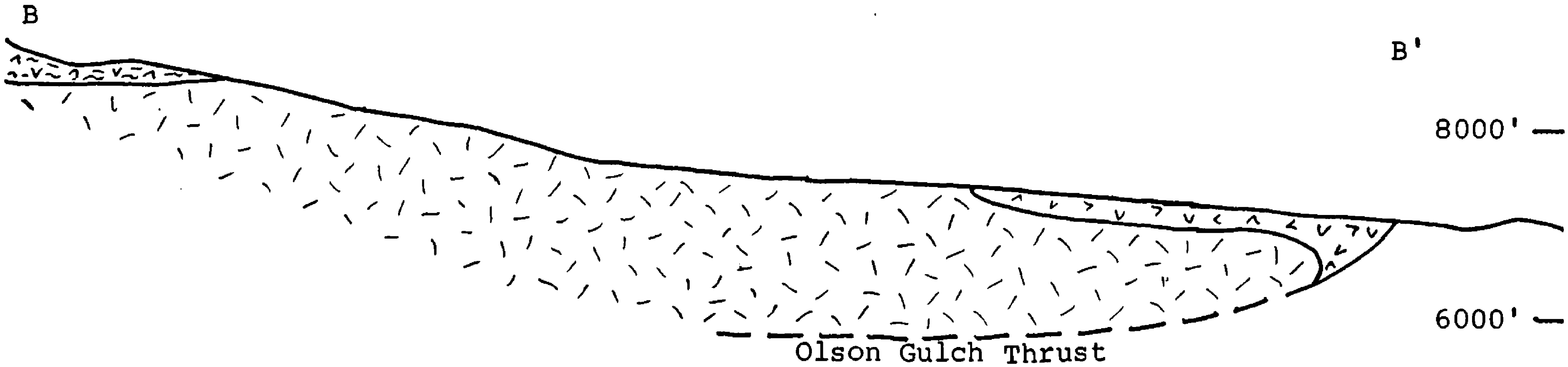


Figure 4-B   Geologic cross-section of Bielenberg Ridge

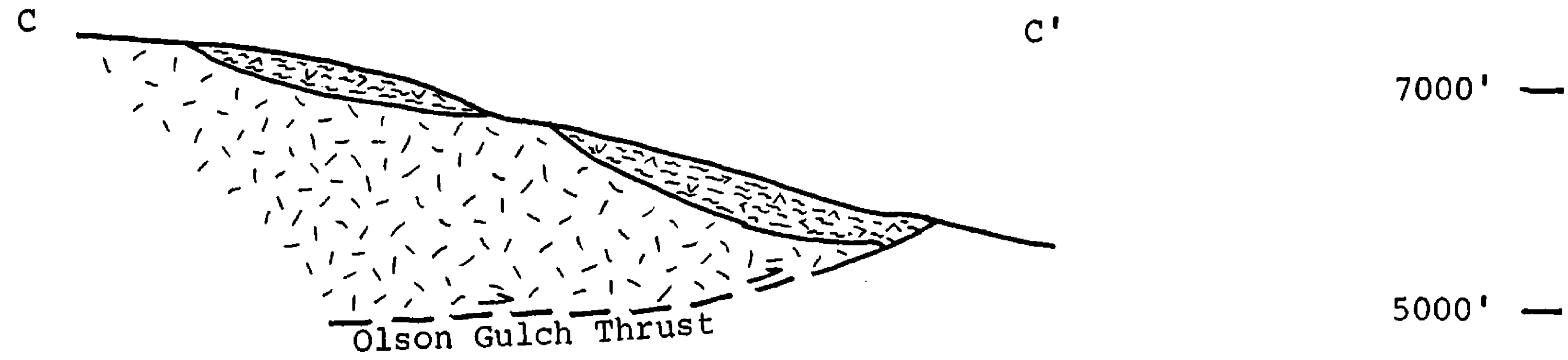


Figure 4-C Geologic cross-section of the north side of Racetrack Creek

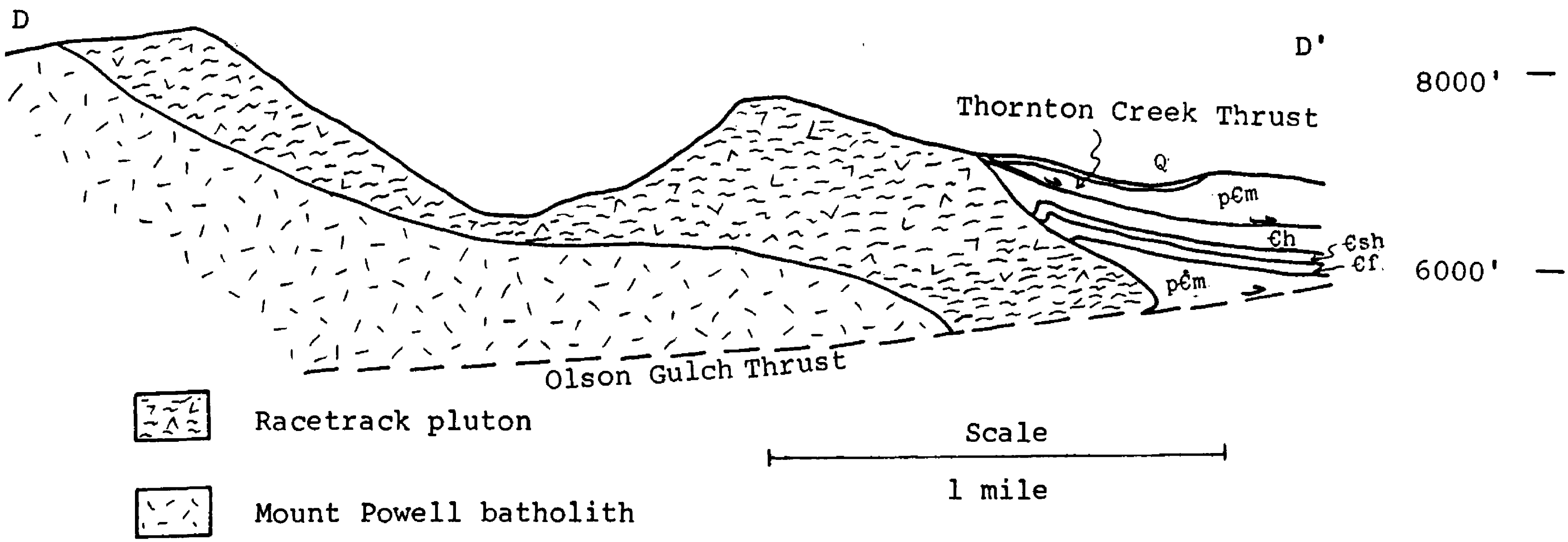


Figure 4-D Geologic cross-section of the south side of Racetrack Creek

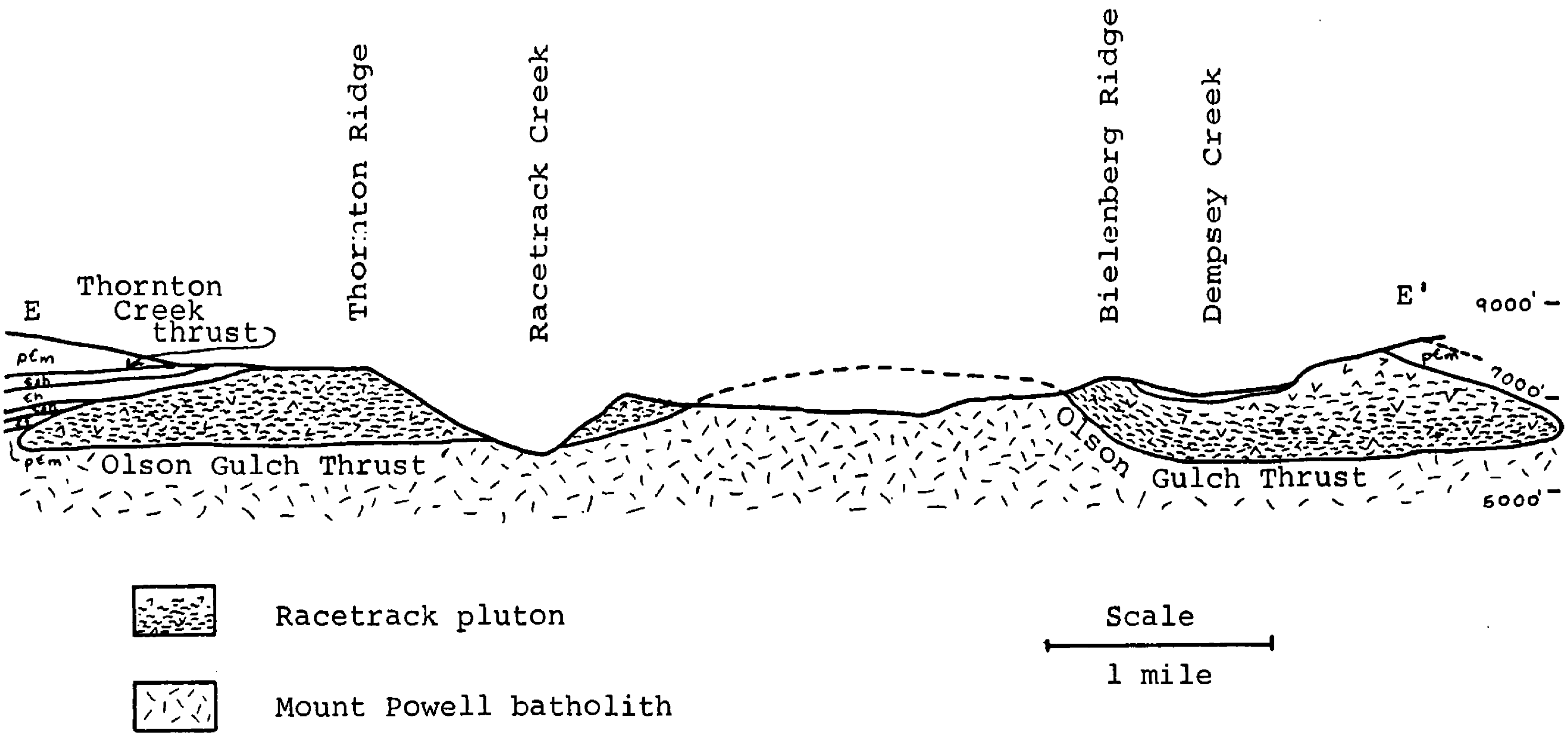
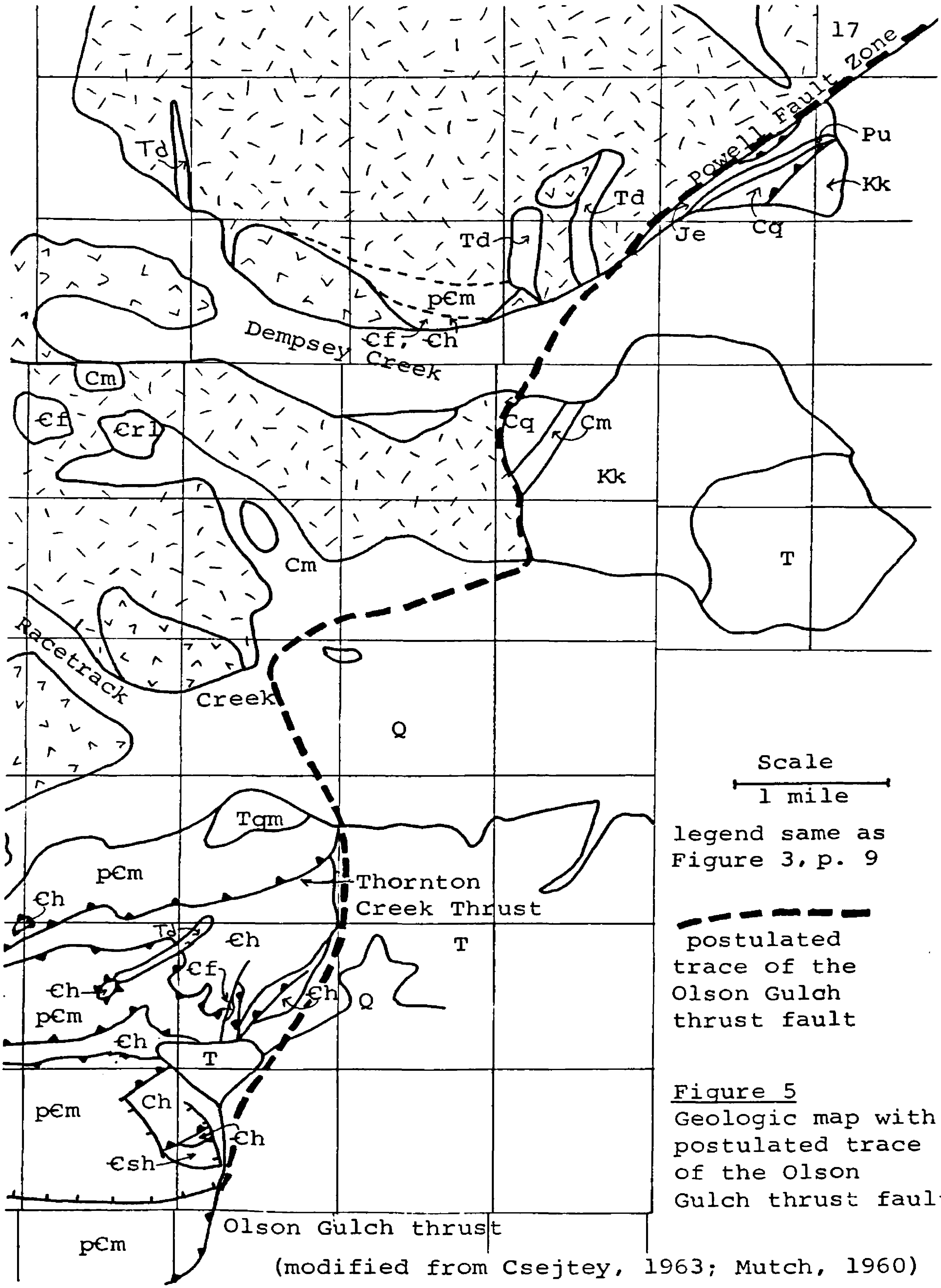


Figure 4-E Geologic cross-section north-south through the Racetrack pluton field area, perpendicular to 4-A through 4-D



legend same as Figure 3, p. 9

postulated trace of the Olson Gulch thrust fault

Figure 5
Geologic map with postulated trace of the Olson Gulch thrust fault

(modified from Csejtey, 1963; Mutch, 1960)

On the north side of Racetrack Creek (Fig. 4-C) glacial cover hides the contact of the hornblende granodiorite with the sedimentary rocks to the east. However, near the end of the hornblende granodiorite outcrop, river and morainal cobbles of cordierite- and andalusite-bearing contact rocks are found. Upstream few sedimentary rocks have been reported, so it is possible that the metasediments occur under cover near the mouth of the Racetrack Creek canyon, and that the contact minerals were formed in response to the intrusion of the Racetrack pluton or the underlying Mount Powell batholith. This contact is proposed to be a continuation of the Olson Gulch Thrust, mapped further south (see Fig. 5). The distinct change in weathering and outcrop from the steeper forested slopes and cliff outcrops to the west, to the grassy slopes of more subdued topography to the east support this hypothesis.

Slightly north of cross-section Fig. 4-C, Mutch has mapped roof remnants of Flathead, Red Lion (?) and Madison limestone (?) in the Mount Powell batholith, but no sedimentary rocks overlie the hornblende granodiorite on the north side of Racetrack Creek.

The bottom of Racetrack Creek is underlain by rocks of the Mount Powell batholith which extend 2 km. east of the granite -- hornblende granodiorite contact on the valley wall. This factor is significant in the explanation of the textural and mineralogical differences between mafic rocks in the Racetrack and Dempsey Creek drainages.

Bielenberg Ridge (Fig. 4-B) is believed to be a bedrock feature for two reasons, 1) it is a logical continuation east of the ridge surrounding the Ryan Lake cirque, and 2) though for most of its length it is grassy and offers only float, an outcrop of porphyritic Mount Powell batholith rock occurs 100 m. south of the ridge. To the east is a large barren spot at point 7074, which looks like severely fractured in-place Quadrant quartzite. Farther east, grassy slopes are underlain by the Cretaceous Kootenai formation. The contact between the igneous and sedimentary rocks is presumably a fault since the attitude of the sediments is nearly vertical and the rocks are badly fractured. It is believed to be correllable with the Olson Gulch thrust farther south (Fig. 5). The presence of the Mount Powell batholith this far east and at this altitude indicates an undulatory contact with the mafic rocks.

On the north side of Dempsey Creek (Fig. 4-A) the contact between the Mount Powell batholith and the diorite (here unmetamorphosed and unfoliated) is at the west end of the section. Uphill or east down the valley toward the diorite-sediment contact are increasing numbers of green calc-silicate inclusions.

Comb layering was also found in the diorite near its contact with the metasediments (sample locations D-14, D-20, see Fig. 9). This layering involves primarily plagioclase needles which grew perpendicular to the long axis of the bed, which parallels the contact with the argillite. Between the layers of plagioclase needles are 2-3 crystal-wide bands of equiangular hornblende. According to Moore and Lockwood (1973) comb layers are found primarily in fairly mafic intrusions along and parallel to the upper contact. They are believed to be formed as water-rich solutions stream upward through channels along the edge of the crystallizing body of magma. The orientation of the comb layers in Dempsey Creek indicates a) the presence of the upper contact of the pluton, and b) that this contact is subparallel to the thrust faults and related foliations in the Racetrack pluton.

The contact between the diorite and the argillite (of the Missoula Group) is highly irregular and shows both intrusive characteristics and zones of shear. The shearing, primarily of the argillite, appears related to the intrusion of the Racetrack magma. The same movements also caused isoclinal folding in the soft sedimentary rocks. If the Racetrack magma was intruded along a thrust fault, as is postulated, the presence of a zone of weakness associated with such a fault would explain the complex manner of intrusion exhibited by the diorite magma.

To the east the diorite is overlain by marble, quartzite and argillite (not mapped by Mutch, 1960, Pl. I). The argillite is part of the Missoula Group; the quartzite could either be of the Flathead Formation or the Missoula Group, and the dolomite and marble are of the Cambrian Hasmark Formation. This sequence of rocks is the same as the sequence of Thornton Ridge.

A short interval of diorite (slightly foliated and containing some orthoclase) separates the meta-sediments from the Powell Fault zone, which Mutch believed to be a steeply-dipping fault (1960, p. 82, Fig. 32). It is interpreted here as a thrust and the smaller thrusts he mapped east of the main fault are slivers broken from or carried up by the toe of the main fault. This fault, bearing striking similarities to the one postulated of Bielenberg Ridge, (Fig. 4-B) is here correllated with the Olson Gulch thrust (see Fig. 5). A slight steepening of a west-dipping thrust toe caused by the emplacement of magmas would explain the

85^{o}E dip which Mutch recorded for the fault.

Considering the strike length and stratigraphic displacement of the thrust faults mapped earlier by Emmons and Calkins (1913), Mutch (1960) and Csejtey (1963), it seems reasonable that there could be another at the edge of the range. This fault delineates the eastern boundary of the Sapphire Plate as described by Hyndman, Talbot and Chase (ms.). The fault also separates the Flint Creek type of thrust fault from the shallower thrusts east of the Boulder batholith. That these faults have been more obscurred and deformed than those to the west can be attributed to post-thrusting intrusion of magmas along the thrust planes, dilating and disrupting the section considerably, and subsequent erosion and burial fo segments of them.

Another piece of evidence supporting the correlation of the Powell Fault with the Olson Gulch Thrust is that nowhere do the high level igneous rocks of the Mount Powell batholith or the Racetrack pluton extend east of the fault into the Deer Lodge Valley. The fault appears to have controlled the locus of magma flow. That the fault acts as a boundary also lends credence to the hypothesis that some of the plutons in the Flint Creeks have been intruded along thrust faults (Csejtey, 1963; Winegar, 1970; Hyndman and others, ms.).

CHAPTER III

MINERALOGY AND TEXTURAL STUDIES

Handspecimen mineralogy and thin-section petrography delineate two distinct rock types. The first is an igneous textured rock with 50% mafic minerals found on the north side of Dempsey Creek (Pl. 2b); the second is a metamorphosed flaser textured rock with 15-20% mafic minerals found in the Ryan Lake cirque and on both sides of Racetrack Creek (Pl. 2a). The second group show a strong foliation which is everywhere visible on large outcrops, though in some cases is not as conspicuous in handspecimen.

Emmons and Calkins (1913, p. 150) recorded the foliation between Racetrack and Thornton Creeks striking NE and dipping 30°SE, an attitude which they believed to be about parallel to the Thornton Creek thrust. This project shows the foliation to be quite variable, though in this area it generally strikes NE and dips SE at $30\text{-}45^{\circ}$ (Fig. 5). Due to undulations and folds in the thrust plane, all these readings could be related to foliation formed at the time of and related to thrusting but subsequently deformed.

Handspecimen texture and mineralogy

Most of the rocks in Dempsey Creek do not show any

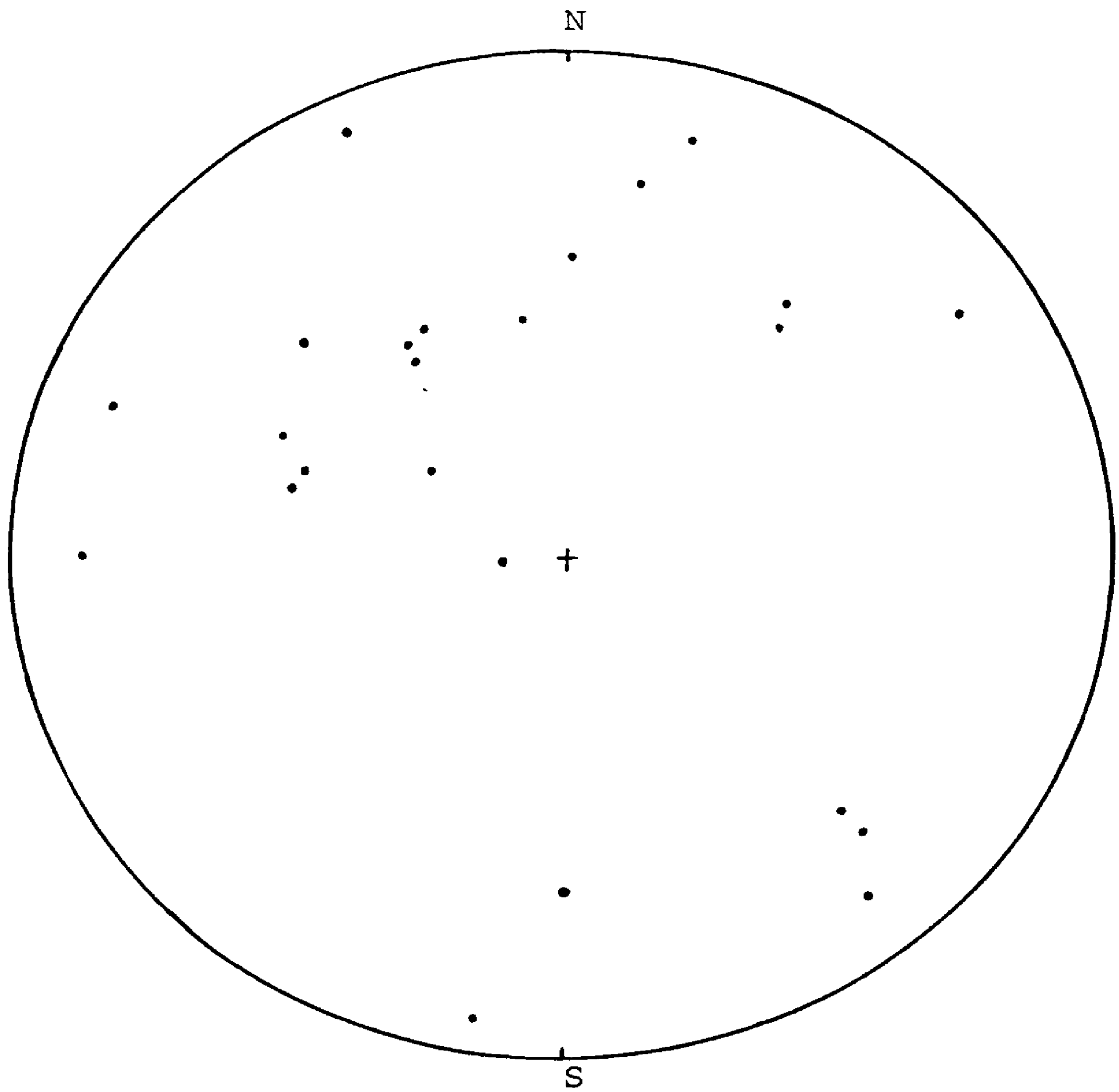


Figure 6   Poles to foliation for the Racetrack pluton

foliation and are much darker than the Racetrack Creek rocks. Handspecimens appear massive and of igneous texture (Pl. 2a). However, at the east end of the Dempsey Creek outcrop area, the rocks show a faint foliation and a texture intermediate between that of the foliated and massive rocks described above. These rocks indicate that mineralogy and texture are gradational between Racetrack and Dempsey Creeks.

The mineralogy of the mafic rocks differs significantly between the Racetrack Creek -- Thornton Ridge outcrops and those of the Dempsey Creek area. In most of the Dempsey Creek outcrops the rock is a massive dark gray to black, igneous-looking hornblende diorite. In most of the Racetrack Creek outcrops it is a foliated black and white hornblende-biotite granodiorite, The change from diorite to granodiorite in Racetrack Creek is believed to be caused by an influx of fluids from the cooling Mount Powell batholith to the north and west, and is discussed further in the section on whole-rock chemistry.

Thin-section petrography -- Dempsey Creek

The Dempsey Creek rocks have an igneous texture, primarily hypidiomorphic granular. They are medium- to fine-grained rocks, composed primarily of plagioclase and slightly less hornblende. Biotite is commonly present in amounts up to 15%, and locally is slightly altered to chlorite. Accessory minerals include sphene, apatite and opaques, generally magnetite with minor pyrite and hematite.

Plagioclase characteristically makes up 45-55% of the rock in Dempsey Creek, but ranges from 40% to 65%. Normal zoning, common in most localities, generally is indistinct because of crystal deformation. Some of the zoning indicates that the grains were broken during crystallization since zoning follows only some of the edges. A secondary zoning suggested in D-6 may have been formed at the time of alteration near the end of the cooling history of the body.

Twinning according to the Carlsbad and Albite laws is almost ubiquitous and Pericline twins are found locally. Deformation has rendered many of the primary twins indistinct and secondary, deformation-caused albite twins commonly develop along fractures or kink planes and taper off into adjacent developing secondary crystals. In many cases smaller crystals result from the breakdown of the larger original plagioclase grains, and their partial development causes patchy or checkerboard extinction found in many thin-sections. D-15 contains two distinct varieties of plagioclase, the primary grains are quite deformed, show bent twins, undulose extinction and fuzzy boundaries, whereas the younger grains are much smaller, show sharp grain boundaries and lack undulose extinction. This evidence of metamorphic activity makes these rocks intermediate in texture between the normal igneous texture of Dempsey Creek and the more thoroughly metamorphic texture shown by samples from Racetrack Creek. It also suggests closer proximity to a conduit of fluids from the Mount Powell batholith, probably the Olson Gulch thrust at the Powell fault zone.

Presence of higher-An cores is suggested by extensive saussuritic alteration in the core zone resulting in fine-grained agglomerates of epidote + sericite ± calcite. Epidote is common along fractures in plagioclase crystals, calcite less so.

<u>Hornblende</u> generally makes up about 35-45% of the rock though it ranges from 15 or 20% up to 50%. Its pleochroism is x=tan, y=olive green, z=blue-green; 2V=65-68° and Z$\wedge$C=15-17°. The grains are subhedral to anhedral and in many cases have paler cores than rims. Sieve texture is very common, with fine-grained quartz + magnetite ± sphene in the core areas.

A few thin-sections (D-3, D-4a) show small grains of augite in hornblende cores, suggesting that the grains may have formed as pyroxene and either have been almost completely resorbed by the liquid before hornblende crystallization started, or were altered to hornblende as conditions in the magma changed with continued crystallization. A combination of these factors may be most nearly correct. The change in pleochroism from shades of brown to green to blue-green indicates that the continuous drop in temperature with continuing crystallization was rapid enough that the whole hornblende grain could not equilibrate with later magma compositions.

Biotite in the Dempsey Creek area is fine-grained and not foliated. Pleochroism is x=tan, z=light to dark brown, and less commonly olive. The biotite is generally present in at least trace amounts, and may account for up to 15% of the sheared rocks. Granular sphene ± magnetite are commonly concentrated along the edges of the biotite.

Chlorite is locally present in trace amounts altering from hornblende or biotite. The only locations where it accounts for more than 2-3% of the whole rock is in sheared zones where 10-15% chlorite is present. This suggests the movement of fluids through fractures and shears, causing the alteration.

Accessory minerals 1 to 2% subhedral to euhedral primary apatite is typically scattered throughout the thin-sections. Sphene is slightly more abundant, locally amounting to 2-3% of the rock. It occurs as large euhedral primary grains as well as as granular secondary grains bordering biotite and chlorite. In several rocks it surrounds cores of iron oxide. Magnetite, pyrite and hematite are generally present either alone or in combination. They do not normally account for more than 1-2% of the rock and nowhere more than

5 per cent.

A few other minerals are present in small amounts. Quartz is primarily found poikilitically enclosed in hornblende, though locally is present in small quantities, particularly in rocks which show some evidence of metamorphism or shearing. In these rocks, the quartz is clearly more recent than any other minerals for it shows almost no undulose extinction and has sharp grain boundaries.

Orthoclase is virtually non-existent in Dempsey Creek rocks. It is found in a few rocks along or very close to joint or fracture surfaces and along the contact with the Mount Powell batholith. In Dempsey Creek orthoclase is not found unrelated to a joint, fracture or contact with the Mount Powell batholith. This strongly suggests that orthoclase has been introduced into the diorites by fluids moving through fracture and shear zones. These fluids were derived from the Mount Powell batholith magmas.

Thin-section petrography -- Racetrack Creek

The rocks of Racetrack Creek and the ridges to the south have a moderately strong metamorphic flaser texture imprinted over the locally still-discernable igneous texture. Remnants of the original igneous texture include coarse interlocking grains of twinned and zoned plagioclase and hornblende. These original grains have been strongly deformed; bent, kinked or fractured grains are common, undulose extinction pervasive. Saussuritic alteration of plagioclase is common and hornblende and biotite partly have altered to chlorite. If the rocks found in Racetrack Creek had remained unsheared, it would be easier to define similarities and differences between these rocks and those found in Dempsey Creek.

Syntectonic metamorphism at the time of the Mount Powell magma intrusion resulted in the development of a strong foliation of biotite and chlorite. Secondary plagioclase and quartz crystals are smaller than the parent grains and a good mortar texture occurs in most samples. This fine-grained mosaic of secondary plagioclase and quartz has developed around the edges of the severely deformed grains. The growth of orthoclase megacrysts found throughout the area is attributed to metasomatism by fluids from the Mount Powell batholith.

Plagioclase ranges in abundance from 15 to 55%, but averages about 45%. Deformation has caused bending, kinking, fracturing, and undulose and checkerboard extinction as in the Dempsey Creek rocks. Once-sharp grain boundaries disintegrated so the larger, formerly interlocking grains are separated by zones of smaller ones. The degree of alteration of the crystals varies widely throughout the area, but where present is the same as in the Dempsey Creek rocks.

Hornblende is much less common than in Dempsey Creek. It ranges from a trace to 45% of the rock, but averages 15%. Where unaltered the hornblende looks exactly like that in the Dempsey Creek rocks and its pleochroism is the same. Though twinning and 60° cleavages can be seen locally, the majority of the hornblende varies directly with the amount of orthoclase in the rock, the degree of deformation, and the ratio of metamorphic to igneous textural indicators.

Biotite and chlorite compose more of the Racetrack rocks than the Dempsey Creek rocks, averaging 10% and ranging from 3-20%. The biotite/chlorite ratio is 4-5:1 but may range as high as 10:1. These minerals from the strong foliation which in handspecimen as well as in thin-section distinguish igneous and metamorphic areas. Biotite is pleochroic with z=brown and x=tan; in chlorite z=green and x= light tan. Chlorite is most commonly found replacing biotite, though locally it appears to be forming directly from hornblende. Chlorite is clearly a secondary mineral whereas some of the biotite may be primary. Both biotite and chlorite have been deformed and in some areas the pattern of biotite distribution suggests recrystallization after deformation.

The biotite/hornblende ratio varies greatly from areas where there is almost no biotite to areas where hornblende is absent.

Quartz is much more common in the Racetrack area than in Dempsey Creek. It makes up from 5 to 25% of the rock, generally about 15%. Here also it is poikilitically included in hornblende crystals, but it also forms larger independent crystals. Grains are not as fractured as plagioclase, but undulose extinction and serate grain boundaries which have spawned smaller quartz grains found in the mortar areas are common.

Orthoclase: Metasomatism by fluids from the Mount Powell batholith, which underlies the mafic rocks in Racetrack Creek, appears to have introduced copious amounts of orthoclase which appears as megacrysts scattered throughout the rock. At one locality (PR-7) the megacrysts are as large as those in the nearby Mount Powell batholith (1½-2 cm.) and make up 60% of the rock. Orthoclase content ranges from 5 to 60%, averaging 15-20%.

These megacrysts are clearly the last-formed crystals for they generally contain grains of quartz, plagioclase, biotite, hornblende and chlorite and do not show the severe effects of deformation exhibited by the hornblende, plagioclase, or even the quartz which is also secondary. Grain boundaries are sharp and only slight undulose extinction is visible.

Lobe-like perthite and less commonly myrmekite are found around the edges of the orthoclase grains. Plaid twinning is fairly common.

Accessory minerals in the Racetrack area are the same as those in Dempsey Creek. Apatite, sphene, magnetite, hematite and pyrite have the same characteristics and are present in similar amounts. Muscovite is present in a more granitic part of the foliated rock (RC-17). Epidote averages 2-3% of the rock in Racetrack Creek, an increase over that in Dempsey Creek rocks. It appears to be a product of hornblende alteration. Calcite is also found locally, along fractures or in cores of plagioclase and less commonly hornblende.

Conclusions based on mineralogy and texture

The major variation in mineralogy between Dempsey and Racetrack Creeks is an increase in quartz and orthoclase in the later, as well as a greater amount of alteration of hornblende and biotite. This change is spacially accompanied by a textural change from igneous to metamorphic. Mineralogical changes occured after the major shearing. It should be emphasized that this is a metamorphic flaser texture caused by deformation rather than regional metamorphism. No high-grade regional metamorphic rocks are present in the Flint Creek Range.

Figure 7 represents the spatial relationships believed to exist within the Racetrack pluton. Shearing related to the movement along the Olson Gulch thrust fault after the Racetrack pluton had crystallized, but while it was still hot was primarily taken up at the bottom and in the more southern part of the pluton. This shearing produced the foliation visible in the field, which eased the later intrusion of fluids as the Mount Powell batholith intruded along the Olson Gulch thrust fault.

In the Dempsey Creek area the upper part of the pluton is visible -- crystals are fractured and deformed, but not to the point of producing a foliation, except for small areas near the contact with the batholith at the west end of the Racetrack pluton outcrop, and at the east end near the Powell fault zone (Fig. 4-A).

In Racetrack Creek the bottom of the pluton is visible, sheared, metasomatized and directly underlain by the Mount Powell batholith (Fig. 4-C).

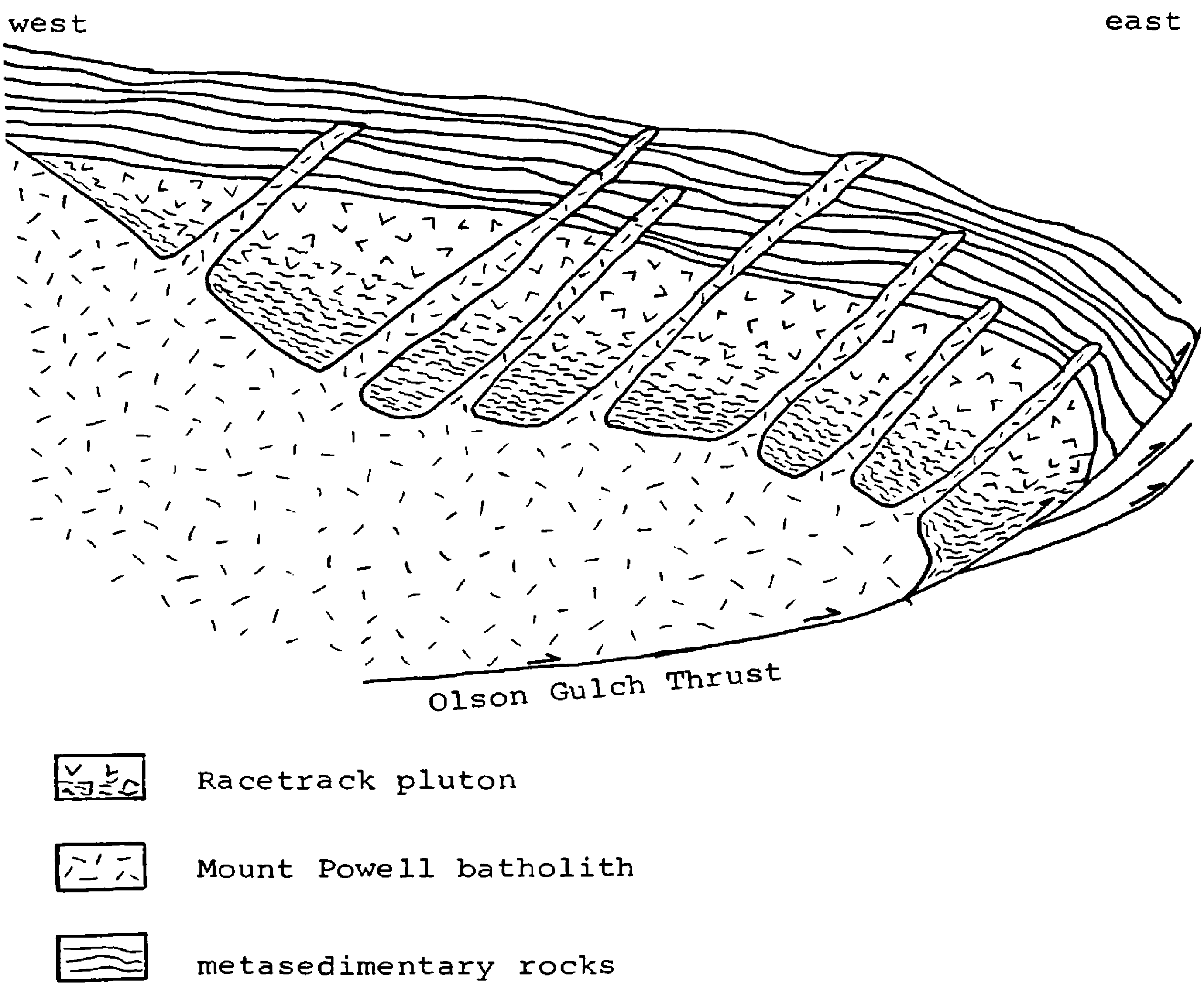


Figure 7 Schematic diagram of the relationships within the Racetrack pluton and between it and surrounding rocks, before erosion. Diagram is about 5 km. across.

CHAPTER IV

WHOLE ROCK CHEMISTRY

Eleven whole rock samples were analyzed for eight major elements to determine the composition of the mafic magma, and to see if there was a consistent variation trend within the Racetrack pluton, and between it and the other major stocks and batholiths of the Flint Creek Range.

Samples for analysis were picked randomly and SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O and TiO_2 were determined by quantitative X-ray spectrographic methods; Na_2O was determined using either a flame photometer or a specific ion electrode meter (for procedure, see Benoit, 1972, appendix II).[1]

The results are shown in Table I, and are plotted with analyses for the Bimetallic stock, Philipsburg batholith, Royal stock and the Mount Powell batholith on Fig. 8. A well-developed trend was noted for all oxides, strong evidence supporting the hypothesis that the rocks in Racetrack and Dempsey Creek areas are part of the same intrusive.

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1) The two different methods used to determine Na_2O had no sample overlap, thus, it is unwise to draw quantitative conclusions between the first group (the 6 lower SiO_2 samples) and the second group (the 5 higher SiO_2 samples). Neither method was as satisfactory as the X-ray spectrometer used for all other elements.

	Dempsey Creek samples							Racetrack Creek samples			
	D-2i	D-6	D-10	D-15b	D-9	D-3	D-4a	PR-3	PR-7	RC-11	HB-1
SiO_2	49.3	49.68	49.82	50.2	54.22	59.48	60.41	61.72	63.41	63.74	64.28
Al_2O_3	20.98	18.47	19.71	19.43	17.53	17.76	17.30	17.59	14.79	17.06	16.03
FeO	9.9	10.59	10.68	10.88	10.22	7.44	7.80	7.17	6.40	6.35	6.13
MgO	5.18	6.60	5.73	6.25	6.03	3.89	2.35	2.06	1.88	1.91	1.78
CaO	10.28	10.25	10.44	9.94	8.03	6.28	6.42	5.76	3.67	5.42	5.10
Na_2O	3.41	2.77	1.27	2.86	2.58	2.95	4.17	4.89	6.46	5.07	4.44
K_2O	1.12	.89	.74	.69	1.76	2.72	2.48	3.02	4.38	3.21	3.47
TiO_2	1.10	1.22	1.15	1.18	1.09	.92	.98	.84	.72	.81	.75
Total	101.27	100.47	99.54	101.43	101.46	101.14	101.91	103.05	101.71	103.56	101.98

Table I Whole rock analyses of the Flint Creek pluton (refer to Figure 9 for sample locations)

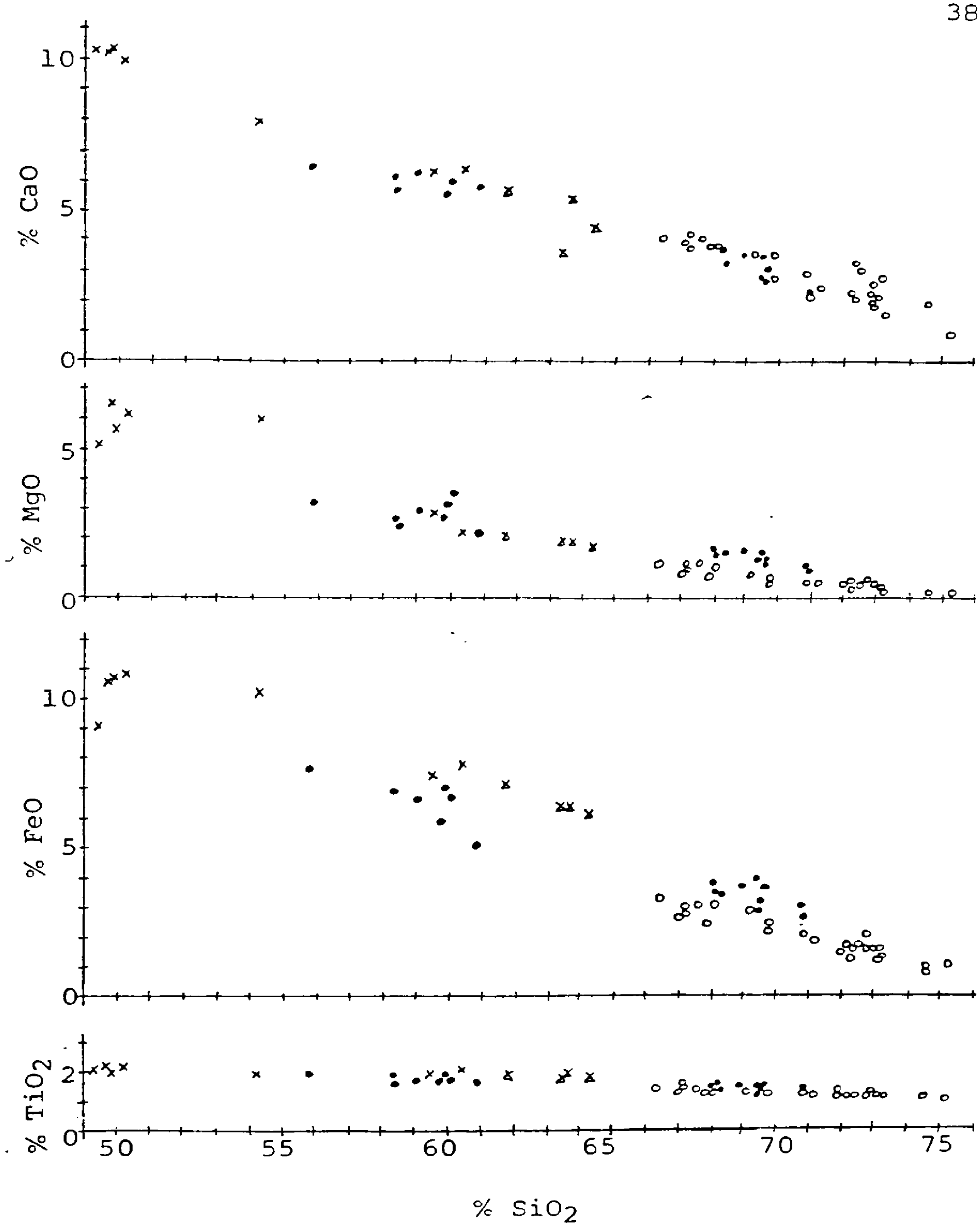

Figure 8 X-ray data for all the plutons in the Flint Creek Range

x Racetrack pluton, Dempsey Creek samples
x̧ Racetrack pluton, Racetrack Creek samples
• Philipsburg batholith and Bimetallic stock *
o Mount Powell batholith and Royal stock *
* data from Hyndman and others, ms.

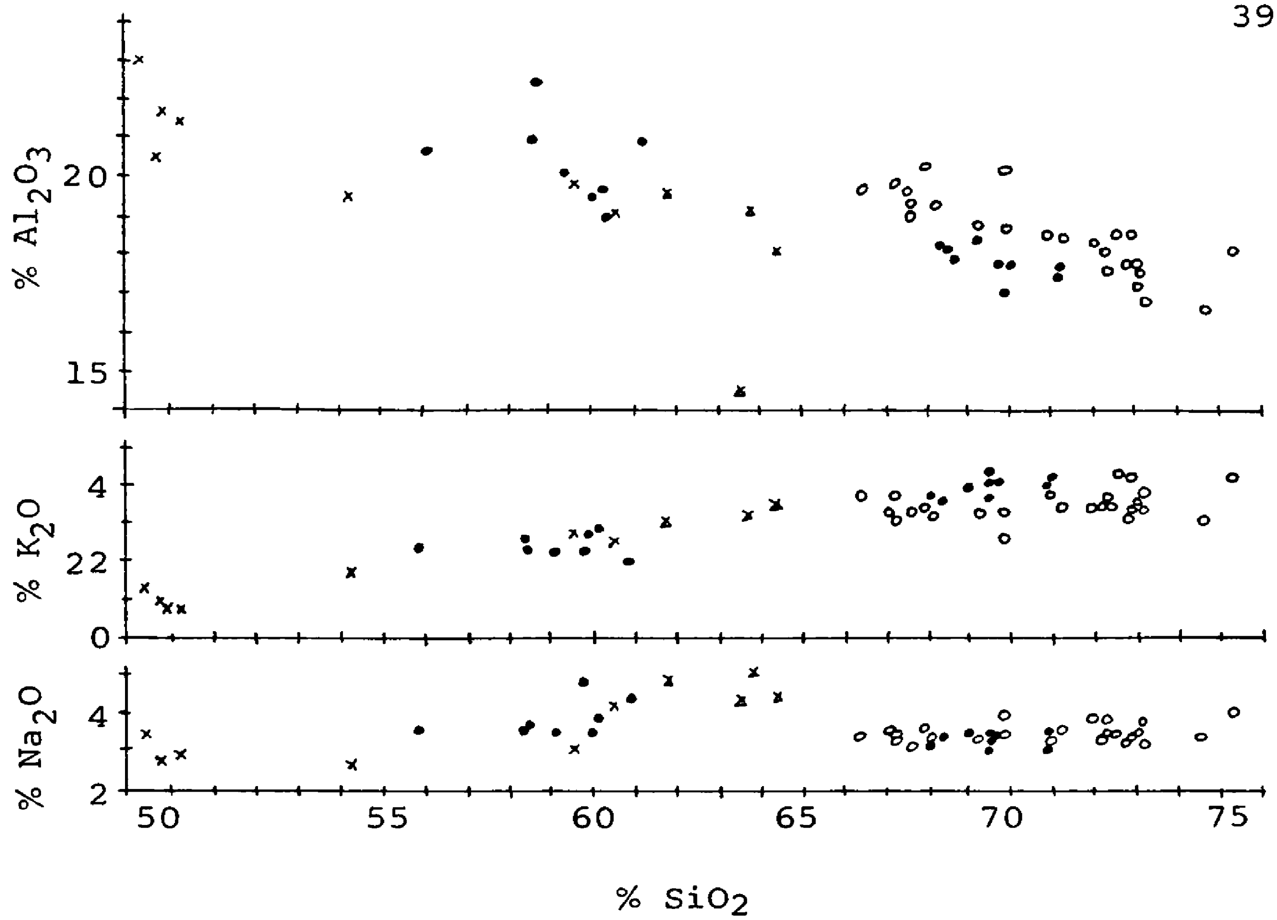

Figure 8 X-ray data for all the plutons in the Flint Creek Range (continued)

SiO_2 and K_2O increase whereas FeO (recalculated from Fe_2O_3), CaO and MgO decrease markedly, Al_2O_3 and TiO_2 decrease slightly.

Possible reasons for this trend include: 1) differentiation of a parent magma, 2) assimilation of country rocks by the parent magma, 3) contamination of part of the intrusive after crystallization. The distinct difference in texture as well as in composition between the rocks of Dempsey and Racetrack Creeks should also be taken into account.

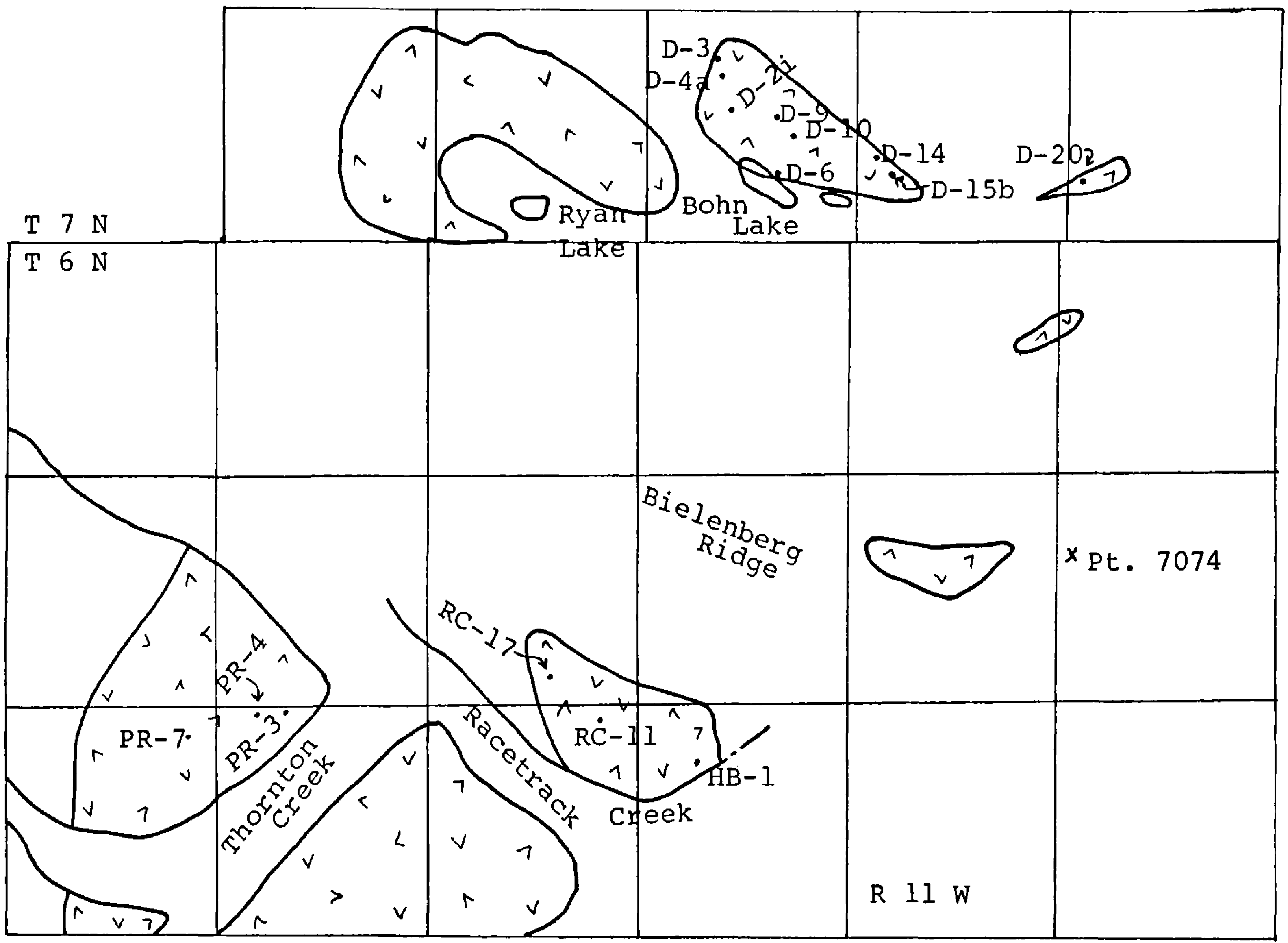

Figure 9 Sample locations for X-ray data

The Racetrack pluton

The original composition of the mafic magma compares well with that of a high-alumina basalt (Hyndman, 1972, p. 122). If the diorite were a Precambrian sill (Mutch, 1960; Allen, 1962) one would expect a different chemical composition, probably more similar to a normal tholeiite, containing less Al_2O_3 and more TiO_2. The four samples of high-alumina basalt composition (D-2i, D-6, D-10, D-15b; see Fig. 9 for sample locations), all from Dempsey Creek, contain no K-feldspar. The other three samples from Dempsey Creek (D-4a, D-9, D-3) contain little K-feldspar, visible only in stained slabs or thin-section. D-9 contains a trace of very fine-grained K-feldspar disseminated throughout the finer-grained portion of the rock and is associated with large granitic dikes, quartzites and argillites. D-4a, containing 2-3% medium-grained K-feldspar, is also associated with a granitic dike. D-3, containing 1-2% medium-grained K-feldspar, is on the contact with the Mount Powell batholith.

It is important to recognize the wide range of composition in the rocks of Dempsey Creek, for example they range from 49.3 to 60.4% SiO_2. Some of these slightly metasomatized rocks are much closer in composition to the rocks from the Racetrack Creek area than to the unaltered Dempsey Creek rocks. This chemical gradation which starts in Dempsey Creek and continues in the Racetrack Creek rocks, supports the single-pluton theory.

The four most felsic samples (PR-3, PR-7, HB-1, RC-11, containing 10-60% k-feldspar) are from the Racetrack Creek -- Thornton Ridge area. Texturally, they are very similar except for PR-7, located on the Racetrack pluton -- Mount Powell batholith contact, which contains 60% 1½cm.-long orthoclase megacrysts, much more than any of the other samples collected. Among these four samples, HB-1 and RC-11 are spatially lower in the Racetrack pluton, and slightly more sheared since they were closer to the thrust.

Differentiation of the parent basalt to form a pluton, 70% of which is compositionally a hornblende-biotite granodiorite, would require that there be a large amount of basalt or more mafic rock in the vicinity. Only 30% of the area here mapped as Racetrack pluton contains rocks of basalt composition and no geophysical evidence indicates that there might be mafic rocks underlying any part of the region.

Field evidence suggests that the diorite in Dempsey Creek overlies the more felsic rocks to the south (see Fig. 7). This is the reverse situation from most differentiated mafic intrusions where the differentiation process involves settling of the first-formed mafic crystals or upward migration of felsic constituents. For these reasons, it is improbable that a differentiation process is involved in variation within the Racetrack pluton.

Assimilation of country rocks by the magma would require melting of a large amount of K-rich rock to explain the considerable increase in K_2O with increasing SiO_2. Partial assimilation of some type of country rock is indicated by the presence of mafic inclusions everywhere in the pluton. These inclusions do not appear to be K-rich, and are thus not believed to be the source of contamination. Nearby formations are primarily quartzites and argillites which contain negligible K_2O. Therefore, assimilation of country rocks also seems a doubtful source of contamination.

Another possible contaminant is the Mount Powell batholith, which forcibly intruded beneath the Racetrack pluton after Racetrack pluton crystallization. Contamination could have been accomplished by movement of magma or water-saturated fluids and/or gases emanating from the magma, or from the aplite and pegmatite dikes which are present throughout the Racetrack pluton (Plate 1).

If the magma from the Mount Powell batholith was the primary contaminant, one would expect numerous granitic dikes to intrude the Racetrack pluton. Granitic dikes are present, but are much less common than pegmatite and aplite dikes, and are believed to be too few in number to be responsible for the degree of contamination involved.

Pegmatite and aplite dikes account for 40-50% of the rocks in the area, and would provide a ready source of contamination. If this source was operative, one would expect K-feldspar to increase toward a dike, which is not true. Everywhere in the Racetrack Creek area, K-feldspar content is 15-20% of the rock, whereas in Dempsey Creek, with approximately the same number of dikes, K-feldspar content is everywhere close to 0%. K-feldspar is noticeable in handspecimen only along the contact with the Mount Powell batholith. No large augen-shaped crystals like those found in Racetrack Creek have been found in Dempsey Creek. Thus, contamination is not related to the presence of the aplite and pegmatite dikes.

Diffusion of fluids and/or gases from a cooling magma have the potential to metasomatize surrounding rocks. Gas and fluid content of the remaining magma increases as crystallization proceeds, concentrating K_2O and SiO_2, elements which have significantly increased in much of the Racetrack pluton. They may be released from the enclosing pluton shell through a zone of weakness and invade the surrounding rock.

It is believed that the escape of gases into a shear zone would account for the changes in both composition and texture exhibited by rocks of the southern (and spatially lower) part of the Racetrack pluton. Shearing related to thrusting which occured after the Racetrack pluton had crystallized, but while it was still hot explains the metamorphic flaser texture of the Racetrack Creek area. This sheared rock, which possibly underwent further episodes of movement as the magma forced its way under the Racetrack pluton, would have facilitated the pervasive metasomatism which occurred.

Correlation with other plutons of the Flint Creek Range

When plotted with the analyses available for the other plutons in the Flint Creek Range, analyses for the rocks of the Racetrack pluton fall along the same variation curves (see Fig. 8) indicating that all the plutons were comagmatic as suggested by Allen (1960, p. 43).

The amount of chemical variation in the original uncontaminated Racetrack pluton was quite small (D-2i, D-6, D-10, D-15b), and is comparable to the variation present in the

Philipsberg batholith. The wide range in composition present in the Racetrack pluton as a whole is caused by contamination by the Mount Powell batholith, discussed earlier.

If it were possible to determine the composition of the fluids which altered the diorite, it would be a simple mathematical problem to prove or disprove their derivation. In this case all the sources for which the composition can be readily determined, have been discounted on the basis of field evidence. Since the fluids have not been preserved, nor is it known whether they were early or late, this demonstration is not possible.

The correspondence of the Dempsey Creek rocks to the composition trends for the plutons of the Flint Creek Range is incompatible with the earlier hypothesis that they were part of a Precambrian diabase sill, like the one found in Lost Creek, to the south. A study of handspecimens and of several thin-sections from the Lost Creek sill shows that the textures are not the same, further supporting their separate origins. Conclusive evidence might be supplied if the chemical composition of the Lost Creek sill were plotted against the pluton curve for the Flint Creeks.

CHAPTER V

SUMMARY AND CONCLUSIONS

Several new interpretations have resulted from this project, clarifying the structure and petrography of the Flint Creek Range, and providing new support for recent work involving the Flint Creek plutons (Hyndman and others, ms.; Hyndman, Talbot and Chase, ms.).

1) On the basis of handspecimen and thin-section textural and petrolgic studies, the hornblende granodiorite of Racetrack Creek (Emmons and Calkins, 1913; Csejtey, 1963) and the diorite of Dempsey Creek, formerly described as a Precambrian diabase sill (Mutch, 1960; Allen, 1962) are now believed to be part of a single pluton named the Racetrack pluton.

2) The Olson Gulch thrust fault (Emmons and Calkins, 1913; Csejtey, 1963) has been extended north from its outcrop in Chinaman Gulch to include the Powell fault zone (Fig. 5). This was done a) on the basis of the change from igneous and slightly metamorphosed Precambrian and lower Paleozoic rocks on the west to unmetamorphosed upper Paleozoic and Cenozoic rocks on the east, and b) because lithologies similar to and in the same order as those mapped on the Olson Gulch plate

south of Thornton Ridge have been found as far north as the north side of Dempsey Creek.

3) This pluton extends no farther east than the postulated trace of the Olson Gulch thrust fault, and its eastern boundary generally coincides with this trace, so it is believed to have intruded along the Olson Gulch thrust. Shearing and isoclinal folding in the overlying Missoula Group argillite indicates that intrusion of the diorite magma was forceful and the rocks were under pressure and temperature conditions such that they could deform plastically.

4) Comparison of the whole rock chemistry of the four major more-felsic plutons in the Flint Creek Range with that of the Racetrack pluton supports Allen's (1962) hypothesis that all the major plutons are comagmatic. Thin-section petrography supports his mineralogical progression from the (augite) + hornblende + biotite-bearing Racetrack pluton to the biotite-bearing Royal stock to the Mount Powell batholith which contains biotite and muscovite. This could be expanded to include the Bimetallic stock containing hornblende and biotite, and the Philipsburg batholith which also contains biotite and hornblende, but has a lower mafic mineral content than the associated Bimetallic stock.

An outline of the structural history and the sequence of events leading to the present rock relationships in the Flint Creek Range is as follows:

1) large-scale thrusting of Precambrian and lower Cambrian rocks from the west, over Paleozoic and younger sedimentary rocks.

2) intrusion of the diorite magma of the Racetrack pluton along the Olson Gulch thrust fault during a lull in thrusting, forming a moderately thin (1½-2 km. thick) lens-shaped pluton, with associated deformation and metamorphism in surrounding Precambrian and Cambrian rocks.

This magma could well be contemporaneous and associated with the Elkhorn Mountain volcanics (late Cretaceous, Robinson, Klepper and Obradovich, 1968) which were extruded less than 10 km. to the east. If Hyndman, Talbot and Chase (ms.) are correct in suggesting that the Boulder batholith and associated rocks erupted from below the end of the thrust zone underlying the Flint Creek Range, it would be easy to imagine that some of the early more mafic magmas were diverted along the Olson Gulch thrust fault where they cooled to form the Racetrack pluton.

3) intrusion of the felsic Mount Powell magma, also along the Olson Gulch thrust fault, and underneath the

Racetrack pluton causing metasomatism and continued shearing in the overlying, already-crystallized Racetrack pluton.

4) minor block faulting within the range and unroofing of all the plutons by erosion.

APPENDIX I

UNIVERSITY OF MONTANA SAMPLE NUMBERS

D-2i	3752
D-3	3757
D-4a	3758
D-6	3753
D-9	3756
D-10	3754
D-15b	3755
HB-1	3762
PR-3	3759
PR-7	3760
RC-11	3761

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Plate 1 Photograph of the north side of Racetrack Creek

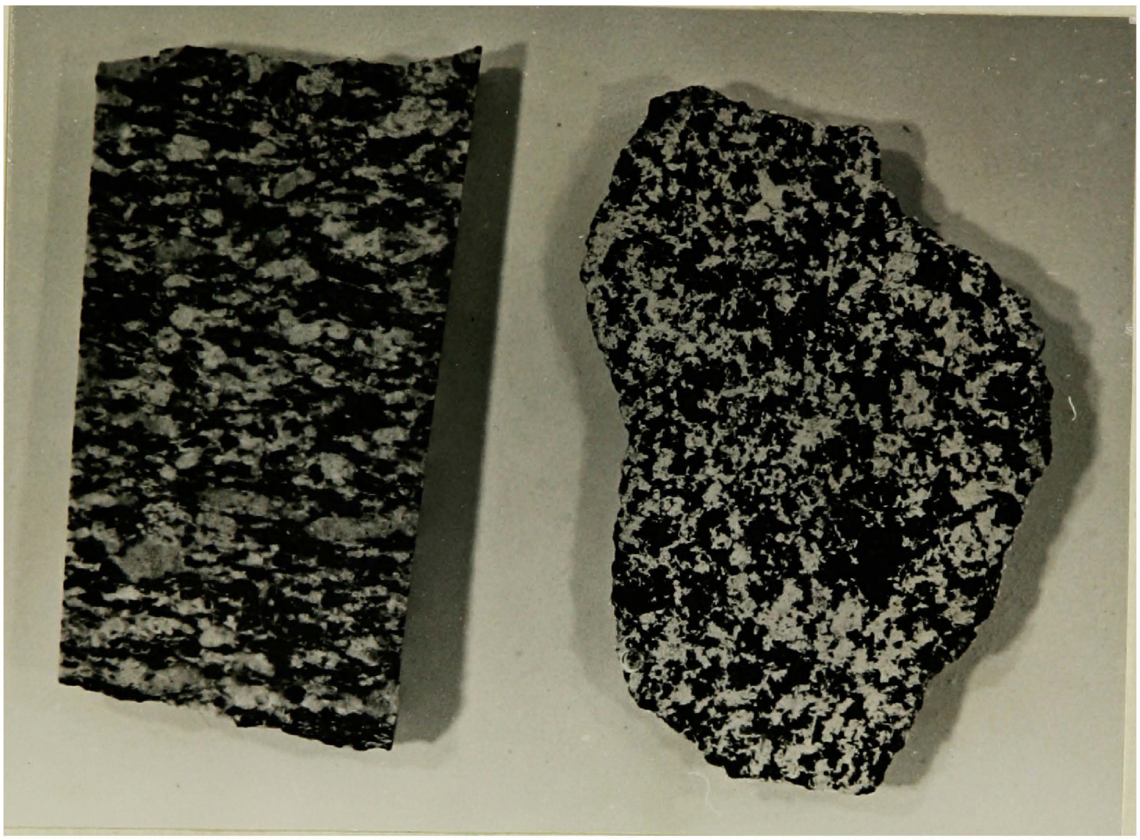

Plate 2a
Racetrack Creek
handspecimen

Plate 2b
Dempsey Creek
handspecimen