AN ABSTRACT OF THE THESIS OF

Karin L. Schultz for the degree of Master of Science

in Geophysics presented on February 11, 1983.

Title: PALEOMAGNETISM OF JURASSIC PLUTONS IN THE CENTRAL KLAMATH MOUNTAINS, SOUTHERN OREGON AND NORTHERN CALIFORNIA

Redacted for Privacy

Abstract approved: ______________ ____________
Shaul Levi

An understanding of the tectonic history of the Klamath Mountains is crucial for a valid paleogeographic reconstruction of the Pacific Northwest. However, prior to this study there were very few paleomagnetic (PM) data from the Klamath Mountains (KM), which resulted in conflicting interpretations about the role of the KM province in the tectonic evolution of western North America. Twenty-eight sites from five unmetamorphosed Middle Jurassic KM plutons with K-Ar ages ranging from 161 to 139 m.y.B.P. yielded stable PM results showing (1) a direction for the 160 m.y.B.P. Ashland pluton (D=324°, I=63°, α_{95}=8°, n=6) nearly concordant with the coeval expected direction (D=337°, I=54°) and (2) clockwise rotated directions for the plutons of Grants Pass (D=045°, I=67°, α_{95}=12°, n=4), Greyback (D=083°, I=63°, α_{95}=9°, n=9), and the Wooley Creek batholith and Slinkard pluton combined (D=037°, I=60°, α_{95}=11°, n=9).

Tectonic interpretations of these PM data are difficult; two interpretations are offered to explain the observed directions. In the first, the mean PM direction of the four plutons with discordant

directions (D=057°, I=65°, α_{95}=7°, n=22) is restored to the expected 150 m.y.B.P. (the average K-Ar age for these four plutons) direction by rotation of a rigid block ~87° in a counterclockwise sense about a vertical axis (the possibility of tilt of these four plutons is disregarded in this interpretation). The Ashland pluton which shows no rotation is problematic. Either there was (is) a tectonic boundary west of the Ashland pluton, separating it from the rotation of the others, or the Ashland pluton was influenced both by clockwise rotation and tilt, the combined effect producing an essentially concordant PM direction. In the second interpretation we distinguish between the northern KM, intruded by the Grants Pass and Greyback Mountain plutons, and the southern region intruded by the Wooley Creek batholith and the Ashland and Slinkard plutons. The bases for this distinction are recent geologic and gravity studies which suggest that post-Middle Jurassic uplift of the domal Condrey Mountain Schist may have caused radially outward tilt of its adjacent terranes and plutons intruded therein, causing some of the observed discordances in their PM directions. Thus, in the second interpretation it is envisioned that (a) the northerly portion of the KM, intruded by the Grants Pass and Greyback plutons, was affected primarily by clockwise rotation about a vertical axis, and (b) discordant directions for the remaining plutons intruded farther south are due primarily to tilt in response to Condrey Mountain uplift. Based on the observed inclinations, there is no evidence of transport of the Klamath Mountain province along lines of longitude since Middle Jurassic time.

Tectonic interpretations of the PM results of this study are consistent with significant post-Middle Jurassic clockwise rotation of the Klamath Mountains. The first interpretation above yields ∿87° of clockwise rotation of the terrane examined. According to the second interpretation, a clockwise rotation of ∿100° is inferred from the average of the PM results of the northern Grants Pass and Greyback plutons. Therefore, 10° to 25° of clockwise rotation of the KM may have occurred prior to the formation of the Oregon Coast Range (∿55 m.y.B.P.) and the two provinces may have rotated together since post-Lower Eocene time.

Paleomagnetism of Jurassic Plutons in the Central Klamath Mountains, Southern Oregon and Northern California

by

Karin L. Schultz

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed February 11, 1983

Commencement June, 1983

APPROVED:

Redacted for Privacy

Associate Professor of Geophysics in charge of major

Redacted for Privacy

Dean of School of Oceanography

Redacted for Privacy

Dean of Graduate School

Date thesis is presented 11 February, 1983

Typed by Karin Schultz for Karin L. Schultz

This thesis is

fondly dedicated to

my parents,

Ford and Frances

ACKNOWLEDGEMENTS

My most sincere appreciation goes to my advisor, Shaul Levi, for his invaluable assistance in all phases of this research, his unfailing moral support, his comments which helped to better this thesis, and his advice, patience, and friendship which greatly contributed to my complete enjoyment of these years spent at Oregon State University.

I would also like to thank the other members of my thesis committee, Bob Duncan, Bob Yeats, and Fred Ramsey, for comments and discussions from which this thesis benefitted.

I am indebted to my officemates, Bob Karlin and Dennis Schultz for their constant encouragement and assistance. Bob's programming expertise and finesse enhanced the progress and smoothness of the lab and his patience aided in my understanding of the computer and its mind. He and Shaul collected the first four sites' samples which provided the impetus for this project. Dennis helped in the collection of <u>every</u> other core, and supplied the good humor and company on totally enjoyable field excursions. I am pleased to have been able to share the serenity and beauty of the Klamath Mountains with him. Shaul, Bob, and Dennis, your friendships are treasured ones of mine.

My understanding of the geology of the Klamath Mountains is largely a result of invaluable discussions in the field and elsewhere with Cal Barnes, Mary Donato, Charlotte Allen, Monty Elliott, Gary Gray, Doug Charlton, Len Ramp, and Jim Wright. In addition, Cal, Mary, Charlotte, and Monty saved many hours of driving time by suggesting suitable sampling sites.

The figures in this thesis were carefully and quickly drafted by Paula Pitts. Figures 5, 9, and 10 were drafted by Joy Denkers. I am thankful to both as well as to David Reinert, who photographed the figures and created beautifully colorful slides for the thesis defense.

Thanks are also due to Bobbi Conard and Dale Bibee for their assistance in using Cyber to generate the final copy of this thesis. Tables and Appendix B were typed by Chris Pyle.

This thesis would never have seen its completion without all the supportive, energetic, compassionate, and talented friends here in Corvallis. I extend my sincere thanks to:

Karen Weliky, Rick Bader, Laurie Pavey, Bill Peterson, and Kris McElwee for making my living environs most comfortable and rewarding;

Glenn Hayman, George Redden, Debbie Cannon, Torrey Karlin, Dave Murray, Dennis Schultz, Wayne Gibson, Clare Reimers, and many others, for the hours spent on the racquetball and squash courts, as well as long bicycle rides through the Oregon countryside which helped keep things in perspective;

Tina Emerick, Al Federman, Bob and Sally Duncan, Dale and Pat Bibee, Mitch Lyle, and Mike Fehler for just being here;

And finally, my fellow geophysics students for their company and good nature. I have learned a great deal from each and every one of them.

Last, but not least, I thank Glenn for just about every reason I have thanked others in the preceding paragraphs, and then some. His understanding was perhaps the most important ingredient in the progress of this research, and his companionship I would rather not be without.

This research was funded by National Science Foundation grant EAR81-09593.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Objectives	2
Suitability of Plutons for Paleomagnetic Study	2
Problems Associated With Paleomagnetic Studies of Plutonic Rocks	3
BACKGROUND	5
Physiographic and Geologic Setting	5
Desciption of the Four Lithologic Belts	8
Eastern Klamath Belt	8
Central Metamorphic Belt	8
Western Paleozoic and Triassic Belt	9
Western Jurassic Belt	9
Tectonic History of the Klamath Mountains	10
Plutonic Rocks of the Klamath Mountains	15
Previous Related Paleomagnetic Work	19
Oregon Coast Range	20
Simpson and Cox Models for Coast Range Rotation	21
Washington Coast Range	23
Cascade Range	24
Eastern Oregon	25
Two Phase Rotation Model	25
Klamath Mountains	26
Sierra Nevada	30
PALEOMAGNETISM OF THE LATE CRETACEOUS HORNBROOK FORMATION	32
Introduction	32
Geology of the Hornbrook Formation	32
Paleomagnetic Sampling and Laboratory Procedures	33
Paleomagnetic Results	34
Anhysteretic and Viscous Remanent Magnetization Studies	38

PALEOMAGNETISM OF KLAMATH MOUNTAIN PLUTONS 42

Introduction 42

Sampling 42

Laboratory Procedures 44

Analysis of Paleomagnetic Data 44
Quality Factors 45
Selection of Stable Direcitons 47
Omission of Samples 47

Nature of Magnetism of Klamath Plutonic Rocks 47
NRM and Behavior Upon AF Demagnetization 47
Stability 64
Polarity 68

Opaque Mineralogy 68

Paleomagnetic Results from Middle Jurassic Plutons 70
Introduction 70
Ages of Plutons Examined 71
Greyback Intrusive Complex 73
Grants Pass Pluton 77
Ashland Pluton 81
Wooley Creek Batholith and Slinkard Pluton 82
Summary of Paleomagnetic Data 88

INTERPRETATION 93

Paleomagnetic Reference Poles of Stable North America 93

Rotation Scheme 93

Interpretation of Paleomagnetic Results 97
Interpretation I: Semi-rigid Body Rotation About a Vertical Axis 97
Extent of the Rotated Block, Timing of Rotation, and Relation to Oregon Coast Range Rotation 98
Tectonic History of the Ashland Pluton 101

Interpretation II: Regional Tilting and Clockwise Rotation 105
Geology of the Condrey Mountain Schist 106
Relative Timing of Pluton Intrusion, Thrusting, and CMS Uplift 107
Evidence for Uplift and Domal Nature of the CMS, Tilt of the Surrounding Terranes 108

Restoration of Wooley Creek/Slinkard and Ashland PM Directions 109
Structural Control for Greyback Intrusive Complex and Grants Pass Pluton 109
Restoration of Greyback and Grants Pass PM Directions 113
Structural Trend of the Klamath Mountains and Interpretation of Paleomagnetic Data 117
Effect of Present Data on Existing Models 118

Summary of Interpretations 120

REFERENCES CITED 124

APPENDIX A: Statistical Measures of Data Reliability 131

APPENDIX B: Summary of Paleomagnetic Data for All Samples from Klamath Mountain Plutons 132

APPENDIX C: Locations and Descriptions of Sampling Sites 144

LIST OF FIGURES

Figure		Page
1.	Generalized geotectonic map of the western United States based on Cohee (1962) and Lawrence (1976)	6
2.	Generalized geology of the Klamath Mountains	7
3.	Paleogeographic map of the continental margin complexes of west-central North America in Middle Late Cretaceous time	11
4.	Schematic diagram showing sequential ages of suturing of accretionary plates of the Klamath Mountains and adjacent Coast Ranges	14
5.	Distribution of plutons in the Klamath Mountains	17
6.	Simpson and Cox (1977) models for Oregon Coast Range rotation, each showing the Pacific Northwest in Middle Eocene time	22
7.	Rotation versus age for geologic units of the Oregon Coast Range	27
8.	Two phase model of Magill et al. (1981) for rotation of the Oregon Coast Range	28
9.	Site mean directions and associated α_{95} values for sites of the Upper Cretaceous Hornbrook Formation	36
10.	Normalized intensity curves for AF demagnetization of natural, viscous, and anhysteretic remanent magnetizations (NRM, VRM, and ARM, respectively) for two samples from the Hornbrook Formation	40
11.	Approximate locations of sampling sites in the plutons of the central Klamath Mountains	43
12.	Grants Pass pluton: Behavior upon AF demagnetization of three representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot	49
13.	Greyback intrusive complex: Behavior upon AF demagnetization of four representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot	51

14. Ashland pluton: Behavior upon AF demagnetization of four representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot 53

15. Slinkard pluton: Behavior upon AF demagnetization of three representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot 55

16. Wooley Creek batholith: Behavior upon AF demagnetization of three representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot 57

17. Distributions of median destructive field (MDF) values for stable (accepted) and unstable (rejected) samples of both normal and reversed polarities for the plutons of (A) Grants Pass, (B) Greyback, (C) Ashland, (D) Slinkard, and (E) Wooley Creek 60

18. Distributions of Q values for stable (accepted) and unstable (rejected) samples of both normal and reversed polarities within the (A) Grants Pass pluton and (B) Greyback intrusive complex 66

19. Stable paleomagnetic directions for reliable samples from site GM 3 69

20. Greyback intrusive complex site mean directions and pluton mean direction with associated circles of 95% confidence 75

21. Grants Pass pluton site mean directions and pluton mean direction with associated circles of 95% confidence 79

22. Ashland pluton site mean directions and pluton mean mean direction with associated circles of 95% confidence 84

23. Wooley Creek batholith and Slinkard pluton site mean directions and associated 95% confidence circles 89

24. Mean paleomagnetic directions and associated circles of 95% confidence for the Jurassic plutons of the Klamath Mountains examined in this study 91

25. Possible reconstructions to explain the tectonic history of the Ashland (ASH) pluton 103

26. Structural corrections of the Wooley Creek/Slinkard (WC/SLK) and Ashland (ASH) mean paleomagnetic directions 110

27. Structural correction of paleomagnetic directions of the Greyback Mountain (GM) and Grants Pass (GP) plutons 114

LIST OF TABLES

Table		Page
1.	Summary of paleomagnetic data for Cretaceous Hornbrook Formation	35
2.	Explanation of field and laboratory quality factors assigned to each paleomagnetic sample	46
3.	Radiometric ages of the Klamath Mountain plutons sampled for this study	72
4.	Summary of paleomagnetic data from the Greyback intrusive complex, southern Oregon	74
5.	Summary of paleomagnetic data from the Grants Pass pluton, southern Oregon	78
6.	Summary of paleomagnetic data from the Ashland pluton, southern Oregon and northern California	83
7.	Summary of paleomagnetic data from the Wooley Creek batholith and Slinkard pluton, northern California	87
8.	Summary of paleomagnetic data from Klamath Mountain plutons, southern Oregon and northern California	92
9.	Jurassic pole positions of Harrison and Lindh (1982) and calculated expected paleomagnetic directions	94
10.	Summary of rotations and paleomagnetic results	96
11.	Mean paleomagnetic directions based on stable sites from the plutons of Grants Pass, Greyback, Wooley Creek and Slinkard	99

PALEOMAGNETISM OF JURASSIC PLUTONS IN THE CENTRAL KLAMATH MOUNTAINS, SOUTHERN OREGON AND NORTHERN CALIFORNIA

INTRODUCTION

Paleomagnetism has been an essential aid to the paleogeographic reconstructions of Cordilleran North America. The hypothesis that the present day structure of western North America may be attributed to large scale right lateral shearing distributed across a broad zone is supported by an increasing number of paleomagnetic data from mostly Mesozoic and Cenozoic rocks from Alaska to Baja California (Beck 1976, 1980). These data demonstrate discordant paleomagnetic directions for which observed declinations are clockwise rotated relative to coeval declinations from the stable North American craton. In some cases, observed inclinations are shallow and thereby suggest the northward translation of various terranes (Beck, 1976, 1980). Tectonic models based on paleomagnetic results from provinces adjacent to the Klamath Mountains (KM), such as the Oregon Coast Range and Cascade Range, suggest different geologic histories for the Pacific Northwest. A rotational history of the KM is inferred from its stratigraphic contacts with these two provinces but, prior to this study, little had been done to test this paleomagnetically. The understanding of the extremely complex geology of the KM has been enhanced by a wealth of studies focused on the petrology and structure of the region. However, without paleomagnetism the tectonic history of the KM province and its role in the evolution of the Pacific Northwest could not be known.

Objectives

This study focuses on the paleomagnetism of five Middle and Upper Jurassic plutons in the central Klamath Mountains of southwestern Oregon and northwestern California. These are the Grants Pass, Ashland, and Slinkard plutons, the Greyback intrusive complex, and the Wooley Creek batholith. The primary objectives of this study were to determine from paleomagnetic results the tectonic history of the KM province subsequent to pluton emplacement and, if possible, to explain the relationship of the tectonism of the Klamath Mountains to that of its surrounding terranes, particularly the Oregon Coast Range.

Suitability of the Plutons for Paleomagnetic Study

Four important factors make these plutonic rocks the most appropriate Klamath Mountain rocks for a paleomagnetic study satisfying our objectives:

1. Their ages have been radiometrically determined by Lanphere et al. (1968) using K-Ar techniques. Additional dates for several plutons, based on U-Pb determinations on zircons have been provided by Allen et al. (1982).

2. They are widely distributed throughout the province.

3. They are the youngest rocks present and probably the least structurally disturbed.

4. They comprise the majority of the unmetamorphosed rocks of the province. Others which exist are the Upper Cretaceous and younger sediments flanking the eastern KM margin and occurring as occasional outliers, and Permian volcanic and sedimentary strata.

Problems Associated With Paleomagnetic Studies of Plutonic Rocks

Due to inhomogeneities in both lithology and grain size, samples from a single plutonic outcrop possess a wide range of magnetic properties, including intensity and directional stability. The slow cooling of intrusions results in their remanence having been acquired over tens of thousands of years. Therefore, samples within a pluton (and frequently within one site) can record normal, reversed, and transitional polarities. In order to adequately average secular variation and compensate for the often substantial number of unstable samples, many cores must be drilled at and measured for each site (10-12 or more c.f. 4-8 for basalts). The problem of structural control is inherent in a paleomagnetic study dealing with intrusives which lack both bedding and exposed contacts. Without such control, any post-emplacement tilt is difficult to ascertain. Therefore, it is important that sampling localities span as large an area as possible in order to average out local tilting and deformation. As an additional measure of structural control, the paleomagnetism of the Upper Cretaceous Hornbrook Formation was also examined. Because sediments of this formation are in direct nonconformable contact with the Ashland pluton, reliable paleomagnetic data would allow for the assumption that at least the Ashland pluton and its host terranes have undergone whatever rotation and/or translation the Hornbrook was subjected to since its Late Cretaceous deposition. However, the remagnetization of the Hornbrook Formation in the the present field (Mankinen and Irwin, 1982; this study) conceals its tectonic history.

BACKGROUND

Physiographic and Geolologic Setting

The Klamath Mountains (KM) geologic province occupies 31,000 square kilometers in northwestern California and southwestern Oregon along the western margin of the Cordilleran orogen (Figure 1). It is geologically and geomorphically distinct from the adjacent provinces of the Coast Ranges to the north and south and the Cascades to the east. The KM feature high relief (up to 2500m), thick and diverse vegetation, and somewhat limited access.

The geology of the Klamath Mountains is extremely complex. The region consists primarily of intensely folded, faulted, and metamorphosed Ordovician to Upper Jurassic eugeosynclinal rocks intruded by Middle to Late Jurassic granitic plutons. These pre-Cretaceous units are often called "subjacent" and are unconformably overlain by "superjacent" sedimentary and volcanic strata of Cretaceous and younger ages.

The gross structural feature is shown in Figure 2 to be an elongate, north-trending arcuate body composed of four concentric, lithologic belts or subprovinces. These terranes of differing metamorphic grade are separated by easterly-dipping thrust faults, the progressively older eastern thrust plates having overridden the western ones. Detailed examinations of the nature and timing of thrusting by Irwin (1966, 1972) and Davis et al. (1979) show that these major thrusts have shallow dips. In addition, the structure has been further complicated by numerous high-angle normal faults active

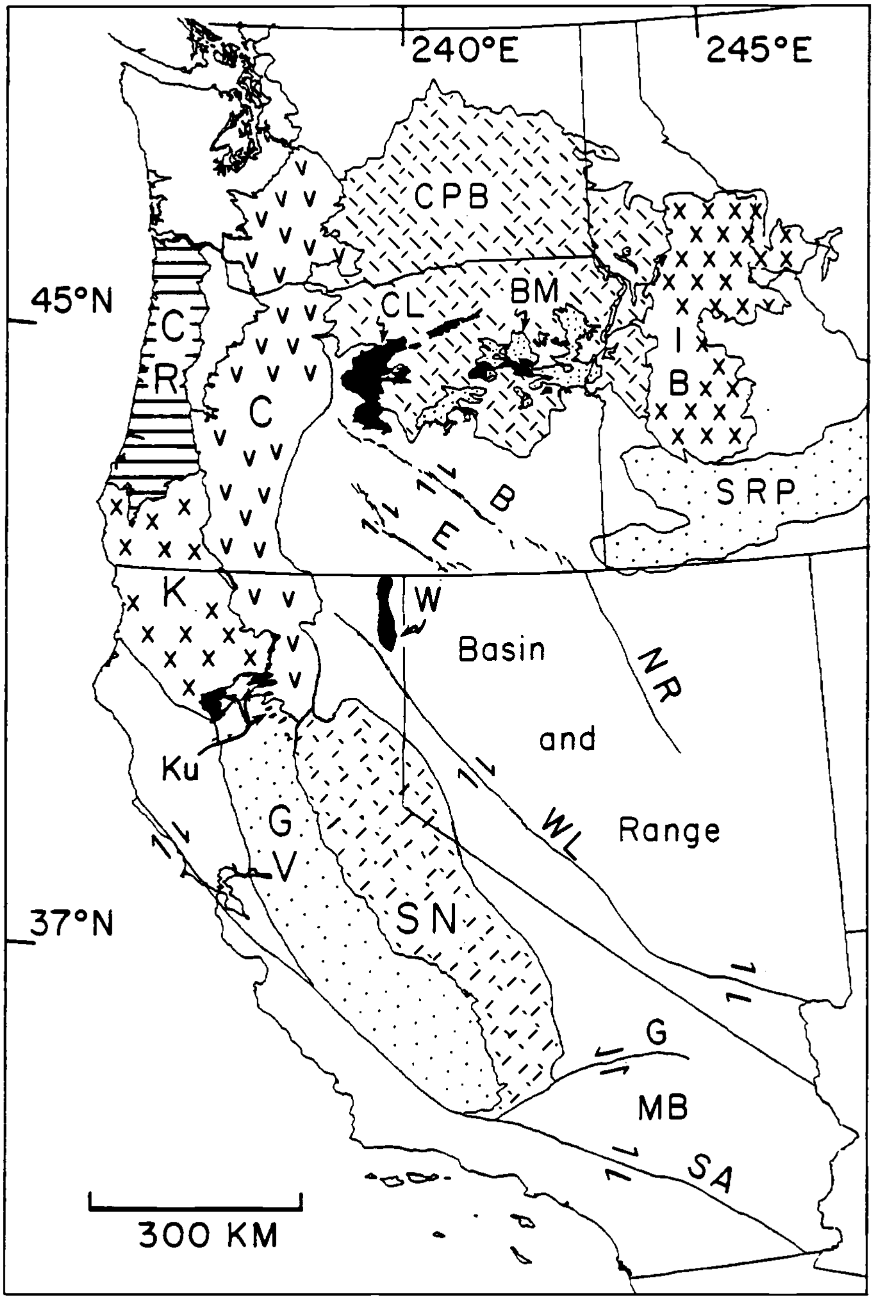


Figure 1. Generalized geotectonic map of the western U.S. based on Cohee (1962) and Lawrence (1976) (modified from Magill and Cox, 1980). K=Klamath Mountains, C=Cascades, CR=Oregon Coast Range, CL=Clarno Formation, BM=Blue Mountains, CPB=Columbia Plateau Basalts, GV=Great Valley, IB=Idaho Batholith, Ku=Upper Cretaceous sediments, MB=Mojave block, NR=Nevada Rift, SN=Sierra Nevada, SRP=Snake River Plain, W=Warner Mountains. Fault Zones: B=Brothers, E=Eugene-Denio, G=Garlock, SA=San Andreas, WL=Walker Lane.

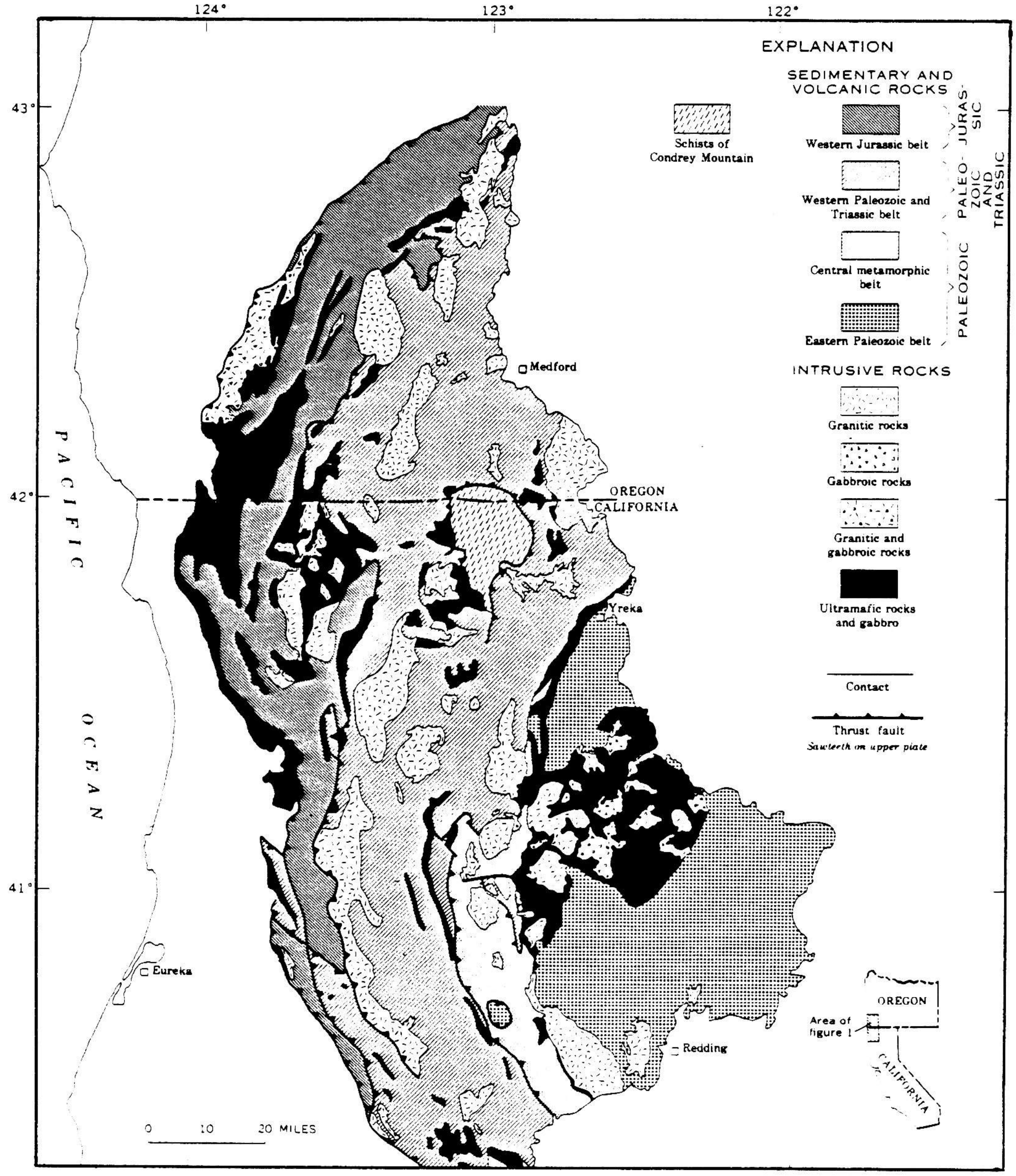


Figure 2. Generalized geology of the Klamath Mountains (after Hotz, 1971).

during the last 30 million years.

It is believed that the Klamath Mountains are a geologic continuation to the northwest of the western Sierra Nevada. Many correlations between structural and lithologic features of the two provinces have been identified by Davis (1969), Hamilton (1969), and Wright (1981), including the similarities between plutonic rocks.

Description of the Four Lithologic Belts

Following Irwin's (1960) terminology the lithologic belts from east to west, respectively, are: the Eastern Klamath belt, the Central Metamorphic belt, the western Paleozoic and Triassic belt, and the western Jurassic belt. The following paragraphs briefly describe each one.

Eastern Klamath Belt

Late Triassic through Middle Jurassic volcanic arc activity is well-preserved in the 12,000 to 15,000 meter thick stratigraphic section of the Eastern Klamath belt. The easterly-dipping Ordovician through Jurassic sequence is buried under Cascade volcanic rocks to the east and is underlain in the west by the Lower Paleozoic Trinity ultramafic sheet.

Central Metamorphic Belt

The metasedimentary Salmon Hornblende Schist and the metavolcanic Abrams Mica Schist comprise the majority of the Central Metamorphic belt. Rb-Sr age determinations by Lanphere et al. (1968), and K-Ar ages by Hotz (1977) for the Abrams and Salmon, respectively, indicate that the two were cometamorphic during Devonian time. Davis (1966) suggests that the former was metamorphosed from oceanic sediments deposited upon the ancient oceanic crust from which the latter was derived.

Western Paleozoic and Triassic Belt

The western Paleozoic and Triassic belt (wTrPz) is the most extensive of the four Klamath belts. It is an assemblage of fine-grained clastic sedimentary rocks, cherts, mafic volcanic rocks, and lenticular marbles. All rocks in the wTrPz have undergone at least lower greenschist facies metamorphism. Some that have been metamorphosed to almandine-amphibolite facies may be higher grade equivalents of the other rocks.

The southern part of the wTrPz subprovince is subdivided into the terranes of North Fork (block-on-block melange), Hayfork (volcaniclastics), and Rattlesnake Creek (dismembered ophiolite), from east to west, respectively. Ando and others (1976) suggest the equivalence of the North Fork and Hayfork terranes. This subdivision is not applied to the central and northern portions of the wTrPz, however, extensions of the Hayfork and North Fork exist and are described as a tectonic melange. The primarily Mesozoic Applegate Group, the portion of the wTrPz extending into Oregon, was metamorphossed to a low grade (Davis, 1966).

Western Jurassic Belt

A several kilometer thick sequence of flysch and volcanic arc deposits of the Galice and Rogue formations comprises the western Jurassic subprovince. This assemblage was metamorphosed at a low grade during very Late Jurassic time (Dott, 1971). Having formed synchronously with wide-spread plutonism in the Sierra Nevada and Klamath regions, these rocks may be the volcanic equivalents of the plutons, although an island-arc setting could also be inferred (Hamilton, 1969). Folded and metamorphosed rocks of the Lower or Middle Jurassic Josephine Peridotite at the base of the western Jurassic belt form the western margin of the Klamath province.

Tectonic History of the Klamath Mountains

Carey (1958) first proposed that the present structure of the western Cordillera of North America resulted from a process of regional right lateral shear of the continent with respect to adjacent plates of the Pacific basin. Such a shearing process occurred within a broad zone along the continental margin, portions of which are undergoing similar motion and have been since at least the close of the Mesozoic (Atwater, 1970). It is believed that the tectonic development of the western Cordillera may be attributed to this shearing process.

To explain the anomalous position of the Klamath Mountains relative to the Sierra Nevada and the anomalous trend of the Blue Mountains of eastern Oregon, the idea of an oroclinal structure (as defined by Carey in 1958) in the Cordillera of North America was proposed by Hamilton and Myers (1966). Hamilton's (1969) model depicts an originally sub-linear orogenic belt (Figure 3), presumably continuous along the entire western Cordillera and analogous to that of present day western South America. This feature formed sometime

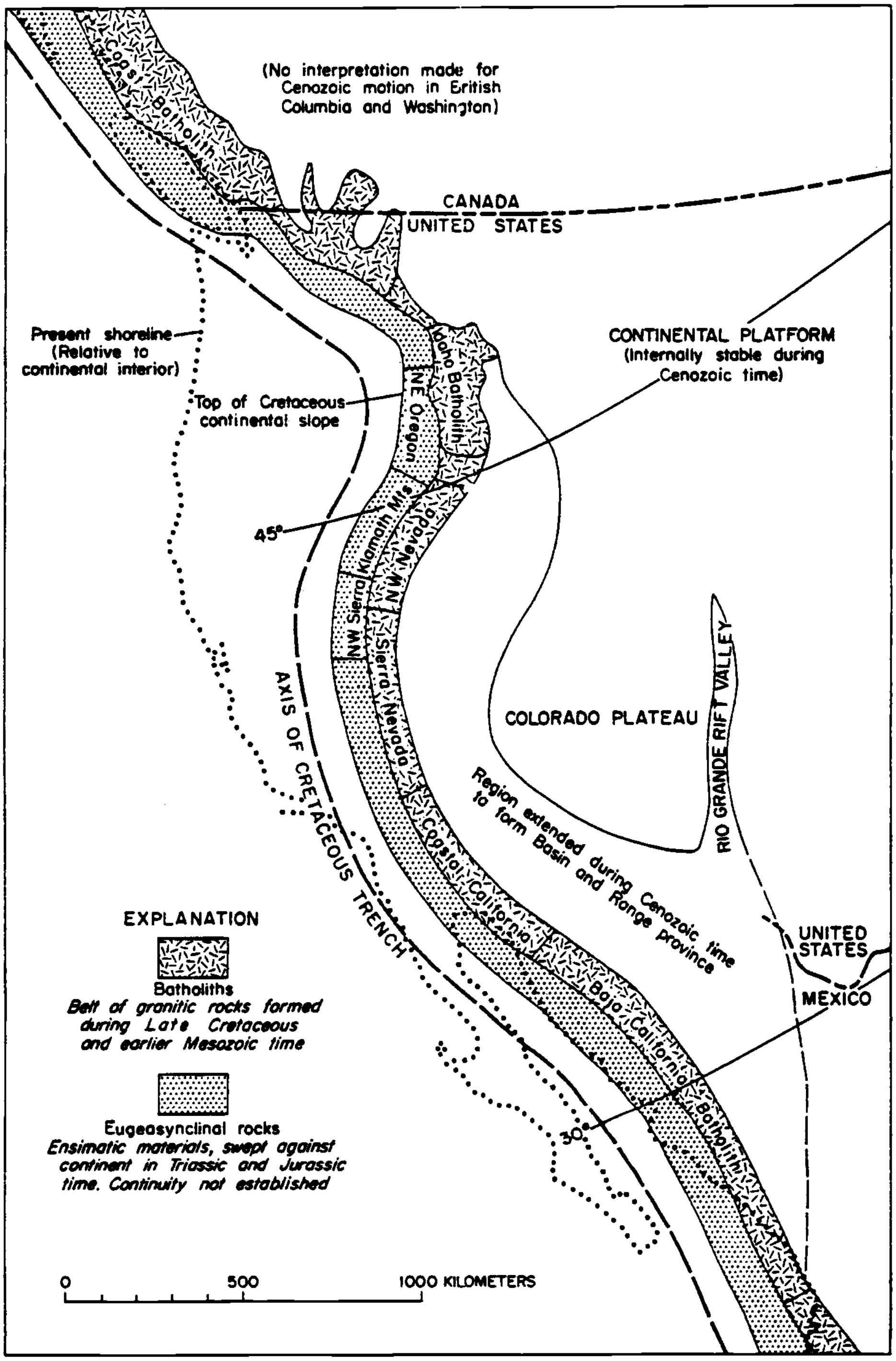


Figure 3. Paleogeographic map of the continental margin complexes of west-central North America in Middle Late Cretaceous time (after Hamilton, 1969). This map was derived by reversal of Cenozoic extension. Paleolatitudes correspond to a pole at 70°N, 175°E, as suggested by paleomagnetic orientations (Hanna, 1967; Helsley, 1967).

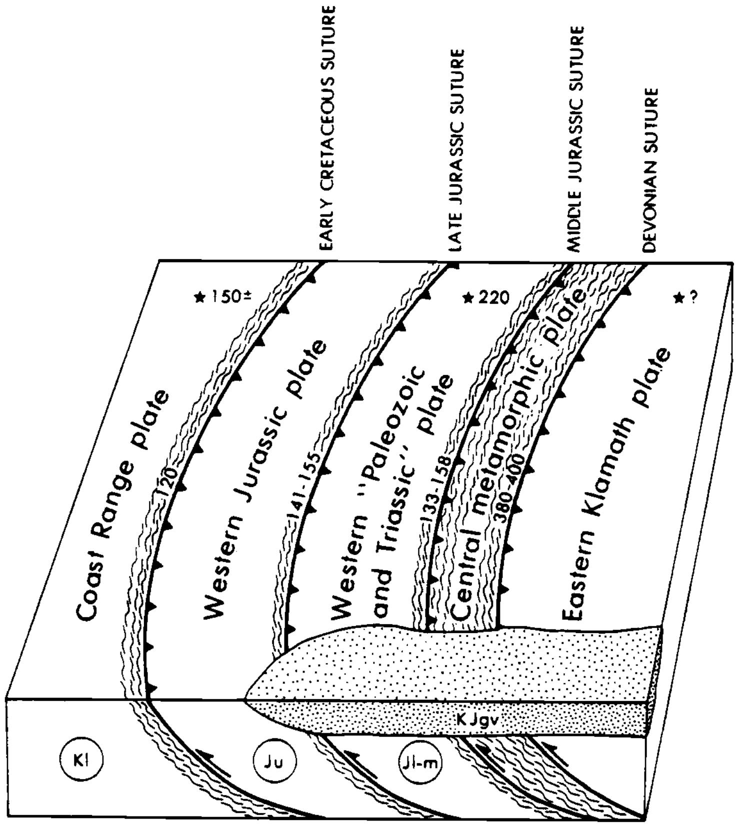
during the Mesozoic as a result of large scale oblique underflow of the Pacific Ocean crust beneath the North American continent. However, the precise times of formation and deformation of the structure are still under investigation. It is postulated that underthrusting and subsequent granitic intrusion had ceased by Early Cretaceous time and that deformation of the orocline occurred as a result of late Cenozoic extension and right lateral strike-slip faulting (Hamilton, 1969).

Evidence is accumulating in support of the idea that the western eugeosynclinal portion of Cordilleran North America comprises a tectonic collage of accreted allochthonous terranes formed during the Mesozoic. It is possible that the Klamath Mountains and Sierra Nevada provinces are allochthonous as well. An increasing number of authors have interpreted the Jurassic rocks of the two provinces to be exotic elements of the Cordillera that were carried to the North American plate atop Pacific Ocean lithosphere and accreted during oblique Jurassic subduction of the oceanic lithosphere beneath the continent (Schwieckert and Cowan, 1975; Dickinson, 1976; and Irwin, 1981). Subsequent rifting of the Klamath Mountain terrane away from its Sierra Nevada counterpart accounts for the present day relative positions of these regions (Irwin, 1966; Davis, 1969; Hamilton, 1969; Schweickert, 1976). The actual time of rifting remains undetermined. Hamilton (1969) originally proposed that rifting occurred during the Tertiary, however, the presence of widespread Upper Cretaceous marine sediments between the two provinces has led Schweickert (1976), Irwin (1977), and Blake and Jones (1977) to postulate an Early Cretaceous time for rifting.

Two principal lines of thought have been developed to elucidate the origin and Mesozoic evolution of the Klamath Mountain province:

(1) The concept that three or more independently evolving Jurassic volcanic arcs are represented within the Klamath Mountain terranes is most recently discussed by Irwin (1981). According to this model, the lithotectonic plates and some intraplate terranes are vestiges of oceanic crust and island arcs that accreted to the North American plate sequentially from east to west. Furthermore, the major eastward-dipping thrust faults separating these terranes are regarded as former sutures along which eastern plates were consecutively underthrust by western ones. Similar earlier arguments presented by Schweickert and Cowan (1975), Dickinson (1976), and Hamilton (1978) are the foundation for this idea. Figure 4 depicts the sequential ages of suturing of these accretionary plates. With the exception of the Devonian suturing of the central metamorphic subprovince to the eastern Klamath subprovince, all plates were accreted during Mesozoic time.

(2) In contrast, Burchfiel and Davis (1981) cite geologic evidence to support the notion that Middle and Late Jurassic volcanic rocks and coeval plutons in the Klamath Mountains are components of a single evolving Jurassic magmatic arc constructed across a previously sutured boundary between continental arc rocks and younger rocks of oceanic affinity. Rather than former sutures, the same Jurassic thrust faults delineate internal Middle and Late Jurassic disruption and imbrication in response to continued oblique plate convergence. In addition, Burchfiel and Davis (1981) argue that not one of these thrust faults can be identified with certainty as being a convergent



EXPLANATION

155 Isotopic age of rock regionally metamorphosed during underthrusting.

★220 Isotopic age of blueschist knockers.

(Ju) Paleontologic age of youngest strata in underthrust (lower) plate. Jl-m (Lower or Middle Jurassic); Ju (Upper Jurassic); Kl (Lower Cretaceous - Valanginian)

KJgv Great Valley sequence: deposited on accreted plates of Klamath Mountains.

Figure 4. Schematic diagram showing sequential ages of suturing of accretionary plates of the Klamath Mountains and adjacent Coast Ranges (after Irwin, 1981).

plate boundary and that at least one crosscuts older structures in both upper and lower plates.

Plutonic Rocks of the Klamath Mountains

Plutonic rocks are widely distributed throughout all four lithic belts of the Klamath Mountains (Figure 2), but the majority were intruded into the wTrPz and central metamorphic belts. They range in size and shape from small stocks and sills to elongate bodies of batholithic proportions with long axes aligned parallel to the regional structural trend.

A comprehensive examination of the plutonic rocks of the KM is presented by Hotz (1971). In addition, several of the plutons have been studied in detail. A broad range of lithologies exists but quartz diorite is the most abundant. Commonly occurring lithologies include trondhjemite, quartz monzonite, granodiorite, and hornblende gabbro. Variations in texture within single plutons may be attributed to multiple intrusions, assimilation of wall rock, and magmatic differentiation (Davis et al., 1965). Many of the larger plutons are composite bodies with the outer intrusive units characteristically being the oldest and most mafic in composition (Davis, 1966).

Based upon the existence of largely concordant contacts and deflection of country rock structures, Davis (1966) suggests that the principal mode of emplacement was by forceful intrusion. Furthermore, he believes that the more elongate bodies, characteristic of the wTrPz, are probably sheetlike in form and were intruded along thrust fault contact zones between major lithologic types. However, the rootless nature of several plutons which intrude the wTrPz suggest that their intrusions preceded thrusting (Allen, 1981; Charlton, 1979; Barnes, 1982).

Davis (1966) recognizes at least two distinct periods of regional metamorphism in the KM, one during the late Paleozoic and the other during Jurassic time. Irwin (1981) contends that additional metamorphic episodes probably occurred. Whether Late Jurassic plutonic intrusion precedes or postdates the regional metamorphism has not been determined, but it appears that plutons have experienced little or no post-emplacement metamorphism.

On the basis of K-Ar ages, Hotz (1971) partitions the Klamath Mountains into four plutonic belts that appear to be progressively older from east to west (Fig. 5) and notes that geochemical similarities are temporally rather than spatially controlled. A discussion of some geochemical and age trends follows.

The Klamath plutons define two distinct petrochemical suites (Davis et al., 1965) — trondhjemitic and calc-alkaline. Relative to the calc-alkaline rocks, those of the trondhjemitic series are characterized by high but fairly constant Na/K and lower Fe/(Fe+Mg) ratios at a given alkali content. In addition, available K-Ar age data on biotite (127-140m.y.) by Lanphere et al. (1968) suggest that they are slightly younger than other Klamath plutons (138-167 m.y.B.P.). Plutons with trondhjemitic affinities are shown in Figure 5. All but two lie within Hotz's "Trinity Mountains plutonic belt" and were emplaced into the Trinity ultramafic complex of the eastern Klamath subprovince as crosscutting features (Charlton, 1982, pers. comm.). The trondhjemitic White Rock and Castle Crags plutons

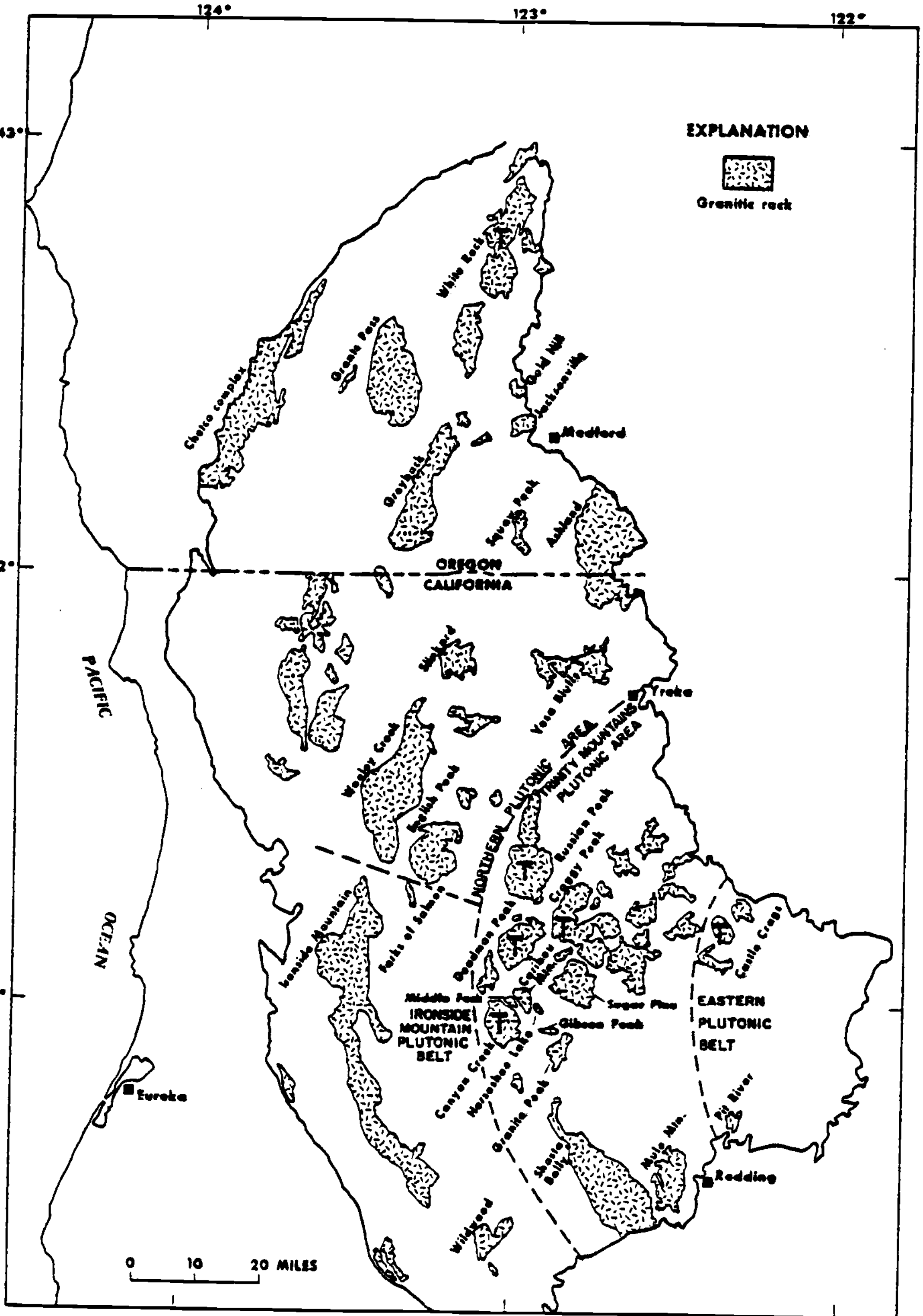


Figure 5. Distribution of plutons in the Klamath Mountains (modified from Hotz, 1971). T=trondhjemitic pluton.

lie outside the Trinity Mountains plutonic belt and are eliminated from the suite of trondhjemitic intrusions (Hotz, 1971).

Plutons comprising the calc-alkaline suite include those of Grants Pass, Greyback, Ashland, Vesa Bluffs, Wooley Creek, Slinkard, and several smaller intrusions. All intrude the wTrPz belt and lie within the region designated by Hotz as the "northern plutonic area". K-Ar ages on hornblende (Lanphere et al., 1968) reveal a weakly apparent northwestward trend toward younger plutons within this area and range from 157 m.y.B.P. for the Ashland pluton (average of three ages) to 136 m.y.B.P. for the Grants Pass pluton.

A third and minor trend of high potassium calc-alkaline geochemistry is displayed in Hotz's "Ironside Mountain plutonic belt". Specifically, this includes the Ironside Mountain batholith and Forks of Salmon and Wildwood plutons which intrude the southern portion of the wTrPz. They are primarily syenodioritic to monzonitic in lithology and are slightly older than the plutons of the calc-alkaline suite.

In summary, with the exception of the western Jurassic subprovince, the KM plutons fall within three petrographically and geochronologically distinct plutonic belts. Progressively younger from west to east these are the Ironside Mountain, northern, and Trinity Mountains plutonic belts. Respectively, they comprise suites that are K-rich calc-alkaline, calc-alkaline, and trondhjemitic. The Chetco and Bear Mountain complexes that intrude the western Jurassic lithic belt are gabbroic and therefore not classified by plutonic belt. Neither has been examined in detail. The differences in geochemistry and age among the existing plutonic suites is thought to be the result of different parental magma compositions rather than fractionation of K-bearing minerals, assimilation of K-poor rocks, or albitization after solidification.

Previous Related Paleomagnetic Work

A thorough review of the copious paleomagnetic (PM) results from studies along the continental margin of western North America is presented by Beck (1976, 1980). A large majority of these data display directions that are discordant relative to coeval paleomagnetic directions for the stable North American craton. These discordant directions are evidence for clockwise rotations (and in some instances possibly northward translations) of tectonic blocks, since respective times of acquisition of primary remanence. Dextral shear between North America and plates of the Pacific Ocean is believed to be responsible for the observed discordances and displacement of virtual geomagnetic poles into the Atlantic Ocean.

Beck (1980) partitions the PM results from the western edge of North America into three geographic regions: a northern section extending from Alaska southward to Vancouver Island and the North Cascades of Washington; a central section spanning the region of western Washington, Oregon, and northwestern California to Cape Mendocino; and a southern section which includes all studies from Cape Mendocino to the Gulf of California. While data from all three regions show clockwise rotations of terranes, only data from portions of the northern and southern regions display statistically significant flattening of the observed inclinations, one interpretation of which is the northward transport of crustal bodies.

The Klamath Mountains (KM) lie in Beck's central region, therefore only PM data reported by Beck (1980) for Oregon and Washington, as well as more recent data are discussed here. In addition, the PM results from Late Cretaceous plutons of the Sierra Nevada are discussed. The relevance of these data is warranted on the basis of existing implications for rifting of the Klamath Mountains away from the Sierra Nevada. Studies from the other two regions are addressed by Beck (1976 and 1980) where more complete reference lists are given.

Oregon Coast Range

The first discordant paleomagnetic direction for the Oregon Coast Range (OCR) was determined by Cox (1957) for the lower to middle Eocene Siletz River Volcanic series, whose direction was apparently clockwise rotated by 70° about a vertical axis with respect to the expected Eocene direction. Following this initial study, many other paleomagnetic investigations have focused on determining the extent of the rotated block as well as the mechanism and timing of its rotation. The geotectonic map of Figure 1 shows the relative geographic positions of the units studied.

Cox's study was expanded by Simpson and Cox (1977) to encompass Eocene through Oligocene sediments and volcanics from a broader geographic region of the OCR. Observed clockwise rotations of 50°-70° relative to the stable craton confirmed the earlier work by Cox. The Tertiary clockwise rotation of the OCR is also substantiated by Clark

(1969), Cox and Magill (1977), Beck and Plumley (1980), and Magill et al. (1981). Together, these data define the rotated OCR block as a single, internally coherent unit extending north from the KM more than 350 km to the Oregon-Washington border and having a width of about 70 km from the coastline eastward. Data of both Simpson and Cox (1977) and Beck and Plumley (1980) are consistent with a constant rotation rate of approximately 1.5°/m.y. from early Eocene to sometime between Miocene and present time.

The internal coherence of the rotated block is inferred by the continuity of outcrop of Eocene Coast Range sedimentary formations and their lack of intense deformation, as well as the internal consistency of paleocurrent directions (Lovell, 1969; Snavely et al., 1964) recorded in turbidites within these formations. In addition, a pronounced gravity high extending the full length of the OCR province (Bromery and Snavely, 1964) coupled with smooth gravity contours further suggests the relatively rigid nature of the rotated crustal block.

Simpson and Cox Models for Coast Range Rotation

Two models for the tectonic evolution of the Pacific Northwest were developed by Simpson and Cox (1977) and are shown in Figures 6A and 6B. Model 1 proposes that the rocks of the OCR formed on a slab of oceanic plate and that the OCR block, thought to extend from just north of the Klamath Mountains to just north of Newport, Oregon (~225 km), arrived at its present position after having been clockwise rotated about a pivot point near its southern end during subduction beneath North America. Alternatively, model 2 assumes that the coastal

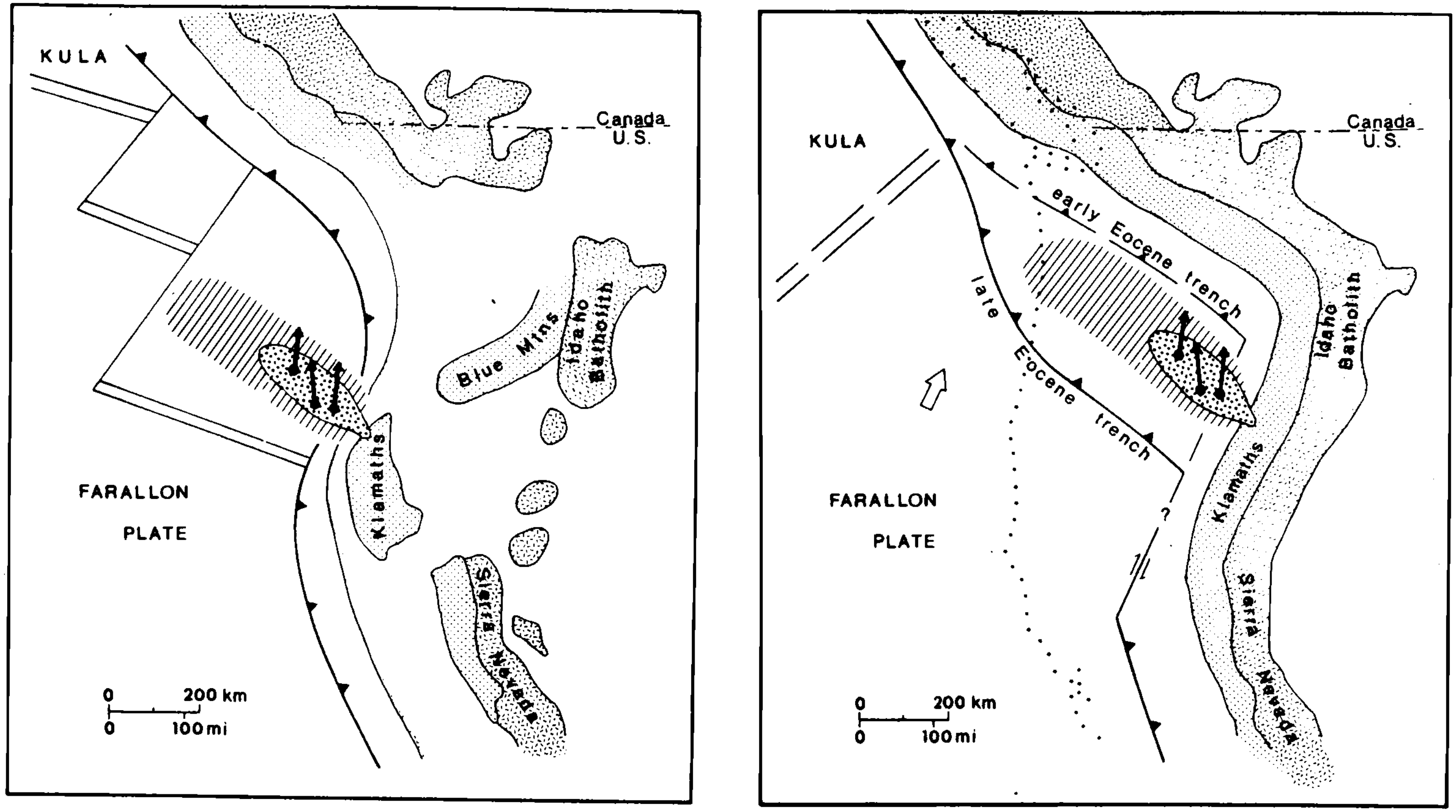


Figure 6. Simpson and Cox (1977) models for Oregon Coast Range rotation (after Simpson and Cox, 1977), each showing the Pacific Northwest in Middle Eocene time. (A) Model 1: Coast Range block (cross-hatched pattern) is shown as part of small plate related to northward migration of Kula-Farallon-North America triple junction. (B) Model 2: Coast Range is shown as block accreted to edge of continent and about to start rotating; subsequent rifting of metamorphic belts (stippled) is similar to that envisioned by Hamilton (1969).

block extends as far north as the Olympic Peninsula, and was rotated about a pivot point near its northern end. Problems exist with both models, and only the paleogeographic reconstruction provided by the second model restores the Klamaths to a position against the line of Cretaceous batholiths in northwestern Nevada and satisfies Hamilton's (1969) idea of early Tertiary rifting of the Klamaths away from the Sierra Nevada. As discussed previously, however, rifting was more likely a Mesozoic event.

Washington Coast Range

Though the timing and mechanism(s) of rotation are yet to be constrained, existing PM data firmly establish that the OCR rotated as a single coherent block. However, the picture in the Washington Coast Range (WCR) is more complex. Tertiary rocks of this province appear to have rotated significantly less than coeval OCR rocks (Globerman and Beck, 1979; Beck and Burr, 1979). It is suggested that perhaps the WCR consists of several blocks that rotated independently upon accretion (Beck, 1980).

Alternatively, if the WCR were once a coherent block, it may have been severely distorted by underthrusting which accompanied orogeny in the Olympic Mountains (Beck and Engebretson, 1982). A PM investigation of the arcuate early to middle Eocene Crescent Formation in southwestern Washington yielded variable amounts of rotation and led Wells and Coe (1980) to suggest that the mechanism for rotation in Washington may have been (and may still be) movement along a conjugate system of strike-slip faults active since the middle Miocene.

Cascade Range

The question of Cascade Range rotation was first addressed in PM studies of southern Washington by Beck and Burr (1979) and Bates et al. (1979). Respectively, these studies focus on the Upper Eocene to Oligocene Goble Volcanics which flank the western Cascades, and the Oligocene Ohanapecosh Formation. Moderate amounts of clockwise rotation (25°±13° for Goble, 23°±16° for Ohanapecosh) led Beck and Burr (1979) to believe that, although the Cascade Range had apparently been clockwise rotated with respect to North America, its rotation was perhaps independent of the Coast Range. Further examination of the Ohanapecosh Formation and two other Oligocene Cascade formations nearby in southern Washington yielded a clockwise rotation of 35°±14° (Bates et al., 1981). The similarity of this result to those of other studies from neighboring parts of the WCR and Washington Cascades implies that the two regions likely rotated as a single unit and at a nearly constant rate from post-Eocene to present time. Magill and Cox (1981) integrated their own data from Oligocene rocks of the western Cascades of Oregon with those of Beck (1962), Beck and Burr (1979), and Bates et al. (1979) and computed an average post-Oligocene clockwise rotation of 27°±7° for the western Cascade Range. This is evidence that, since early to middle Eocene OCR rocks exhibit more than 70° of clockwise rotation, nearly 50° of OCR rotation must have occurred between Eocene and pre-Cascade time. The onlap of Cascade upon Coast Range rocks in south-central Oregon and in northern California precludes independent rotation of the two provinces.

Magill et al. (1982) compare the paleomagnetic results of the presumably late Miocene basalt of Pack Sack Lookout and its possible correlative, the Pomona Member of the Columbia River Basalt Group. These units are respectively located to the west and east of the Cascades and are believed to be the product of a single eruption. On the basis of differing paleomagnetic directions of these two units, Magill et al. suggest that the clockwise rotation of southwestern Washington appears to have been associated with rotation of large portions of western Oregon and southern Washington, while the region east of the Cascades exhibits no evidence for tectonic rotation. The Cascade Range appears to coincide with the tectonic boundary separating rotated and unrotated regions of Washington.

Eastern Oregon

Evidence for tectonic rotation does exist, however, for Mesozoic rocks east of the Cascades in Oregon. Clockwise rotations of 66°±21° and 60°±29° are recorded in the Middle and Upper Triassic Seven Devils Group (Hillhouse et al., 1982) and the Upper Jurassic-Lower Cretaceous plutons of the Blue Mountains (Wilson and Cox, 1980), respectively. In order to account for the lack of rotation of the Pomona Member, rotation of the eastern Oregon block must either have occurred prior to late Miocene time or been independent of the Columbia River Plateau. A pre-late Eocene period of rotation for the Blue Mountains is favored by Wilson and Cox on the basis of statistically insignificant rotation of the late Eocene-Oligocene Clarno Formation to the west of the Blue Mountains (Beck et al., 1978).

Two Phase Rotation Model

Using all the available data from the Coast Ranges and Cascades of Oregon and Washington, Magill et al. (1981) have advanced a two phase rotation model to explain the observed discordant directions and tectonic evolution of the Pacific Northwest. The model for two stage rotation of the Cascades and OCR was arrived at by applying a weighted least squares fit of a third order polynomial to the data in Figure 7 for rotation versus age. They propose that Phase I occurred during the Eocene interval of 50-42 m.y.B.P. as a result of fragmentation of the Farallon plate and rotation of a fragment during its accretion to North America (Figure 8A). This earlier phase resulted in 50° of CW rotation about a southern pivot point and is essentially model 1 of Simpson and Cox (1977). Following an interval of tectonic quiescence during late Eocene through Oligocene time, Phase II rotation took place (and may still be occurring) as an effect of differential extension of the Basin and Range province to the east. It accounts for 27° of post-25 m.y.B.P clockwise rotation about a northern pivot point (Figure 8B) and requires that since that time, the Cascades, Coast Range, Klamath Mountains, and Sierra Nevada all rotated in a clockwise sense and moved westward together, retaining their present east-west spacing. Phase II is essentially model 2 of Simpson and Cox (1977), but has been modified to account for the Mesozoic rifting of the Klamaths away from the Sierra Nevada.

Klamath Mountains

Very few paleomagnetic investigations other than the present study have been undertaken in the Klamath Mountains province due to widespread metamorphism as well as little or no evidence for postmagnetization deformation. Cretaceous outliers and Tertiary sediments in

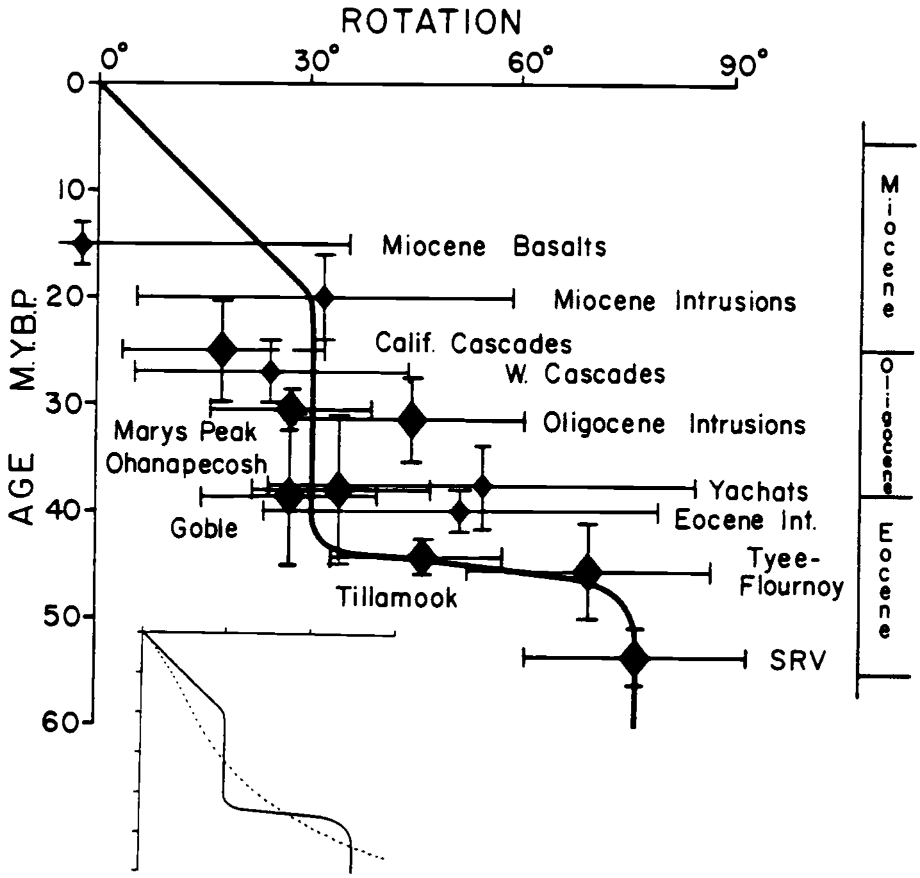


Figure 7. Rotation versus age for geologic units of the Oregon Coast Range (after Magill and Cox, 1980). Rotation error bars are the ΔR values for the individual studies. Inset shows a weighted least squares fit of the data to a third order polynomial (dotted curve) and the suggested curve (solid) of Magill and Cox (1980) which is constrained by their interpretation of the regional geology.

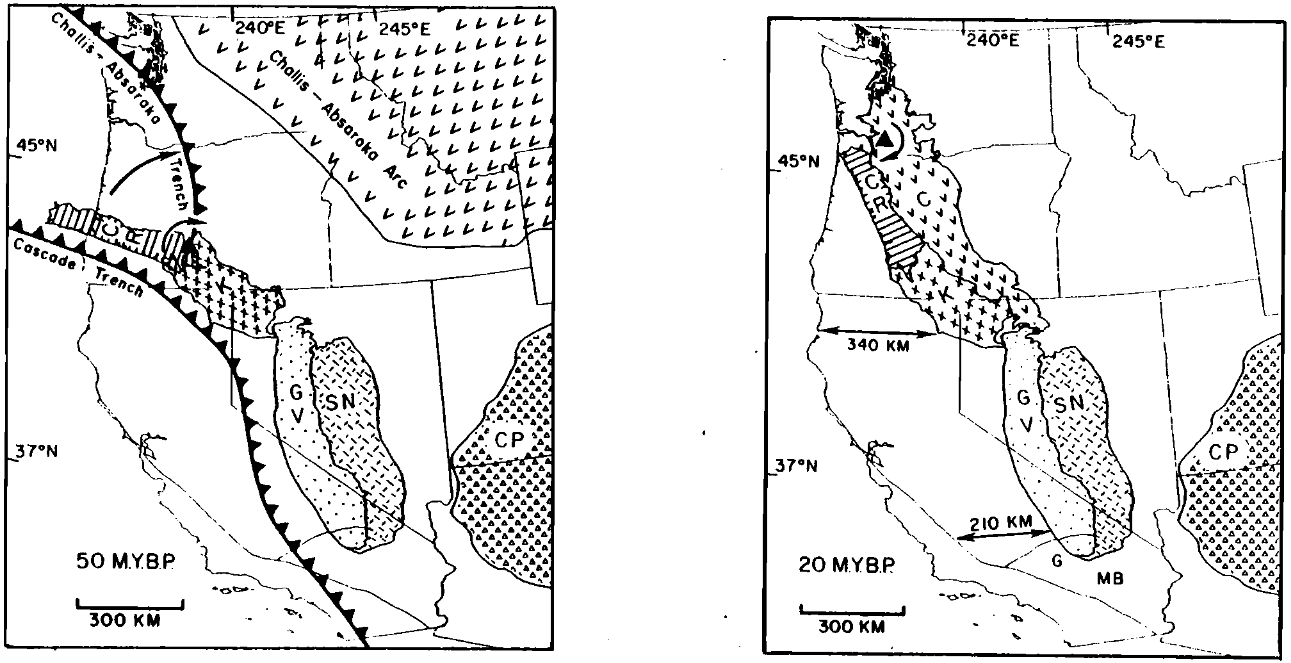


Figure 8. Two phase model of Magill et al. (1981) for rotation of the Oregon Coast Range. Position of primary blocks of the present western U.S. continental margin at the beginning of: (A) Phase I rotation, 50 m.y.B.P. and (B) Phase II rotation, 20 m.y.B.P. See Figure 1 for present position of blocks. Triangle represents pivot at southern end in A and northern end in B of Coast Range block.

the southern Klamath Mountains were examined by Mankinen and Irwin (1982) and include the marine Upper Jurassic to Upper Cretaceous Great Valley sequence and the Upper Cretaceous Hornbrook Formation, as well as the non-marine Eocene Montgomery Creek and Oligocene Weaverville formations. Results indicate that the rocks are largely remagnetized. However, data from specimens which were judged to have escaped remagnetization suggest a possible post-Cretaceous clockwise rotation of 11.5° ± 15.8°. Compared with existing data from the OCR, these findings indicate that the OCR and KM did not behave as a single rigid block during the early Tertiary and that post-Oligocene rotation, if real, is less than that proposed by Magill and Cox (1981) for the OCR-KM-Cascades block.

Preliminary paleomagnetic results by Mankinen et al. (1982) reveal variable amounts of clockwise rotation for rocks of the Eastern Klamath belt. Permian through Jurassic volcanic and sedimentary strata have primary remanence directions which are clockwise rotated by more than 100° with respect to coeval expected directions for stable North America. Age progressive rotation is not apparent. Lower and Middle Jurassic strata demonstrate 50° of clockwise rotation relative to the stable craton. On the basis of these data, it is suggested that rotation of the Eastern Klamath terrane began during Late Triassic or Early Jurassic time, perhaps in response to its accretion to the continental margin. The lack of rotation of the superjacent Cretaceous strata reported by Mankinen and Irwin (1982) indicate that rotation must have been completed by Cretaceous time.

Sierra Nevada

The majority of the available PM results from the Sierra Nevada are from the central portion of the province in the vicinity of Yosemite National Park. All data indicate that the Sierra Nevada province has not been displaced relative to stable North America since Late Cretaceous time. Grommé and Merrill (1965) examined the paleomagnetism of 85 m.y. old granites from the Sonora Pass area (40 miles north of Yosemite Valley) and confirmed the earlier results of Currie et al. (1963) that the paleomagnetic poles recorded in these rocks are concordant with two Cretaceous poles from rocks in Quebec. These findings are further substantiated by the work of Grommé et al. (1967) for the Late Jurassic to Early Cretaceous Guadalupe Mountains igneous complex and Bucks batholith diorite. It was concluded from their study that apparent polar wandering during Mesozoic time was due to continental drift rather than true polar wandering as an independent process.

Frei et al. (1982) report $5° \pm 4°$ of poleward translation and $5° \pm 7°$ of clockwise rotation of the central Sierra Nevada since 83 m.y.B.P., on the basis of PM results obtained for two Upper Cretaceous (96 and 83 m.y.) plutons in that region. They point out that the lack of Sierra Nevada rotation does not support tectonic models requiring large counterclockwise rotation of the Sierras during Basin and Range extension, but a model of clockwise rotation during early Tertiary extension followed by a comparable amount of counterclockwise rotation during late Tertiary Basin and Range extension (Magill et al., 1981) is still feasible.

The lack of rotation of the Sierra Nevada is also indicated by the paleomagnetic investigation of Hannah and Verosub (1980) of the Permian Reeve Formation and the Devonian Taylor Formation in the northern portion of the province. On the basis of the paleomagnetic data and geologic observations, they conclude that these Paleozoic volcanic rocks were remagnetized during Late Jurassic time. In addition, they propose that the Sierra Nevada block has behaved as a single tectonic unit that has experienced no significant rotation since at least Cretaceous time.

Unlike the central and northern Sierra Nevada, the southernmost portion of the province has apparently undergone clockwise rotation since Upper Cretaceous time. Kanter and McWilliams (1982) interpret paleomagnetic data from the Upper Cretaceous Bear Valley Springs pluton as evidence for $45° \pm 14°$ of clockwise rotation since that time. Such a rotation is believed to be in accord with the east-west trend of the southernmost part of the province, and it is suggested that the observed rotation is part of a large oroclinal bend due to right lateral shear along a proto-San Andreas transform. The lack of rotation of the Miocene Kinnick Formation (Kanter and McWilliams, 1982) constrains the time of rotation to be between 80 and 20 m.y.B.P.

PALEOMAGNETISM OF THE LATE CRETACEOUS HORNBROOK FORMATION

Introduction

Paleomagnetic investigation of the Late Cretaceous sediments of the Hornbrook Formation was undertaken to study the post-Late Cretaceous rotational history of the Klamath Mountains. In addition, any post-early Tertiary rotation/translation found for the Hornbrook Formation might also have affected the Ashland pluton, and perhaps a greater portion of the Klamath province. The Hornbrook sediments were especially promising since they are neither deformed nor metamorphosed and would permit a candid interpretation of the régional tectonic history subsequent to deposition.

Regrettably, data presented herein confirm the recent remagnetization of the Hornbrook Formation established by Mankinen and Irwin (1982). Samples for their study were obtained from the lower, medium- to coarse-grained units of the Hornbrook Formation. Aware of their results, this study focused on the upper mudstone unit in hopes that its magnetic particles would be sufficiently fine to possess stable primary remanence.

Geology of the Hornbrook Formation

The Late Cretaceous marine transgressive sediments of the Hornbrook Formation are exposed for approximately 225 km along a northwesterly strike from Shasta Valley, California, to Bear Creek Valley, Oregon. Northeasterly dips vary from 20°-30° throughout the formation and shallow toward the northwest. This formation directly onlaps with great unconformity the subjacent strata of the central metamorphic and western Paleozoic and Triassic belts of the Klamath Mountains, including the Ashland pluton.

Elliott (1971) originally recognized four mapable lithologic units, assigning the lower two to the Hornbrook Formation and the upper two to the Hilt Formation. More recently he has regrouped the entire 1350m sequence into four distinct units of the Hornbrook Formation (Elliott, pers. comm., 1981). Resistant and thickly bedded, medium-grained gray to greenish-gray arenites and wackes, as well as pebble-cobble conglomerates comprise the lower A through C members of the Hornbrook Formation. The overlying D member totals nearly 1000m and is characterized by very fine-grained dark gray to olive gray, friable mudstones with a large admixture of very fine-grained sand and silt. Well-bedded outcrops exist but indistinct bedding is more common. Blueschist minerals in the basal sandstones indicate a Klamath Mountain source for the Hornbrook Formation.

Magnetite was determined by Elliott to be the most abundant opaque mineral present. Comprising 2.5-2.8% of all minerals, magnetite particles exist as "equant, moderately-rounded and discernably smaller" particles altered in varying degrees to reddish hematite and yellow limonite (Elliott, 1971).

Paleomagnetic Sampling and Laboratory Procedures

Eighty cores were drilled from five well-bedded sites within the upper mudstone unit and one site from fine-grained sandstones of the lowermost Member A. Locations and descriptions of sampling outcrops are given in Appendix C. Two localities were sampled by extracting carefully oriented hand specimens; standard sampling techniques (Doell and Cox, 1965) were employed at the remaining four sites. Cores were sawed to obtain as many 2.5 cm long specimens as possible.

Four pilot samples from each site (2 from each of 2 cores) were stepwise demagnetized in alternating fields (AF) up to 250-300 Oe and measured on a Schonstedt digital spinner magnetometer (model DSM-1). The remaining samples (1 per core) were magnetically cleaned at 50 Oe intervals to peak fields of 250 Oe. Directions were corrected for bedding orientation using attitudes taken at each drill core. Based upon the degree of clustering for structurally corrected directions, a single cleaning field was selected for each site (usually 100 Oe). Corresponding directions for all samples at that AF level were analyzed according to the methods of Fisher (1953) to obtain a mean direction for each site, as well as the statistical parameters, k and α_{95}.

Paleomagnetic Results

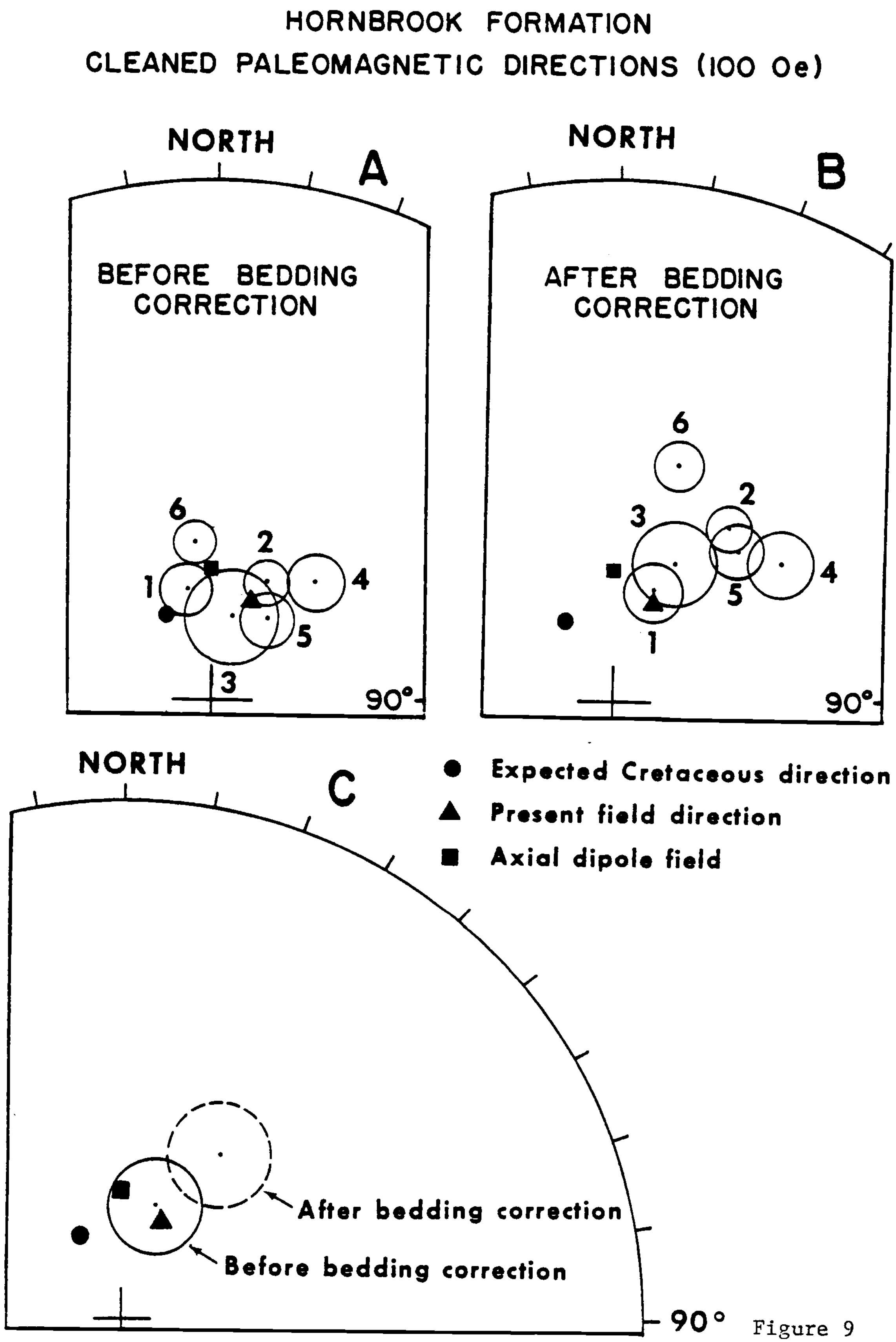
Table 1 summarizes the PM data obtained for the Hornbrook Formation. Mean directions for each site are based on sample directions (1 sample per core only) at 100 oe. Directions before and after bedding correction are shown on the stereonet plots of Figure 9A and 9B with associated circles of 95% confidence. All samples are normally magnetized and stereonet plots are lower hemisphere projections. Dispersal of site mean directions upon structural correction may imply

Table 1: Summary of Paleomagnetic Data for Cretaceous Hornbrook Formation

	Stable Directions (100 Oe)							
	Uncorrected		Corrected					
Site	D_u(°)	I_u(°)	D_c(°)	I_c(°)	α_{95}(°)	k	$n(N_T)$	Average Bedding Attitude
HB 1	348	64	020	64	5	177	6(6)	N 0.2°W 15°NE
HB 2	025	62	032	46	4	82	21(21)	N 44°W 17°NE
HB 3	014	70	024	57	8	63	6(6)	N 52°W 14.5°NE
HB 4	039	56	049	45	6	52	13(13)	N 11°W 13.6°NE
HB 5	032	68	038	49	6	75	10(10)	N 45°W 19.4°NE
HB 6	354	56	014	39	4	137	9(9)	N 39°W 24.2°NE
Formation Mean Direction								
Uncorr.	015	64			9	52	6(6)	
Corr.			030	51	10	44	6(6)	
Expected Paleofield			D	I	ΔD	ΔI		
Late K (ca. 90 myBP)			331	69	4	2		
Present Field Direction			020	66				

α_{95} is radius of circle of 95% confidence. k is precision parameter. n is number of samples (one per core) used in calculation of site mean direction. N_T is total number of cores drilled.

Figure 9. Site mean directions and associated α_{95} values for sites of the Upper Cretaceous Hornbrook Formation. (A) Site means before bedding correction and (B) site means after bedding correction. (C) Formation mean directions and corresponding α_{95} values (before and after bedding correction) computed for the six sites.



HORNBROOK FORMATION
CLEANED PALEOMAGNETIC DIRECTIONS (100 Oe)
NORTH
A
BEFORE BEDDING CORRECTION
6
2
1
4
5
3
90°
NORTH
B
AFTER BEDDING CORRECTION
6
2
3
4
5
1
90°
NORTH
C
Expected Cretaceous direction
Present field direction
Axial dipole field
After bedding correction
Before bedding correction
90°

Figure 9

that remanence was acquired after tilting, however, the increase in α_{95} and decrease in k values are slight and might not be significant.

The combined directions for the six sites before and after bedding correction are shown on the stereonet plot of Figure 9C. The fact that the uncorrected mean direction is intermediate and not statistically distinct from the directions of either the present field or the axial dipole field strongly suggests the recent remagnetization of the Hornbrook Formation. This is further supported by the similarity of natural remanent magnetization (NRM) intensities to those of viscous remanent magnetization acquired over ten weeks in the laboratory. In addition, appliction of bedding correction displaces this mean direction to a position unlike that of either the present field or the expected Cretaceous field (Figure 9C).

Anhysteretic and Viscous Remanent Magnetization Studies

Studies by Rimbert (1959) and Levi and Merrill (1976) have shown that anhysteretic and thermal remanent magnetization (ARM and TRM, respectively) have similar stabilities with respect to AF demagnetization. Although depositional remanent magnetization (DRM) is definitely not TRM, the AF stability of DRM is often similar to that of TRM and by analogy to ARM, since the detrital grains in which the remanence resides possess an intrinsic TRM. An assumption which follows is that for a given rock or mineral, if NRM and ARM have similar coercivities, the NRM is likely a TRM.

To assess the nature of the remanent magnetization possessed by the Hornbrook Formation, as well as the possibility of its remagnetization, ARM was given to two samples from each of the six sites. These samples were first stepwise AF demagnetized to 1000 Oe to remove as much remanence as possible. ARM was then produced in each sample by superimposing a DC field of 0.5 Gauss on an AF with 1000 Oe peak field. The induced ARM was demagnetized in a fashion identical to that for NRM demagnetization.

The same samples were later allowed to acquire viscous remanent magnetization in the laboratory field for ten weeks. All samples showed similar behaviors of NRM, ARM, and VRM upon AF demagnetization. Figure 10 compares these findings for two typical Hornbrook samples. While NRM and VRM have nearly identical coercivities, both are distinctly less stable than that of ARM. In addition, the VRM intensity acquired in ten weeks was comparable to the NRM intensity. These facts suggest that the remanence possessed by the Hornbrook Formation is likely of viscous origin.

Figure 10. Normalized intensity curves for AF demagnetization of natural, viscous, and anhysteretic remanent magnetizations (NRM, VRM, and ARM, respectively) for two samples from the Hornbrook Formation. Sample 81,29,5,2 is from the lower arenaceous Member A, sample 81,16,3,6 is from the mudstone of the uppermost Member D of the formation. The similarity of NRM and VRM suggests that the remanence possessed by the Hornbrook Formation is likely of viscous origin.

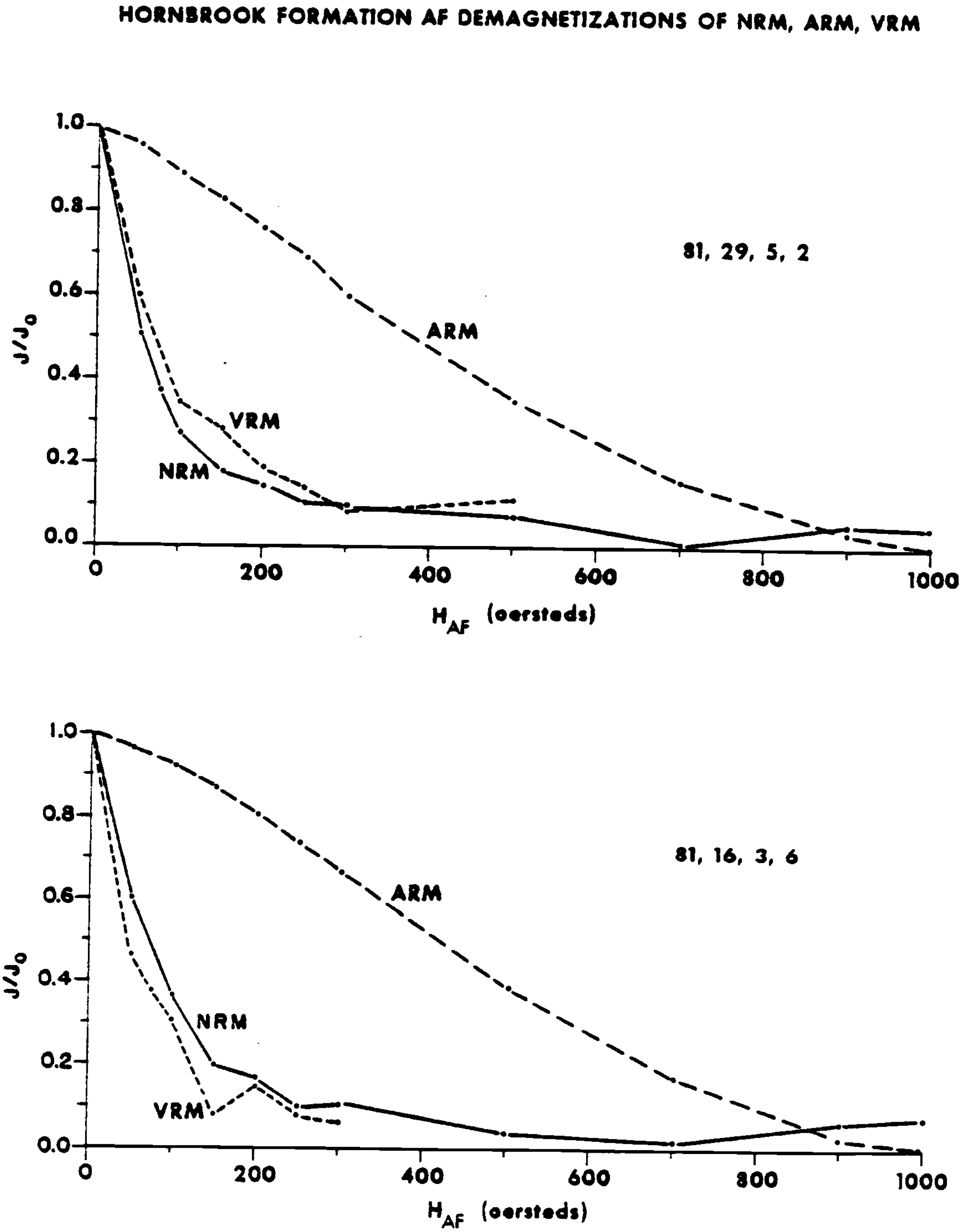

HORNBROOK FORMATION AF DEMAGNETIZATIONS OF NRM, ARM, VRM
1.0
0.8
0.6
0.4
0.2
0.0
J/J₀
81, 29, 5, 2
ARM
VRM
NRM
0
200
400
600
800
1000
H_AF (oersteds)
1.0
0.8
0.6
0.4
0.2
0.0
J/J₀
81, 16, 3, 6
ARM
NRM
VRM
0
200
400
600
800
1000
H_AF (oersteds)

Figure 10

PALEOMAGNETISM OF KLAMATH MOUNTAIN PLUTONS

Introduction

Five Middle to Upper Jurassic plutons of the central Klamath Mountain Province were sampled for paleomagnetic study. Shown in Figure 11, these are the plutons of Grants Pass, Ashland, and Slinkard, the Greyback intrusive complex, and the Wooley Creek batholith. All intrude the western Paleozoic and Triassic subprovince and lie within Hotz's (1971) northern plutonic belt. These plutons are calc-alkaline in nature and are believed to be unmetamorphosed.

Sampling

Employing the standard paleomagnetic technique described by Doell and Cox (1965), seven to thirteen cores were drilled from each of thiry-seven sampling localities within the five plutons. Figure 11 shows the approximate locations of these sampling sites. The distribution of sites within these plutons is: Ashland - 9 sites; Grants Pass - 5 sites; Greyback - 10 sites; Slinkard - 6 sites; and Wooley Creek - 7 sites. Cores were fully oriented with a Brunton compass, and orientations are accurate to within 2°. The drilled cores were sawed in the laboratory to obtain two specimens each after discarding the weathered ends ($\sim$0.5-1.0 cm). Due to drilling difficulties, the more silicic lithologies frequently yielded but one specimen.

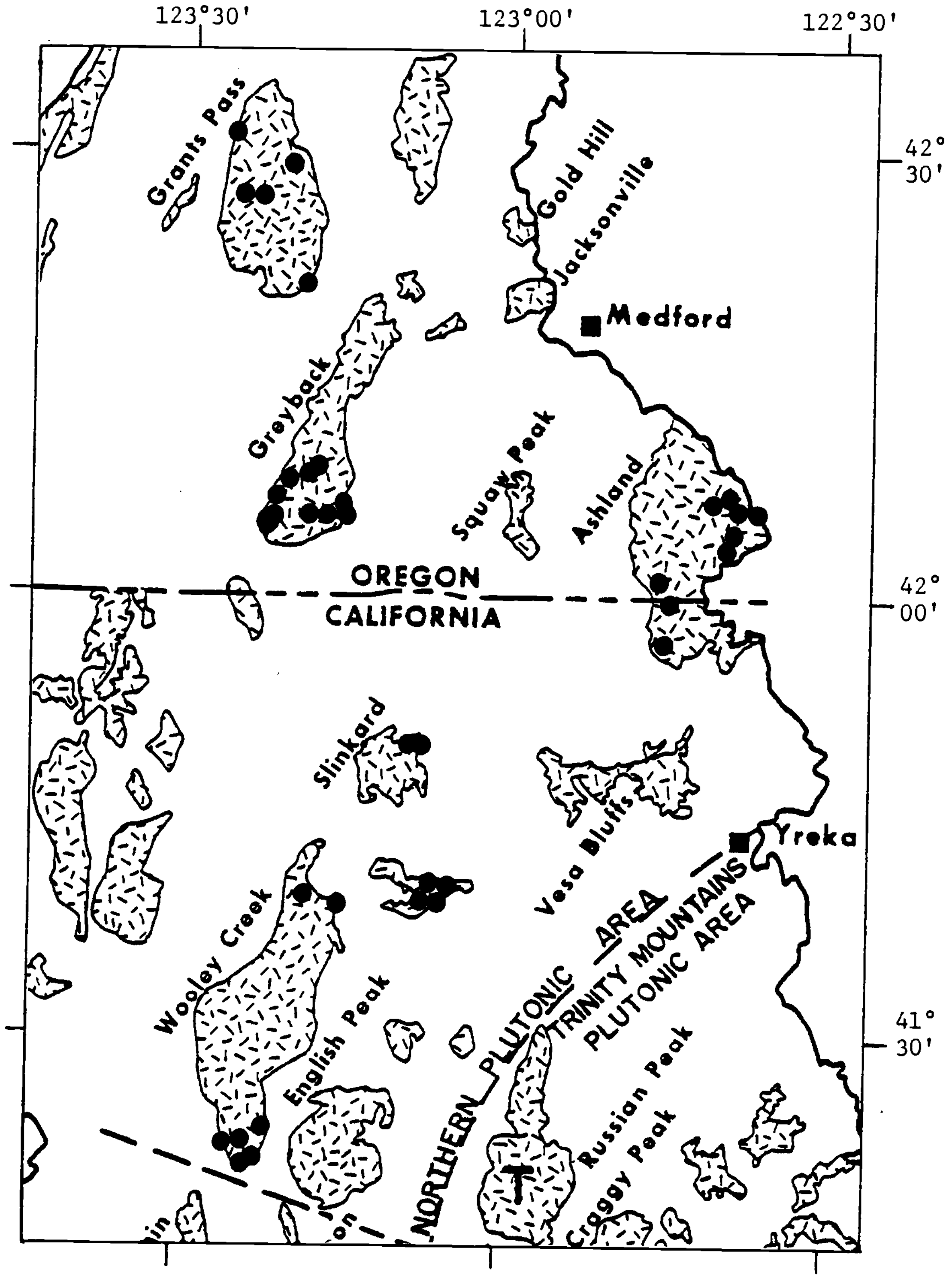


Figure 11. Approximate locations of sampling sites in the plutons of the central Klamath Mountains (shown by closed circles). (Enlarged from Fig. 5, after Hotz, 1971).

Laboratory Techniques

Three representative specimens from each site were selected from independent cores for stepwise demagnetization in alternating fields (AF) up to 300-1000 oersted (Oe) and measurement on a Schonstedt digital spinner magnetometer (model DSM-1). A demagnetization sequence for the remaining samples in each site was selected on the basis of the directional stabilities, coercivities, and polarities of the respective pilots. Reversely magnetized specimens typically required demagnetization to higher AF levels (700-1000 Oe) for sufficient removal of secondary components of magnetization. The more stable sites permitted elimination of several demagnetization steps whereas sites whose pilot samples lacked directional stability required the detailed stepwise demagnetization of the remaining specimens. Only one specimen per core (usually the one furthest into the outcrop) was subjected to AF demagnetization, however, suspect data frequently required treatment of companion samples.

Analysis of Paleomagnetic Data

Many problems are inherent in a PM study of plutonic rocks. Just as pilot samples are not necessarily representative of entire sites, cores within a single site often exhibit a wide range of natural remanent magnetism (NRM) and median destructive field (MDF) values. Such variations result primarily from inhomogeneities in both lithology and grain size.

The inhomogeneous character of plutonic rocks is manifested not only in their compositional and textural variabilities but in the broad spectrum of PM properties which they possess. Within-site generalizations were therefore prohibited, and stable PM directions were chosen individually for each specimen by the method described in this section. Site means were then computed according to the method of Fisher (1953), using only one direction for each core. The statistical parameters, k and α_{95}, described in Appendix A, were computed as measures of data reliability and degree of clustering of directions. Finally, mean directions for sites within a pluton were vectorally averaged by the same method to yield a mean PM direction for each pluton, as well as the corresponding α_{95} and k values.

Quality Factors

Quality factors were assigned to each sample to aid in the comparison and tabulation of their relative stabilities and reliabilities. Each received two such factors, thereby being classified according to its field quality as well as its laboratory quality. Table 2 specifies the criteria which must be met for each classification of both quality factors. The "field quality" factor (1F=best through 3F) accounts for the degree of certainty in core orientation as well as the coherency of the outcrop from which the core was taken. The "laboratory quality" factor (AA=best through D) refers to the degree of directional stability of a sample upon AF demagnetization. Appendix B lists all samples and their respective quality factors.

Table 2: Explanation of Field and Laboratory Quality Factors Assigned to Each Paleomagnetic Sample

---

Field Quality Factors

1F - Core oriented with confidence (uncertainty $\leq 2°$). Block from which core drilled has apparently not moved relative to remainder of outcrop.

2F - Slight uncertainty in orientation of core resulting from either breakage of core during orientation or loose/tight fit of orienting tool on core. Additional 1-2° uncertainty in orientation.

3F - Questionable orientation due to: a) excessive play in orienting tool during orientation of core, as for very short cores in highly silicic sites where drilling was difficult, b) breakage of core during drilling and inability to orient precisely, c) dubious nature of block from which core extracted with respect to remaining outcrop.

Laboratory Quality Factors

AA - Very tight clustering of directions for entire demagnetization sequence with possible exception of NRM direction and/or directions at AF levels >700 Oe. On 23 cm diameter streonet, cluster of AA sample has diameter of ≤ 1.8 cm ($\sim$that of a dime). Tightness of cluster permits selection of direction corresponding with a single AF level as stable direction.

A - Tight clustering of directions for demag. sequence. Cluster diameter ≤ 3.1 cm ($\sim$that of half dollar piece) on stereonet of 23 cm diameter.

B - Directions cluster at ≥ 3 sequential demag. levels.

C - No clustering of directions, though a trend may exist.

D - Highly unstable behavior of sample yielding no apparant trend of directions.

Selection of Stable Directions

For only about one third of the samples was the stable direction chosen to be that corresponding with a single AF demagnetization level. Stable PM directions were determined for the remaining two thirds by vectorally averaging three or more clustering directions at sequential AF levels. The stable direction for a sample was taken as that corresponding with a single AF level only if the sample was rated as AA lab quality or if the direction at that level represented the mean direction (to within 2-3°) obtained by averaging over an interval. For the sake of consistency, stable directions for AA samples were taken as that nearest the MDF level for that sample. In rare cases (<1%), stable directions of two samples from one core were averaged to obtain a stable direction for that core.

Omission of Samples

For the sites considered to be paleomagnetically reliable, 86% of the cores were used in the calculation of site mean directions. Cores comprising the remaining 14% were eliminated if either of the following criteria were met:

1) Lab quality factor equals C or D.

2) Stable direction deviates from the respective site mean direction by two or more angular standard deviations.

Nature of Magnetism of Klamath Plutonic Rocks

NRM and Behavior Upon AF Demagnetization

Natural remanent magnetization values for samples from the KM plutons fall between 1 E-6 and 3 E-3 Gauss and are tabulated in Appendix B. Values within single sites occasionally span comparable ranges. In addition to large variations in NRM intensities, cores exhibit a broad range of stabilities. The behavior upon AF demagnetization of representative samples for each pluton is depicted on the stereonet projections of Figures 12A, 13A, 14A, 15A, and 16A. The corresponding normalized intensity curves shown in Figures 12B, 13B, 14B, 15B, and 16B display the wide ranges in MDF values of both stable and unstable samples. Comparison of stereonet plots and J/J_o curves for individual samples within a pluton illustrates that higher MDFs are not indicative of greater directional stabilities.

In general, J/J_o curves for directionally stable samples typically show a regular decay of NRM intensities upon AF demagnetization, whereas those for unstable samples (81,22,6,2 (GM 6), Fig. 13B; 80,4,5,1 (ASH 1), Fig. 14B; and 82,4,6,2 (SLK 3); Fig. 15B) often display abrupt fluctuations in intensity. Unstable samples such as these frequently experience unsystematic polarity reversals throughout demagnetization sequences. In comparison with other plutons, a large number of SLK samples were unstable and are typified by sample 82,4,6,2 (Figure 15B). Hence, 58% of all Slinkard samples were rejected in the final analysis. Stable reversely magnetized (R) samples are usually characterized either by an initial increase followed by a fairly regular decrease in intensity upon AF demagnetization (e.g. Greyback sample 80,8,3,1 in Fig. 13B) or failure to decay upon AF demagnetization (e.g. Ashland sample 81,17,9,2 in Fig. 14B; Slinkard sample 82,5,7,2 in Fig. 15B).

Figure 12. Grants Pass pluton: Behavior upon AF demagnetization of three representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot. Closed (open) symbols represent lower (upper) hemisphere projections.

Symbol	Sample (Site)	J_o	Lab Quality	
●	79,3,2,1 (GPE 1)	3.40 E-4	AA	
△ ▲	79,4,5,2 (GPN 1)	1.65 E-5	C	*
■	81,18,1,2 (GPW 1)	5.68 E-5	AA	

*Rejected sample

GRANTS PASS PLUTON
AF DEMAGNETIZATION

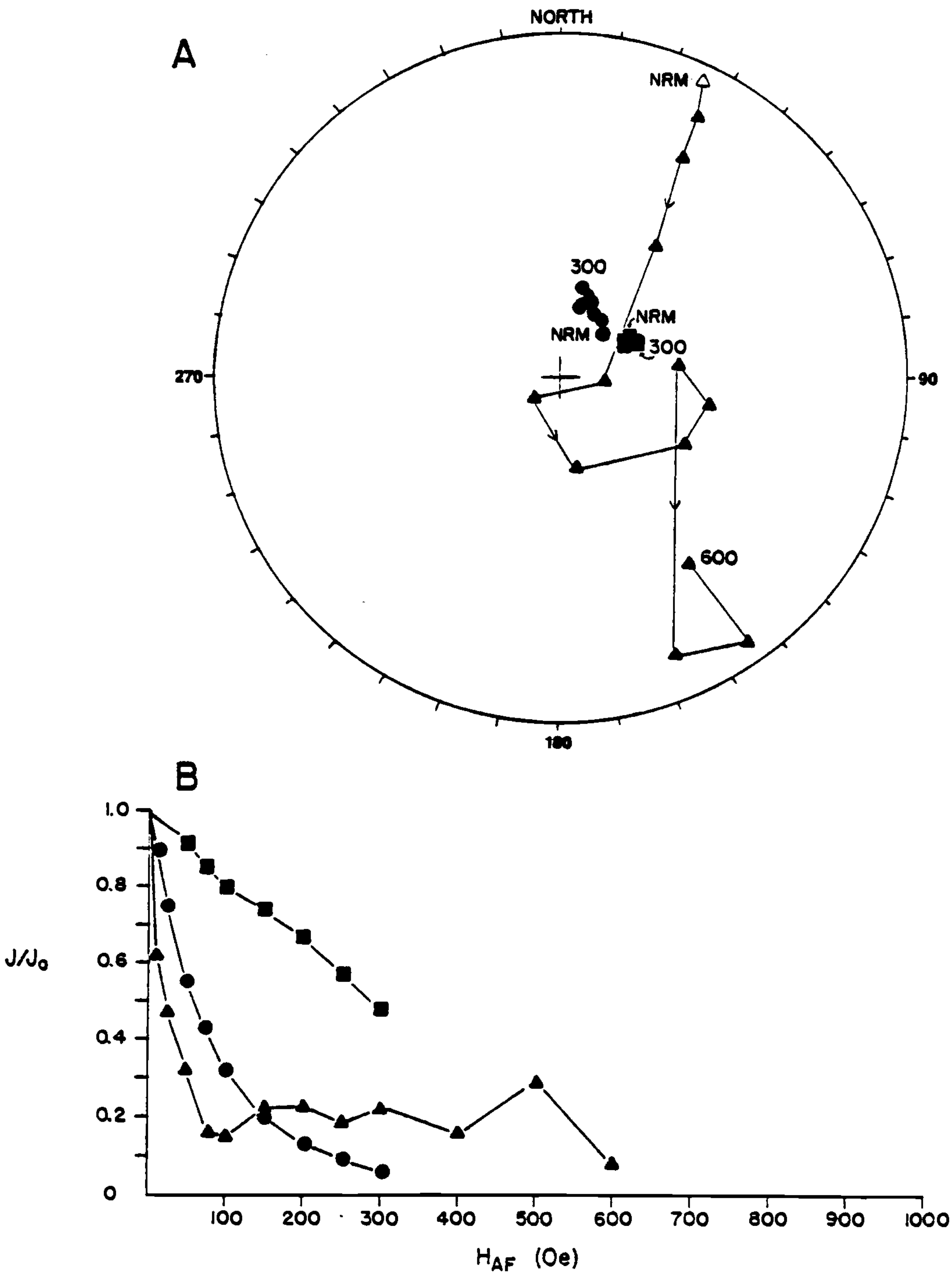


Figure 12

Figure 13. Greyback intrusive complex: Behavior upon AF demagnetization of four representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot. Closed (open) symbols represent lower (upper) hemisphere projections.

Symbol	Sample (Site)	J_o	Lab Quality	
◆	79,2,5,1 (GM 1)	5.18 E-6	AA	
○	80,8,3,1 (GM 4)	2.34 E-6	A	
△ ▲	81,22,6,2 (GM 6)	5.00 E-6	D	*
■	81,23,1,2 (GM 7)	3.50 E-4	AA	

*Rejected sample

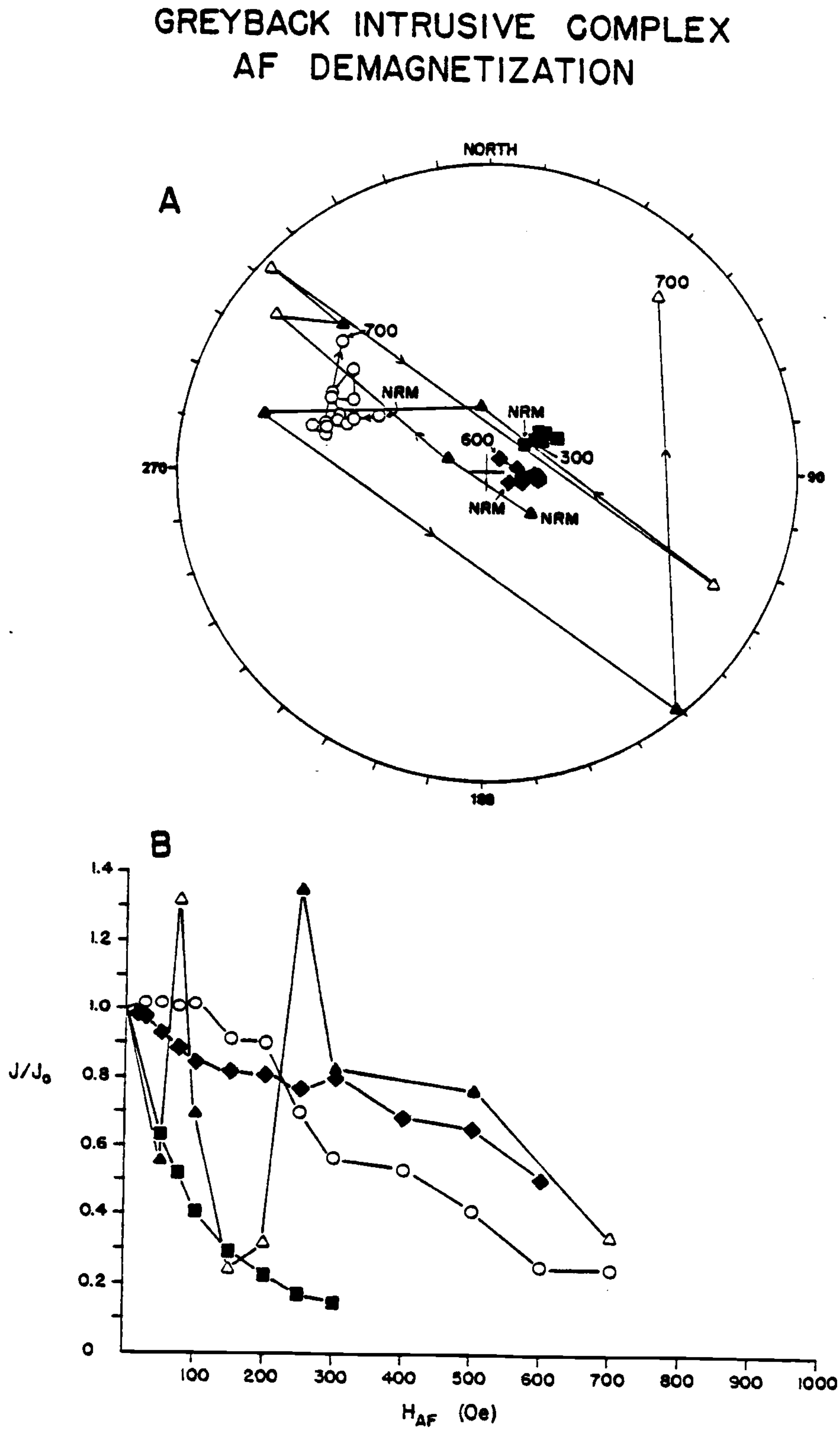

GREYBACK INTRUSIVE COMPLEX
AF DEMAGNETIZATION
NORTH
A
700
700
NRM
NRM
600
300
NRM
NRM
270
90
180
B
1.4
1.2
1.0
J/Jo
0.8
0.6
0.4
0.2
0
100
200
300
400
500
600
700
800
900
1000
HAF (Oe)

Figure 13

Figure 14. Ashland pluton: Behavior upon AF demagnetization of four representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot. Closed (open) symbols represent lower (upper) hemisphere projections.

	Sample (Site)	J_o	Lab Quality	
○ ●	80,4,5,1 (ASH 1)	6.91 E-7	C	*
□ ■	81,12,7,2 (ASH 4)	2.65 E-5	B/C	*
◇	81,17,9,2 (ASH 7)	2.48 E-5	AA	
▲	81,17,11,2 (ASH 7)	7.47 E-5	A	

*Rejected sample

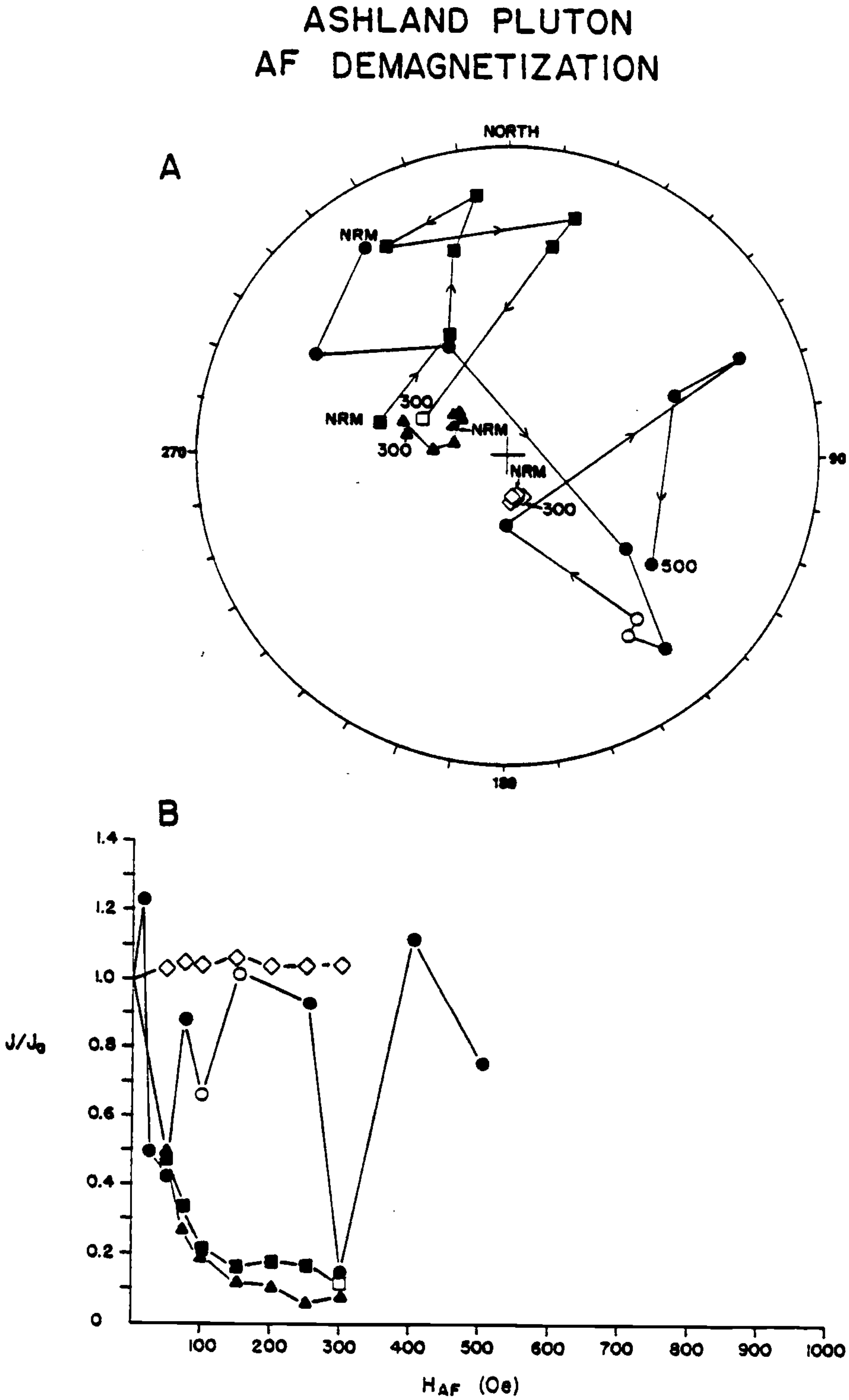
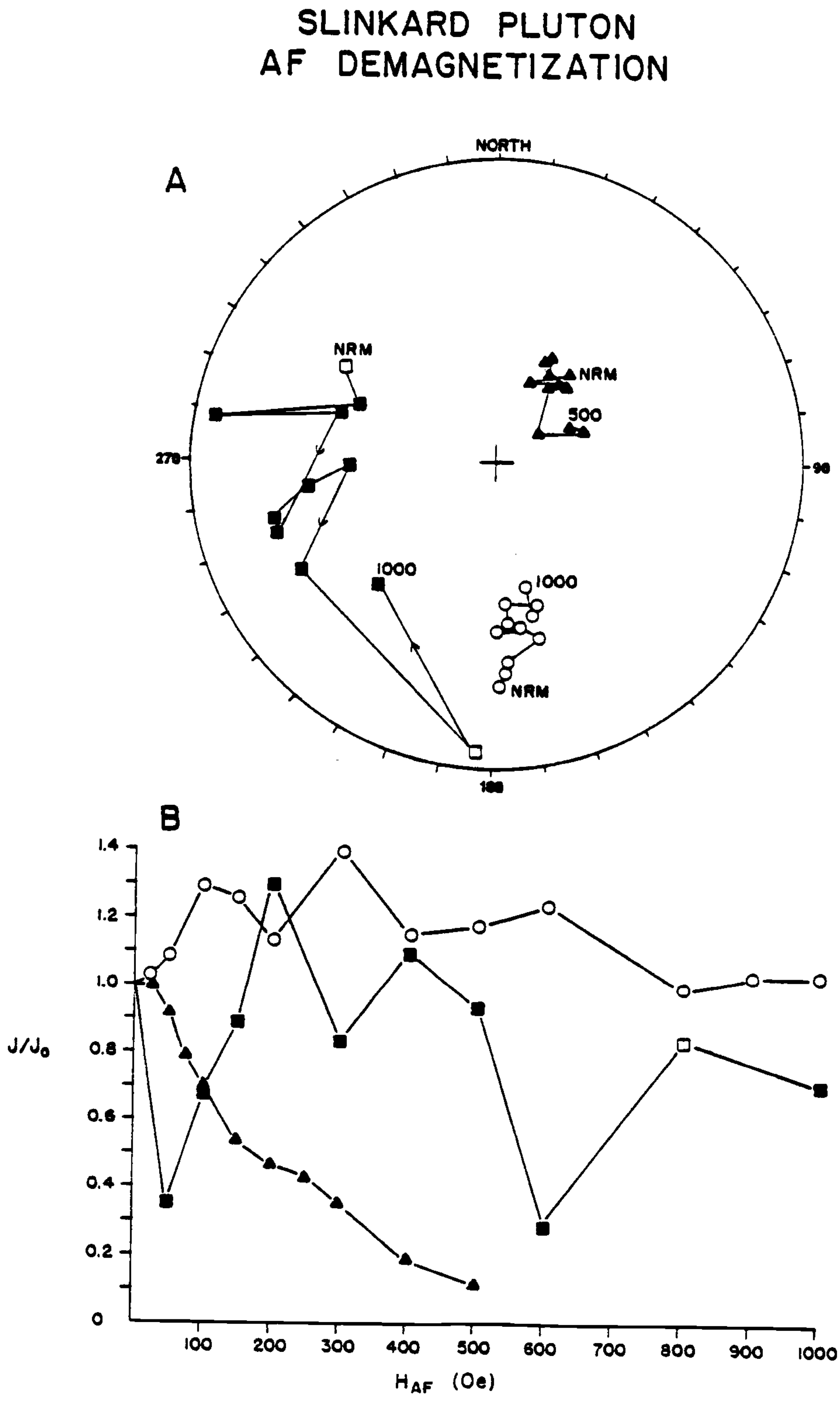

ASHLAND PLUTON
AF DEMAGNETIZATION
A
NORTH
NRM
NRM
300
NRM
300
NRM
NRM
300
500
270
90
180
B
1.4
1.2
1.0
J/J0
0.8
0.6
0.4
0.2
0
100
200
300
400
500
600
700
800
900
1000
HAF (Oe)

Figure 14

Figure 15. Slinkard pluton: Behavior upon AF demagnetization of three representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot. Closed (open) symbols represent lower (upper) hemisphere projections.

	Sample (Site)	J_o	Lab Quality	
□ ■	82,4,6,2 (SLK 3)	2.09 E-6	B/C	*
○	82,5,7,2 (SLK 4)	6.56 E-7	A	
▲	82,6,5,2 (SLK 5)	4.83 E-7	A	

*Rejected sample



SLINKARD PLUTON
AF DEMAGNETIZATION
A
NORTH
NRM
NRM
500
270
90
1000
1000
NRM
180
B
1.4
1.2
1.0
J/J0
0.8
0.6
0.4
0.2
0
100
200
300
400
500
600
700
800
900
1000
HAF (Oe)

Figure 15

Figure 16. Wooley Creek batholith: Behavior upon AF demagnetization of three representative samples as depicted on (A) stereonet projection and (B) normalized intensity plot. Closed (open) symbols represent lower (upper) hemisphere projections.

	Sample (Site)	J_o	Lab Quality	
▲	81,6,8,2 (WC 3)	1.67 E-4	AA	
□ ■	82,8,6,1 (WC 6)	1.81 E-6	B	*
○	82,9,8,2 (WC 7)	2.13 E-6	AA	

*Rejected sample

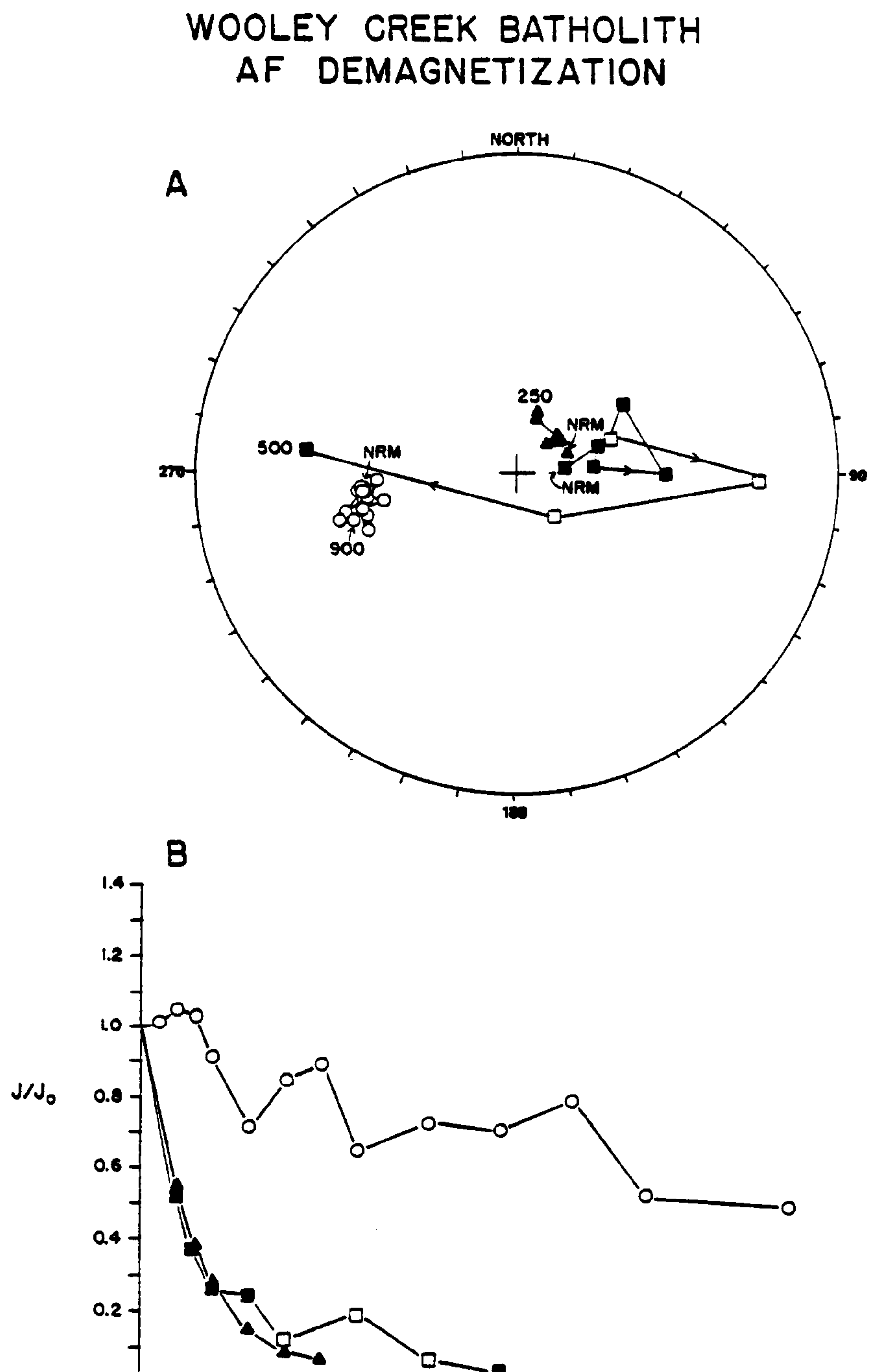

WOOLEY CREEK BATHOLITH
AF DEMAGNETIZATION
A
NORTH
270
90
180
250
NRM
NRM
500
NRM
900
B
J/J$_o$
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
100
200
300
400
500
600
700
800
900
1000
H$_{AF}$ (Oe)

Figure 16

The histograms of Figures 17A-17E show the distribution within each pluton of MDF values for directionally stable (accepted) and unstable (rejected) samples of both normal and reversed polarities. Distributions for the Grants Pass pluton (Fig. 17A), Ashland pluton (Fig. 17C), and the Wooley Creek batholith (Fig 17E) are heavily skewed toward the low end of the MDF range, with median values $<$100 Oe (considering accepted samples only) for each pluton. In contrast, MDF values are more evenly distributed for the samples of the Greyback complex (Fig. 17B) and Slinkard pluton (Fig. 17D), with median MDF values (accepted samples only) in the 201-300 Oe and 301-400 Oe ranges, respectively.

Both the Greyback intrusive complex and Wooley Creek batholith have considerably higher percentages of reversely magnetized samples which were used in the final analysis (31% and 50%, respectively) than do the plutons of Grants Pass (3%), Ashland (14%), and Slinkard (22%). However, the median MDF value for the directionally stable (accepted) reversed samples of the Wooley Creek batholith (51-100 Oe range) is markedly lower than that for the Greyback complex (301-400 Oe range).

As demonstrated previously by plots of normalized intensity (Figures 12B, 13B, 14B, 15B, and 16B), MDF alone is not a reliable stability criterion for the plutonic rocks of this study. The relationship of directional stability to MDF was examined in a histogram (not shown) displaying the distribution of sample lab quality (AA through D, Table 2) in different ranges of MDF for samples from all plutons. Samples of A/B and better quality show a

Figure 17. Distribution of median destructive field (MDF) values for stable (accepted) and unstable (rejected) samples of both normal and reversed polarities for the plutons of (A) Grants Pass, (B) Greyback, (C) Ashland, (D) Slinkard, and (E) Wooley Creek. Normal samples represented by striped pattern (alternating=accepted, open=rejected), reversed samples represented by dotted pattern (closed=accepted, open=rejected).

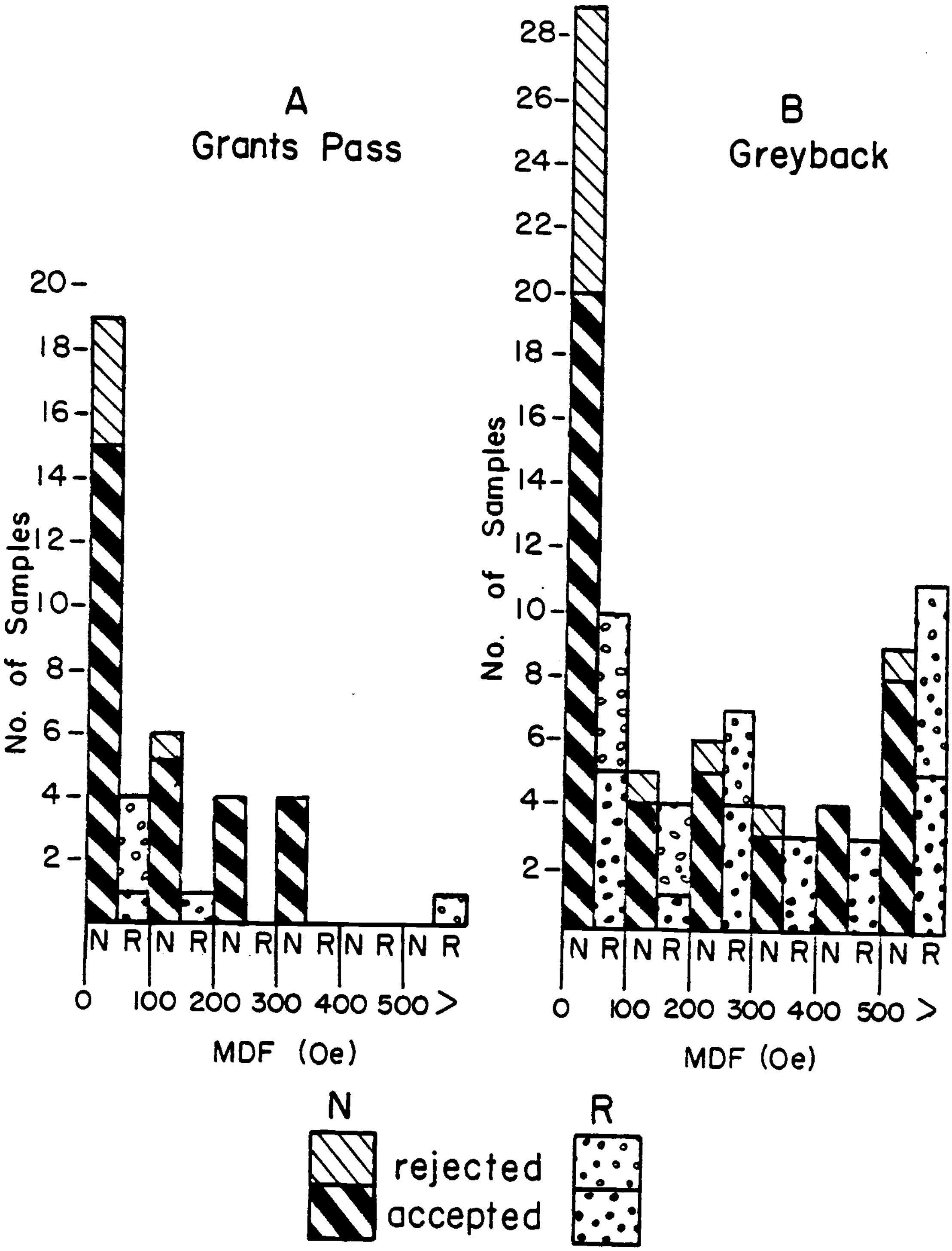

A
Grants Pass
No. of Samples
20-
18-
16-
14-
12-
10-
8-
6-
4-
2-
N R N R N R N R N R N R
0 100 200 300 400 500 >
MDF (Oe)
B
Greyback
No. of Samples
28-
26-
24-
22-
20-
18-
16-
14-
12-
10-
8-
6-
4-
2-
N R N R N R N R N R N R
0 100 200 300 400 500 >
MDF (Oe)
N
R
rejected
accepted

Figure 17

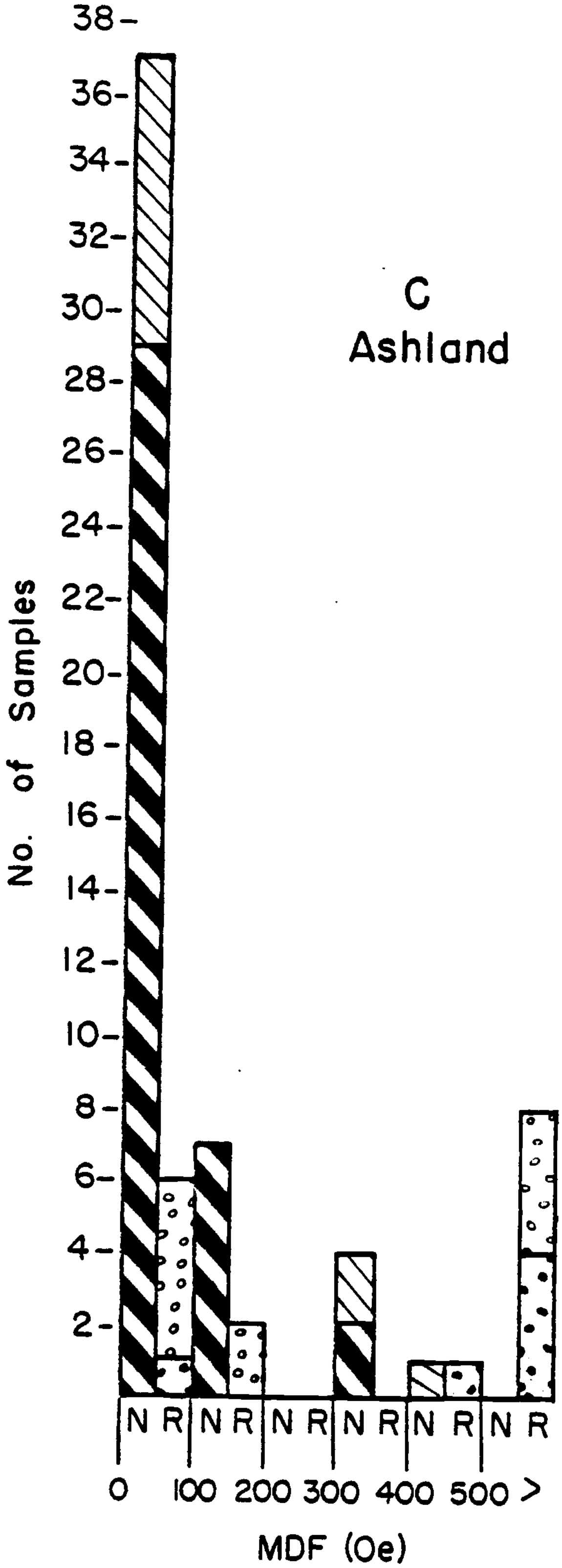


Figure 17 (cont'd)

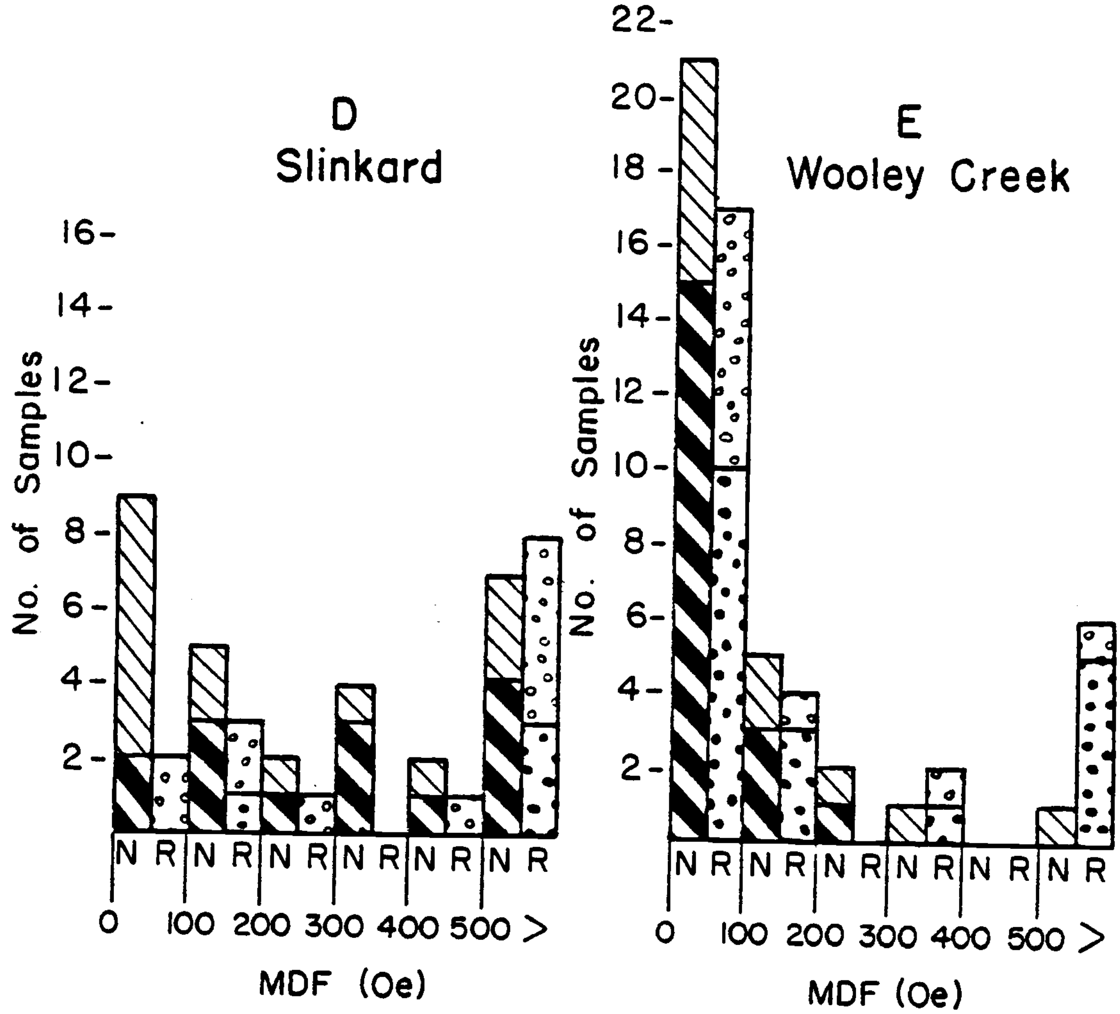


Figure 17 (cont'd)

general bimodal distribution whereas more unstable samples have lower MDFs. Proportionately speaking, samples of poorer lab quality (B through D) have a higher occurrence of MDFs <100 Oe while stabler samples have MDF values >200 Oe.

Stability

In paleomagnetic studies dealing with plutonic rocks, a large portion of the suite of samples is often rejected on the basis of instability. Unfortunately, there exists no reliable field criterion to aid in the selective sampling of outcrops; one merely samples what is available, providing the rocks are fresh and coherent. Suspicions that rocks which appeared in hand sample to be more mafic would contain a higher percentage of Fe-Ti minerals, or that more fine-grained rocks might possess fine-grained, stable minerals proved false. Sites consisting of both felsic and/or medium- to coarse-grained rock yielded stable samples as well as site mean directions with high directional clustering among cores.

Likewise, in the laboratory there exists no easily measurable quantity whereby stable and unstable samples can be distinguished and the chances of obtaining reliable PM results might be maximized. Several relationships between properties of the Klamath plutonic rocks were examined in hopes that such a criterion might be established. An increase of NRM intensity was noted for samples of increasing low field magnetic susceptibility, χ. This is expected, since both quantities are proportional to the volume percent of magnetite. Interestingly, directionally stable and rejected specimens of both polarities were evenly distributed throughout the ranges of both NRM and χ. Correlations between MDF and either χ or NRM (not shown) were very poor, and no trends were observed for samples distinguished on the basis of polarity (N vs. R) or directional stability.

The Koenigsberger ratio, Q, is defined as the ratio of remanent to induced magnetization and is given by

$$Q_n = J_n / \chi H,$$

where Q_n is the ratio of the intensity of NRM (J_n) to that induced by the Earth's field (H) at the sampling site. This ratio has sometimes been used as a stability criterion, with higher Q values corresponding with greater stability. Very poor correlations were observed (not shown) between Q and MDF for the samples from the Greyback complex and the Grants Pass pluton, suggesting that Q and MDF do not sample the same property for these rocks.

The histograms of Figures 18A and 18B show the distributions of log Q values for samples from the Grants Pass and Greyback plutons, respectively. Q values range from 0.1 to 9.5 for the former and from 0.003 to 43 for the latter, although $\sim$90% of the samples within the latter fall between 0.01 and 2.0. There is an apparent correlation between Q and stability for the Grants Pass pluton; 75% of the samples with log Q < 0 (i.e. Q < 1) are from site GPN (site rejected due to instability), 67% of the samples with log Q between 0.2 and 0.6 (1.6 < Q <4) are from site GPE 1 (stable site), and 94% of the samples with log Q betweem 0.6 and 1.0 (4 < Q < 10) are from the three GPW sites (very stable). This type of correlation does not exist for the samples from the Greyback intrusive complex (Fig. 18B).

Figure 18. Distribution of Q values for stable (accepted) and unstable (rejected) samples of both normal and reversed polarities within the (A) Grants Pass pluton and (B) Greyback intrusive complex. Patterns as in Figure 17.

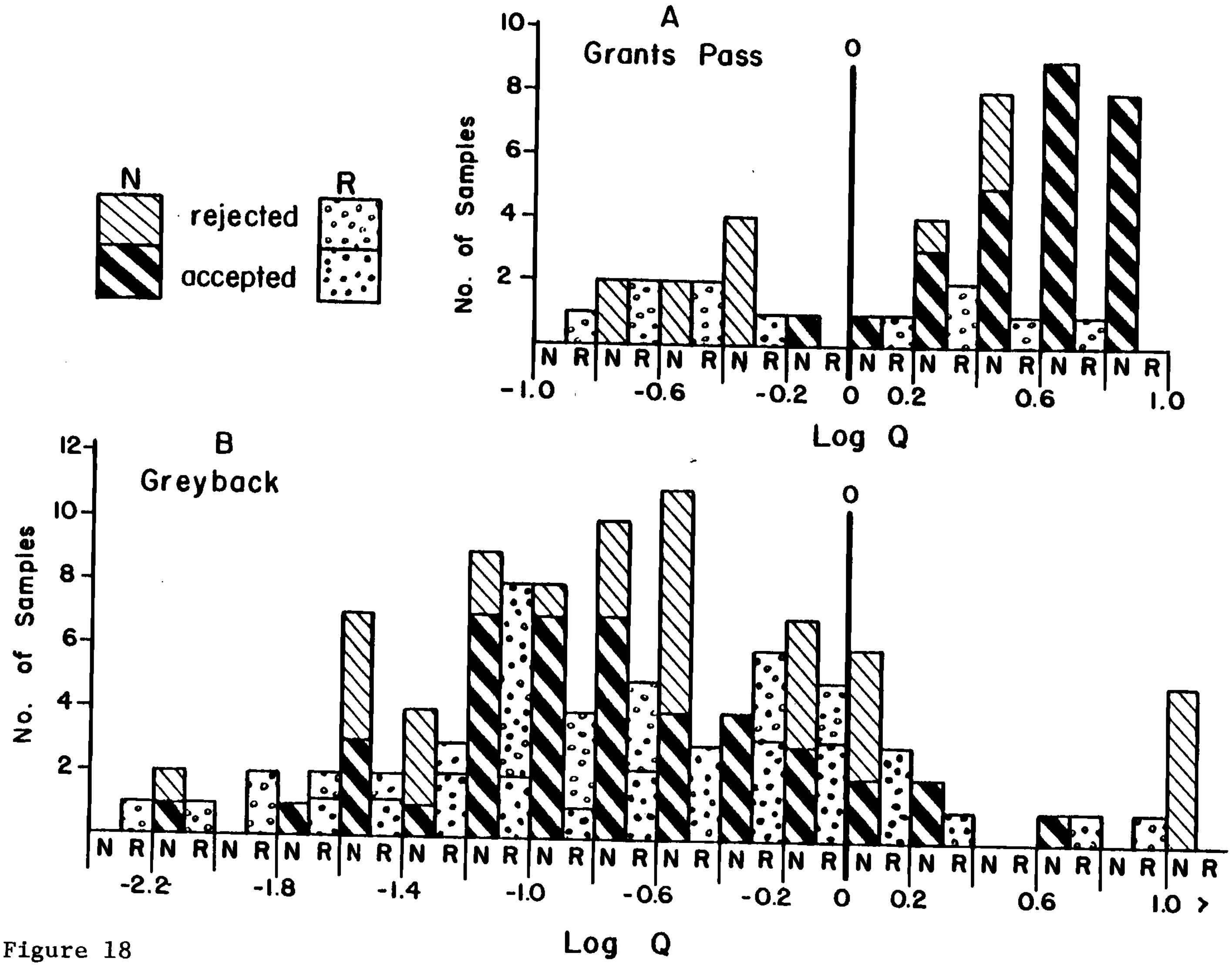

N
R
rejected
accepted
A
Grants Pass
No. of Samples
Log Q
B
Greyback
No. of Samples
Log Q

Figure 18

Polarity

Many of the sites examined in this study contain both normally and reversely magnetized cores, perhaps having cooled through a polarity transition of the Earth's magnetic field or having been formed by multiple intrusions. A striking feature of these mixed polarity sites is that cores of reversed polarity generally display shallower inclinations than cores of normal polarity, while declinations are approximately antipodal. This is graphically depicted on the stereonet projection of Figure 19, which shows stable directions for normal and reversed samples from a typical mixed polarity site. Also noteworthy is that seven of the nine rejected sites contain samples of both polarities.

Opaque Mineralogy

Seventeen polished sections from stable and unstable cores were microscopically examined under reflected light to investigate the relationships between stability and both grain size and mineralogy of magnetic phases. The percentage of total opaques present is less than 1% for 14 of the samples, the remaining three possessed 1-3%. Grain sizes range from <0.04mm - 0.8mm so mineral recognition was often difficult. Pure magnetite is present as isotropic subhedral, octahedral grains in thirteen (possibly fifteen) samples, constituting 10-50% of total opaques. Exsolution was detectable at a magnification of 200x in only two of the samples. Replacement of magnetite by pyrite and/or chalcopyrite was frequently observed. One or two anisotropic opaque phases were present in 15-16 of the

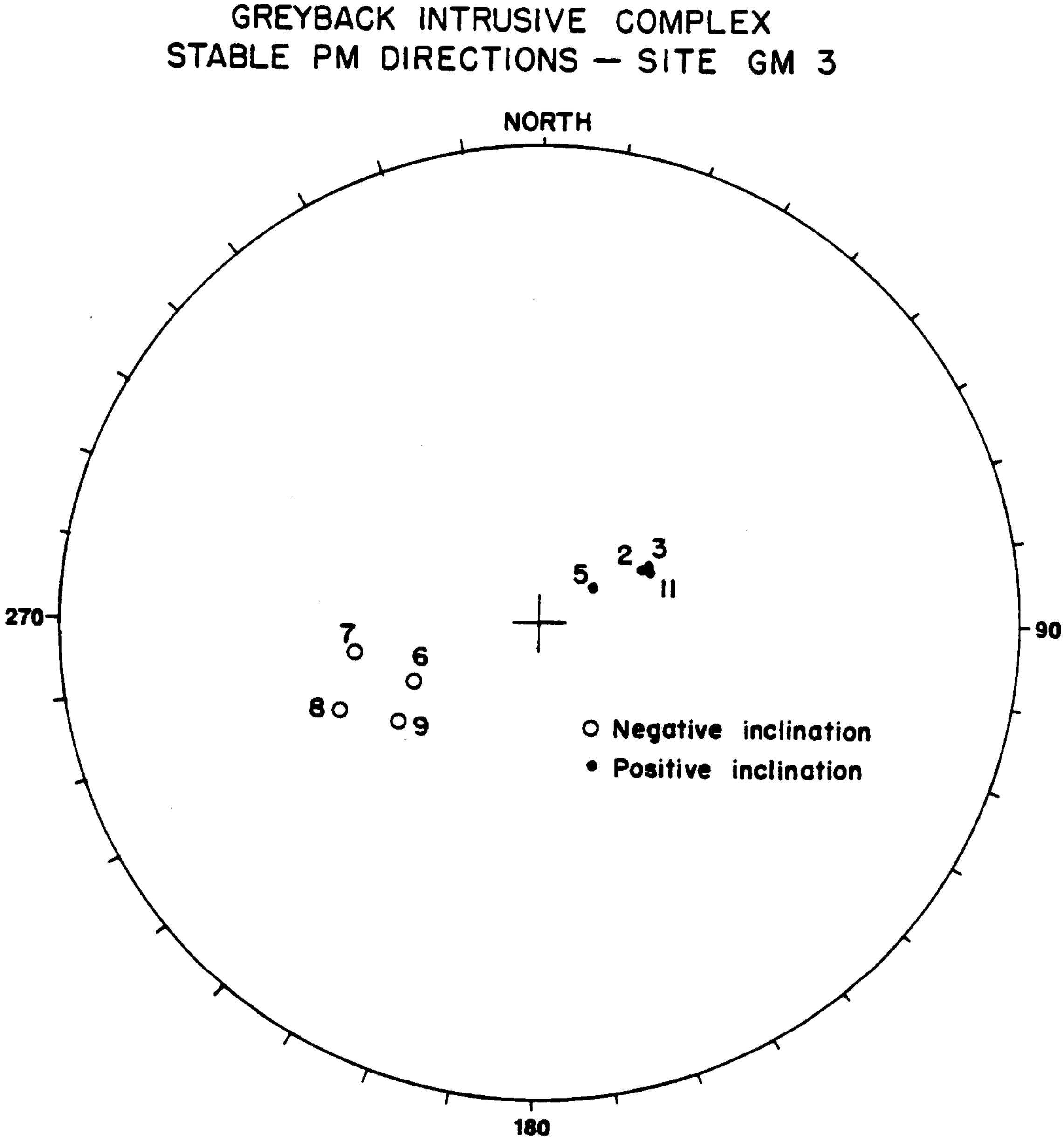


Figure 19. Stable paleomagnetic directions for reliable samples from site GM 3. Though normal and reversed samples are antipodal with respect to declination, inclinations of the latter are shallower.

samples; crystals were frequently twinned, occurring as primary subhedral to anhedral crystals. Distinctions between hematite and ilmenite were rarely possible.

For the polished sections examined, no obvious mineralogical differences exist between stable and unstable samples. In the reversely magnetized cores, magnetite appears to comprise a smaller percentage of the total volume of opaque minerals than in normally magnetized cores. Further examination of the opaque mineralogy of additional samples is necessary before correlations between stability and either grain size or mineralogy can be made, and microprobe analysis is required for identification of the anisotropic phases.

Paleomagnetic Results from Middle Jurassic Plutons

Introduction

This section presents the paleomagnetic data of this study individually for each pluton. Site means and associated circles of 95% confidence for the Greyback intrusive complex, Grants Pass pluton, Ashland pluton, and the Wooley Creek batholith and Slinkard pluton combined are plotted on the stereonet projections of Figures 20-23, and listed Tables 4-7, respectively. Figure 11 shows the distribution of sampling sites within these plutons. Site descriptions and locations are given in Appendix C. Site polarities (N, normal; R, reversed; M, mixed) are designated on the basis of the polarities of samples used in site mean calculations.

Pluton mean directions, calculated from stable sites, are also shown in Figures 20-23, in addition to the expected Jurassic directions. These expected directions, computed from Harrison and Lindh (1982), are discussed in the following chapter as are the discordances between observed pluton mean directions and expected directions.

As stated previously, all plutons sampled are calc-alkaline in nature, were intruded into the western Paleozoic and Triassic subprovince, and lie within Hotz's (1971) northern plutonic belt.

Ages of Plutons Examined

Radiometrically determined ages for the plutons examined in this study are listed in Table 3. Column A contains the average K-Ar ages determined on hornblende from Lanphere et al. (1968) and Hotz (1971). Application of the correction according to Dalrymple (1979) increases these ages by approximately 2.6%; the corrected values are given in column B. For comparison, column C lists the available U-Pb ages determined on zircons by Jason Saleeby (Allen et al., 1982). This list is incomplete, but current work by Saleeby will provide additional ages.

Though the magmatic age of plutonic rocks is more accurately represented by U-Pb ages, the time of blocking of the remanence is probably better approximated by the K-Ar ages. Because of potential problems associated with argon loss from biotite, yielding apparently younger K-Ar ages, the K-Ar ages for hornblende (Table 3, column B) are considered best estimates of the time of remanence acquisition for the respective plutons. In the following chapter,

Table 3: Radiometric Ages of the Klamath Mountain Plutons Sampled for This Study

Pluton	A K-Ar hrnbd. age (my)	B Corrected K-Ar age (my)	C U-Pb age (my)
Grants Pass	136 (1)	139	**
Greyback	149 (2)	153	Not sampled
Ashland	157 (3)	161	**
Wooley Creek	152 (1)	156	162 ± 2
Slinkard	153 (1)	157	163 ± 3

Column A: K-Ar ages from Lanphere et al. (1968) and Hotz (1971) determined on hornblende. No. in ( ) refers to number of available dates averaged; both Greyback ages are 149 my; the three Ashland dates are 146, 160, and 166 my.

Column B: Corrected K-Ar age computed from Dalrymple (1979).

Column C: U-Pb ages from Allen et al. (1982). ** in progress by Jason Saleeby at Cal. Inst. Tech. (pers. comm., 1982).

the observed PM directions are compared with reference poles closest in age to these K-Ar hornblende ages.

Greyback Intrusive Complex

Ninety-two cores were collected at ten sampling localities within the Greyback intrusive complex in southern Oregon. The 153 m.y. old pluton (K-Ar hornblende, Table 3) is exposed over an elongate, NE-trending area of approximately 250 km^2. Sampling sites span a 30 km^2 area just east of Oregon Caves National Monument at the southern end of the pluton (Figure 11). Adjacent sites are separated by <1 to 3 km and the maximum site separation is 8 km. Sampling outrops range in length from 20-100 m.

Paleomagnetic results are summarized in Table 4 and site mean directions and associated 95% confidence circles are shown on the stereonet projection of Figure 20A. Considering only samples used in the site mean calculation, three of the ten sites possess only normally magnetized cores (sites GM 1, 5, 10), two contain only reversely magnetized cores (sites GM 4 and 6), and the remaining five possess cores of both polarities (GM 2, 3, 7, 8, 9). A broad range of stabilites exist, and MDF values vary from <30->1000 Oe throughout the pluton, commonly spanning 200-300 Oe within a single site.

Only one of the ten sites (GM 6, reversed) was eliminated in the final analysis, as stable directions could not be determined for its samples. Two sites of mixed polarity (GM 7 and GM 9) have relatively large circles of 95% confidence (α_{95}=23° and 30°, respectively), but were not rejected since the mean direction of the remaining seven

Table 4: Summary of Paleomagnetic Data from the Greyback Intrusive Complex, Southern Oregon

	Stable Direction					Core Polarity†	
Site	D(°)	I(°)	α_{95}(°)	k	$n(N_T)$	N	R
GM 1	083	73	7	58	8(9)	8(9)	--
GM 2	067	69	13	22	7(9)	4(5)	3(4)
GM 3	066	56	9	43	8(11)	4(7)	4(4)
GM 4	281	-40	11	34	7(10)	0(2)	7(8)
GM 5	056	71	14	19	7(9)	7(9)	--
GM 6 *	NO STABLE DIRECTION					--	0(9)
GM 7	130	66	23	9	6(8)	4(4)	2(4)
GM 8	064	62	13	18	9(9)	8(8)	1(1)
GM 9	084	56	30	5	7(8)	3(3)	4(5)
GM 10	088	63	14	21	7(9)	7(9)	--
Mean of GM Sites							
	083	63	9	32	9(10)		

α_{95} is radius of circle of 95% confidence about mean direction; k is precision parameter; n is number of samples (one per core) used in calculation of (D, I); N_T is total number of cores measured.

†N is normal polarity, R is reversed polarity. (8)9 signifies that 8 cores out of 9 total were used in the site mean calculation, 1 was rejected. Appendix B summarizes data on a sample-by-sample basis.

* Rejected site.

Figure 20. Greyback intrusive complex site mean directions (Fig. 20A) and pluton mean direction (Fig. 20B) with associated circles of 95% confidence. Triangle = present field direction, square = axial dipole field. Expected directions for 130-170 m.y.B.P. are shown by closed circles. All projections are lower hemisphere. Open symbol represents reversely magnetized site mean direction inverted through the origin.

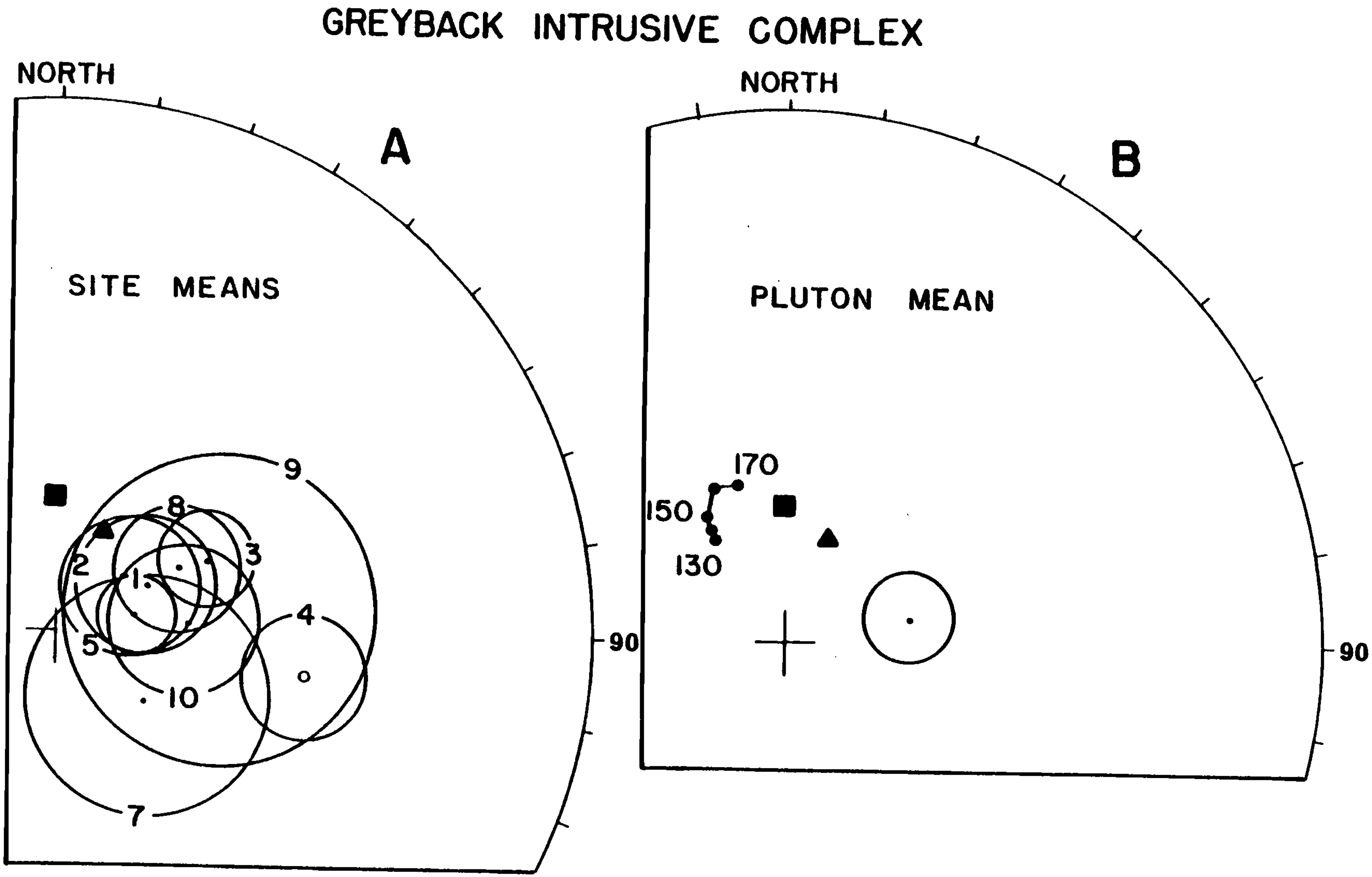

GREYBACK INTRUSIVE COMPLEX
NORTH
A
SITE MEANS
9
8
3
2
1
4
5
10
7
90
NORTH
B
PLUTON MEAN
170
150
130
90

Figure 20

sites (D=078°, I=63°, α_{95}=10°, k=34) is nearly identical to that which includes these two sites. The paleomagnetic direction of the combined data from the nine stable sites of the Greyback intrusive complex is D=083°, I=63° (α_{95}=9°, k=32), and is plotted on Figure 20B.

Grants Pass Pluton

The Grants Pass pluton is located just north of the Greyback intrusive complex in southern Oregon. Its age of magnetization is 139 m.y.B.P. (K-Ar hornblende, Table 3). The paucity of fresh outcrops permitted sampling of only five sites within the pluton's ∿280 km^2 areal extent. Six to ten cores were drilled at each site for a total of 39 cores. Sampling localities span an area of ∿50 km^2 across the central portion of the pluton and are distinguished on the basis of their relative geographic locations: GPE, east; GPN, north; and GPW, west (Figure 11). The greatest lateral separation is 15 km (between sites GPE 1 and GPW 3). Sites GPW 1 and GPW 2, however, are separated by only 200 meters.

Site mean paleomagnetic directions are tabulated in Table 5 and plotted on Figure 21A. On the basis of samples used in site mean calculations, site GPN 1 is of mixed polarity and all others are normally magnetized. All sites are directionally stable, with the exception of GPN 1 whose samples are characterized by low median destructive fields (<100 Oe) and highly erratic behavior upon AF demagnetization. Samples from site GPE 1 (MDFs also <100 Oe) yielded stable directions, but the similarity of the GPE 1 mean PM direction (D=013°, I=65°, α_{95}=12°) with the present field direction

Table 5: Summary of Paleomagnetic Data from the Grants Pass Pluton, Southern Oregon

	Stable Direction					Core Polarity†	
Site	D(°)	I(°)	α_{95}(°)	k	n(N_T)	N	R
GPN 1 *	NO STABLE DIRECTION					0(4)	0(2)
GPE 1	013	65	12	24	7(7)	7(7)	--
GPW 1	054	66	5	145	7(10)	7(7)	0(3)
GPW 2	038	67	3	387	8(8)	8(8)	--
GPW 3	074	65	4	181	8(8)	8(8)	--
Mean of GP Sites							
Including GPE 1	045	67	12	60	4(5)		
Excluding GPE 1	056	67	11	122	3(5)		

Explanation as in Table 4.

Figure 21. Grants Pass pluton site mean directions (Fig. 21A) and pluton mean direction (Fig. 21B) with associated circles of 95% confidence. Triangle = present field direction, square = axial dipole field. Expected directions for 130-170 m.y.B.P. are shown by closed circles. All projections are lower hemisphere.

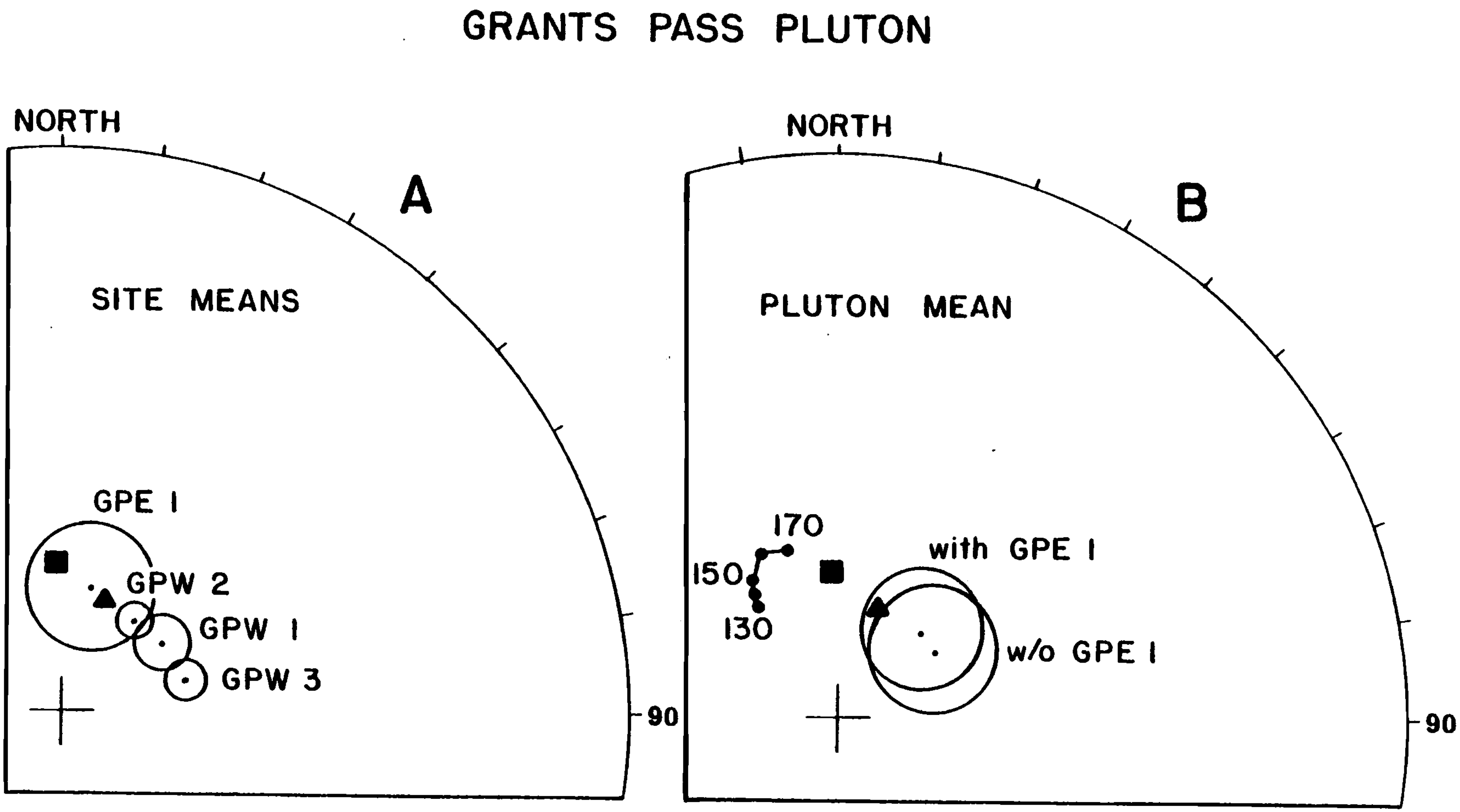

GRANTS PASS PLUTON
NORTH
A
SITE MEANS
GPE I
GPW 2
GPW 1
GPW 3
90
NORTH
B
PLUTON MEAN
170
150
130
with GPE I
w/o GPE I
90

Figure 21

makes this site suspect for remagnetization in the Earth's present geomagnetic field.

The majority of the samples from the three GPW sites are normally magnetized and of AA laboratory quality (refer to Table 2). For any GPW site, mean directions at 100, 150, 200, and 250 Oe are nearly identical, and stable directions were chosen at 200 Oe for all samples. The three cores of site GPW 1 that were omitted from the calculation of its site mean PM direction (Table 5, Appendix B) were of reversed or transitional polarity, yielded directions removed from the mean by more than two angular standard deviations, and had considerably lower MDF values than other cores from that site. In addition, all were drilled from mafic inclusions.

Excluding GPN 1, the four stable GP sites have a combined mean direction of D=045°, I=67° (α_{95}=12°, k=60). Since the possibility of remagnetization exists for GPE 1, the mean direction excluding this site was also computed (D=056°, I=67°, α_{95}=11°, k=122). These observed mean directions and their 95% confidence circles are plotted on Figure 21B.

Ashland Pluton

The Ashland pluton straddles the Oregon-California border along the easternmost boundary of the Klamath Mountain province. The 161 m.y.B.P. pluton (K-Ar hornblende from Table 3) occupies an area of ∿400 km^2, approximately two-thirds of which is in Oregon. Seventy-two cores were drilled at nine sampling localities, four along the western and southwestern margin (2 in Cal., 2 in Ore.), one along the eastern margin in Oregon, and four in the Mount Ashland region of

Oregon (Figure 11). The area of the sampled region is ∿300 km^2; site separations range from 2 km to 23 km, and outcrops vary from 12 meters to 100 meters in length.

Paleomagnetic results from the Ashland pluton are summarized in Table 6 and stable site means and associated circles of 95% confidence are plotted on Figure 22A. Considering samples used in site mean calculations, sites ASH 6 and 7 are of mixed polarity, all others are normally magnetized. Three of the nine sites were rejected: Site ASH 2 was too weakly magnetized for accurate measurement on the spinner magnetometer, site ASH 9 contained highly unstable samples, and site ASH 1 was six standard deviations removed from the mean of the six stable Ashland sites (Figure 22A), in addition to having poor grouping of directional data (α_{95}=37°, k=12).

The mean direction of D=324°, I=63° (α_{95}=8°, k=67) for the six stable ASH sites is plotted on Figure 22B. This observed direction is nearly concordant with that expected for 160 m.y.B.P., the Ashland pluton being the only pluton examined in this study which displays no discordance of direction.

Wooley Creek Batholith and Slinkard Pluton

The Wooley Creek batholith (WCB) and Slinkard pluton (SP) occupy roughly 400 km^2 and 120 km^2, respectively, in the central part of the Klamath Mountain province in northernmost California. Their K-Ar (hornblende) ages are 156 and 157 m.y.B.P., respectively (Table 3). The geographic proximity of the two intrusions, as well as their mutually dipping foliations, indicate that they dip toward each other and may be connected at depth (Barnes, 1982; Allen, 1981). Their

Table 6: Summary of Paleomagnetic Data from the Ashland Pluton, Southern Oregon and Northern California

Site	Stable Direction					Core Polarity†	
	D(°)	I(°)	α_{95}(°)	k	$n(N_T)$	N	R
ASH 1 *	066	34	37	12	3(7)	3(4)	0(3)
ASH 2 *	TOO WEAK FOR MEASUREMENT ON SPINNER MAGNETOMETER						
ASH 3	326	51	20	12	6(7)	6(6)	0(1)
ASH 4	323	64	16	12	8(9)	8(8)	0(1)
ASH 5	302	61	15	18	7(9)	7(7)	0(2)
ASH 6	337	61	9	33	9(9)	7(7)	2(2)
ASH 7	338	76	9	32	10(13)	4(5)	6(8)
ASH 8	327	64	12	21	8(9)	8(9)	--
ASH 9 *	NO STABLE DIRECTION					0(4)	0(2)
Pluton Mean							
	324	63	8	67	6(9)		

Explanation as in Table 4.

Figure 22. Ashland pluton site mean directions (Fig. 22A) and pluton mean direction (Fig. 22B) with associated circles of 95% confidence. Triangle = present field direction, square = axial dipole field. Expected directions for 130-170 m.y.B.P. are shown by closed circles. All projections are lower hemisphere.

ASHLAND PLUTON

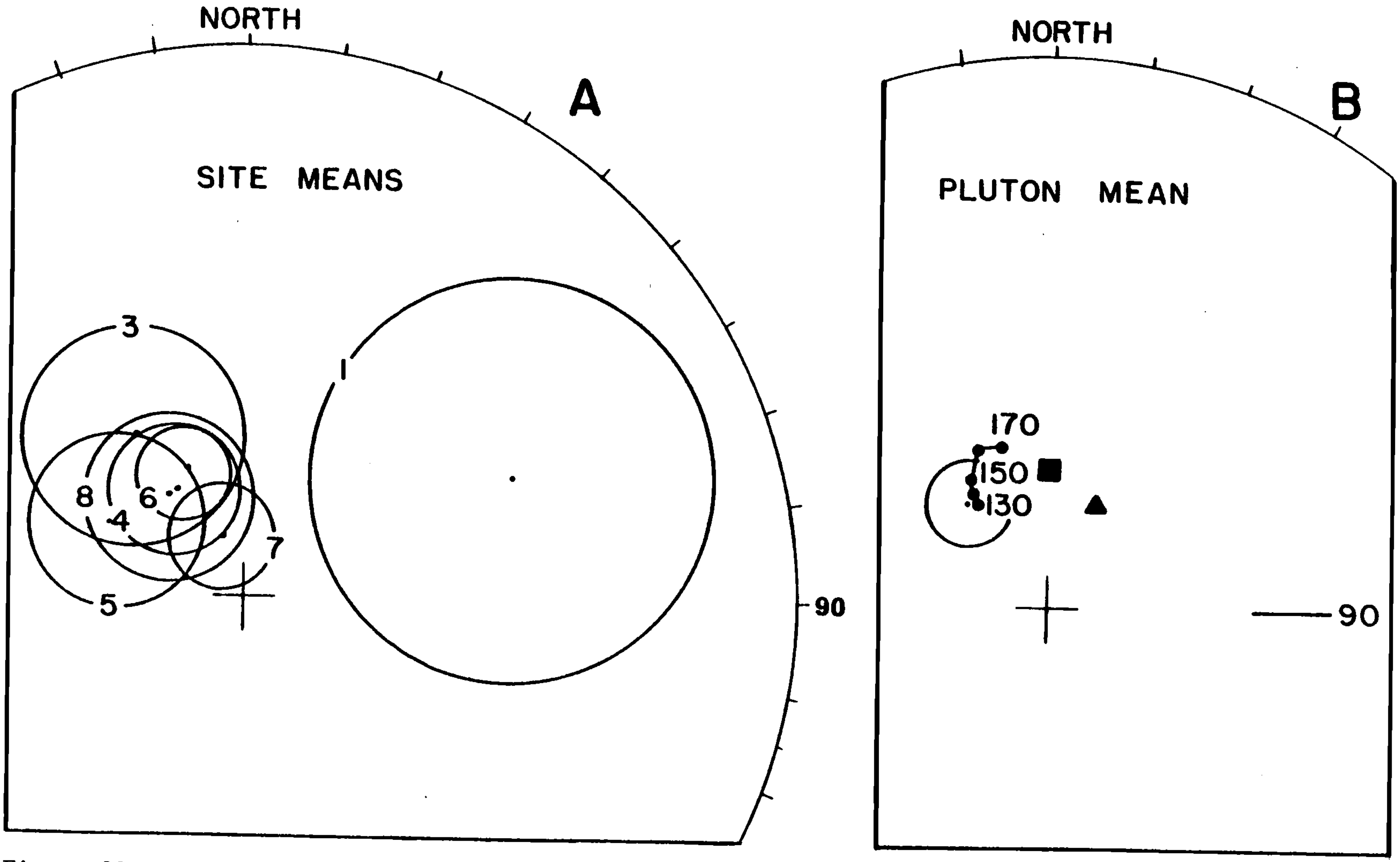


Figure 22

comagmatism during Middle Jurassic time is further evidenced by colinear major element trends, similar lithologies, and identical U-Pb age determinations (162±2 m.y.B.P. for WCB, 163±3 m.y.B.P. for SP; Allen et al., 1982). For these reasons, the WCB and SP are herein considered to be a single intrusive body, and paleomagnetic results for the two are presented together.

Six to ten cores were obtained from each of seven sites within the WCB and six sites within the SP for a total of 119 cores. The distribution of these sites is shown on Figure 11. Portions of the WCB and SP lie within the Marble Mountain Wilderness area and could not be sampled. Five sampling localities of the WCB lie within a 60 km^2 area of the southern portion of the pluton, south of the wilderness area. The remaining two sites, separated by 5 km, are located 26 km north of the wilderness area. Four of the six Slinkard pluton sampling localities are confined to a 23 km^2 area along the eastern margin of the pluton, also north of the wilderness area and 13 km east of the two northern WCB localities. The remaining two Slinkard sites are located ∿16 km north of the other four SP sites and are separated by only 500 m. The total area of the WCB and SP sampled is ∿1200 km^2.

Table 7 summarizes the PM results for the Wooley Creek batholith and Slinkard pluton. Considering samples used in site mean calculations, three of the thirteen sites are normally magnetized (WC 3, 6, and SLK 2), two are reversely magnetized (WC 5 and 7), and nine contain samples of both polarities. Sites WC 1 and SLK 1, 3, and 6 were rejected on the basis of the high degree of sample instability. In addition, many samples from site SLK 1 were too weakly magnetized

Table 7: Summary of Paleomagnetic Data from the Wooley Creek Batholith and Slinkard Pluton, Northern California

Site	Stable Direction					Core Polarity†	
	D(°)	I(°)	α_{95}(°)	k	n(N_T)	N	R
WC 1 *	NO STABLE DIRECTION					0(5)	0(3)
WC 2	046	47	13	24	7(7)	6(6)	1(1)
WC 3	033	76	7	67	8(10)	8(10)	—
WC 4	356	79	13	24	7(7)	6(6)	1(1)
WC 5	221	-43	12	26	7(8)	--	7(8)
WC 6	050	63	18	26	4(8)	4(7)	0(1)
WC 7	248	-54	18	12	7(9)	0(1)	7(8)
SLK 1 *	NO STABLE DIRECTION					0(5)	0(2)
SLK 2	003	68	10	35	7(7)	7(7)	—
SLK 3 *	NO STABLE DIRECTION					0(3)	0(5)
SLK 4	028	45	23	10	6(8)	4(6)	2(2)
SLK 5	030	55	18	11	8(8)	5(5)	3(3)
SLK 6 *	NO STABLE DIRECTION					0(4)	0(2)
Individual Pluton Means							
WC	046	61	15	22	6(7)		
SLK	023	57	21	35	3(6)		
Combined Pluton Mean							
WC/SLK	037	60	11	24	9(13)		

Explanation as in Table 4.

for accurate measurement on a spinner magnetometer. All rejected sites possess samples of both polarities.

The stereonet projections of Figures 23A and 23B depict the site mean directions for the WCB and SP, respectively. At the 95% confidence level, 5 sites have directions similar to the present field direction. The individual pluton means of Table 7, plotted in Figure 23C, are similar at the 95% confidence level. The group mean direction of D=037°, I=60°, (α_{95}=11°, k=24) calculated for the six stable WCB and three stable SP sites is shown in Figure 23D with the present field, present axial dipole field, and expected Middle Jurassic directions.

Summary of Paleomagnetic Data

Paleomagnetic directions determined for the Middle Jurassic plutons examined in this study are shown on the steroenet in Figure 24. Except for that of the Ashland pluton, all directions are clockwise rotated from those calculated from Harrison and Lindh (1982) for the stable North American craton. Table 8 summarizes the paleomagnetic data for these plutons, as well as the data for the Wooley Creek and Slinkard plutons taken independently.

Eight of the thirty-seven sites were either sufficiently unstable or magnetically weak and were rejected prior to determination of site mean directions. All eight rejected sites are of mixed polarity. One additional site (ASH 1) was omitted on the basis of its anomalous direction and high degree of intersite scatter (α_{95}=37°).

Figure 23. Wooley Creek batholith and Slinkard pluton site mean directions (Figs. 23A and 23B, respectively) and associated 95% confidence circles. The mean directions for the sites in Figs. 23A (n=6) and 23B (n=3) are shown in Figure 23C; the combined Wooley Creek/Slinkard mean direction (n=9) is depicted in Figure 23D. Triangle = present field direction, square = axial dipole field. Expected directions for 130-170 m.y.B.P. are shown by closed circles. All projections are lower hemisphere; open symbols represent reversely magnetized site mean directions inverted through the origin.

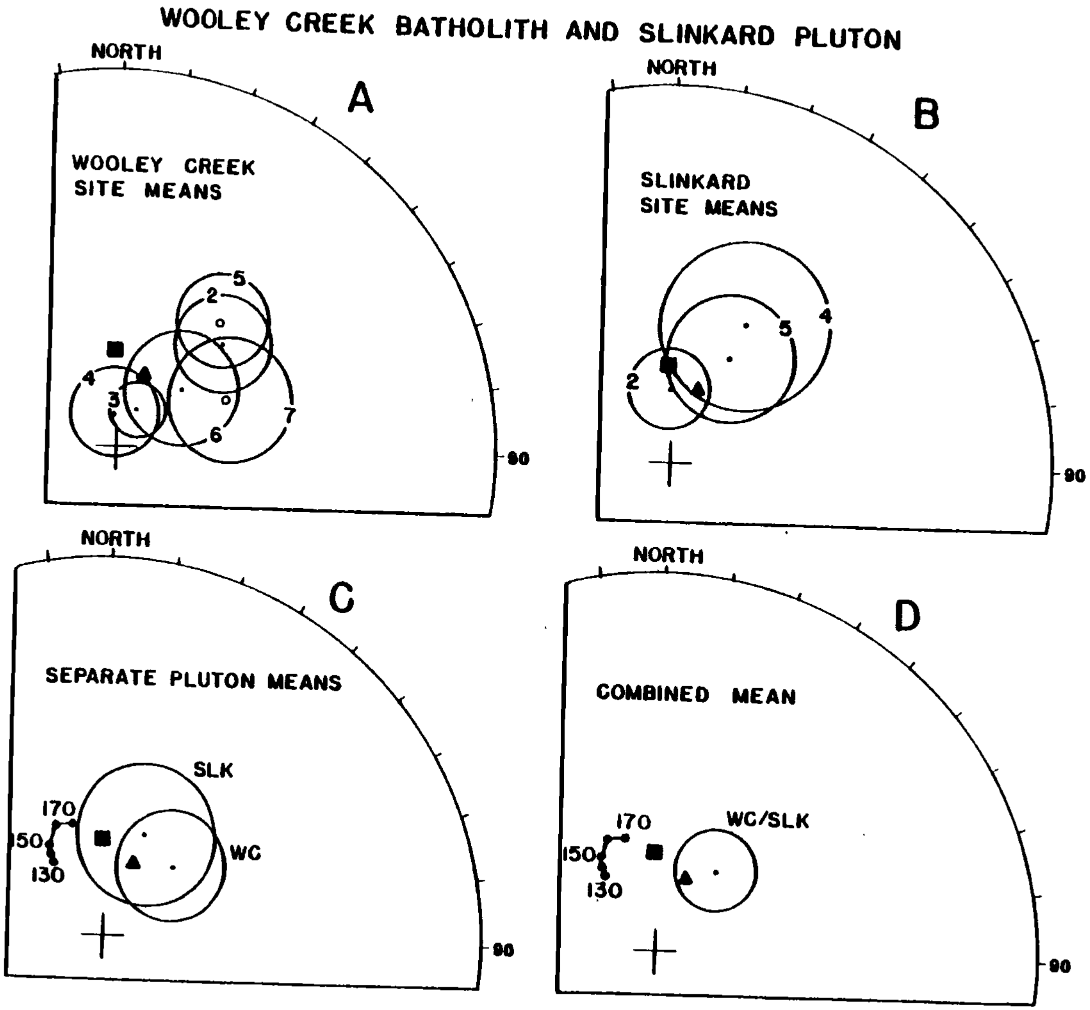

WOOLEY CREEK BATHOLITH AND SLINKARD PLUTON
NORTH
A
WOOLEY CREEK
SITE MEANS
2
3
4
5
6
7
90
NORTH
B
SLINKARD
SITE MEANS
2
4
5
90
NORTH
C
SEPARATE PLUTON MEANS
SLK
WC
170
150
130
90
NORTH
D
COMBINED MEAN
WC/SLK
170
150
130
90

Figure 23

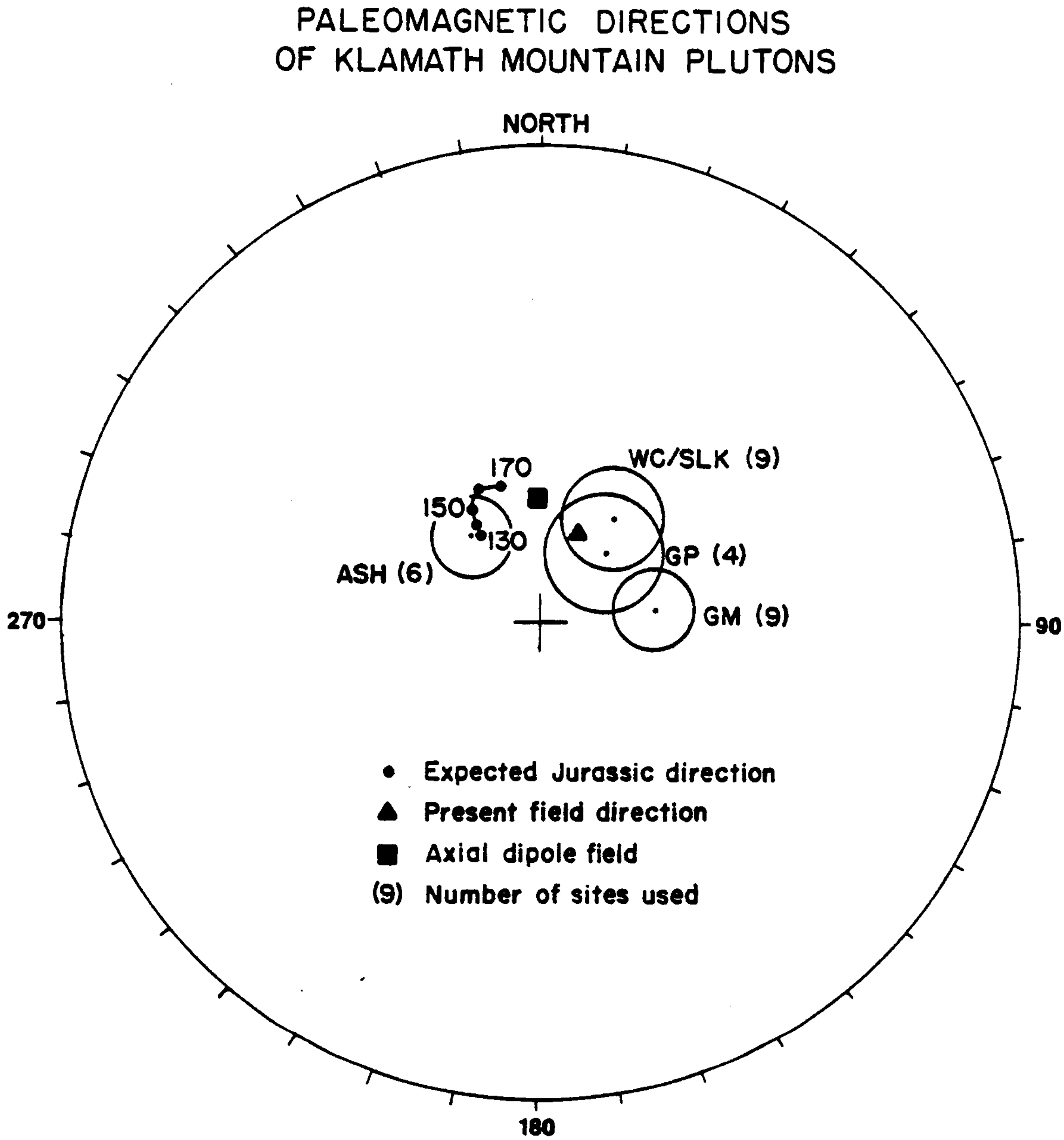


Figure 24. Mean paleomagnetic directions and associated circles of 95% confidence for the Jurassic plutons of the Klamath Mountains examined in this study. All projections are lower hemisphere.

Table 8: Summary of Paleomagnetic Data from Klamath Mountain Plutons, Southern Oregon and Northern California

Pluton	Stable Direction					Site Polarity			Age (myBP)	Coordinates	
	D(°)	I(°)	α_{95}(°)	k	n(N_T)	N	R	M		Lat. (°N)	Long. (°E)
Grants Pass	045	67	12	60	4(5)	4	—	—	139	42.45	236.60
Greyback	083	63	9	32	9(10)	3	1	5	153	42.11	236.67
Ashland	324	63	8	67	6(9)	4	—	2	161	42.06	237.29
Wooley Creek/ Slinkard	037	60	11	24	9(13)	2	2	5	*	41.59	236.76
Wooley Creek	046	61	15	22	6(7)	2	2	2	156	41.45	236.63
Slinkard	023	57	21	35	3(6)	1	—	2	157	41.72	236.88

α_{95} is a radius of circle of 95% confidence about D, I; k is precision parameter; n is number of sites used in calculation of pluton mean direction; N_T is total number of sites sampled.

Site polarity tabulated on basis of sites used in pluton mean calucation; N is normal polarity, R is reversed polarity, M is mixed polarity.

Age is best estimate for time of remanence acquisition (K-Ar on hornblende, from Table 3, column B). * Not directly determined.

Coordinates are averages based on latitudes and longitudes of sites within a given pluton.

INTERPRETATION

Paleomagnetic Reference Poles of Stable North America

Previous studies aimed at determining paleomagnetic pole positions for stable North America emphasize the paucity of Jurassic data. In addition, comparison of various polar wander paths reveals that the greatest interpath discrepancies exist for the time period of 160-180 m.y.B.P. (Harrison and Lindh, 1982). The uncertainties in Middle Jurassic pole positions are due primarily to the lack of exposures of marine deposits of this age in North America.

The paleomagnetic results obtained in this study are compared with the paleomagnetic poles for the stable craton determined by Harrison and Lindh (1982). Table 9 lists the pole positions for the time period 130-180 m.y.B.P. as well as the expected directions, calculated for the center of the sampled region (41.93°N, 236.97°E) and uncertainties associated with each. The uncertainty in inclination (ΔI_x) (Wilson and Cox, 1980) is

$$\Delta I_x = 2A_{95}/(1 + 3 \cos^2 p)$$

and the uncertainty in declination (ΔD_x) is

$$\Delta D_x = \arcsin (\sin A_{95}/\sin p)$$

where A_{95} is the circle of 95% confidence about the pole and p is the paleocolatitude, the angular distance from the sampling site to the expected paleopole.

Rotation Scheme

To assess the discordance of the paleomagnetically determined

Table 9: Jurassic Pole Positions of Harrison and Lindh (1982) and Calculated Expected Paleomagnetic Directions

Pole Age (myBP)	Pole Position[a]				Expected Paleofield Direction[b]				
	Lat. (°N)	Long. (°E)	A_{95}(°)	N	D_x(°)	I_x(°)	p(°)	ΔD_x(°)	ΔI_x(°)
130	66.2	164.3	5.8	14	327.2	63.3	45.2	8.2	4.7
140	66.0	156.5	5.6	11	327.5	60.7	48.3	7.5	4.8
150	66.6	147.8	5.7	10	329.9	58.1	51.2	7.3	5.2
160	69.7	132.4	7.5	10	336.5	54.3	55.1	9.2	7.6
170	75.9	121.3	9.9	7	345.1	55.1	54.4	12.2	9.8
180	69.9	96.6	5.4	13	346.3	45.0	63.4	6.0	6.7

[a]Pole positions from Harrison and Lindh (1982). A_{95} is the circle of 95% confidence about the pole. N is number of studies.

[b]Expected paleofield direction calculated from Harrison and Lindh (1982). Geographic coordinates used in calculating D_x and I_x are 41.93°N, 236.97°E, corresponding with the center of the sampled region. Uncertainties in D_x and I_x, ΔD_x and ΔI_x, are calculated according to Wilson and Cox (1980) as in the text.

directions for the Klamath Mountain plutons of this study, the values of rotation (R) and flattening (F) were computed by the equations of Beck (1980):

$$R = D_o - D_x$$

and

$$F = I_x - I_o,$$

where D_o and I_o are the components of the observed direction and D_x and I_x are the components of the expected direction calculated from the appropriate reference pole of Harrison and Lindh (1982). In addition, the 95% confidence limits (ΔR, ΔF) were computed by the equations:

$$\Delta R = (\Delta D_o^2 + \Delta D_x^2)^{1/2}$$

and

$$\Delta F = (\Delta I_o^2 + \Delta I_x^2)^{1/2}$$

where

$$\Delta D_o = \arcsin(\sin \alpha_{95}/\cos I_o),$$

$$\Delta I_o = \alpha_{95},$$

and, as before,

$$\Delta D_x = \arcsin(\sin A_{95}/\sin p),$$

$$\Delta I_x = 2A_{95}/(1 + 3\cos^2 p).$$

In these equations (also from Beck, 1980), $\alpha_{95}(A_{95})$ is the circle of 95% confidence about the observed direction (reference pole), and p is the paleocolatitude.

The values of $R \pm \Delta R$ and $F \pm \Delta F$ are summarized in Table 10 with the paleomagnetic data for each of the plutons examined. Ages of reference poles used in calculating these values are also listed. Because of their geographic proximity and identical ages, the PM data

Table 10: Summary of Rotations and Paleomagnetic Results

Pluton	PM Direction					VGP[a]			Age (myBP) Comparison Pole[b]	Rotation[c] $\pm\Delta R$(°)	Flattening $\pm\Delta F$(°)
	D(°)	I(°)	α_{95}(°)	k	n(N_T)	Lat. (°N)	Long. (°E)	A_{95}(°)			
Grants Pass	045	67	12	60	4(5)	58.6	296.5	19.8	140	77.6±32.9	-6.3±12.9
Greyback	083	63	9	32	9(10)	33.4	292.0	12.5	150	113.1±21.3	-4.9±10.4
Ashland	324	63	8	67	6(9)	64.7	167.6	11.6	160	-12.5±20.1	-8.7±11.0
Wooley Creek/ Slinkard	037	60	11	24	9(13)	63.3	310.0	14.4	150	67.1±23.6	-1.9±12.2
Slinkard	023	57	21	35	3(6)	72.8	331.1	25.8	150	53.1±41.8	1.1±21.6
Wooley Creek	046	61	15	22	6(7)	57.8	304.2	19.7	150	76.1±33.1	-2.9±15.9

[a] A_{95} is a radius of circle of 95% confidence about virtual geomagnetic pole (VGP).
[b] Age of paleomagnetic pole nearest to age of pluton and used in calculation of $R \pm \Delta R$ and $F \pm \Delta F$ (from Table 9).
[c] A positive (negative) value of R represents clockwise (counterclockwise) rotation. Positive (negative) value of F represents northward (southward) translation, disregarding tilt possibilities.

from the Wooley Creek and Slinkard plutons were merged, but the paleomagnetic and rotation data from each are reported separately as well. With the exception of the Ashland pluton, the paleomagnetic directions are clockwise rotated (R is positive) and significant at the 95% confidence level. There is no apparent correlation between the rotation of the plutons and either their geographic locations or ages. Statistically insignificant values of $F \pm \Delta F$ suggest that there has been no north-south translation of the Klamath Mountain province since Middle Jurassic time.

Interpretation of Paleomagnetic Results

Two alternatives are proposed in explanation of the discordant paleomagnetic directions observed for the plutons of the Klamath Mountains. Because of the geologic complexity of the province, the interpretations presented are considered speculative. Additional paleomagnetic work on other KM plutons is needed in order to constrain the interpretations offered herein.

Interpretation I: Semi-rigid Body Rotation About a Vertical Axis

This alternative considers the simplest interpretation of the paleomagnetic data presented in this study. Any possible post-intrusional tilting is disregarded and the plutons are considered to have been intruded into a coherent block which has undergone no significant post-intrusional internal deformation, although differences in the observed PM directions of the plutons may actually reflect differences in rotation within this block. Discordances in pluton mean directions are attributed to a post-Middle Jurassic clockwise rotation of this block about a vertical axis. The concordant direction of the Ashland pluton, however, is problematic to this interpretation. Since the discrepancy between the PM pole of the Ashland pluton and the remaining plutons may actually reflect a different tectonic history of the former, the Ashland pluton is not considered to be a part of the rotated block and possible explanations of its tectonic history are offered later.

Using the PM data from the stable sites of the Grants Pass, Greyback, Wooley Creek, and Slinkard plutons, mean PM directions were calculated for site mean α_{95} values less than or equal to 15°, 20°, 25°, and 30° (Table 11). Since there is no significant difference between the mean directions and the associated confidence limits, all 22 sites were considered in the final analysis. The calculated four-pluton mean direction of D=057°, I=65° (α_{95}=7°, k=22, n=22) is clockwise rotated by 87°$\pm$18° from the expected 150 m.y.B.P. direction of D=330°, I=58°.

Extent of the Rotated Block, Timing of Rotation, and Relation to Oregon Coast Range Rotation

On the basis of the paleomagnetic data obtained in this study, the rotated block is believed to encompass a minimum area of approximately 8200 square kilometers. It includes the Grants Pass pluton and Greyback intrusive complex in southern Oregon and the Slinkard pluton and Wooley Creek batholith in northern California, as well as the terranes into which all four were intruded. Additional paleomagnetic work is needed to determine the extent of the rotated block but

Table 11: Mean Paleomagnetic Directions Based on Stable Sites from the Plutons of Grants Pass, Greyback, Wooley Creek, and Slinkard

Site Mean α_{95}	D(°)	I(°)	α_{95}(°)	k	n(N_T)
≤15°	056	65	8	24	16(22)
≤20°	055	66	7	26	19(22)
≤25°	055	65	7	22	21(22)
≤30° *	057	65	7	22	22(22)

α_{95} is radius of circle of 95% confidence about mean direction; k is precision parameter, n is number of sites used in calculation, N_T is number of stable sites for the four plutons.

*Accepted four-pluton mean direction.

the concordant direction of the Ashland pluton suggests that the easternmost extent of the block may lie to the west of this pluton, within the western Paleozoic and Triassic subprovince.

If the observed discordances are indeed a result of simple clockwise rotation about a vertical axis, two important and related questions follow: First, when did rotation of the Klamath block occur? Second, did the Klamath Mountains and Oregon Coast Range rotate together? Due to the uncertain nature of the KM-OCR boundary as well as the lack of post-Jurassic PM results from the Klamaths, answers to either issue are difficult to ascertain.

If one assumes that the KM and OCR rotated as a single unit, then removal of the $77° \pm 16°$ clockwise rotation (Simpson and Cox, 1977) of the Lower Eocene Siletz River Volcanics of the Oregon Coast Range from the observed Klamath Mountain rotation leaves on the order of 10° of clockwise rotation that occurred between about 150 m.y.B.P. and Lower Eocene time. Thus it appears that most of the KM rotation occurred since the Lower Eocene.

Geologic evidence to support the co-rotation of the Klamath Mountains and Oregon Coast Range is two-fold:

1) The KM province was a major source for the Middle Eocene sediments of the OCR Tyee and Flournoy formations (Snavely et al., 1964; Lovell, 1969; Baldwin, 1974). Also, the Lower Eocene Roseburg Formation, correlative with the Siletz River Volcanics, contains exotic blocks of schist, greenstone, and conglomerate derived from the Klamaths (Baldwin, 1974).

2) The Middle Eocene sediments of the OCR appear, in general,

to be in depositional contact with the Mesozoic rocks of the KM (Magill and Cox, 1981).

Though these facts might suggest that the Tertiary OCR rotation was accompanied by rotation of the Klamath Mountains, such a conclusion is premature on the basis of the available knowledge. Further examination of the contact is needed. Where exposed, the contact of the two provinces is obscured by moderate folding and faulting. In addition, Baldwin (1964) suggests that the prominent northwest trend of folds in the Roseburg Formation is indicative of underthrusting from the northwest of the Roseburg beneath the Jurassic terranes of the Klamaths.

Tectonic History of the Ashland Pluton

Because of its concordant paleomagnetic direction, the Ashland pluton does not conform to the above model of simple clockwise rotation about a vertical axis. Four possible alternatives are presented to explain the tectonic history of the Ashland pluton and the terranes into which it was intruded.

1) The Ashland "block" was neither rotated nor tilted, and the direction recorded in the pluton actually represents the direction of the stable North American craton during Middle Jurassic time. This would imply the existence of a paleotectonic boundary west of the Ashland pluton separating it from the discordant intrusives and their host terranes. However there is no known surface expression of such a tectonic boundary and it is inferred solely on the basis of the existing paleomagnetic data.

2) The pluton and its host terranes were tilted to the northeast prior to clockwise rotation of the semi-rigid Klamath block. Direct onlap of the northeasterly dipping marine sediments of the Upper Cretaceous Hornbrook Formation with the Ashland pluton is evidence of post-depositional tilting of the latter. Elliott (1971) reports a general northwesterly strike and rather constant 10°-20° northeasterly dip of the Hornbrook strata. Moderate variations in strike preclude the application of an exact tilt correction. An average bedding attitude of N32°W, 17°NE, calculated from the attitudes measured at the six sites sampled for this thesis, was taken as an appropriate minimum tilt correction for the Ashland pluton. In Figure 25A, the pluton mean direction is structurally corrected by removal of the calculated 87° clockwise rotation followed by removal of a 17° north-westerly tilt about a S29°W strike (the attitude of the Hornbrook Formation after removal of 87° rotation), consistent with the presumed interpretations of tilt and subsequent rotation. The ~60-75 m.y. age difference between the Ashland pluton and Hornbrook Formation permits the possibility of a greater than 17° tilt for the former. Removal of a tilt of any magnitude about the S29°W strike, however, fails to restore the direction of the Ashland pluton to the expected mean direction of the other plutons.

3) The pluton and its host terranes were tilted to the northeast after clockwise rotation of the semi-rigid Klamath block. As an alternative to (2) and Figure 25A, the stereonet in Figure 25B depicts the structurally corrected Ashland PM direction by removal of the tilt of the Hornbrook Formation before back-rotation of the Klamath block.

Figure 25. Possible reconstructions to explain the tectonic history of the Ashland (ASH) pluton. Reconstruction (A) is consistent with alternative 2 of text in which the Ashland pluton was tilted prior to rotation of the proposed Klamath tectonic block. Accordingly, the direction is structurally corrected by removal of the 87° clockwise rotation followed by removal of the tilt measured for the onlapping sediments of the Hornbrook Formation. In contrast, reconstruction (B) illustrates alternative 3 in which the pluton was tilted after rotation and the two step structural correction is accomplished by removal of tilt followed by CCW rotation. Neither (A) nor (B) restore the ASH direction to the pre-rotation mean of the other four plutons.

POSSIBILITIES FOR TECTONIC HISTORY OF ASHLAND PLUTON

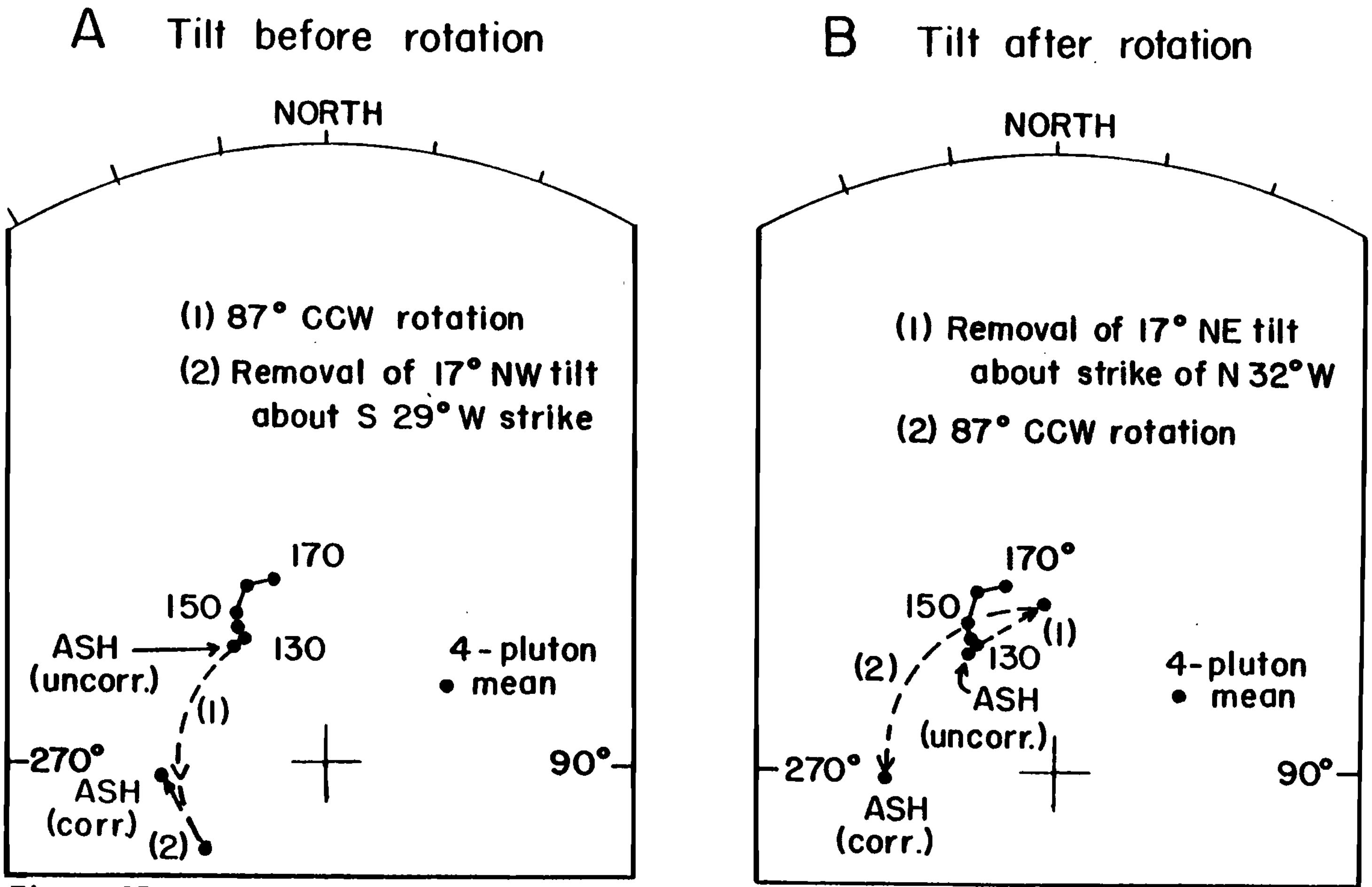


Figure 25

In this case, the Ashland pluton approaches the mean direction of the other plutons, but correction about a more northerly strike is required for a more desirable result.

4) Tilt of the Ashland pluton and clockwise rotation of the Klamath block occurred simultaneously. The relative timing of tilt and rotation is unresolvable. If rotation of the KM block is post-Lower Eocene and tilt is post-Late Cretaceous, then it is perhaps more probable that the two events were at least partially concurrent.

Obvious difficulties arise with all four reconstructions, particularly the timimgs of both tilt and rotation as well as the actual tilt magnitude of the Ashland pluton. The lack of unmetamorphosed sediments older than the Hornbrook strata in the Ashland region further conceals the essential structural control.

That a combination of tilt and rotation would result in a concordant direction for the Ashland pluton is perhaps too coincidental. In addition, is seems unlikely that only this pluton and its host terranes would have been affected by the previously discussed tilting event. Existing though poorly constrained evidence for tilting of some of the other plutons studied paleomagnetically is accounted for in the interpretation presented below.

Interpretation II: Regional Tilting and Clockwise Rotation

Interpretation I accounts for the observed discordances of the Klamath Mountain plutons by clockwise rotation of the terranes into which they were intruded. Field geologic observations by other workers, however, suggest that discordances in some of the plutons examined may be at least partially due to the post-intrusion domal uplift of the Condrey Mountain Schist which lies within the "ring" formed by the plutons of Greyback, Ashland, Vesa Bluffs, and Slinkard (Figure 2). This interpretation demonstrates that the discordances in observed PM directions for the more southerly plutons of Ashland, Wooley Creek, and Slinkard can be attributed to tilt in response to CMS uplift. As for the plutons farther north, the Greyback intrusive complex may or may not have been affected by such an uplift event, but it is unlikely that the Grants Pass pluton was affected. Clockwise rotation is thought to be the primary cause of the discordance found for these two plutons.

Prior to presentation of interpretation II, it is appropriate to discuss the geology of the Condrey Mountain Schist region and the relative timing of thrusting, CMS uplift, and pluton intrusion. Evidence for the domal nature of the uplift is also discussed.

Geology of the Condrey Mountain Schist

The Condrey Mountain Schist (CMS) is exposed through a 650 square kilometer subcircular window of the amphibolite facies rocks of the wTrPz on the California-Oregon border (Figure 2). Hotz (1979) reports that the contact between the CMS and the overlying wTrPz rocks is "undoubtedly a thrust", dipping radially outward everywhere except where modified by high-angle faulting. The primarily greenschist facies rocks of the dome-shaped CMS were formed by metamorphism of graywacke and minor amounts of volcanic rocks (Hotz, 1979) during Late

Jurassic time. Lanphere et al. (1968) and Suppe and Armstrong (1972) report isotopic dates of 141 m.y. (muscovite) and 155±3 m.y. (whole rock), respectively, for the metamorphic age of the CMS. Age and correlation of the protolith is uncertain, however, the equivalence of the CMS with the Galice Formation of the western Jurassic sub-province is suggested by Klein (1977) on the basis of their lithologic similarities as well as the structural position of both beneath the Rattlesnake Creek terrane of the wTrPz. Gravity interpretations by Barnes (1982) support this correlation, but Galice and CMS ages are slightly incompatible. However, Klein also notes that since fossils are scant in the Galice, and its stratigraphy is not well known, there may exist parts of the formation which predate CMS metamorphism.

Relative Timing of Pluton Intrusion, Thrusting, and CMS Uplift

The post-intrusional time for thrusting of the wTrPz plate over the lower plate (including the CMS) is suggested by gravity interpretations by Barnes et al. (1982) which show the basal detachment of the Wooley Creek batholith and Ashland pluton by this thrusting event. The cataclastic eastern marginal facies of the Slinkard pluton (Allen, 1981) further suggests that both the Wooley Creek batholith and Slinkard pluton were truncated during thrusting. Following from these interpretations, U-Pb age determinations on zircons from these two intrusions constrain the time of thrusting to be later than 162±2 m.y.B.P. (Allen et al., 1982). The onset of uplift of the CMS, resulting in its exposure through the wTrPz, is also confined by this U-Pb age to be post-162±2 m.y.B.P. It is likely that uplift began shortly after thrusting and subsequent metamorphism of the CMS, perhaps in response to diapiric rise of the hotter, less dense material of the lower plate through the upper wTrPz plate. This regional uplift may still be continuing today.

Evidence for Uplift and Domal Nature of the Condrey Mountain Schist, Tilt of the Surrounding Terranes

Factors suggesting the post-thrusting uplift of the CMS are the exposure of lower plate rocks within the upper wTrPz plate and the radial outward dip of the thrust bounding the CMS. In addition, gravity data (Barnes, 1982) indicate that uplift has a minimum vertical extent of 6 km. Further evidence for the domal uplift is the decrease in metamorphic grade of the overlying rocks with distance away from the CMS (Hotz, 1979).

The effect of this regional uplift on the terranes surrounding CMS is not well defined due to the complex tectonic and metamorphic history of the Klamath province. However, several observations suggest that these terranes have been tilted away from the center of uplift. The Cretaceous sediments of the Hornbrook Formation to the northeast which flank the KM have a northeasterly dip. Similarly, the tabular Vesa Bluffs pluton to the south-southwest has a southerly dip (Hotz, 1979). Exposures of deeper levels of the Wooley Creek batholith, and Slinkard and Ashland plutons nearer to the CMS suggest that these plutons which have intruded the upper plate have also been tilted away from the CMS (Donato, 1975; Allen, 1981; Barnes, 1982). Tilt of the Wooley Creek batholith was further examined by Barnes (1982) and estimates of the pressure and temperature regimes of contact metamorphic mineral assemblages at three localities adjacent to the WCB indicate that the batholith has been tilted west-soutwestward by 35° or more.

Restoration of Wooley Creek/Slinkard and Ashland PM Directions

As in interpretation I, the mean PM direction of the Ashland pluton was structurally corrected by removal of the 17° northeasterly tilt of the onlapping Cretaceous Hornbrook Formation about a N32°W strike. Since the Hornbrook Formation is Late Cretaceous in age, its 17° dip should be a minimum estimate for tilt of the Jurassic Ashland pluton. Tilt estimates for the Wooley Creek batholith by Barnes (1982) range from ~35° toward S70°W to ~55° toward S80°W, depending upon the pressure estimates chosen. Because all samples except one that were used for P-T estimates are from the southern end of the batholith and yield a post-intrusion tilt of 20°-35°, the value of 35° toward S70°W was selected as the best estimate of tilt. Accordingly, the combined Wooley Creek/Slinkard direction of D=037°, I=60° was corrected to D=312°, I=71°.

Structurally corrected directions and associated α_{95} values for these plutons are shown on Figure 26. The corrected WC/SLK direction is much nearer to the path of expected Middle Jurassic directions than its uncorrected direction, though not exactly coincident at the 95% confidence level.

Structural Control for Greyback Intrusive Complex and Grants Pass Pluton

Though structural control for the Wooley Creek, Slinkard, and Ashland plutons is poorly constrained, it is nearly lacking for the Greyback intrusive complex and the Grants Pass pluton. The relative

Figure 26. Structural corrections of Wooley Creek/Slinkard (WC/SLK) and Ashland (ASH) mean paleomagnetic directions. The ASH direction is corrected by removal of 17° NE tilt about a strike of N32°W (attitude of onlapping Upper Cretaceous Hornbrook sediments). The mean direction for the combined WC/SLK data is corrected by removal of 35° tilt about a N20°W strike (calculated from P-T extimates by Barnes (1982) on contact metamorphic mineral assemblages adjacent to the Wooley Creek batholith). Circles of 95% confidence are shown for structurally corrected directions. Application of these corrections brings observed PM directions nearer to respective coeval directions.

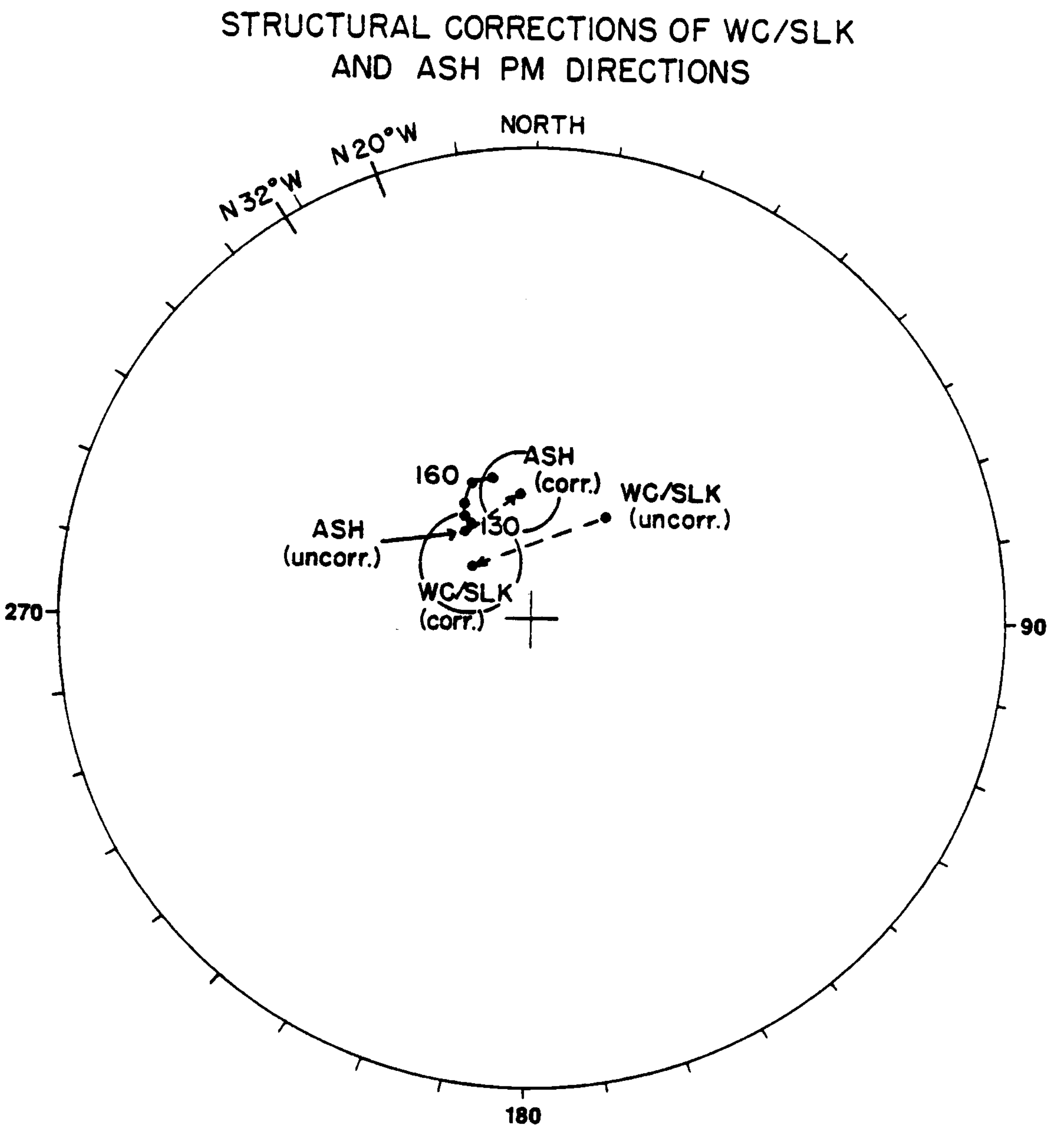

STRUCTURAL CORRECTIONS OF WC/SLK
AND ASH PM DIRECTIONS
NORTH
N20°W
N32°W
ASH
(corr.)
160
WC/SLK
(uncorr.)
ASH
(uncorr.)
130
WC/SLK
(corr.)
270
90
180

Figure 26

timing of intrusion of the Grants Pass pluton and thrusting of the western Jurassic belt under the wTrPz, the event which apparently truncated the Wooley Creek, Slinkard, and Ashland plutons, is uncertain. Snoke (1977) reports that the Grants Pass pluton intrudes the western Jurassic-wTrPz boundary and therefore puts a lower limit on fault movement at 139 m.y.B.P. (the K-Ar age of the Grants Pass pluton). However, Ramp (1982, pers. comm.) believes that part of the eastern contact of the Grants Pass pluton with the western Jurassic belt is thrusted while the remainder appears to be intrusive on the basis of sulfide mineralization and wall rock alteration along the central-western contact. The presence of nearly horizontal Albian (∿100-106 m.y.B.P.) strata deposited on the Galice-Rogue basement at Graves Creek near Galice (Gray, pers. comm., 1982) suggests that the Grants Pass pluton has experienced no post-Cretaceous tilting. The possibility of post-intrusion tilting prior to Albian time still exists, but evidence is lacking. On the basis of the available field evidence, it is assumed that the Grants Pass pluton has not been tilted and that most or all of the discordance in its direction is due to clockwise rotation about a vertical axis.

The Greyback intrusive complex has been examined in previous studies in even less detail than the other plutons sampled for this study and its post-intrusion history is yet more uncertain than that of the other plutons sampled. The most thorough study known is the petrologic examination of the complex and its contact aureole by Godchaux (1969). The reliability of its mean PM direction of

D=083°, I=63°, (α_{95}=9°, k=32, n=9) is supported by the large number of sites, both inter- and intrasite consistency of directions, and a positive reversal test in at least one site. Therefore, the 113.1°± 25.5° of clockwise rotation of the observed direction with respect to the expected 150 m.y.B.P. direction for stable North America is well demonstrated, but explanations are difficult and highly speculative.

Restoration of Greyback and Grants Pass Paleomagnetic Directions

If uplift of the CMS did, in fact, cause tilt of the Wooley Creek, Slinkard, and Ashland plutons, then, on the basis of the comparable distances from the CMS to the Greyback complex and other plutons, a northwesterly post-intrusion tilt of the Greyback complex is possible. The lack of evidence for tilt of the complex makes reconstructions difficult, but Figure 27A demonstrates that removal of a northwesterly tilt can restore the discordant Greyback direction to the expected 150 m.y.B.P. direction. Restoration of the observed discordant direction for the Greyback complex requires removal of a 48° northwesterly tilt about a strike of N28°E. The magnitude of this inferred tilt is substantial for a body of its size and distance from the center of uplift, however, the direction of tilt seems reasonable when considering the relative locations of the CMS and Greyback intrusive complex (see Figure 2).

Recalling that evidence suggests that the Grants Pass pluton may not have been tilted, at least since 100 m.y.B.P., it may be wrong to assume that the discordance of the Greyback complex is due strictly to tilt. Perhaps the Greyback complex experienced the same 78°±33°

Figure 27. Structural correction of paleomagnetic directions of the Greyback Mountain (GM) and Grants Pass (GP) plutons. Figure 27A illustrates that removal of 48°NW tilt about a N28°E strike is required to restore the observed paleomagnetic direction for the GM to the calculated 150 m.y.B.P. direction. Alternatively, structural corrections are applied to the GP and GM mean paleomagnetic directions to account for tilt of the GM pluton before and after its rotation with the GP pluton in Figures 27B and 27C, respectively. The northwesterly tilt inferred from Figure 27C is consistent with that expected for tilt of the GM in response to domal uplift of the Condrey Mountain Schist.

STRUCTURAL CORRECTION OF PM DIRECTIONS OF GREYBACK AND GRANTS PASS PLUTONS

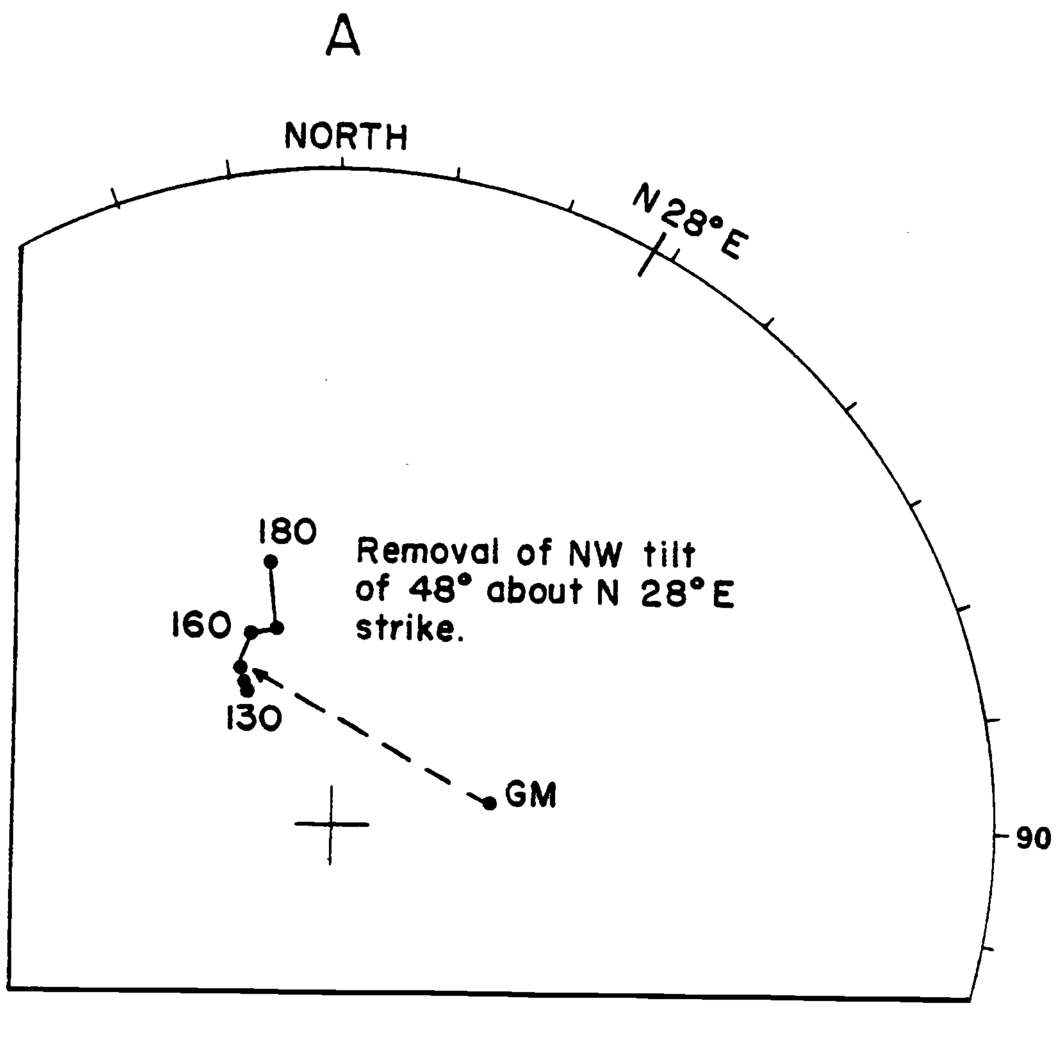


Figure 27

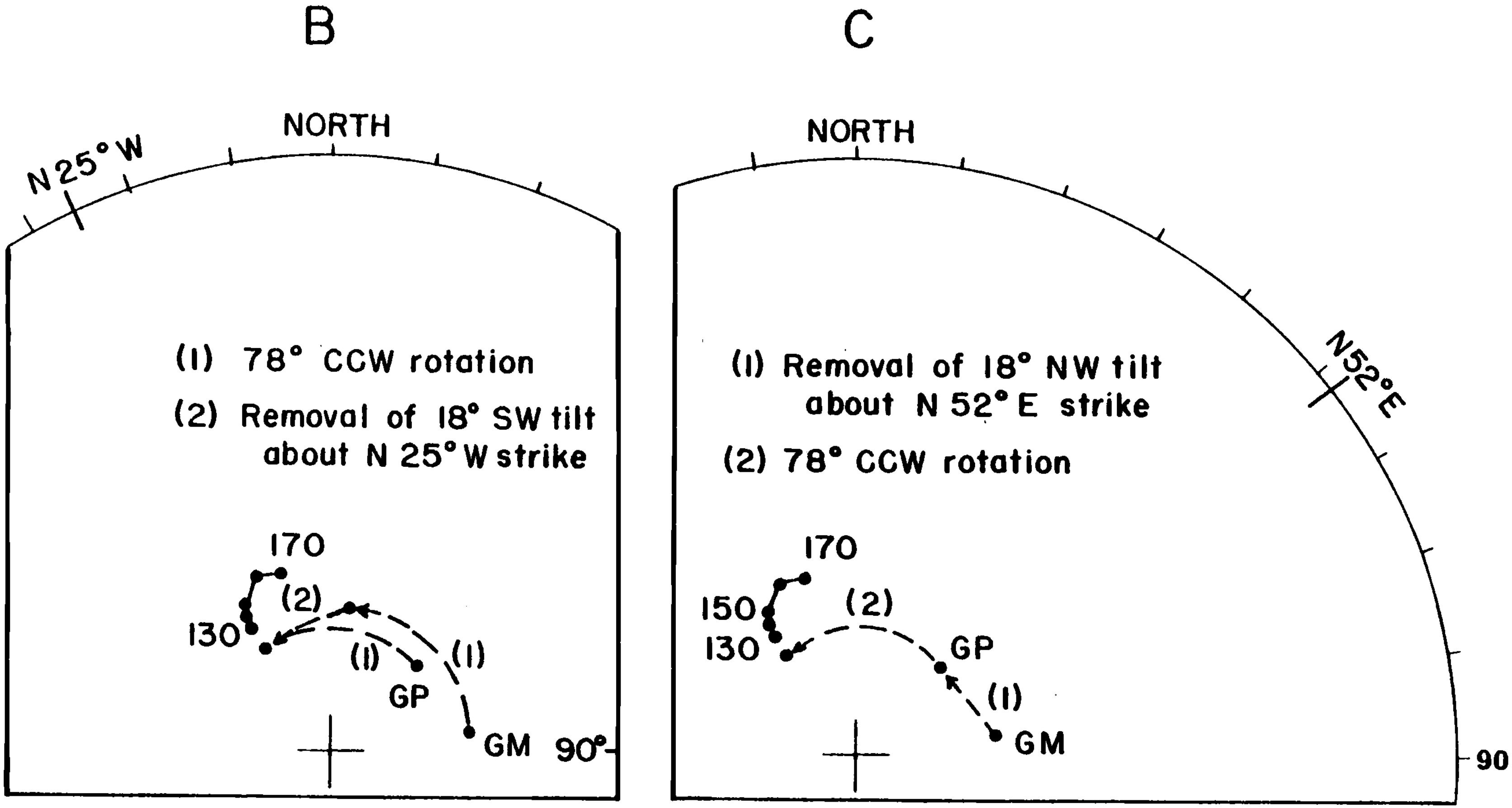


Figure 27 (cont'd)

clockwise rotation as the Grants Pass pluton, and the remainder of its discordance is a result of tilt, either before or after rotation of the "Grants Pass-Greyback block". If tilt occurred before rotation, it must have been on the order of 18° toward S65°W, whereas if tilt occurred after rotation it was approximately 18° toward N38°W (compare Figures 27B and 27C). Alternatively, the additional 35° clockwise rotation of the 153 m.y. old Greyback complex may be a result of its rotation prior to the 139 m.y.B.P. intrusion of the Grants Pass pluton, or of differential rotation between the two. Further examination of the Greyback intrusive complex is needed in order to address the question of its post-intrusional tilting.

Structural Trend of the Klamath Mountains and Interpretation of Paleomagnetic Data

The arcuate trend and westward bulge of the Klamath Mountains is an enigma to geologists. A paleomagnetic study of plutons along the N-S length of the arc could aid in determining whether the arcuate map pattern of the province represents its original shape or the deformation of an originally linear feature due to regional tectonic forces.

Generally speaking, the Greyback and Grants Pass plutons lie within the N-NE trending portion of the KM province, and the Wooley Creek batholith, and Slinkard and Ashland plutons to the south lie within the N-NW trending portion. Structural trends in the Sierra Nevada are also N-NW. If the Klamath Mountains are a continuation of the Sierra Nevada, then, in view of the lack of post-Cretaceous Sierran rotation (Grommé and Merrill, 1965; Grommé et al., 1967; Hannah and Verosub, 1980; and Frei et al., 1982), it seems plausible that the southern N-NW trending part of the KM has not experienced any rotation since the Middle Jurassic intrusion of plutons. It has been shown in this interpretation of the PM data that the discordances observed for the southerly plutons can be accounted for by post-intrusional tilting, whereas those observed for the more northerly plutons intruded into the N-NE trending part of the province are believed to be primarily the result of clockwise rotation. One possible explanation of these observed PM directions and the regional trend of the KM is the rotation of only the northern portion of the province, perhaps in response to Tertiary rotation of the Oregon Coast Range, resulting in the deformation of a "Klamath orocline".

Effect of Present Data on Existing Models

The two phase rotation model for the Oregon Coast Range offered by Magill et al. (1981) does not require any Phase I rotation of the Klamath Mountain province during the time period of 50-42 m.y.B.P. Rather, it remained fixed in a northwest trending position straddling the present Oregon-California-Nevada borders (Figure 8A). The proposed Phase II, however, requires that the KM province participated in the ~30° of post-25 m.y.B.P. clockwise rotation of the Oregon Coast Range and Cascades. If interpretation I of the present data is accepted and the KM block has been rotated 87°±18° since Middle Jurassic time, then approximately 60° of the total clockwise rotation determined for the Klamath Mountains occurred between Middle Jurassic time and the beginning of Phase II rotation, active from 20 m.y.B.P. to the present. The results of this study can be used to generalize the

Magill et al. model by recognizing that at least part of the KM province participated in Phase I rotation and that it is possible that some KM rotation (∿10°) may have occurred prior to the Lower Eocene.

The results of Mankinen and Irwin (1982) and Mankinen et al. (1982) suggest that at least the eastern Klamath subprovince was not a part of the semi-rigid OCR block, and its rotation may have been independent of the remainder of the KM province. As stated previously, the findings of these studies indicate that clockwise rotation of the eastern Klamath belt (100° post-Permian, 50° of which is post-Jurassic) must have been completed prior to deposition of the Upper Cretaceous Great Valley sequence and other sediments, which show no significant rotation (11.5° ±15.8°, Mankinen and Irwin, 1982). Taken at face value, the results of Mankinen and Irwin (1982) might indicate that most of the rotation recorded by the Jurassic plutons occurred prior to the deposition of the Great Valley sediments, or that the extreme southern part of the province where Mankinen and Irwin sampled is decoupled from the northern part of the province sampled for this study. But the actual rotation of these Upper Cretaceous sediments, or lack thereof, is difficult to assess due to the remagnetization to which the majority have been subjected.

In Hamilton's (1969) configuration for Late Cretaceous Cordilleran North America (Figure 3), the Klamath Mountains are considered to have been part of a continuous metamorphic belt parallel to a line of Cretaceous batholiths including those of the Sierra Nevada, northwestern Nevada, and Idaho. The Klamath Mountains are depicted with a N-NE trend, with respect to the Late Cretaceous pole, and comprise the southern portion of an eastward bulge of these belts. Again assuming the 87° of post-Jurassic clockwise rotation of interpretation I, the PM data of this study suggest that the original Middle to Late Jurassic orientation of the KM was nearly perpendicular to that envisioned by Hamilton. Taking into account the ~60° of post-Upper Triassic rotation of the Blue Mountains of eastern Oregon (Wilson and Cox, 1980), the portion of the metamorphic and eugeosynclinal belts which are shown in Hamilton's model as an eastward bulge would be more accurately depicted as a westward bulge.

Summary of Interpretations

The geologic complexity of the Klamath Mountains provides challenging problems in interpretation of the paleomagnetic results obtained from the five Middle Jurassic plutons examined in this study. On the basis of these data, speculations can be made on the tectonic history of Klamath Mountains since the time of intrusion (~140-160 m.y.B.P.). Except for the Ashland pluton which has a concordant PM direction, the plutons examined possess PM directions that are clockwise rotated by 67° to 113° with respect to coeval directions expected for the stable North American craton. Concordant inclinations for all plutons suggest that the Klamath Mountains have not been transported along lines of longitude since Middle Jurassic time.

In interpretation I, the discordances in PM directions are believed to have resulted from 87°±18° of post-Middle Jurassic clockwise rotation of a semi-rigid tectonic block which includes the Grants

Pass, Greyback, Slinkard and Wooley Creek plutons. The presence of KM derived Tertiary sediments in the adjacent Oregon Coast Range, the possible onlap of Coast Range rocks on the Klamath Mountain terranes, and similar amounts of clockwise rotation of the KM and OCR provinces ($77° \pm 16°$ for the oldest Oregon Coast Range rocks) suggest that the two provinces have rotated together since Lower Eocene time (~55 m.y.B.P.). The additional 10° of clockwise rotation (if significant) observed for the Klamath Mountains, however, suggests that the Klamaths may have begun rotating prior to formation of the oldest Oregon Coast Range rocks.

Although the four discordant paleomagnetic directions are averaged to obtain a mean direction, and the rotated block is assumed in interpretation I to have undergone no significant internal deformation since the time of pluton intrusion, the differences in rotations for the individual plutons might actually reflect differential rotation of smaller tectonic blocks. Similarly, the concordant direction of the Ashland pluton may be suggestive of a different tectonic history of the terranes into which it was intruded. There are no known surface expressions of faults to delineate smaller tectonic blocks. All five plutons were intruded into the western Paleozoic and Triassic subprovince of the Klamath Mountains.

Perhaps the greatest difficulty in interpreting the paleomagnetic data presented in this study arises from the lack of structural control for these plutons. The plutons are massive, and the metamorphic nature of host terranes further obscures any indication of paleohorizontal. The Late Cretaceous sediments of the Hornbrook

Formation, which flank the eastern margin of the Ashland pluton, are the only known unmetamorphosed rocks in contact with any of these plutons and indicate a post-Late Cretaceous tilt of ∿17° toward N58°E for the Ashland pluton. However, additional tilt may have occurred during the ∿60 m.y. post-intrusional, pre-depositional interval. In interpretation II it is demonstrated that the discordant directions for the more southerly plutons (Wooley Creek/Slinkard, Ashland, and, in part, Greyback) may be attributed to tilting, consistent with geologic observations which suggest the post-intrusional uplift of the domal Condrey Mountain Schist. Geologic field observations also suggest that the terranes surrounding the CMS and intruded by the plutons may have been tilted away from the center of CMS uplift in response to its uplift. In addition, a southwesterly tilt of ∿35° for the Wooley Creek batholith was calculated by Barnes (1982) from P-T estimates of contact metamorphic mineral assemblages adjacent to the batholith. Structural corrections required for restoration of the observed directions to the respective expected directions are consistent with these observations, but the actual magnitudes and directions of tilts are poorly constrained. Further geologic investigations are needed in order to better determine the tilt corrections which should be applied to the paleomagnetic directions for these plutons.

If tilt is disregarded and interpretation I is considered correct, the paleomagnetic results presented in this study suggest that the Klamath Mountains may have rotated with the Oregon Coast Range during the Tertiary. If so, at least part of the Klamath Mountain province rotated clockwise during Phase I (50-42 m.y.B.P.)

of the two phase model of Magill et al. (1981), and rotation of the Klamaths may have begun prior to the formation of the oldest Oregon Coast Range rocks ($\sim$55 m.y.B.P.). Counterclockwise rotation of the Klamaths restores the province to a roughly W-NW trending position, in contrast to its northeasterly trend in Hamilton's (1969) paleogeographic reconstruction, suggesting that the easterly bend of the Late Cretaceous orocline in the region of the Pacific Northwest was more likely to the west.

REFERENCES CITED

Allen. C.M., Intrusive relations and petrography of the Slinkard pluton, central Klamath Mountains, California, M.S. thesis, 120 pp., Univ. of Oregon, Eugene, Oregon, 1981.

Allen, C.M., C.G. Barnes, M.A. Kays, and J.B. Saleeby, Comagmatic nature of the Wooley Creek batholith and the Slinkard pluton and age constraints on tectonic and metamorphic events in the western Paleozoic and Triassic belt, Klamath Mountains, N. California (abstract), Geol. Soc. Am. Abstr. Programs, 14(4), 145, 1982.

Atwater, T., Implications of plate tectonics for the Cenozoic tectonic evolution of western North America, Geol. Soc. Amer. Bull., 81, 3513-3536, 1970.

Ando, C.J., P. Cashman, and G.A. Davis, Structural and stratigraphic equivalence of the Stuart Fork, North Fork, and Hayfork terranes, central Klamath Mountains, California (abstract), Geol. Soc. Amer. Abstr. Programs, 8(3), 349-350, 1976.

Baldwin, E.M., Thrust faulting in the Roseburg area, Oregon, Ore Bin, 26, 176-184, 1964.

Baldwin, E.M., Eocene stratigraphy of southwestern Oregon, Ore. Dep. Geol. Mineral Ind. Bull., 83, 40pp., 1974.

Barnes, C.G., Geology and petrology of the Wooley Creek batholith, Klamath Mountains, northern California, Ph.D. dissertation, 214 pp., Univ. of Oregon, Eugene, Oregon, 1982.

Barnes, C.G., R.C. Jachens, and M.M. Donato, Evidence for basal detachment of the western Paleozoic and Triassic belt, northern Klamath Mountains, California (abstract), Geol. Soc. Am. Abstr. Programs, 14(4), 147, 1982.

Bates, R.G., M.E. Beck, Jr., and R.W. Simpson, Preliminary paleomagnetic results from the southern Cascade Range of southwestern Washington, EOS Trans. AGU, 60(46), 816-817, 1979.

Bates, R.G., M.E. Beck, Jr., and R.F. Burmester, Tectonic rotations in the Cascade Range of southern Washington, Geology, 9, 184-189, 1981.

Beck, M.E., Jr., Paleomagnetism of a thick Tertiary sequence in northern California, Rep. AFCRL 62-821, 45 pp., U.S. Air Force Cambridge Res. Lab., 1962.

Beck, M.E., Jr., Discordant paleomagnetic pole positions as evidence of regional shear in the western Cordillera of North America, Am. Jour. Sci., 276, 694-712, 1976.

Beck, M.E., Jr., Paleomagnetic record of plate-margin tectonic processes along the western edge of North America, J. Geophys. Res., 85(B12), 7115-7131, 1980.

Beck, M.E., Jr. and C.D. Burr, Paleomagnetism and tectonic significance of the Goble Volcanic Series, southwestern Washington, Geology, 7, 175-179, 1979.

Beck, M.E., Jr. and D.C. Engebretson, Paleomagnetism of small basalt exposures in the West Puget Sound area, Washington, and speculations on the accretionary origin of the Olympic Mountains, J. Geophys. Res., 87(B5), 3755-3760, 1982.

Beck, M.E., Jr., D.C. Engebretson, C.S. Grommé, E.M. Taylor, and J.W. Whitney, Paleomagnetism of Middle Tertiary Clarno Formation, north-central Oregon: constraint on models for tectonic rotation, EOS Trans. AGU, 59(12), 1058, 1978.

Beck, M.E., Jr. and P.W. Plumley, Paleomagnetism of intrusive rocks in the Coast Range of Oregon: Microplate rotations in middle Tertiary time, Geology, 8, 573-578, 1980.

Blake, M.C., Jr. and D.L. Jones, Tectonics of the Yolla Bolly junction and its significance to the tectonic history of northern California, Geol. Soc. Amer. Abstr. Programs, 9, 391, 1977.

Blake, M.C., Jr. and D.L. Jones, Plate tectonic history of the Yolla Bolly Junction, northern California, Guidebook for the 73rd Annual Meeting of the Cordilleran Section, Geol. Soc. Amer., Sacramento, California, 1977.

Bromery, R.W. and P.D. Snavely, Jr., Geologic interpretation of reconnaissance gravity and aeromagnetic surveys in northwestern Oregon, U.S. Geol. Surv. Bull., 1181-N, N1-N13, 1964.

Burchfiel, B.C. and G.A. Davis, Triassic and Jurassic tectonic evolution of the Klamath Mountains-Sierra Nevada geologic terrane, In: The Geotectonic Development of California, Rubey Vol. I, edited by W.G. Ernst, p. 50-70, Prentice-Hall, Englewood Cliffs, 1981.

Carey, S.W., The tectonic approach to continental drift, In: Continental Drift Symposium, Geology Dept., University of Tasmania, Hobart, 177-358, 1958.

Charlton, D.W., Geology of part of the Ironside Mountain quadrangle, northern California Klamath Mountains, Ph.D. dissertation, 542 pp., Univ. of California, Santa Barbara, California, 1979.

Clark, H.C., Remanent magnetism, cooling history, and paleomagnetic record of the Marys Peak sill, Oregon, J. Geophys. Res., 74, 3143-3160, 1969.

Cohee, G.V. (compiler), Tectonic map of the United States, exclusive of Alaska and Hawaii, U.S. Geol. Surv. and Amer. Ass. Petrol. Geol., Tulsa, Okla., 1962.

Cox, A., Remanent magnetization of Lower to Middle Eocene basalt flows from Oregon, Nature, 179, 685-686, 1957.

Cox, A. and J. Magill, Tectonic rotation of Oregon Coast Range, EOS Trans. AGU, 58(12), 1126, 1977.

Currie, R.G., C.S. Gromme, and J. Verhoogen, Remanent magnetization of some Upper Cretaceous granitic plutons in the Sierra Nevada, California, J. Geophys. Res., 68, 2263-2279, 1963.

Dalrymple, G.B., Critical tables for conversion of K-Ar ages from old to new constants, Geology, 7, 558-560, 1979.

Davis, G.A., Metamorphic and granitic history of the Klamath Mountains, In: Geology of Northern California: Cal. Div. Mines and Geology Bull., 190, 39-50, 1966.

Davis, G.A., Tectonic correlations, Klamath Mountains and western Sierra Nevada, California, Geol. Soc. Amer. Bull., 80, 1095-1108, 1969.

Davis, G.A., M.J. Holdaway, P.W. Lipman, and W.D. Romey, Structure, metamorphism, and plutonism in the southcentral Klamath Mountains, California, Geol. Soc. Amer. Bull., 74(3), 331-348, 1965.

Davis, G.A., C.J. Ando, P.H. Cashman, and L. Goullaud, Cross section of the central Klamath Mountains, California, Geol. Soc. Amer. Map and Chart Series, MC-281, 1979.

Dickinson, W.R., Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in western North America, Can. J. Earth Sci., 13, 1268-1287, 1976.

Doell, R.R. and A. Cox, Measurement of the remanent magnetization of igneous rocks, U.S. Geol. Survey Bull. 1203-A, 1-32, 1965.

Donato, M.M., The geology and petrology of a portion of the Ashland pluton, Jackson County, Oregon, M.S. thesis, 89 pp., Univ. of Oregon, Eugene, Oregon, 1975.

Dott, R.H., Geology of southwestern Oregon Coast, Bull. 69, State of Oregon, Dept. of Geol. and Min. Ind., 54-58, 1971.

Elliott, M.A., Stratigraphy and petrology of the Late Cretaceous rocks near Hilt and Hornbrook, Siskiyou County, California, and Jackson County, Oregon, Ph.D. thesis, 171 pp., Oregon State Univ., Corvallis, Oregon, 1971.

Fisher, R.A., Dispersion on a sphere, Proc. Royal Soc. London, Series A 217, 295-305. 1953.

Frei, L.S., J.R. Magill, and A.V. Cox, Paleomagnetic results from the central Sierra Nevada: constraints on reconstructions of the western United States, EOS Trans. AGU, 63(45), 916, 1982.

Globerman, B.R. and M.E. Beck, Jr., Cenozoic rotations of the western Cordillera: New evidence from the Washington Coast Range, EOS Trans. AGU, 60(46), 817, 1979.

Godchaux, M.M., Petrology of the Greyback igneous complex and contact aureole, Klamath Mountains, southwestern Oregon, Ph.D. dissertation, Univ. of Oregon, Eugene, Oregon, 1969.

Gray, G., personal communication, 1982, address: Department of Geological Sciences, Univ. Texas, Austin, Texas, 78712.

Grommé, C.S. and R.T. Merrill, Paleomagnetism of Late Cretaceous granitic plutons in the Sierra Nevada, California: further results, J. Geophys. Res., 70(14), 3407-3420, 1965.

Grommé, C.S., R.T. Merrill, and J. Verhoogen, Paleomagnetism of Jurassic and Cretaceous plutonic rocks in the Sierra Nevada, California, and its significance for polar wandering and continental drift, J. Geophys. Res., 72, 5661-5684, 1967.

Hamilton, W., Mesozoic California and the underflow of Pacific mantle, Geol. Soc. Amer. Bull., 80, 2409-2430, 1969.

Hamilton, W., Mesozoic tectonics of the western United States, In: D.G. Howell and K.A. McDougall (eds.), Mesozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium, 2, 33-72, Pacific Section, Soc. of Econ. Paleontol. and Mineral., Los Angeles, California, 1978.

Hamilton, W. and W.B. Myers, Cenozoic tectonics of the western United States, Rev. Geophysics, 4, 509-549, 1966.

Hanna, W.F., Paleomagnetism of Upper Cretaceous volcanic rocks of southwestern Montana, J. Geophys. Res., 72, 595-610, 1967.

Hannah, J.L. and K.L. Verosub, Tectonic implications of remagnetized Upper Paleozoic strata of the northern Sierra Nevada, Geology, 8, 520-524, 1980.

Harrison, C.G.A. and T. Lindh, A polar wandering curve for North America during the Mesozoic and Cenozoic, J. Geophys. Res., 87(B3), 1903-1920, 1982.

Helsley, C.E., Paleomagnetism of Cretaceous rocks from North America, EOS Trans. AGU, 48, 83-84, 1967.

Hillhouse, J.W., C.S. Grommé, and T.L. Vallier, Paleomagnetism and Mesozoic tectonics of the Seven Devils volcanic arc in northeastern Oregon, J. Geophys. Res., 87(B5), 3777-3794, 1982.

Hotz, P.E., Plutonic rocks of the Klamath Mountains, California and Oregon, U.S.G.S. Prof. Paper 684-B, 1971.

Hotz, P.E., Geology of the Yreka quadrangle, California, U.S.G.S. Bulletin 1436, 72 pp., 1977.

Hotz, P.E., Regional metamorphism in the Condrey Mountain quadrangle, north-central Klamath Mountains, California, U.S.G.S. Prof. Paper 1086, 1979.

Irwin, W.P., Geologic reconnaissance of the northern Coast Ranges and Klamath Mountains, with a summary of the mineral resources, Bull. Calif. Div. Mines Geol., 179, 1-80, 1960.

Irwin, W.P., Geology of the Klamath Mountain province, In: E.H. Bailey (ed.), Geology of northern California: California Div. Mines and Geology Bull., 190, 19-38, 1966.

Irwin, W.P., Terranes of the western Paleozoic and Triassic belt in the southern Klamath Mountains, California, U.S. Geol. Survey Prof. Paper 800-C, C103-111, 1972.

Irwin, W.P., Review of Paleozoic rocks of the Klamath Mountains, In: Paleozoic paleogeography of the western United States, edited by J.H. Stewart, C.H. Stevens, and A.E. Fritsche, Los Angeles: Society of Economic Paleontologists and Mineralogists, 1977.

Irwin, W.P., Tectonic accretion of the Klamath Mountains, In: The Geotectonic Development of California, Rubey Vol. I, edited by W.G. Ernst, p. 29-49, Prentice-Hall, Englewood Cliffs, N.J., 1981.

Kanter, L.R. and M.O. McWilliams, Rotation of the southernmost Sierra Nevada, California, J. Geophys. Res., 87(B5), 3819-3830, 1982.

Klein, C.W., Thrust plates of the north-central Klamath Mountains near Happy Camp, California, Calif. Div. Mines and Geol. Spec. Rep., 129, 23-26, 1977.

Lanphere, M.A., W.P. Irwin, and P.E. Hotz, Isotopic age of the Nevadan Orogeny and older plutonic and metamorphic events in the Klamath Mountains, California, Geol. Soc. Amer. Bull., 79, 1027-1052, 1968.

Lawrence, R.D., Strike-slip faulting terminates the Basin and Range province in Oregon, Geol. Soc. Amer. Bull., 87, 846-850, 1976.

Levi, S. and R.T. Merrill, A comparison of ARM and TRM in magnetite, Earth Planet. Sci. Lett., 32, 171-184, 1976.

Lovell, J.P.V., Tyee Formation: Undeformed turbidites and their lateral equivlents, mineralogy and paleogeography, Geol. Soc. Am. Bull. 80, 9-22, 1969.

Magill, J. and A. Cox, Tectonic rotation of the Oregon Western Cascades, Spec. Paper 10, 67 pp., Dept. of Geol and Mineral Ind., Portland, Oregon, 1980.

Magill, J. and A. Cox, Post-Oligocene tectonic rotation of the Oregon western Cascade Range and the Klamath Mountains, Geology, 9, 127-131, 1981.

Magill, J., A. Cox, and R. Duncan, Tillamook Volcanic Series: Further evidence for tectonic rotation of the Oregon Coast Range, J. Geophys. Res., 86(B4), 2953-2970, 1981.

Magill, J., R. Wells, R.W. Simpson, and A.V. Cox, Post 12 m.y. rotation of southwest Washington, J. Geophys. Res., 87(B5), 3761-3776, 1982.

Mankinen, E.A. and W.P. Irwin, Paleomagnetic study of some Cretaceous and Tertiary sedimentary rocks of the Klamath Mountains province, California, Geology, 10, 82-87, 1982.

Mankinen, E.A., W.P. Irwin, and C.S. Grommé, Tectonic rotation of the eastern Klamath Mountains terrane, California, EOS Trans. AGU, 63(45), 914, 1982.

Ramp, L., personal communication, 1982, address: Oregon Department of Geology and Mineral Industries, Grants Pass, Oregon.

Rimbert, F., Contributional'etude de l'action de champs alternatifs sur les aimantations remanentes des roches, applications l'geophysiques, Rev. Inst. Fr. Petrole, 14, 1-75, 1959.

Saleeby, J.B., personal communication, 1982, address: Div. of Geological and Planetary Sciences, Calif. Inst. Tech., Pasadena, Cal.

Schweickert, R.A., Early Mesozoic rifting and fragmentation of the Cordilleran orogen in the western USA, Nature, 260, 586-591, 1976.

Schweickert, R.A. and D.S. Cowan, Early Mesozoic tectonic evolution of the western Sierra Nevada, California, Geol. Soc. Amer. Bull., 86, 1329-1336, 1975.

Simpson, R.A. and A. Cox, Paleomagnetic evidence for tectonic rotation of the Oregon Coast Range, Geology, 5, 585-589, 1977.

Snavely, P.D., Jr., H.C. Wagner, and N.S. MacLeod, Rhythmic-bedded eugeosynclinal deposits of the Tyee Formation, Oregon Coast Range, Kans. Geol. Surv. Bull. 169, 11, 461-480, 1964.

Snoke, A.W., A thrust plate of ophiolitic rocks in the Preston Peak area, Klamath Mountains, California, Geol. Soc. Amer. Bull., 88, 1641-1659, 1977.

Streckeisen, A.L., Classification and nomenclature recommended by the IUGS subcommission of systematics of igneous rocks, Geotimes, 18(10), 26-30, 1973.

Suppe, J. and R.L. Armstrong, Potassium-argon dating of Franciscan metamorphic rocks, Am. Jour. Sci., 272, 217-233, 1972.

Wells, R. and R. Coe, Tectonic rotations in southwest Washington, EOS Trans. AGU, 61(46), 949, 1980.

Wilson, D. and A. Cox, Paleomagnetic evidence for tectonic rotation of Jurassic plutons in Blue Mountains, eastern Oregon, J. Geophys. Res., 85(B7), 3681-3689, 1980.

Wright, J.E., Geology and U-Pb Geochronology of the Western Paleozoic and Triassic subprovince Klamath Mountains, northern California, Ph.D. dissertation, 300 pp., Univ. California, Santa Barbara, California, 1981.

APPENDICES

APPENDIX A

Statistical Measures of Data Reliability

Stable paleomagnetic directions of samples within a site were averaged by the method of Fisher (1953) to give a site mean direction. The goodness of the data are described by two calculated statistical parameters, k and α_{95}:

k The precision parameter, κ, determines the dispersion of points on a sphere. $\kappa=0$ for a uniform distribution (random directions) whereas κ is large when points cluster about the true mean. The best estimate of κ is given by Fisher (1953) for $k>3$ as

$$k=(N-1)/(N-R),$$

where N is the number of directions and R is the length of the vector sum of direction cosines characterizing a direction of magnetization.

α_{95} The true mean direction of a population of N directions lies within a circular cone about the resultant vector R with a semi-angle α at a probability level (1-P) for $k>3$, where

$$\cos \alpha_{(1-P)} = 1- \frac{N-R}{R} \left[(1/P)^{1/(N-1)}-1\right]$$

and P is taken as 0.05.

APPENDIX B

Summary of Paleomagnetic Data for All Samples from Klamath Mountain Plutons

Paleomagnetic data for all samples measured in this study are tabulated alphabetically by pluton and numerically by site.

Explanation

SAMPLE #	Year, site, core, sample. #1 samples are those nearest to the surface of the outcrop. * denotes samples used in site mean calculation.
J_{NRM}	NRM intensity in Gauss (emu/cc). Exponent may vary from site to site.
MDF	Median destructive field (Oe).
QUALITY	Assignment of quality factors is discussed in text.
AF LEVELS	AF levels (Oe) vectorally averaged to give D_S, I_S for that sample. Number in ( ) refers to number of levels used to determine mean, inclusive of end points. An 'OMITTED' sample possesses either an anomalous direction or a more stable companion that was included in the site mean.
D_S, I_S	Stable declination and inclination for sample computed over designated interval of AF LEVELS.
α_{95}'/k'	α_{95}' = angular radius of the 95% circle of confidence. $k' = (N' - 1)/(N' - R)$ = precision parameter associated with D_S, I_S of each sample in the designated interval. Both are denoted by ($'$) to signify that directions at different AF levels for a particular sample are not independent vectors, α_{95}' usually $< 10°$ for AA, $<15°$ for A, and $<20°$ for B samples.

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
ASH 1 (OMITTED)							
80,4,1,1*	131 E-6	74	1F,B	25-150(5)	056.7	+15.7	2°/1615
80,4,3,1	443	108	2F,AA	100(1)	043.5	-32.6	
80,4,4,1*	7	95	1F,C/D	75-100(2)	085.4	+31.1	11°/478
80,4,5,1	0.69	25	1F,C	OMIT			
80,4,5,2	0.89	86	1F,B/C	12.5-75(4)	346.4	+59.2	7°/152
80,4,6,1*	0.91	110	1F,A	25-150(5)	052.2	+52.2	7°/119
80,4,6,2	0.74	>500	1F,B/C	12.5-75(4)	036.7	+25.4	9°/104
80,4,7,1	0.80	>300	1F,B	100-200(3)	233.9	+59.2	16°/63
ASH 3							
81,1,1,2	0.74 E-4	83	2F,A/B	50-150(4)	061.3	-40.9	3°/874
81,1,2,2*	0.15	46	1F,B/C	12.5-75(4)	313.0	+73.8	16°/32
81,1,3,2*	0.30	40	1F,B/C	50-250(6)	303.9	+36.4	14°/24
81,1,4,1	0.49	49	1F,B	OMIT			
81,1,4,2*	0.50	41	1F,B	50-100(3)	313.2	+25.2	9°/172
81,1,5,1*	0.15	39	1F,B/C	50-100(3)	329.1	+58.7	9°/176
81,1,5,2	0.24	41	1F,C	OMIT			
81,1,6,2*	0.48	43	1F,B/C	12.5-100(5)	014.9	+61.9	7°/113
81,1,7,1*	0.12	39	1F,B/C	50-100(3)	340.8	+39.6	13°/93
81,1,7,2	0.07	34	1F,C/D	OMIT			
ASH 4							
81,12,1,2*	0.58 E-4	39	1F,B	75-150(3)	286.0	+67.4	17°/54
81,12,2,2*	0.54	40	1F,B/C	50-150(4)	295.3	+37.8	9°/109
81,12,3,2*	0.62	42	1F,B/C	50-150(4)	302.7	+43.7	15°/38
81,12,4,1	13.8	80	2F,AA	300(1)	095.6	-16.1	
81,12,4,2	12.5	83	2F,AA	300(1)	092.1	-06.6	
81,12,5,2*	1.39	63	1F,A	150-250(3)	349.0	+64.5	6°/386
81,12,6,2*	0.98	49	1F,A	100-250(4)	334.4	+62.5	3°/1339
81,12,7,1*	0.44	38	1F,B	50-250(6)	264.7	+73.7	10°/62
81,12,7,2	0.27	47	1F,B/C	75-150(3)	342.0	+15.5	20°/38
81,12,8,2*	0.67	41	1F,B	100-200(3)	004.1	+55.5	11°/122
81,12,9,2*	0.92	55	1F,A	50-150(4)	032.4	+60.9	1°/4757
ASH 5							
81,13,1,1	0.91 E-4	59	1F,B	50-100(3)	302.8	-24.9	3°/2061
81,13,1,2	1.06	73	1F,AA	75(1)	303.2	-21.8	
81,13,2,2*	0.40	44	1F,B	75-150(3)	265.4	+51.9	16°/62
81,13,3,2*	0.57	41	1F,A	50-250(6)	324.5	+64.0	6°/141
81,13,4,1*	0.29	47	2F,B/C	50-100(3)	301.4	+36.7	10°/150
81,13,4,2	0.45	43	2F,B	50-100(3)	292.4	+28.0	5°/524
81,13,5,1*	0.11	56	1F,B	50-200(5)	278.0	+55.7	12°/42
81,13,5,2	0.13	40	1F,B/C	150-250(3)	260.4	+38.8	17°/55
81,13,6,2	0.17	43	1F,C	OMIT			
81,13,7,2*	0.11	42	1F,B	75-200(4)	305.6	+63.9	13°/48
81,13,8,1*	0.25	44	1F,B	50-100(3)	298.1	+74.0	7°/331
81,13,8,2	0.27	37	1F,B/C	75-150(3)	237.5	+22.8	8°/222
81,13,9,2*	0.08	61	1F,B/C	50-200(5)	353.5	+57.9	13°/38

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
ASH 6							
81,14,1,2*	154 E-5	51	1F,AA	50(1)	001.6	+60.5	
81,14,2,2*	28.3	42	1F,AA	50(1)	324.1	+61.2	
81,14,3,2*	11.4	58	1F,A	75-250(5)	327.9	+44.9	4°/318
81,14,4,2*	0.12	>300	1F,AA	300(1)	345.4	+57.2	
81,14,5,2*	0.39	>300	1F,AA	300(1)	330.7	+66.5	
81,14,6,1*	5.60	45	1F,A/B	50-150(4)	351.2	+44.9	11°/65
81,14,7,2*	0.99	200	2F,AA	200(1)	001.0	+73.6	
81,14,8,1	1.02	136	2F,B/C	OMIT			
81,14,8,2*	1.07	139	2F,B	500-900(3)	112.0	-62.2	21°/37
81,14,9,1*	0.36	160	1F,B/C	75-200(4)	345.5	+66.3	4°/473
81,14,9,2	0.25	131	1F,B/C	300-900(4)	107.7	-66.0	23°/16
ASH 7							
81,17,1,2	0.14 E-5	141	2F,B/C	OMIT			
81,17,2,2*	0.11	60	2F,B/C	150-300(4)	203.8	-66.3	15°/39
81,17,3,2*	0.47	189	1F,A	50-200(5)	039.3	+78.0	5°/213
81,17,4,2	0.11	>900	2F,B/C	OMIT			
81,17,5,2*	0.37	>300	1F,B/C	75-300(6)	080.0	-84.3	5°/164
81,17,6,2*	1.09	68	1F,A	75-200(4)	354.3	+58.2	4°/466
81,17,7,2*	1.09	>300	2F,AA	300(1)	197.9	-81.3	
81,17,8,2*	1.05	>300	1F,AA	300(1)	115.8	-74.9	
81,17,9,2*	2.48	>300	2F,AA	300(1)	163.9	-72.5	
81,17,10,1	10.4	35	1F,B/C	50-100(3)	261.2	+42.4	23°/30
81,17,10,2	5.36	36	1F,B/C	150-250(3)	175.3	+58.6	49°/7
81,17,11,2*	7.47	49	2F,A	50-300(7)	290.0	+63.7	7°/69
81,17,12,2*	9.35	44	1F,B	50-200(5)	326.5	+64.3	7°/169
81,17,13,2*	1.08	28	1F,B	75-300(6)	119.9	-83.1	8°/65
ASH 8							
81,27,1,2*	0.74 E-6	118	1F,B	50-100(3)	331.6	+48.0	27°/21
81,27,2,1*	2.01	282	2F,B	75-150(3)	355.8	+65.2	13°/89
81,27,2,2	2.79	61	2F,B	50-150(4)	042.9	+47.8	19°/23
81,27,3,2*	5.03	111	2F,A	50-150(4)	012.5	+60.0	6°/208
81,27,4,2*	1.13	44	1F,B	50-250(6)	324.6	+50.1	18°/14
81,27,5,2*	2.00	129	1F,B	75-250(5)	330.1	+76.4	17°/20
81,27,6,2*	1.39	>300	1F,B/C	100-200(3)	275.7	+52.0	19°/42
81,27,7,2*	4.37	154	2F,A/B	50-200(5)	312.9	+68.9	9°/72
81,27,8,2	0.28	>300	2F,C/D	75-200(4)	344.4	+16.7	41°/6
81,27,9,2*	0.19	>300	1F,B	100-250(4)	303.8	+60.7	15°/39
ASH 9 (OMITTED)							
81,28,1,2	0.30 E-6	weak	1F	Stable directions could not be determined.			
81,28,2,2	0.33	weak	1F				
81,28,3,2	0.36	65	1F,C/D				
81,28,4,2	8.66	44	1F,B/C				
81,28,5,2	0.23	>300	1F,C				
81,28,6,2	0.61	>300	2F,C				

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
81,28,7,2	0.17	>1000	1F,B				
81,28,8,1	0.98	>900	1F,B/C				
81,28,8,2	0.64	>300	1F,B/C				
81,28,9,1	0.37	weak	1F				
81,28,9.2	0.27	weak	1F				
GM 1							
79,2,1,1*	0.67 E-5	465	1F,A	150-300(4)	117.1	+67.3	7°/171
79,2,1,2	0.98	>600	1F,A	150-300(4)	064.2	+69.7	6°/232
79,2,2,1*	1.64	316	1F,A	150-300(4)	066.3	+69.0	7°/157
79,2,3,1	0.16	>600	1F,B/C	50-200(5)	028.0	+49.0	6°/163
79,2,4,1*	0.12	>600	1F,A	50-300(7)	080.9	+64.0	8°/52
79,2,4,2	0.18	519	1F,B	50-250(6)	126.0	+58.8	14°/23
79,2,5,1*	0.52	600	1F,AA	600(1)	039.8	+81.5	
79,2,6,1*	0.61	378	1F,A	150-300(4)	053.0	+81.2	5°/395
79,2,7,1*	1.63	>300	2F,AA	300(1)	098.0	+59.5	
79,2,7,2	2.00	>600	2F,AA	600(1)	097.0	+63.5	
79,2,8,1*	0.12	>300	1F,A	150-300(4)	091.4	+75.6	7°/180
79,2,9,1*	0.29	>300	1F,A	150-300(4)	066.6	+72.5	4°/429
79,2,9,2	0.24	>300	1F,A	150-300(4)	090.9	+80.4	6°/219
GM 2							
80,6,1,1*	1.26 E-4	460	1F,AA	500(1)	050.1	+74.9	
80,6,1,2	1.23	464	1F,AA	500(1)	055.5	+79.8	
80,6,2,1	47.2	46	2F,B	400-900(5)	263.2	-46.5	14°/32
80,6,2,2	30.5	77	2F,B	250-500(4)	300.0	+43.1	7°/196
80,6,3,1*	0.61	142	2F,A	150-300(4)	341.4	+75.6	2°/1622
80,6,3,2	0.36	200	2F,A	150-300(4)	307.4	+68.5	5°/310
80,6,4,1	0.48	71	2F,B	150-300(4)	298.9	+67.1	3°/777
80,6,5,1*	3.96	79	2F,B	150-300(4)	246.5	-51.9	1°/6195
80,6,5,2	6.84	41	2F,A	50-150(7)	308.0	-47.7	4°/500
80,6,6,1*	2.03	36	1F,A	150-300(4)	054.8	+82.0	2°/1925
80,6,6,2	2.34	35	1F,A	150-300(4)	080.9	+80.0	3°/1286
80,6,7,1*	5.70	44	2F,A	150-300(4)	114.0	+73.0	4°/645
80,6,8,1*	3.13	270	1F,AA	300(1)	252.2	-52.8	
80,6,9,1*	1.17	666	1F,AA	300(1)	255.1	-55.5	
GM 3							
80,7,1,1	1.86 E-3	57	1F,A/B	50-150(3)	195.3	+20.1	7°/315
80,7,1,2	1.74	53	1F,A/B	200-300(3)	162.2	+55.2	13°/86
80,7,2,1*	0.12	265	2F,A	200-300(3)	063.4	+63.2	2°/2773
80,7,3,1*	0.11	288	3F,AA	200-300(3)	062.1	+63.4	2°/6340
80,7,4,1	0.13	29	1F,A/B	50-300(7)	277.3	+75.0	5°/126
80,7,4,2	0.11	24	1F,A	75-200(4)	074.4	+19.1	4°/612
80,7,5,1*	0.15	278	2F,A	150-250(3)	059.0	+74.7	12°/102
80,7,6,1*	0.55	359	2F,AA	300(1)	246.0	-47.0	
80,7,6,2	0.84	345	2F,AA	300(1)	251.8	-43.3	
80,7,7,1*	0.36	433	2F,AA	300(1)	261.5	-46.9	

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}′/k′
80,7,8,1*	1.39	381	1F,AA	300(1)	246.2	-41.2	
80,7,8,2	0.19	468	1F,AA	500(1)	258.6	-33.4	
80,7,9,1*	0.55	445	1F,AA	300(1)	236.1	-49.6	
80,7,10,1	9.12	84	1F,A	OMIT- 1" FROM CORE 1 IN OUTCROP - USED AS CHECK.			
80,7,11,1*	0.10	>250	1F,A	150-250(3)	063.1	+63.2	2°/4673
GM 4							
80,8,1,1	0.64 E-5	68	2F,B/C	50-200(5)	222.4	+26.6	4°/368
80,8,1,2	0.32	62	2F,B/C	25-100(4)	186.4	+41.2	9°/112
80,8,2,1*	0.14	118	2F,B/C	150-300(4)	286.8	-42.4	11°/73
80,8,3,1*	0.23	425	1F,A	50-300(7)	289.3	-35.5	3°/343
80,8,3,2	0.18	235	1F,B/C	50-200(5)	263.8	-39.5	8°/100
80,8,4,1*	0.34	34	1F,B/C	100-250(4)	274.7	-29.2	8°/134
80,8,4,2	0.08	180	1F,B/C	25-200(6)	268.1	-39.5	4°/353
80,8,5,1	0.19	78	1F,C/D	OMIT			
80,8,5,2	0.13	68	1F,C/D	OMIT			
80,8,6,1	0.17	83	2F,C/D	OMIT			
80,8,6,2	0.14	88	2F,C/D	OMIT			
80,8,7,1*	3.69	619	1F,AA	300(1)	278.9	-50.9	
80,8,7,2	2.14	>300	1F,AA	300(1)	278.7	-37.5	
80,8,8,1*	3.66	251	2F,AA	300(1)	281.0	-48.9	
80,8,8,2	5.49	138	2F,A	150-300(4)	276.9	-52.3	3°/1011
80,8,9,1*	5.25	32	2F,A/B	75-300(6)	278.7	-16.0	5°/169
80,8,9,2	3.74	42	2F,B	200-300(3)	282.8	-14.5	10°/158
80,8,10,1*	7.66	275	2F,A	50-300(7)	280.8	-53.0	1°/4667
GM 5							
81,21,1,2*	0.26 E-4	180	1F,AA	200(1)	077.9	+46.1	
81,21,2,2*	0.44	259	3F,A	12.5-100(5)	054.7	+83.3	4°/423
81,21,3,2*	0.30	90	1F,A	100-200(3)	063.3	+71.2	3°/1741
81,21,4,2*	3.42	42	1F,A	150-250(3)	025.9	+81.6	14°/76
81,21,5,1	2.57	40	2F,B	50-250(5)	087.5	+40.4	15°/27
81,21,5,2*	2.87	32	2F,B	100-250(4)	188.5	+88.4	24°/16
81,21,6,2*	2.33	37	1F,B	50-200(4)	034.4	+50.1	10°/92
81,21,7,1	0.39	51	1F,C	OMIT			
81,21,7,2	0.56	42	1F,C	OMIT			
81,21,8,1	1.02	45	3F,C	OMIT			
81,21,8,2	1.11	42	3F,B	150-250(3)	215.6	+62.1	11°/137
81,21,9,2*	1.00	121	3F,B	100-250(4)	052.9	+63.1	5°/404
GM 6 (OMITTED)							
81,22,1,2	0.41 E-5	274	2F,D	Stable directions could not be determined.			
81,22,2,2	0.19	>700	2F,D				
81,22,3,2	0.26	>700	1F,C/D				
81,22,4,2	1.07	271	1F,D				
81,22,5,2	0.21	>700	1F,D				
81,22,6,2	0.50	625	2F,D				

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
81,22,7,2	1.78	178	1F,D				
81,22,8,2	1.25	43	2F,D				
81,22,9,2	1.08	>700	1F,D				
GM 7							
81,23,1,2*	349 E-6	79	1F,AA	100(1)	053.5	+66.1	
81,23,2,1	12.1	282	2F,D	50-150(4)	166.3	-66.8	12°/60
81,23,2,2	7.30	183	2F,C/D	OMIT			
81,23,3,1*	0.64	>300	1F,A	75-200(4)	149.2	+79.5	6°/238
81,23,3,2	0.37	97	1F,B	50-150(3)	148.2	+48.9	14°/42
81,23,4,1	7.74	>300	2F,B/C	75-150(3)	353.3	-08.4	30°/18
81,23,4,2	12.9	266	2F,D	OMIT			
81,23,5,2*	1.57	>700	1F,B	150-300(3)	288.2	-65.2	17°/31
81,23,6,2*	0.76	>700	2F,B/C	50-250(5)	342.0	-34.8	15°/25
81,23,7,2*	48.2	99	2F,AA	100(1)	082.3	+71.3	
81,23,8,2*	2.36	604	2F,A/B	100-250(4)	153.3	+41.0	4°/525
GM 8							
81,24,1,1*	0.87 E-5	>300	1F,AA	50-150(4)	087.6	+66.8	3°/757
81,24,1,2	2.86	>900	1F,B	50-150(4)	190.6	+55.8	9°/103
81,24,2,2*	15.9	45	2F,B	50-150(4)	084.2	+43.1	19°/24
81,24,3,1	17.3	55	1F,B	100-250(4)	018.0	+80.0	11°/69
81,24,3,2*	9.70	58	1F,A/B	50-150(4)	011.1	+59.9	3°/1353
81,24,4,2*	3.71	54	1F,B/C	50-100(3)	059.6	+74.3	7°/344
81,24,5,2*	13.8	50	1F,B	50-100(3)	079.8	+60.9	12°/109
81,24,6,1	0.03	>300	1F,B/C	OMIT			
81,24,6,2*	1.27	>300	1F,B	50-100(3)	104.3	+70.6	10°/146
81,24,7,1	0.52	60	2F,C	50-150(4)	017.3	+35.7	10°/91
81,24,7,2	1.75	700	2F,C	50-200(5)	111.9	+28.4	14°/32
7,1 & 7,2 *	(average)				067.1	+42.7	180°/3
81,24,8,1*	0.22	41	1F,A	50-150(4)	061.0	+71.7	8°/139
81,24,8,2	0.03	46	1F,D	OMIT			
81,24,9,1*	0.33	>1000	1F,B/C	500-1000(4)	215.7	-40.8	20°/23
81,24,9,2	0.44	63	1F,D	OMIT			
GM 9							
81,25,1,1	16.2 E-5	125	1F,AA	150-200(3)	056.9	+76.8	4°/980
81,25,1,2*	26.6	78	1F,AA	75(1)	063.9	+82.3	
81,25,2,2*	0.46	300	1F,A/B	75-250(5)	284.0	-20.6	5°/227
81,25,3,1	0.83	>300	1F,AA	300(1)	010.7	+65.9	
81,25,3,2*	0.48	294	1F,AA	300(1)	356.8	+61.3	
81,25,4,1	0.05	>900	1F,C/D	OMIT			
81,25,4,2	0.06	158	1F,C/D	50-100(3)	260.6	-13.6	17°/51
81,25,5,2*	9.51	87	1F,A	300-900(4)	294.0	-43.0	13°/50
81,25,6,2*	4.36	79	1F,A	300-900(4)	290.0	-41.0	18°/26
81,25,7,2*	1.16	330	2F,AA	300(1)	273.6	-26.8	
81,25,8,2*	79.0	45	1F,A	75-200(4)	354.4	+51.7	4°/554

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
GM 10							
81,26,1,1*	0.87 E-5	45	1F,B	100-200(3)	073.1	+77.3	14°/79
81,26,1,2	0.85	40	1F,A	50(1)	212.0	+75.2	
81,26,2,2*	0.35	>250	2F,AA	250(1)	101.6	+56.2	
81,26,3,1	0.35	135	1F,B	200-300(3)	261.3	+14.0	12°/104
81,26,3,2	0.33	234	1F,A/B	50-150(4)	279.7	-14.8	10°/88
81,26,4,1	7.74	62	1F,A	50-200(5)	284.2	+12.1	2°/1041
81,26,4,2	8.73	154	1F,A	100-250(4)	292.5	+14.1	3°/1432
81,26,5,1*	0.03	>250	2F,B	50-100(3)	079.9	+41.5	15°/72
81,26,5,2	0.03	>300	2F,A	50-250(6)	017.1	+38.5	5°/126
81,26,6,2*	0.44	60	1F,A	100-300(5)	040.4	+68.5	7°/134
81,26,7,2*	0.45	46	1F,A/B	75-200(4)	108.5	+81.0	9°/108
81,26,8,2*	0.20	128	1F,B	100-300(5)	098.7	+57.0	10°/55
81,26,9,1*	0.29	56	1F,B	75-150(3)	099.7	+46.3	10°/154
81,26,9,2	0.19	132	1F,C	150-250(3)	066.4	+31.3	30°/18
GPE 1							
79,3,1,1*	0.20 E-3	97	1F,AA	100(1)	350.3	+65.1	
79,3,1,2	0.81	72	1F,AA	75(1)	015.1	+55.9	
79,3,2,1*	0.34	60	1F,AA	75(1)	018.2	+63.5	
79,3,2,2	0.27	92	1F,AA	100(1)	008.8	+61.5	
79,3,3,1*	0.18	84	1F,AA	100(1)	008.2	+61.5	
79,3,3,2	0.25	84	1F,AA	100(1)	014.8	+63.3	
79,3,4,1*	0.17	69	2F,A	50-250(6)	348.1	+57.7	6°/118
79,3,4,2	0.23	55	2F,A/B	50-100(3)	343.8	+15.6	2°/2899
79,3,5,1*	0.19	88	1F,A/B	75(1)	035.4	+60.4	
79,3,5,2	0.13	81	1F,B	75(1)	019.3	+52.6	
79,3,6,1*	0.08	88	2F,B/C	100(1)	075.8	+57.3	
79,3,6,2	0.17	76	2F,B	250-600(5)	236.2	-56.8	10°/65
79,3,7,1*	0.08	49	1F,B/C	100(1)	334.6	+65.2	
79,3,7,2	0.03	86	1F,C	OMIT			
GPN 1 (OMITTED)							
79,4,1,1	0.12 E-4	38	1F,B	100-350(6)	326.2	+23.8	10°/42
79,4,1,2	0.12	37	1F,B/C	25-100(4)	357.5	-34.0	17°/29
79,4,2,1	0.04	63	1F,C	50-200(5)	326.9	+16.1	30°/7
79,4,2,2	0.13	24	1F,B/C	25-100(4)	060.2	+36.9	19°/25
79,4,3,1	0.07	70	1F,B/C	100-250(4)	200.0	+48.3	30°/10
79,4,3,2	0.08	22	1F,C	75-150(3)	293.6	-15.9	20°/41
79,4,4,1	0.11	101	1F,B/C	150-300(4)	195.5	+32.2	25°/26
79,4,4,2	0.14	42	1F,C	OMIT			
79,4,5,1	0.13	54	1F,C	OMIT			
79,4,5,2	0.17	23	1F,C	75-300(6)	115.2	+64.1	21°/11
79,4,6,1	0.11	101	2F,C	50-100(3)	038.5	+04.3	3°/1541
79,4,6,2	0.10	33	2F,C	OMIT			

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
GPW 1							
81,18,1,2*	0.57 E-4	290	2F,AA	200(1)	066.5	+63.2	
81,18,2,2*	0.51	182	1F,AA	200(1)	067.4	+68.5	
81,18,3,2*	0.94	>250	1F,AA	200(1)	059.8	+64.2	
81,18,4,2*	0.34	250	1F,AA	200(1)	056.2	+58.0	
81,18,5,2	0.35	>900	2F,B/C	500-900(3)	146.0	-56.7	20°/38
81,18,6,2*	0.43	>250	2F,AA	200(1)	037.3	+61.5	
81,18,7,2*	0.36	165	1F,AA	200(1)	050.7	+71.5	
81,18,8,2	0.23	35	1F,B	500-900(3)	349.4	+77.0	15°/73
81,18,9,2	0.10	45	1F,B	50-150(4)	329.9	+77.4	9°/103
81,18,10,2*	0.67	127	1F,AA	200(1)	042.7	+69.3	
GPW 2							
82,1,1,2*	2.32 E-4	75	1F,AA	200(1)	043.1	+69.8	
82,1,2,2*	2.10	59	1F,AA	200(1)	038.7	+67.1	
82,1,3,2*	2.26	45	1F,AA	200(1)	029.8	+67.5	
82,1,4,2*	3.31	42	1F,AA	200(1)	048.4	+64.7	
82,1,5,2*	2.71	43	1F,AA	200(1)	026.6	+68.3	
82,1,6,2*	1.72	66	1F,AA	200(1)	049.7	+65.8	
82,1,7,2*	1.10	71	1F,AA	200(1)	030.6	+67.9	
82,1,8,2*	1.21	50	1F,AA	200(1)	035.5	+62.5	
GPW 3							
82,11,2,2*	2.77 E-3	90	1F,AA	200(1)	075.4	+64.1	
82,11,3,2*	1.98	89	1F,AA	200(1)	081.8	+66.6	
82,11,4,2*	1.68	255	1F,AA	200(1)	075.4	+69.6	
82,11,5,2*	2.37	146	2F,A	200(1)	073.9	+64.0	
82,11,6,2*	1.35	>250	1F,AA	200(1)	064.8	+62.6	
82,11,7,2*	2.33	195	1F,AA	200(1)	095.2	+59.9	
82,11,8,2*	1.14	>250	2F,AA	200(1)	068.3	+62.2	
82,11,9,2*	1.31	300	1F,AA	200(1)	055.8	+68.0	
SLK 1 (OMITTED)							
81,2,1,2	43.0 E-6	>250		Too weak for accurate measurement on spinner magnetometer.			
81,2,2,2	1.13	>250					
81,2,3,2	0.12	>100					
81,2,4,2	0.15	>100					
81,2,5,2	0.38	97					
81,2,6,2	0.35	188					
81,2,7,2	0.34	>75					
81,2,8,2	0.09	>75					
SLK 2							
81,3,1,1*	6.93 E-7	190	1F,B	50-150(4)	290.6	+78.1	18°/26
81,3,2,2*	9.56	48	1F,AA	50-250(6)	008.7	+69.8	3°/715
81,3,3,2*	1.92	>700	2F,B	50-250(6)	042.9	+68.0	16°/19
81,3,4,2*	14.1	>250	1F,AA	250(1)	352.3	+60.4	

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
81,3,5,2*	2.02	>250	2F,AA	75-150(3)	015.1	+72.7	3°/1590
81,3,6,2*	3.32	>250	1F,AA	250(1)	357.2	+50.7	
81,3,7,2*	1.11	596	1F,B	100-250(4)	002.2	+63.2	14°/44
SLK 3 (OMITTED)							
82,4,1,2	1.56 E-6	475	1F,C/D	Site mean direction could not be determined due to lack of agreement among cores.			
82,4,2,2	26.0	85	1F,B/C				
82,4,3,2	0.14	>700	1F,B/C				
82,4,4,2	1.92	>1000	1F,B/C				
82,4,5,2	3.09	490	1F,B/C				
82,4,6,2	2.09	39	1F,B/C				
82,4,7,2	1.15	>1000	1F,B/C				
82,4,8,2	1.75	>1000	1F,B/C				
SLK 4							
82,5,1,1*	1.43 E-6	500	1F,AA	200(1)	055.1	+71.3	
82,5,1,2	0.10	>400	1F,B	50-300(6)	342.4	-60.8	48°/3
82,5,2,1	0.09	149	1F,C	OMIT			
82,5,3,1*	0.27	265	1F,A	50-300(7)	031.0	+36.0	5°/132
82,5,3,2	0.47	48	1F,B	150-250(3)	357.5	+36.9	4°/1086
82,5,4,1	5.26	>1000	1F,A	250-1000(8)	233.8	-23.2	3°/403
82,5,4,2*	7.37	>1000	1F,B	300-800(5)	233.4	-21.2	5°/227
82,5,5,2*	0.75	181	1F,AA	50-300(6)	000.6	+54.5	4°/330
82,5,6,1	0.46	130	1F,C	50-100(3)	022.0	+19.4	7°/362
82,5,6,2	0.14	>400	1F,B/C	100-250(4)	068.2	+45.8	27°/13
6,1 & 6,2 *	(average)				041.4	+34.8	6°/130
82,5,7,1	0.40	68	1F,B/C	200-300(3)	169.4	-31.1	6°/417
82,5,7,2	0.66	1000	1F,A	500-1000(4)	168.4	-39.5	6°/246
7,1 & 7,2 *	(average)				168.9	-35.3	18°/184
82,5,8,1	1.59	238	3F,B	50-250(6)	190.9	-37.8	10°/50
82,5,8,2	0.49	64	3F,C	25-75(3)	316.5	+82.5	25°/26
SLK 5							
82,6,2,2*	5.75 E-7	90	1F,A	200-500(5)	004.9	+66.8	7°/113
82,6,3,2*	2.39	414	1F,AA	250-500(3)	323.6	+60.8	7°/305
82,6,4,1*	2.02	147	2F,A/B	50-100(3)	348.6	+44.7	14°/80
82,6,5,2*	4.83	175	1F,A	50-200(5)	029.0	+51.3	5°/196
82,6,6,2*	2.01	>1000	2F,A	200-1000(6)	226.7	-37.2	5°/145
82,6,7,2*	87.0	131	1F,B	150-300(4)	229.8	-32.4	9°/98
82,6,8,1*	14.5	347	1F,A	150-300	083.8	+63.6	7°/198
82,6,8,2	3.36	350	1F,B/C	OMIT			
82,6,9,2*	5.12	804	1F,B	250-600(5)	227.0	-47.9	9°/67

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
SLK 6 (OMITTED)							
82,10,2,2	9.04 E-7	46	1F,C/D	Site mean direction could not			
82,10,3,2	17.6	198	1F,B/C	be determined due to lack			
82,10,5,1	8.52	65	1F,A	of agreement among cores.			
82,10,6,1	8.00	39	1F,C				
82,10,8,1	3.61	94	2F,C				
82,10,9,1	5.22	39	1F,C				
WC 1 (OMITTED)							
81,4,1,2	13.7 E-6	40	1F,C	Stable directions could not			
81,4,2,2	0.38	125	1F,B	be determined.			
81,4,3,2	0.61	43	2F,B				
81,4,4,2	0.08	78	2F,C				
81,4,5,2	288	34	2F,C				
81,4,6,2	25.5	91	1F,C				
81,4,7,2	29.8	170	1F,C				
81,4,8,2	20.2	>250	1F,C				
WC 2							
81,5,1,2*	3.96 E-6	234	2F,A/B	12.5-100(5)	053.2	+42.0	5°/281
81,5,2,1*	1.35	179	1F,A/B	100(1)	010.9	+66.1	
81,5,2,2	3.59	82	1F,A/B	100(1)	321.8	+63.3	
81,5,3,2*	4.23	368	1F,A/B	150-250(3)	230.1	-24.2	4°/1128
81,5,4,2*	7.60	109	1F,A	100-200(3)	056.5	+43.7	10°/157
81,5,5,1*	1.58	65	1F,B	25-250(5)	049.4	+52.0	14°/24
81,5,5,2	1.07	90	1F,B	50-200(5)	143.8	+69.8	11°/53
81,5,6,2*	2.65	170	2F,A	50-100(3)	026.1	+51.9	5°/751
81,5,7,2*	0.93	>250	1F,B	75-100(2)	054.9	+40.1	17°/222
WC 3							
81,6,1,1*	1.24 E-4	79	2F,AA	150(1)	345.2	+75.0	
81,6,2,2*	1.88	68	2F,AA	75(1)	006.4	+83.1	
81,6,3,2*	1.79	57	1F,AA	75(1)	057.6	+83.9	
81,6,4,2*	1.72	54	2F,AA	75(1)	035.8	+74.4	
81,6,5,1*	2.88	48	1F,AA	75(1)	045.2	+67.9	
81,6,6,2*	2.05	53	1F,A	75(1)	067.9	+80.9	
81,6,7,2*	1.90	49	1F,AA	75(1)	022.6	+61.9	
81,6,8,2*	1.67	58	1F,AA	75(1)	050.1	+72.1	
81,6,9,1	0.02	131	1F,A	100-200(3)	045.7	+36.1	11°/126
81,6,9,2	0.01	>200	1F,A	75-150(3)	028.1	+35.4	6°/481
81,6,10,1	0.01	158	1F,B	75-200(4)	029.1	+51.3	11°/65

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
WC 4							
81,7,1,2*	17.4 E-4	47	1F,A/B	75(1)	001.2	+65.4	
81,7,2,2*	6.76	47	1F,A/B	50-100(2)	186.4	+77.8	19°/172
81,7,3,2*	11.3	49	2F,AA	50-100(2)	321.9	+73.4	5°/3135
81,7,4,1	0.32	65	3F,B	250(1)	231.6	-41.1	
81,7,4,2*	0.16	45	3F,B	300-500(2)	251.1	-66.9	58°/21
81,7,5,2*	3.35	67	1F,AA	100(1)	329.7	+68.9	
81,7,6,2*	18.8	57	1F,A	75(1)	330.9	+69.1	
81,7,7,2*	8.65	51	2F,A	75-100(2)	030.5	+80.5	3°/9020
WC 5							
82,7,1,2*	4.20 E-6	37	1F,B	75-250(5)	239.2	-40.8	25°/10
82,7,2,1	3.73	58	1F,C	300-700(3)	259.1	-13.3	29°/19
82,7,2,2	4.09	52	1F,B	500-600(2)	168.1	-41.6	22°/134
2,1 & 2,2 *	(average)				231.0	-32.0	51°/3
82,7,3,2*	11.9	34	1F,B	250-500(4)	195.9	-44.2	19°/23
82,7,4,2*	8.61	32	1F,B/C	150-300(3)	213.8	-36.2	16°/34
82,7,5,1	24.5	41	1F,C	500-900(3)	213.4	-41.1	51°/4
82,7,5,2	13.6	38	1F,C	700-900(2)	252.6	-70.3	78°/13
5,1 & 5,2*	(average)				221.2	-53.0	86°/11
82,7,6,1	9.60	39	1F,C/D	150-500(5)	230.9	-51.4	82°/2
82,7,6,2	8.40	38	1F,C/D	150-300(4)	177.6	-32.3	36°/7
6,1 & 6,2 *	(average)				195.9	-43.5	37°/3
82,7,7,1	10.7	45	1F,B/C	200-700(4)	268.5	-43.5	25°/14
82,7,7,2	87.2	37	1F,B/C	100-200(3)	270.0	+73.0	13°/86
82,7,8,2*	2.28	61	1F,B	300-700(3)	245.2	-39.9	17°/53
WC 6							
82,8,1,1	3.98 E-6	48	1F,C	50-500(9)	250.2	+13.3	2°/58
82,8,1,2	3.83	48	1F,B/C	OMIT			
82,8,2,1*	5.29	39	2F,C	150-250(3)	026.5	+47.7	57°/6
82,8,3,1	2.94	49	1F,B	25-75(3)	145.0	+84.6	7°/287
82,8,4,1	4.35	55	1F,B/C	300-800(5)	257.8	+41.8	19°/16
82,8,5,1*	3.65	62	1F,B	100-300(5)	072.7	+60.2	25°/16
82,8,5,2	6.66	53	1F,B/C	OMIT			
82,8,6,1	1.81	54	1F,B	50-150(4)	086.7	+53.4	47°/14
82,8,6,2*	0.82	68	1F,B	25-150(4)	077.8	+74.6	15°/25
82,8,7,1*	1.04	106	3F,B	50-400(8)	045.7	+63.4	13°/16
82,8,7,2	0.76	38	3F,B/C	OMIT			
82,8,8,1	7.39	48	2F,B/C	300-800(6)	127.1	-48.5	4°/39

SAMPLE #	J_{NRM} (GAUSS)	MDF	QUALITY	AF LEVELS	D_S (°)	I_S (°)	α_{95}'/k'
WC 7							
82,9,1,1*	9.72 E-7	500	1F,A	50-500(8)	296.3	-57.6	5°/115
82,9,2,1*	4.19	617	1F,B/C	200-500(4)	305.4	-85.7	29°/11
82,9,3,1*	8.23	129	1F,B/C	50-150(4)	230.8	-59.1	17°/28
82,9,4,1	5.41	674	2F,B/C	50-200(5)	223.2	+49.0	11°/53
82,9,5,2*	7.02	668	1F,B	150-500(5)	255.2	-36.1	14°/32
82,9,6,1	7.87	696	1F,C	OMIT			
82,9,6,2*	5.88	128	1F,B/C	200-300(3)	224.5	-41.0	41°/10
82,9,7,2*	9.15	743	1F,B	50-250(6)	226.3	-43.0	9°/52
82,9,8,2*	21.3	835	1F,AA	25-900(13)	259.3	-37.7	2°/322
82,9,9,1	4.45	1000	1F,C	OMIT			

APPENDIX C

Locations and Descriptions of Sampling Sites

The following summary lists the location and description of each of the 37 sites within the five Klamath Mountain plutons as well as the six sites within the Upper Cretaceous Hornbrook Formation sampled for paleomagnetic study. Sampling localities are arranged alphabetically according to pluton, sites from the Hornbrook Formation are described at the end.

Three maps distributed by the USFS were found to be particularly useful and the appropriate map for each site is given. Topographic maps listed are 15' quadrangles from the states of Oregon and California.

Rock names were assigned according to the classification scheme of Streckeisen (1972). Textures are hypidiomorphic granular except when otherwise stated.

Abbreviations used:

Lat	Latitude
Long	Longitude
FSR	Forest Service Route
KNF	Klamath National Forest
SNF	Siskiyou National Forest
RRNF	Rogue River National Forest

ASHLAND PLUTON

ASH 1--Bullion Mtn (80,4)
Hornbrook quad., Siskiyou Co., CA.
Lat=41°56'47"N, Long=122°45'03"W
SW 1/4 Sec 2, T47N, R8W, KNF.

Roadcut near peak and on south side of Bullion Mtn, 2.95 mi from intersection of roads to Buckhorn Bally Lookout, Shaft Rock, and Hilt along road toward Shaft Rock. Outcrop consists of fairly intact medium-grained gabbro. 7 cores obtained within lateral distance of 30m and within 3-4m from road level.

ASH 2--Hungry Creek (80,5)
Condrey Mountain quad., Siskiyou Co., CA.
Lat=41°58'25"N, Long=122°46'15"W
Intersection of Secs. 27, 28, 33, 34, T48N, R8W, KNF.

Roadcut on north side of FSR 48N01 along Hungry Creek, 0.5 miles east of Beaver Creek. Moderately weathered outcrop of medium-grained granodiorite. 7 cores drilled within lateral distance of 10-12m and within 8-10m of road level.

ASH 3--Mt. Ashland Ski Area road (81,1)
Ashland quad., Jackson Co., OR.
Lat=42°03'44"N Long=122°38'48"W
SE 1/4 Sec 24, T40S, R1E, KNF or RRNF.

Exit from I5 and proceed to Mt. Ashland Ski Area road turnoff. Site is 2.4 miles west from intersection and marked by an "X" of two very prominant veins of more silicic material cutting through very weathered medium-grained granodiorite representative of Donato's (1975) first intrusive phase. Fresh granodiorite blocks also present. 7 cores drilled within lateral distance of 60m along road from fresher material only.

ASH 4--Mt. Ashland Ski Area road (81,12)
Ashland quad., Jackson Co., OR.
Lat=42°03'47"N Long=122°40'00"W
NE 1/4 of NW 1/4 Sec 26, T40S, R1E, KNF or RRNF.

Very large roadcut at sharp turn in road 2.3 miles west of ASH 3. Marked by spray paint graffiti "Willy-n-Nina". Very leucocratic biotite quartz monzonite of Donato's (1975) second intrusive phase. 9 cores drilled; 7 from mafic veins and inclusions, 2 from host monzonitic rock.

ASH 5--Bull Gap (81,13)
Ashland quad., Jackson Co., OR.
Lat=42°05'48"N Long=122°40'14"W
Central portion of boundary between Secs. 11 & 14, T40S, R1E, RRNF.

Continue toward summit of Mt. Ashland along ski area road and turn north on FSR 2080 toward Bull Gap. Fresh roadcut outcrop of medium-grained granodiorite is 6.0 miles from turnoff. Moderately fractured with numerous cross-cutting silicic veins. 9 cores drilled within approx. 100m portion of outcrop along road.

ASH 6--North of Bull Gap (81,14)
Ashland quad., Jackson Co., OR.
Lat=42°06'58"N Long=122°40'34"W
SE 1/4 Sec 2, T40S, R1E, RRNF.

Roadcut outcrop 3.2 miles north of Ash 5 along FSR 2080. Quite mafic with abundant cross-cutting veins of very silicic, coarse-grained rock. Host rock consists of moderately weathered, medium-grained granodiorite with fresher blocks of similar lithology. 9 cores from fresher material only.

ASH 7--Interstate 5 (81,17)
Ashland quad., Jackson Co., OR.
Lat=42°05'52"N Long=122°36'26"W
SE 1/4 Sec. 8, T40S, R2E, RRNF.

Roadcut outcrop of southbound I5 just south of rest stop south of Ashland. Within sight of very large outcrop of pluton to the south that is above freeway at railroad overpass. Locally foliated, medium-to coarse-grained granodiorite with potassium feldspar phenocrysts up to 2cm in longest dimension. Fine-grained mafic inclusions are elongate and semi-parallel to trend of foliation. 13 cores; 9 mafic inclusions, 4 host rock.

ASH 8--Wagner Glade Gap (81,27)
Talent quad., Jackson Co., OR.
Lat=42°06'29"N Long=122°47'16"W
NW 1/4 Sec. 11, T40S, R1W, RRNF.

Proceed 12.85 miles south from Talent on Rapp Rd. along Wagner Creek to 0.25 mile long roadcut outcrop. Site confined to middle part of outcrop where rock is freshest and most mafic. Medium-grained quartz diorite. 9 cores within lateral distance of 40 meters.

ASH 9--Beaver Creek (81,28)
Talent quad., Jackson Co., OR.
Lat=42°01'12"N Long=122°46'48"W
SE 1/4 Sec. 2, T41S, R1W, KNF or RRNF.

Proceed north from Beaver Creek Forest Service Station for 5.7 miles along FSR 40S14 (KNF map says 40S16). At intersection of 40S14 and 41S22, go west along 41S22. Fairly fresh roadcut outcrop on west side of West Branch Long John Creek. Medium- to coarse-grained quartz diorite. 9 cores.

GRANTS PASS PLUTON

GPE 1--Grants Pass East (79,3)
Grants Pass quad., Josephine Co., OR.
Lat=42°25'46"N Long=123°18'53"W
NW 1/4 of NE 1/4 Sec. 20, T36S, R5W, SNF.
**Sampled and described by Dr. Shaul Levi and Robert Karlin.

Outcrop on south bank of Rogue River next to fallen old bridge 2 about 2 miles east of Grants Pass (off Acacia). Riverbed exposure of slightly foliated, moderately weathered biotite quartz diorite.
7 cores.

GPN 1--Grants Pass North (79,4)
Grants Pass quad., Josephine Co., OR.
Lat=42°28'39"N Long=123°20'58"W
NE 1/4 Sec 1, T36S, R6W, SNF.
**Sampled and described by Dr. Shaul Levi and Robert Karlin.

Outcrop is about 2 miles north of Grants Pass on frontage road, just south of I5 overpass. Consists primarily of highly weathered rock and talus-covered slope, however, at base of slope near road are portions of fresh, medium-grained quartz monzonite. 6 cores drilled within lateral distance of about 12m along road.

GPW 1--Applegate River (81,18)
Grants Pass quad., Josephine Co., OR.
Lat=42°24'12"N Long=123°27'06"W
SE 1/4 of NW 1/4 Sec. 31, T36S, R6W, SNF.

From city of Grants Pass take 99W and then 199W to west side of Applegate River. Park after turning north toward Merlin. Exposures of foliated medium-grained quartz diorite on west bank of river. Rocks are moderately weathered on surface and smooth from water erosion. Occasional felsic dikes and large inclusions of more mafic foliated rock. Locally fractured but easily drilled. 10 cores; 2 from mafic inclusions, 8 from host rock.

GPW 2--Applegate River (82,1)
Grants Pass quad., Josephine Co., OR.
Lat=42°24'12"N Long=123°27'06"W
SE 1/4 of NW 1/4 Sec. 31, T36S, R6W, SNF.

200m north along Applegate River from GPW 1. Outcrop similar to GPW 1. Medium-grained pyroxene quartz diorite. 8 cores.

GPW 3--Merlin, Oregon (82,11)
Glendale quad., Josephine Co., OR.
Lat=42°31'03"N Long=123°26'41"W
NE 1/4 Sec. 19, T35S, R6W, SNF.

Roadcut outcrop 1.2 miles west of Merlin Trading Post in central Merlin along road toward Galice. 25m long outcrop of weathered but intact, medium- to coarse-grained granite. 9 cores.

GREYBACK MOUNTAIN INTRUSIVE COMPLEX

All sampling localities within the Greyback Mountain intrusive complex are located on the Oregon Caves 15' quadrangle, Josephine County, Oregon.

GM 1 (79,2)
Lat=42°07'34"N Long=123°21'47"W
SE 1/4 Sec. 1, T40S, R6W, SNF.

Roadcut on FSR 3941, 7.8 miles east of junction with State Route 46 (near Greyback Recreation Site), adjacent to switchback over creek. Very heterolithologic outcrop but principal rock type is quartz diorite. 9 cores within lateral distance of about 45m; 7 cores in roadcut, 2 from streambed.

GM 2--Little Sugarloaf Peak (80,6)
Lat=42°08'25"N Long=123°19'49"W
NE 1/4 Sec. 31, T39S, R5W, SNF.

Continue on FSR 3941 east of Low Divide. Bear left to head east on dead end road through northern portion of Sec. 31, nearly to end of road. Moderately fractured roadcut just east of quarry. Medium-grained quartz diorite. 9 cores; 7 drilled along road, 2 in quarry.

GM 3--Little Sugarloaf Peak (80,7)
Lat=42°08'25"N Long=123°19'49"W
NE 1/4 Sec. 31, T39S, R5W, SNF.

Fifty meters west of GM 2 at bend in road. Rock type as in GM 2. 11 cores drilled within 2-3m of road within lateral distance of 100m.

GM 4--Mt. Elijah (80,8)
Lat=42°05'33"N Long=123°22'29"W
NW 1/4 Sec. 14, T40S, R6W, SNF.

Roadcut 0.75 miles west of Bigelow Lakes on FSR 4045. Medium- to coarse-grained gabbro intruded by aplite dikes and fewer mafic dikes. Outcrop is about 50m in length and moderately to heavily fractured but blocks appear in place. 10 cores at road level.

GM 5--Sturgis Fork Road (81,21)
Lat=42°05'28"N Long=123°18'00"
NW 1/4 Sec. 16, T40S, R5W, RRNF.

Large roadcut outcrop at hairpin turn of FSR 3930, 3 miles north from intersection with Miller Lake Rd. (bear right at fork in road and follow road marked "END OF ROAD 4 MILES"). Fine- to medium-grained quartz diorite with occasional inclusions of metasedimentary rock. 9 cores drilled within lateral distance of 25m and 9m from road level.

GM 6--Sturgis Creek (81,22)
Lat=42°05'10"N Long=123°16'41"W
SW 1/4 Sec. 15, T40S, R5W, RRNF.

Creek bed outcrop 3.0 miles west along Sturgis Creek from Thompson Creek road. Easternmost portion of outcrop contains much incorporated country rock, but more suitable outcrop is 25m upstream. Fresh, fine- to medium-grained gabbro with several mafic, very fine-grained veins up to 4-5 meters thick. 9 cores within 20m along stream.

GM 7--Sturgis Creek (81,23)
Lat=42°05'28"N Long=123°15'57"W
NW 1/4 Sec. 14, T40S, R5W, RRNF.

Roadcut outcrop along Sturgis Creek, 1.5 miles west from Thompson Creek (0.4 miles E of GM 6). Outcrop of medium- to coarse-grained gabbro varies from fresh and unfractured to highly fractured and/or weathered rock. Possible displacement of some blocks. 8 cores drilled within 40m interval along road.

GM 8--Sturgis Creek (81,24)
Lat=42°05'41"N Long=123°17'26"W
NE 1/4 Sec. 16, T40S, R5W, RRNF.

Minorly fractured stream bed outcrop of south-flowing stream along Sturgis Fork road (FSR 3930), 2.3 miles from intersection with Miller Lake road (0.8 miles E of GM 5). Medium-grained hornblende gabbro. 9 cores drilled within 50m from base of falls near road.

GM 9--Bigelow Lakes (81,25)
Lat=42°05'10"N Long=123°22'12"W
SE 1/4 Sec. 14, T40S, R6W, SNF.

Enormous outcrop in clearing, 0.25 miles to south side of FSR 4045, 0.75 miles east of site GM 4. Highly fractured and moderately weathered medium-grained gabbro. 8 cores from fresher medium-grained veins within easternmost N-S trending ridge.

GM 10--Road to Bigelow Lakes (81,26)
Lat=42°06'22"N Long=123°22'29"W
NW 1/4 of NE 1/4 Sec.11, T40S, R6W, SNF.

Two portions of roadcut outcrop separated by 0.1 miles. Westernmost portion is 0.6 miles east of intersection of FSR 4046 and 4045 on 4046. Medium- to coarse-grained quartz diorite. 9 cores; 4 from western portion, 5 from eastern.

SLINKARD PLUTON

SLK 1--Scott River (81,2)
Scott Bar quad., Siskiyou Co., CA.
Lat=41°39'29"N Long=123°06'36"W
SE 1/4 Sec. 16, T44N, R11W, KNF.

Roadcut outcrop 0.6 miles north of Bridge Flat campground along Scott River. Very fresh, slightly fractured exposures of highly foliated, medium-grained biotite quartz diorite. 8 cores drilled within about 110m portion along road.

SLK 2--Seiad Valley (81,3)
Seiad Valley quad., Siskiyou Co., CA.
Lat=41°49'34"N Long=123°08'07"W
SE 1/4 Sec. 17, T46N, R11W, KNF.

Quarry along Klamath River Highway (State Highway 96), 1.9 miles east of FSR 46N46 to Lake Mountain L.O. just east of Seiad Valley. Fresh exposures of foliated medium-grained quartz diorite separated by weathered portions. Difficult to tell if some blocks are in place, however, samples drilled from apparently undisturbed blocks. 7 cores.

SLK 3--North Fork Kelsey Creek (82,4)
Scott Bar quad., Siskiyou Co., CA.
Lat=41°39'23"N Long=123°08'00"W
SW 1/4 Sec. 20, T15N, R11W, KNF.

Roadcut outcrop 0.2 miles west of Scott River along FSR 11W12 (N. Fk. Kelsey Cr.). Fractured and moderately weathered outcrop (25-30m long) of slightly foliated granodiorite. 8 cores.

SLK 4--Scott River Road (82,5)
Scott Bar quad., Siskiyou Co., CA.
Lat=41°40'00"N Long=123°06'29"W
NE 1/4 Sec. 16, T44N, R11W, KNF.

Roadcut outcrop 1.0 mile north of Bridge Flat campground along Scott River Road (0.5 mi. N of SLK 1). Excellent exposures of foliated, medium-grained biotite quartz diorite. Outcrop is about 50m long, including 12-15m interval of weathered material (not sampled). 8 cores.

SLK 5--Scott River Road (82,6)
Scott Bar quad., Siskiyou Co., CA.
Lat=41°40'21"N Long=123°06'00"W
SW 1/4 Sec. 10, T44N, R11W, KNF.

Roadcut outcrop 2.0 miles north of Bridge Flat Camp, 1.3 miles south from FSR 46N64 at Gold Flat. Outcrop extends for approx. ~100m though portions are highly weathered and fractured (not sampled). Medium-grained biotite quartz diorite. 9 cores.

SLK 6--Seiad Valley (82,10)
Seiad Valley quad., Siskiyou Co., CA.
Lat=41°49'34"N Long=123°08'07"W
SW 1/4 Sec. 17, T46N, R11W, KNF.

Roadcut outcrop 0.3 miles west of SLK 2. Outcrop is about 50m long and consists of foliated and moderately weathered, medium-grained, granodiorite. 9 cores.

WOOLEY CREEK BATHOLITH

WC 1--Bear Creek (81,4)
Ukonom Lake quad., Siskiyou Co., CA.
Lat=41°38'52"N Long=123°15'53"W
SE 1/4 Sec. 19, T44N, R12W, KNF.

At Happy Camp, turn south onto FSR 15N06, follow sign to Bear Creek Trail. Below bridge is creek bed outcrop of foliated garnet-bearing diorite. Garnets occur in roughly spherical aggregates up to 5 cm in diameter. Near eastern contact of WCB with amphibolite facies rocks of wTrPz. 8 cores; 2 downstream from bridge, 6 upstream.

WC 2--Sulfur Springs (81,5)
Ukonom Lake quad., Siskiyou Co., CA.
Lat=41°39'18"N Long=123°18'50"W
SW 1/4 of SE 1/4 Sec. 29, T15N, R8E, KNF.

Approximately 12-13 miles south of Happy Camp at Sulfur Springs campground. Creek bed outcrop under bridge of medium- to coarse-grained tonalite. Good possibility of hydrothermal alteration due to presence of major joint sets and hotsprings. 7 cores drilled from both sides of creek.

WC 3--Steinacher Creek Rd. (81,6)
Forks of Salmon quad., Siskiyou Co., CA.
Lat=41°24'00"N Long=123°22'21"W
NW 1/4 of SW 1/4, Sec. 27, T12N, R7E, KNF.

From Murderer's Bar east of Oak Bottom campground, proceed 1.65 miles northeast along FSR 12W20. Two good outcrops of moderately weathered fine- to medium-grained granite along road. 8 cores drilled within continuous 30m portion of outcrop bounded by decomposed granite. Two cores drilled from mafic dioritic inclusions within weathered granite about 1/4 mi SW (toward Salmon R.) from outcrop of other 8 cores.

WC 4--Salmon River (81,7)
Forks of Salmon quad., Siskiyou Co., CA.
Lat=41°20'24"N Long=123°23'46"W
NE 1/4 Sec. 20, T11N, R7E, KNF.

Approximately 0.7 miles SE of Indian Bottom Mine at Grant Bluffs along Salmon River. Outcrops below road and in roadcut, but sampling was confined to riverbed outcrop. Very fine-grained porphyritic gabbro with pyroxene phenocrysts. Pyrite present in minor amounts. Near eastern contact of pluton with wTrPz. Large inclusions (up to 3m across) of incorporated Hayfork terrane meta-sediments, as well as skarns and calc-silicates in lesser amounts. 7 cores; difficult to drill due to presence of complex joint systems.

WC 5--Steinacher Creek Rd. (82,7)
Forks of Salmon quad., Siskiyou Co., CA.
Lat=41°23'03"N Long=123°24'42"W
SE 1/4 Sec. 31, T12N, R7E, KNF.

Roadcut outcrop along FSR 12W20, 0.6 miles north of intersection with Salmon River Road, just north of gate across road. Several short (approx. 20m) outcrops of moderately fractured, coarse-grained granodiorite. 8 cores drilled along road within 15m extent.

WC 6--Salmon River (82,8)
Forks of Salmon quad., Siskiyou Co., CA.
Lat=41°20'36"N Long=123°24'06"W
SW 1/4 Sec. 17, T11N, R7E, KNF.

Riverbed outcrop of medium-grained granodiorite on Salmon River 5.15 miles east of intersection of FSR 12W20 with Salmon River Rd. Park at trail leading to abandoned mining claim and hike down trail. At bottom of hill, turn sharply to right, head toward water. 8 cores.

WC 7--Salmon River (82,9)
Forks of Salmon quad., Siskiyou Co., CA.
Lat=41°22'37"N Long=123°25'17"W
NW 1/4 Sec. 6, T11N, R7E, KNF.

At Murderer's Bar under bridge of FSR 12W20 over Salmon River. Medium-grained granodiorite. 9 cores.

UPPER CRETACEOUS HORNBROOK FORMATION

The locations of sampling sites of the Upper Cretaceous Hornbrook Formation are given below. All samples, with the exception of site HB 6, were obtained (either by oriented hand sample or drill core) from the fine-grained upper mudstone member of the formation described in text. All sites contain well-bedded, undeformed sediments.

HB 1--Hilt (81,11)
Hornbrook quad., Siskiyou Co., CA.
Lat=42°00'00"N Long=122°36'21"W
NW 1/4 Sec.24, T48N, R7W, KNF.
Average bedding attitude: N 0.2°W, 15°NE.
Steep roadcut outcrop on east side of I5, directly across from Stateline Mobil station at Hilt exit. Outcrop consists primarily of very fissile, thinly bedded mudstone. 6 oriented hand samples taken from moderately consolidated 15-20cm thick mudstone interbeds.

HB 2--Dead Indian (81,15)
Ashland quad., Jackson Co., OR.
Lat=42°11'24"N Long=122°39'12"W
SW 1/4 Sec. 12, T39S, R1E, RRNF.
Average bedding attitude: N 44°W, 17°NE.
Superb 0.25 mile long roadcut outcrop at right angle turn of Dead Indian Road, 0.75 miles north of State Route 66. Turbidite sequence of mudstones and sandstones with well-consolidated beds, ranging in thickness from 2-3mm to 0.5m, interbedded with friable shales and mudstones. 21 cores drilled within stratigraphic thickness of about 6m.

HB 3--"Geology Lane" (81,16)
Hornbrook quad., Siskiyou Co., CA.
Lat=41°59'13"N Long=122°36'56"W
NE 1/4 Sec. 26, T48N, R7W, KNF.
Average bedding attitude: N 52°W, 14.5°NE.
Hillside outcrop on "Geology Lane". From Stateline Mobil station at Hilt exit off I5, proceed toward valley to west. At bottom of hill, cross railroad tracks and bear left onto "Geology Lane". Outcrop is 0.5 miles from tracks on east side of road. Six oriented hand samples, 3 from each of 2 well-consolidated 20cm thick mudstone beds.

HB 4--Oregon-California border (81,19)
Hornbrook quad., Siskiyou Co., CA.
Lat=42°00'21"N Long=122°36'45"W
SE 1/4 Sec. 14, T48N, R7W, KNF.
Average bedding attitude: N 11°W, 13.6°NE.
Steep roadcut outcrop on east side of I5 at Ore-Cal border consisting of numerous well-consolidated mudstone beds separated by fissile shales and mudstones. 13 cores drilled from 4 beds ranging in thickness from 10-20cm and located between 4m and 10m upsection from road level. Lateral extent of sampling area approx. 15m.

HB 5--Dead Indian Highway (81,20)
Ashland quad., Jackson Co., OR.
Lat=42°11'24"N Long=122°39'12"W
SW 1/4 Sec. 12, T39S, R1E, RRNF.
Average bedding attitude: N 45°W, 19.4°NE.

Roadcut outcrop 10m stratigraphically upsection from site HB 2. 10 cores drilled within stratigraphic thickness of 3m.

HB 6--Interstate 5 (81,29)
Ashland quad., Jackson Co., OR.
Lat=42°05'00"N Long=122°36'22"W
SE 1/4 Sec. 17, T40S, R2E, RRNF.
Average bedding attitude: N 39°W, 24.2°NE.

Roadcut outcrop on west side of southbound I5, 0.6 miles north of exit to Mt. Ashland. One of the lower members of the formation. Outcrop consists of fine- to medium-grained gray sandstone in beds up to 1m thick separated by brownish-gray shaly interbeds. Some sandstone beds are normally graded and contain fossiliferous and/or conglomeratic layers (up to 15cm thick) with pebble-sized clasts. 9 cores drilled from 3 sandstone beds over a stratigraphic thickness of 4-5m.