Geometry, kinematics, and emplacement mechanisms of the Philipsburg batholith within the Sevier fold-and-thrust belt, Flint Creek Range, western Montana
by Michael Patrick OConnell

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Spatial and temporal overlap of silicic magmatism and contractile deformation is prominent in the Late Cretaceous Sevier orogenic belt of western Montana. An understanding of the geometric, kinematic, and temporal relationships between magmatism and thrust belt development in this region can provide insights into the development of intra-arc and back-arc “foreland” thrust belts.

Contractile deformation in the Flint Creek Range of western Montana occurred contemporaneously with the intrusion of several small to moderate-sized (20-50 km2) epizonal (1-2 kbar) plutons. K-Ar and apatite fission track dates for these plutons range from about 74 to 62 Ma, broadly overlapping development of the fold-and-thrust belt in the study area. The Philipsburg batholith is surrounded predominantly by Precambrian metasedimentary rocks in the hanging wall of the Georgetown-Princeton thrust, a major thrust system of the region. The batholith also intrudes Paleozoic strata in the footwall. The western margin of the batholith contains weak or no fabric development in the pluton and the contact is sharply discordant with local structures and bedding-parallel metamorphic foliation. The eastern margin is characterized by largely concordant pluton wall geometries, strong magmatic fabrics, and contact-parallel country rock foliations.

Regionally, the Georgetown-Princeton thrust dips steeply (65-75°) westward. Within the 1-2 km structural aureole, the fault becomes east-dipping and is folded concordant to the batholith wall. Earlier models for emplacement of the Philipsburg batholith propose a sheet-like intrusion that post-kinematically exploited the low-angle Georgetown-Princeton thrust zone. In contrast, this study is unique in that it presents evidence for different mechanisms of emplacement being active during intrusion of the two plutons which comprise the Philipsburg batholith. The contrasting nature between observations made along the western margin (weak magmatic fabircs, discordant batholith margins and country rock structures) and those made along eastern margin (strong magmatic fabrics, concordant bathoith margins and country rock structures), is good evidence that the magma forming the Bimetallic stock (the western pluton) was intruded more passively while the Dora Thom pluton (the eastern pluton) was intruded more forcefully into the surrounding country rock.

The “room problem” is the question of volumetric accommodation of the intrusion of large plutons in a region undergoing tectonic shortening. This study demonstrates that intense deformation in western Montana, although contractile, is a necessary component to explaining the high concentration of shallowly emplaced plutons throughout the region.

GEOMETRY, KINEMATICS, AND EMPLACEMENT MECHANISMS OF THE PHILIPSBURG BATHOLITH WITHIN THE SEVIER FOLD-AND-THRUST BELT, FLINT CREEK RANGE, WESTERN MONTANA

by

Michael Patrick O'Connell

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Earth Sciences

Montana State University - Bozeman, Montana

April 2001

APPROVAL

Of a thesis submitted by

Michael Patrick O'Connell

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. David Lageson ______________________ 4-23-01

Approved for the Department of Earth Sciences

Dr. James Schmitt ______________________ 4-23-01

Approved for the College of Graduate Studies

Dr. Bruce R. McLeod ______________________ 4-23-01

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University-Bozeman, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature ______

Date 4/18/01

ACKNOWLEDGEMENTS

I would like to express my most sincere gratitude to Dave Lageson for introducing me to this unique and most interesting project within the fold-and-thrust belt. I wish to thank him for the invaluable days in the field and his input and interpretations of my data. I would also like to thank Tom Kalakay for his thought-provoking insight and knowledge about this research. I thank Todd Feeley and Jim Schmitt for their availability to answer questions and for their general help throughout my entire graduate experience. Dave Mogk was invaluable for his knowledge of metamorphic petrology that aided in my interpretations. He also provided me contact with Dr. Darrell Henry, whom I also would like to thank for providing the geobarometric data in this study.

Funding was provided by the D.L. Smith Memorial Scholarship, the Love Award (WGA), the Colorado Scientific Society, and a Department of Earth Sciences teaching assistantship. I would also like to thank S&ME, Inc. for providing me with continued financial support of my thesis after leaving Montana.

Thanks also to my good friends and fellow graduate comrades who were so supportive, and made my three years in Montana unforgettable. Thanks in particular to Stewart Dixon, Angela and Jim Nutaro, Garret Slaugenhoup, Andy and Camy Toth, and Jeff LaRock.

My wife Amy deserves many thanks for her emotional support and putting up with the long nights at the office.

TABLE OF CONTENTS

TABLE OF CONTENTS---Continued

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES---Continued

LIST OF FIGURES---Continued

Page

LIST OF PLATES

Plate

ABSTRACT

Spatial and temporal overlap of silicic magmatism and contractile deformation is prominent in the Late Cretaceous Sevier orogenic belt of western Montana. An understanding of the geometric, kinematic, and temporal relationships between magmatism and thrust belt development in this region can provide insights into the development of intra-arc and back-arc "foreland" thrust belts.

Contractile deformation in the Flint Creek Range of western Montana occurred contemporaneously with the intrusion of several small to moderate-sized (20-50 km^2) epizonal (1-2 kbar) plutons. K-Ar and apatite fission track dates for these plutons range from about 74 to 62 Ma, broadly overlapping development of the fold-and-thrust belt in the study area. The Philipsburg batholith is surrounded predominantly by Precambrian metasedimentary rocks in the hanging wall of the Georgetown-Princeton thrust, a major thrust system of the region. The batholith also intrudes Paleozoic strata in the footwall. The western margin of the batholith contains weak or no fabric development in the pluton and the contact is sharply discordant with local structures and bedding-parallel metamorphic foliation. The eastern margin is characterized by largely concordant pluton wall geometries, strong magmatic fabrics, and contact-parallel country rock foliations.

Regionally, the Georgetown-Princeton thrust dips steeply (65-75^{o}) westward. Within the 1-2 km structural aureole, the fault becomes east-dipping and is folded concordant to the batholith wall. Earlier models for emplacement of the Philipsburg batholith propose a sheet-like intrusion that post-kinematically exploited the low-angle Georgetown-Princeton thrust zone. In contrast, this study is unique in that it presents evidence for different mechanisms of emplacement being active during intrusion of the two plutons which comprise the Philipsburg batholith. The contrasting nature between observations made along the western margin (weak magmatic fabircs, discordant batholith margins and country rock structures) and those made along eastern margin (strong magmatic fabrics, concordant bathoith margins and country rock structures), is good evidence that the magma forming the Bimetallic stock (the western pluton) was intruded more passively while the Dora Thorn pluton (the eastern pluton) was intruded more forcefully into the surrounding country rock.

The "room problem" is the question of volumetric accommodation of the intrusion of large plutons in a region undergoing tectonic shortening. This study demonstrates that intense deformation in western Montana, although contractile, is a necessary component to explaining the high concentration of shallowly emplaced plutons throughout the region.

CHAPTER 1

INTRODUCTION

Study Objectives

In western Montana, structural development of the Sevier fold-and-thrust belt occurred contemporaneously with Late Cretaceous arc-magmatism, which developed as a result of the subduction of the Farallon plate beneath North America (Davis et al., 1978; Hamilton, 1978; Lund, 1988; Lund and Snee, 1988). A similar relationship between magmatism and crustal shortening is observed throughout the Cordilleran (i.e., Sierra Nevada plutons, Idaho batholith), but is not well understood (Robinson et al., 1968; Lanphere and Reed, 1973; Hyndman et al., 1975; Hyndman, 1980; Baken, 1981; Hyndman, 1983; Schmidt et al., 1990; Fillipone and Yin, 1994). This relationship raises questions concerning volumetric accommodation of large plutons intruded into regions undergoing tectonic shortening. The "room problem" is addressed by this detailed study of processes and timing relations of emplacement of the Philipsburg batholith in the Sevier fold-and-thrust belt, western Montana.

The Philipsburg batholith, located in the Flint Creek Range of western Montana (Figure 1), offers an ideal setting to study the temporal and kinematic problems associated with magmatic intrusion in a contractional environment. The batholith is the westernmost of three major igneous bodies exposed within the Flint Creek Range. The Royal stock and the Mount Powell batholith are located immediately east of the Philipsburg batholith. In general, these intrusions become more felsic from west to east within the Flint Creek Range.

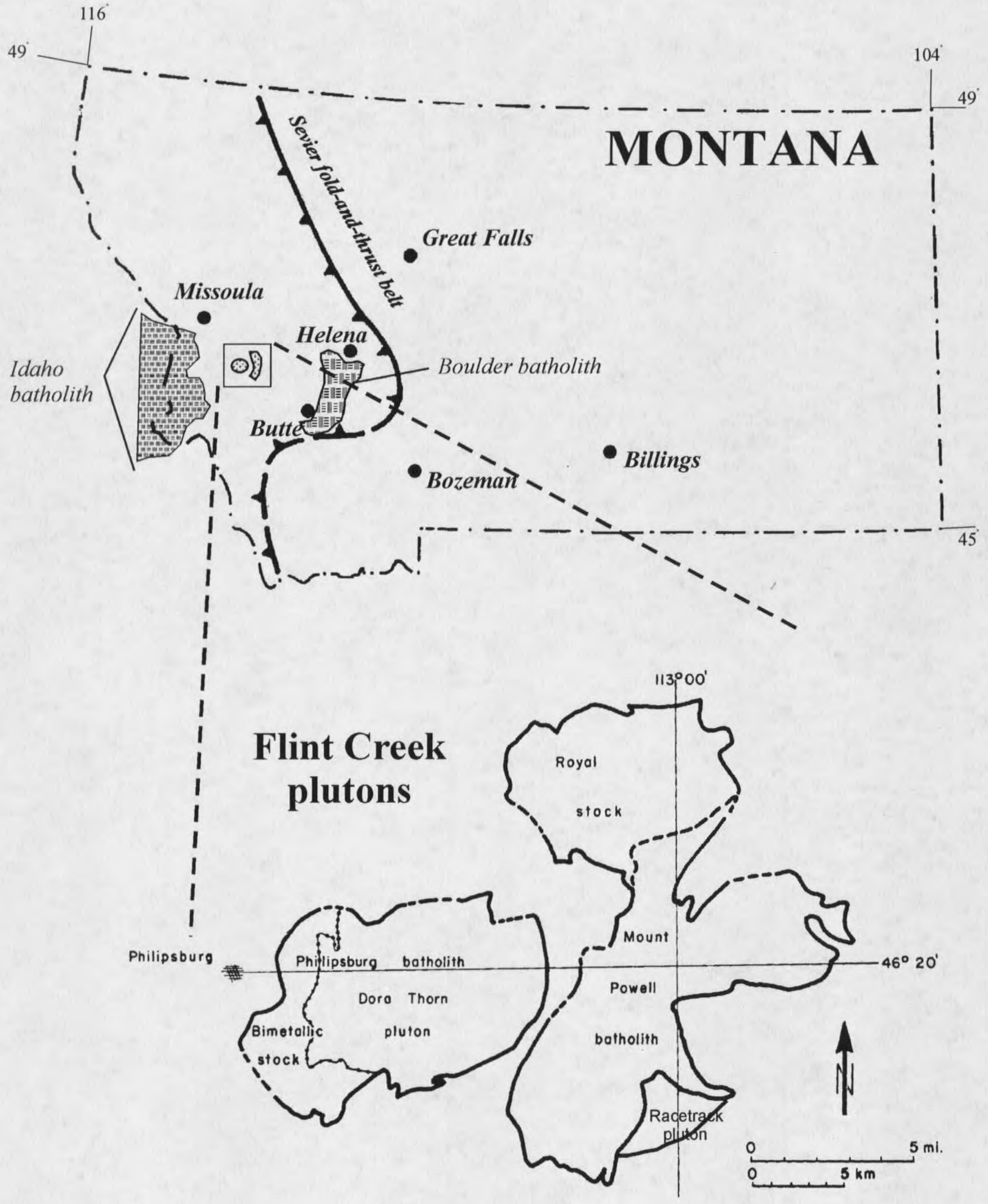

Figure 1. Area Map showing geographical locations of the Flint Creek plutons, Boulder batholith, Idaho batholith, and major towns in relation to the thrust belt in western Montana. Modified from Hyndman et al., 1982.

The Philipsburg batholith lies in the core of a very intensely deformed portion of the fold-and-thrust belt at the leading edge of the Sapphire plate, a major thrust sheet of the region. The majority of surface exposures of the batholith lie within the hanging wall of the principal thrust of the region, the Georgetown-Princeton thrust. However, the majority of good outcrops are found primarily in the eastern portions of the hanging wall and in the footwall where the Dora Thorn pluton interacts with the major structures (Hyndman et al., 1981). Deformational intensity of the wall rocks increases toward the eastern edge of the Philipsburg batholith where tightly folded upper Paleozoic and Mesozoic metasedimentary rocks separate the Philipsburg and Mount Powell batholiths to the west and east, respectively (Figure 2).

The moderate size of the Philipsburg batholith (~ 170 km^2), good exposures in the region surrounding the batholith, and the foundation of previous work in the area provides an opportunity to address the principal objectives of this study, which are to:

(1) Determine the relative timing of movement along the Georgetown-Princeton thrust relative to intrusion of the Philipsburg batholith.

(2) Determine possible emplacement mechanisms and construct a model for intrusion of the Philipsburg batholith within the kinematic framework of the thrust belt.

The goal of this project is to construct a kinematic model for intrusion of the Philipsburg batholith. This research will result in expanded knowledge of how magmatism was involved in the development of the fold-and-thrust belt of western

Montana. Moreover, it will assist future studies directed toward understanding magmatic intrusion in contractional orogens.

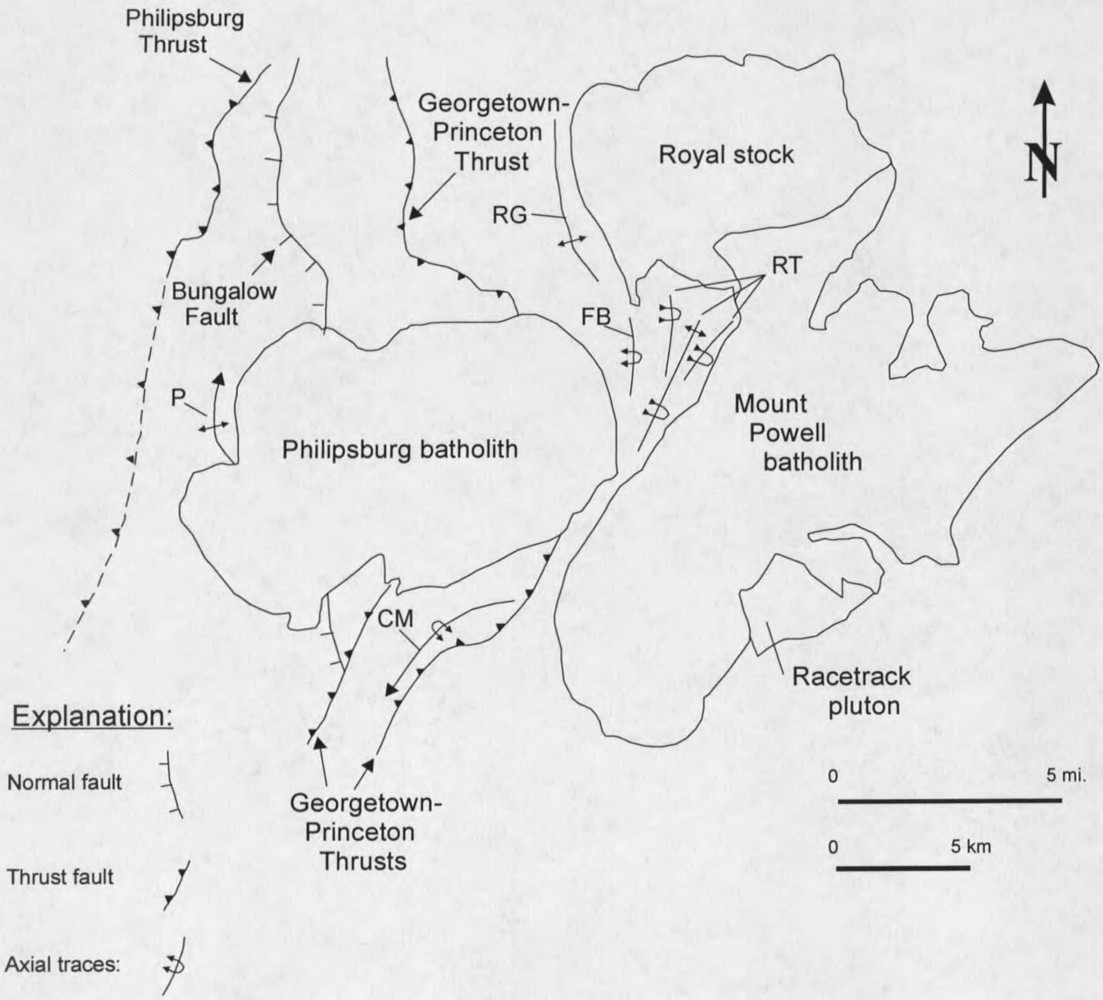

Figure 2. Generalized geologic map of the Flint Creek plutons with major faults and folds surrounding the Philipsburg batholith. P - Philipsburg anticline; CM - Cable Mountain anticline; RG - Royal Gold Creek anticline; FB - Finley Basin anticline; RT - Racetrack folds. Uncertain position of fault traces through the batholith are shown with dashed lines and question marks.

Procedures

Previous investigations regarding the kinematic sequence of structural events in the Flint Creek Range have been limited, focusing on either the style of deformation of country rocks (e.g., Baken, 1984), or on the geochemical and petrological aspects of the plutons (e.g., Hyndman, 1982). This study employs a variety of methods to address the nature of interaction(s) between magmatism, particularly emplacement of the Philipsburg batholith, and development of principal folds and thrust faults in the western part of the Flint Creek Range.

Field mapping and structural data

Field mapping of pluton-wallrock contacts is crucial for placing the Philipsburg batholith into a reasonable structural and geometric position within the deformed country rock. Through mapping, the three-dimensional geometry of the plutonic contact can be determined and compared to structural elements of the country rock (e.g., bedding planes and tectonic foliations) (e.g., Fillipone and Yin, 1994). These data can be useful in making inferences about the interactions between the pluton and wall rocks (Hutton, 1988; Paterson et al., 1991; Miller and Paterson, 1992; Paterson and Fowler, 1993; Glazner and Miller, 1997) and the nature of emplacement (ballooning, stoping, diapism, etc.).

In addition to strictly geometric orientations of faults and folds in the country rock, kinematic data were also collected from measurements of metamorphic mineral lineations and microstructural analysis of porphyroblasts (Vernon, 1989; Paterson et al., 1991; Paterson and Tobisch, 1992; Morgan and Law, 1998).

Field data have been compiled into a composite geologic map of the area (Plate 1). Base maps used for Plate 1 are the U.S.G.S. 7.5-minute quadrangles of the Philipsburg, Fred Burr Lake, Pozega Lakes, and southern portions of the Maxville and Pikes Peak quadrangles. The geology was compiled from this study and of the work of Calkins and Emmons (1915), McGill (1959), Baken (1984), Wallace et al. (1986), Wallace (1987), Sherry (1997), and Lewis (1998).

Geothermobarometry

In this study, aluminum-in-hornblende (AH) geothermobarometry is used in the Philipsburg batholith primarily to estimate depth of emplacement, but also to determine the degree of any post-emplacement tectonism associated with the structural development of the study area. Samples were collected from four different localities within the Philipsburg batholith. Thin sections were cut and polished in the lab, then shipped to Dr. Darrell Henry of Louisiana State University for analysis of the specified hornblendes in each section. Pressure and temperature calculations were made by Dr. Darrell Henry and returned.

Pluton fabric data

Magmatic foliation orientation and the use of mafic enclave orientations as two dimensional strain markers are both useful for determining the three-dimensional geometry of pluton contacts and the amount of strain within the pluton during emplacement (Ramsay, 1989; Cruden, 1990; Lagarde et al., 1990; Guglielmo, 1993; Paterson and Vernon, 1995, Glazner and Miller, 1997). In recent studies, data collected from various plutons have been used with country rock data (i.e., metamorphic porphyroblasts, bedding orientations) to distinguish between forceful versus passive styles of emplacement (Ramsay, 1989; Karlstrom, 1989; Paterson and Fowler, 1993; Paterson et al., 1993; Paterson and Vernon, 1995; Paterson et al., 1996).

Regional Geologic Overview

Sevier fold-and-thrust belt in western Montana

The Cordilleran fold-and-thrust belt was initiated by back-arc shortening in response to subduction of the Farallon plate beneath the western margin of North America (Davis et al., 1978; Hamilton, 1978; Lund, 1988; Lund and Snee, 1988). In western Montana, the resulting deformation is characterized by regional folding, thrusting, and reverse faulting. The two distinct styles of contractional faulting in the region are Sevier-style (dominantly thin-skinned thrusting) and Laramide-style (thick-skinned or basement-involved reverse faulting) (Burchfiel and Davis, 1975; Schmidt and O'Neill, 1982; Schmidt and Garihan, 1983; Lageson and Schmitt, 1994). In southwest Montana, the spatial distribution of the two deformational styles are largely controlled by the extent of the structurally inverted Middle Proterozoic Belt Basin (Harrison et al., 1974; Woodward, 1981; Woodward, 1983).

The Belt Supergroup is a Middle Proterozoic stratigraphic succession of rocks that was deposited in the Belt Basin formed during inferred rifting of the western North America (Winston, 1986). Rock types range from argillites and quartzites to meta-carbonates. The Belt Supergroup is thousands of meters thick in the west and pinches out to the east within the Belt embayment (McMannis, 1965; Woodward 1981). Structurally, the extent of the Belt embayment is mimicked by a convex-eastward salient of the Sevier fold-and-thrust belt (the Helena salient).

The southern limit of the Helena salient is marked by the Perry line (Harris, 1957), the Willow Creek fault (Robinson, 1963), or more recently the southwest Montana transverse zone (SMTZ) (Schmidt and O'Neill, 1982). The SMTZ is an east-west trending, regional transverse lateral ramp which structurally inverts the southern margin of the Belt Basin. It also divides Sevier-style deformation to the north from Laramide-style, basement involved deformation to the south (Winston, 1986; Lageson, 1989).

In western Montana, the fold-and-thrust belt has been divided into several distinct thrust sheets (Ruppel et al., 1981). Of particular interest to this study is the Sapphire sheet in west-central Montana which has also been referred to as the Skalkaho slab (Doughty and Sheriff, 1992). The Flint Creek plutons are at the leading edge of the Sapphire thrust sheet. Major thrusts in the area place Proterozoic Belt rocks over younger Paleozoic shales and carbonate rocks and Mesozoic clastic and carbonate rocks. The study area is located in the Flint Creek Range at the highly deformed leading edge of the Sapphire plate (Hyndman et al., 1975; Hyndman, 1980; Baken, 1984)

Late Cretaceous magmatism in western Montana

Large-scale magmatism ranging in age from approximately 90-55 Ma occurred contemporaneously with contractional deformation in western Montana during the Late Cretaceous and Paleogene. The result is a widespread distribution of voluminous granitic igneous bodies within the fold-and-thrust belt and Laramide foreland of southwestern Montana, which range in size from hundreds of square kilometers to just a few square kilometers (Figure 3). Major batholiths of the region include the Idaho, Boulder, Tobacco Root, and Pioneer batholiths. Like the Flint Creek plutons, these igneous bodies all have similar crustal positions (epizonal, with the exception of parts of the Idaho batholith), compositions (primarily granite to tonalite with some diorites and gabbros), and age ranges (~90-55 Ma). The Philipsburg and Mt. Powell batholiths of the Flint Creek Range are part a group of smaller intrusions emplaced between the large Bitterroot lobe of the Idaho batholith (90-70 Ma) to the west and Boulder batholith (80-70 Ma) to the east (Table 1) (Tilling et al., 1968; Klepper et al., 1971; Ehinger, 1972; Hamilton and Myers, 1974; Tilling, 1974; Rutland et al., 1989).

Previous Investigations

Original geologic mapping of the Flint Creek Range was done by F.C. Calkins and W.H. Emmons (Emmons, 1907; Emmons and Calkins, 1913; Calkins and Emmons, 1915). Their work was done primarily in the interest of mineral exploration and resulted in the first detailed geologic maps and rock descriptions of the area. Remapping and more detailed rock descriptions of various portions of the Flint Creek Range were done in