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GRADUATE COLLEGE

# PALEOMAGNETIC EVIDENCE FOR STRUCTURAL ROTATION IN THE PACIFIC NORTHWEST

A DISSERTATION

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in partial fulfillment of the requirement for the

degree of

DOCTOR OF PHILOSOPHY

By
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Norman, Oklahoma
1978

PALEOMAGNETIC EVIDENCE

FOR STRUCTURAL ROTATION

IN THE PACIFIC NORTHWEST

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I could not have done the work without the encouragement of my wife, Jeanne, and able field assistance by my son, Nye.

## ABSTRACT

The paleomagnetic directions of Upper Jurassic and Cretaceous intrusives and Tertiary extrusives in western Idaho, eastern Oregon, and northern Nevada were investigated for indications of regional tectonic rotation. Assessment of the reliability of paleomagnetic directions was a major problem in the study of the intrusives. Nine of thirty-four sites were rejected after AF and thermal demagnetization because of instability or scatter. Remaining results are of variable quality but definitely suggest clockwise rotations up to $90^{\circ}$ or more; results are presented as a contour map of equal rotation. Paleomagnetic directions of Tertiary extrusives, primarily Steens Mountain and Columbia River Basalts of Miocene age, are indicative of up to $35^{\circ}$ of clockwise rotation; results are also presented as a contour map of equal rotation.

Two regional geologic Tertiary expansion models, one by Hamilton and one by Heptonstall were tested against the paleomagnetic data. Both models have successes and failures.

The clockwise rotation may have resulted from the development of an orocline, regional strike-slip faulting, or expansion of the Basin and Range province.

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PALEOMAGNETIC EVIDENCE

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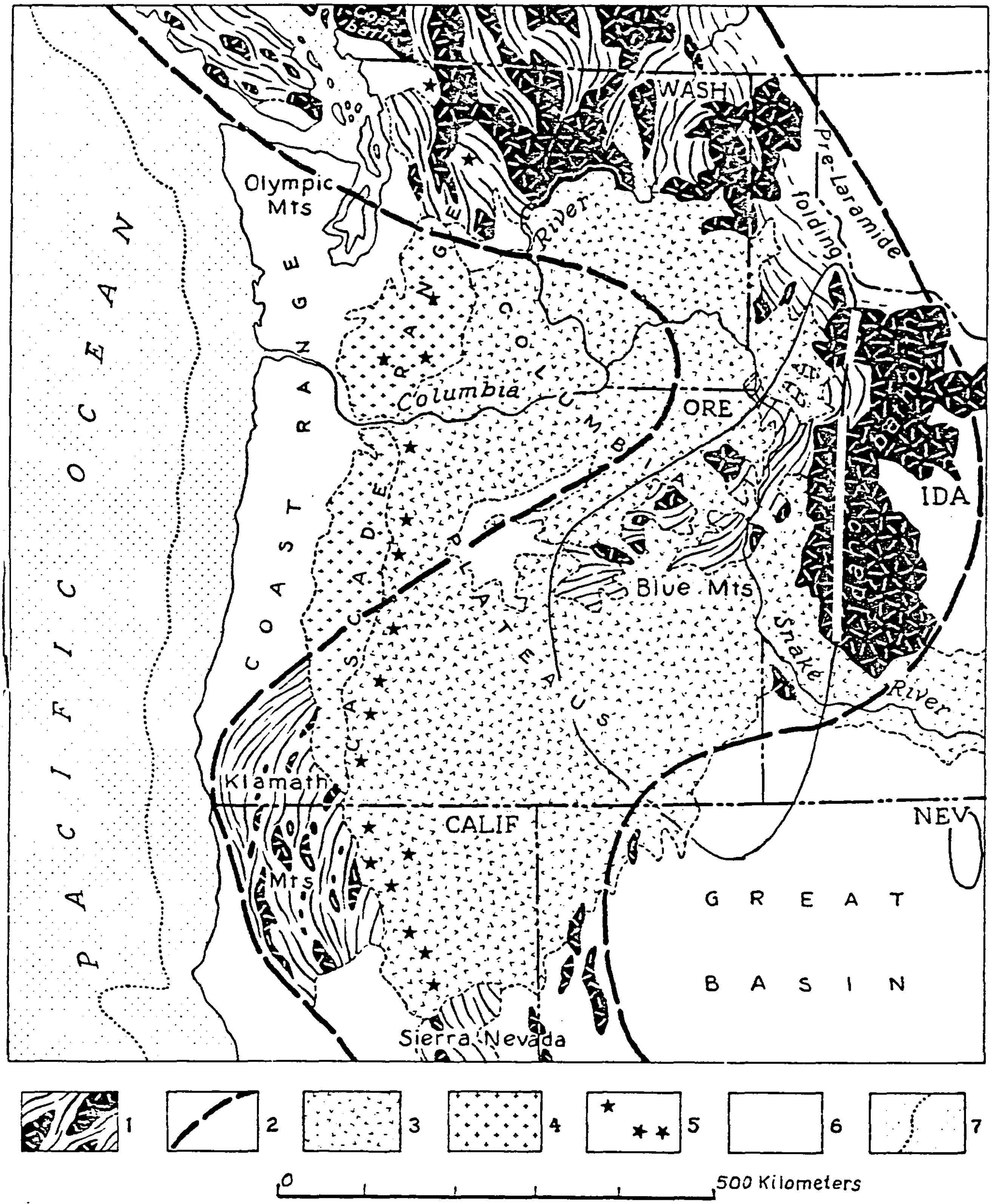
# CHAPTER I INTRODUCTION

## Description of Problem

For many years geologists have commented on the arcuate pattern of Mesozoic and Paleozoic rocks in California, Oregon, Idaho, and Washington (see Figure I-1 from King, 1977). The question to be considered is: Is this pattern a primary feature, or was it formed by later structural deformation? Geologic history, facies distribution and paleomagnetic studies may help in the investigation. In this thesis we will examine primarily the eastern portion of this arcuate feature in eastern Oregon, western Idaho, and northern Nevada. The area of paleomagnetic study is outlined on Figure I-1. An attempt will also be made to fit this area into the regional Cordilleran geologic history.

## The Columbia Arc

Becker (1934) suggested that many structures of the western United States were related to clockwise torque in the western part of the continent. Billingsly and Locke (1941) termed the arcuate pattern the "Oregon Arc." Wilson (1954) maintained that the pattern was of primary origin.




Map of the northwestern volcanic province of Washington, Oregon, and adjacent states, showing its relation to the Columbia arc. Data from Geologic Map of United States (1974).

*Explanation of symbols.* 1–Basement rocks deformed by Nevadan orogeny; metamorphic rocks lined, plutonic rocks solid. 2–Inferred margins of Nevadan orogenic belt. 3–Plateau basalts of Miocene and later age. 4–Andesitic volcanics of Cascade Range. 5–Volcanic cones of Cascade Range, mostly of Quaternary age. 6–Other rocks, mainly sedimentary rocks of Mesozoic and Tertiary ages, but including some older Tertiary volcanics. 7–Edge of continental area.

Figure I-1. The Columbia Arc, from King (1977). Courtesy of Princeton University Press. Area of paleomagnetic study for thesis.

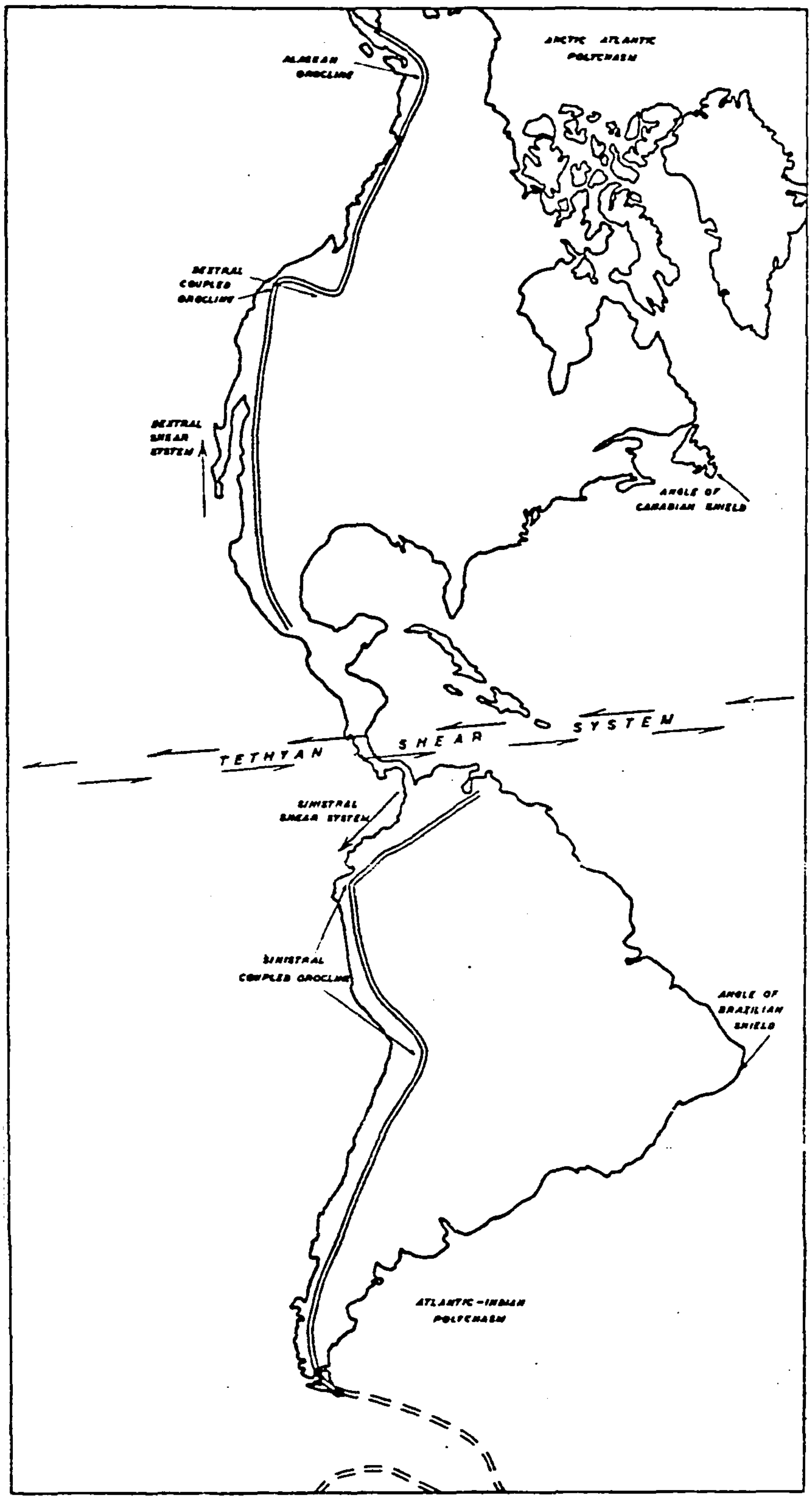



Figure I-2. Oroclines of North and South America. From Carey (1958). Courtesy of S. W. Carey.

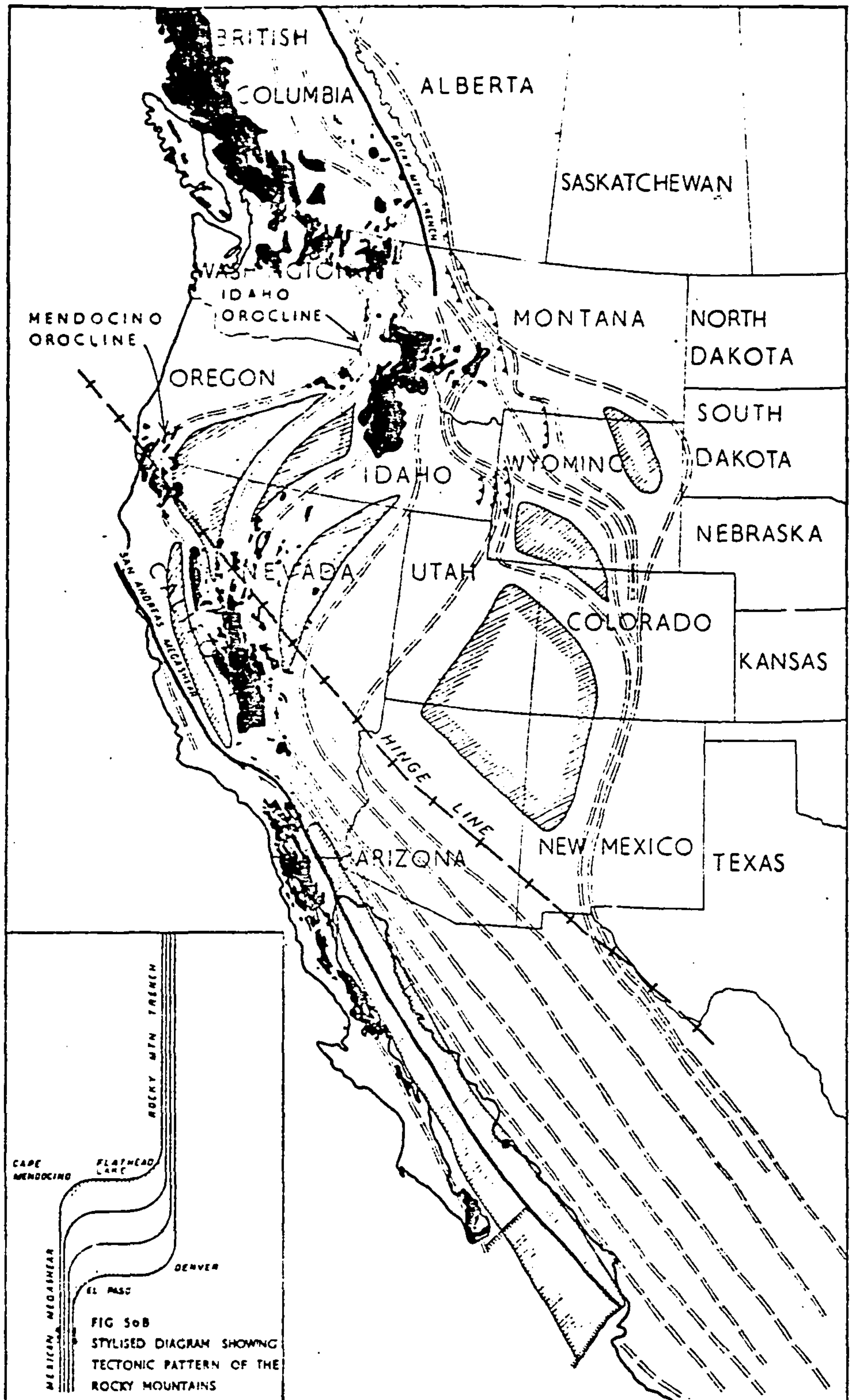



Figure I-3. Tectonic plan of the Rocky Mountains. From Carey (1958). Courtesy of S.W. Carey.

Carey (1958) proposed the orocline hypothesis to explain major changes in trend in orogenic belts of the world. Figure I-2 shows his interpretation of oroclines in North and South America. Figure I-3 shows greater detail in the western United States. His proposal for this area was based on right lateral movement on the San Andreas Fault and Rocky Mountain Trench to produce the resultant pattern.

Burnham (1959) showed that trace elements in metallogenic provinces bend to the northeast parallel to the California-Oregon portion of the "Oregon Arc." Moore (1959) discussed the easterly swing of the quartz diorite line into the Idaho Batholith. He suggested a relationship to the boundary between continental crust to the east and oceanic crust to the west.

Wise (1963) discussed the "Cordilleran sprawl" of the western United States and believed that many features are consistent with Carey's orocline hypothesis (see Figure I-4). He suggested that paleomagnetic data might be used to test the orocline hypothesis.

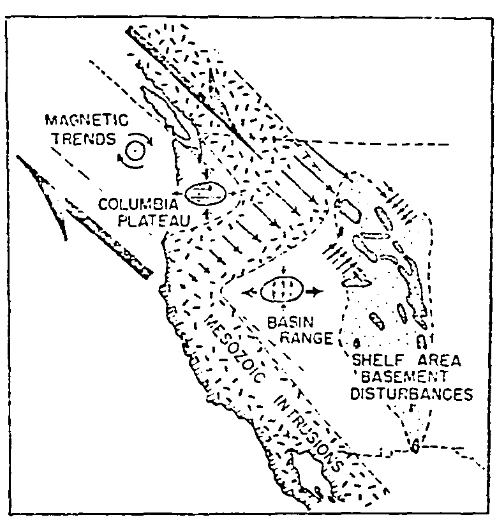



Figure I-4. Hypothetical stress distribution in the Cordilleran region. Small arrows in Wyoming indicate combined compression and shear to produce parallelogram pattern. From Wise (1963). Courtesy of Geological Society of America.

Irving (1964) demonstrated that paleomagnetic data collected by Cox (1957) in the Eocene Siletz River Volcanics in western Oregon suggest clockwise rotation. Watkins (1965) showed that paleomagnetic directions in Miocene volcanics in eastern Oregon suggest about 15 degrees of clockwise rotation since Miocene time. This rotation is relatively minor and would presumably be subsequent to the major hypothesized rotation.

Taubeneck (1965) proposed the adoption of the term "Columbia Arc" as a formal name for the arcuate pattern of the Nevadan orogenic belt. However, he rejected Watkins' conclusion of post-Miocene rotation on four counts: (1) a huge swarm of Miocene Columbia River feeder basalt dikes trend between 341$^{\circ}$ and 351$^{\circ}$ in Oregon, Idaho and Washington. They do not vary in direction in accordance with Watkins' proposed rotation; (2) the Blue Mountain front is continuous across the area where it should be bent if post-Miocene rotation had occurred; (3) the Pliocene-Pleistocene volcanoes of the Cascades are aligned north-south across the area of proposed post-Miocene rotation; and (4) Pliocene faults in western Idaho are undeformed. Taubeneck stated that possible pre-Miocene tectonic rotation was not considered in detail. However, he believed that lack of distortion of the northeast trending Oxbow-Cuprum shear zone of Mesozoic age is good evidence for primary origin for the configuration of the Nevadan structural zone.

Greenwood and Reid (1969) described large, steeply plunging sigmoidal folds in central Idaho which involve late precambrian rocks. One fold is intruded by cross-cutting Cretaceous granite. They believe that the presence of these folds supports pre-Tertiary rotation.

Hamilton (1969) proposed that during Cretaceous time the geology of the west coast of the United States was relatively simple (see Figure I-5). The North American continent was bordered by a subduction zone. He proposed that Cenozoic movements separated the structural elements into the present complex distribution (see Figure I-6). The arcuate shape on Hamilton's reconstruction (Figure I-5) may suggest that an arcuate shape was developed by Cretaceous time. It may then have been intensified by later movements.

Gilluly (1970) reviewed the orocline hypothesis and rejected it. He plotted normal fault traces of Basin and Range faults and stated that the faulting is not such as to favor the reverse "S" curve in the outcrop of Mesozoic plutons and the quartz diorite line of Moore (1959).

Smith, et al (1971) show that Cretaceous granitic rocks in northwestern Nevada are similar in age and chemistry to intrusives in the Sierra Nevada mountains and in the Idaho Batholith. The western Nevada rocks provide a compositional and physical link between the Sierra Nevada and Idaho Batholiths and delineate the eastward bend of the Cordilleran belt. Smith, et al mention the possible relationship of the Mendocino fracture zone to this bend.

Taubeneck (1973) described the "Trans-Idaho Discontinuity" which trends from central Idaho through southeast Washington. Permo-Triassic rocks, south of the discontinuity, strike at approximately right angles to northwest trends in Precambrian rocks north of the discontinuity. The feature is pre-Columbia River Basalt. Maxwell (1974) included a map which depicts continuity of ultramafic rocks from northern California into eastern Oregon (see Figure I-7) and also shows the Trans-Idaho

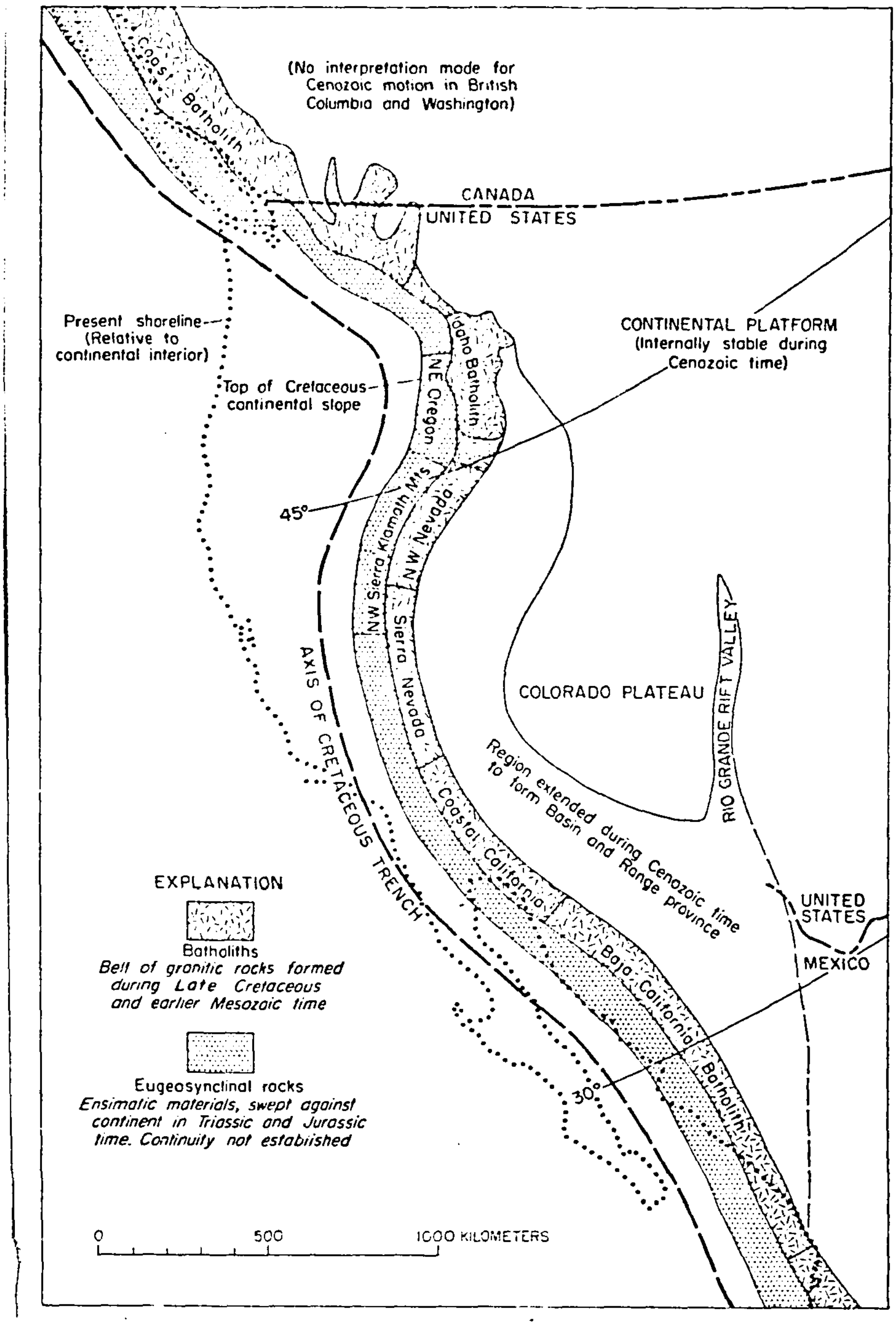



Figure I-5. Paleogeographic map of the continental-margin of west central North America in middle Late Cretaceous time. From Hamilton (1969). Courtesy of Geological Society of America.

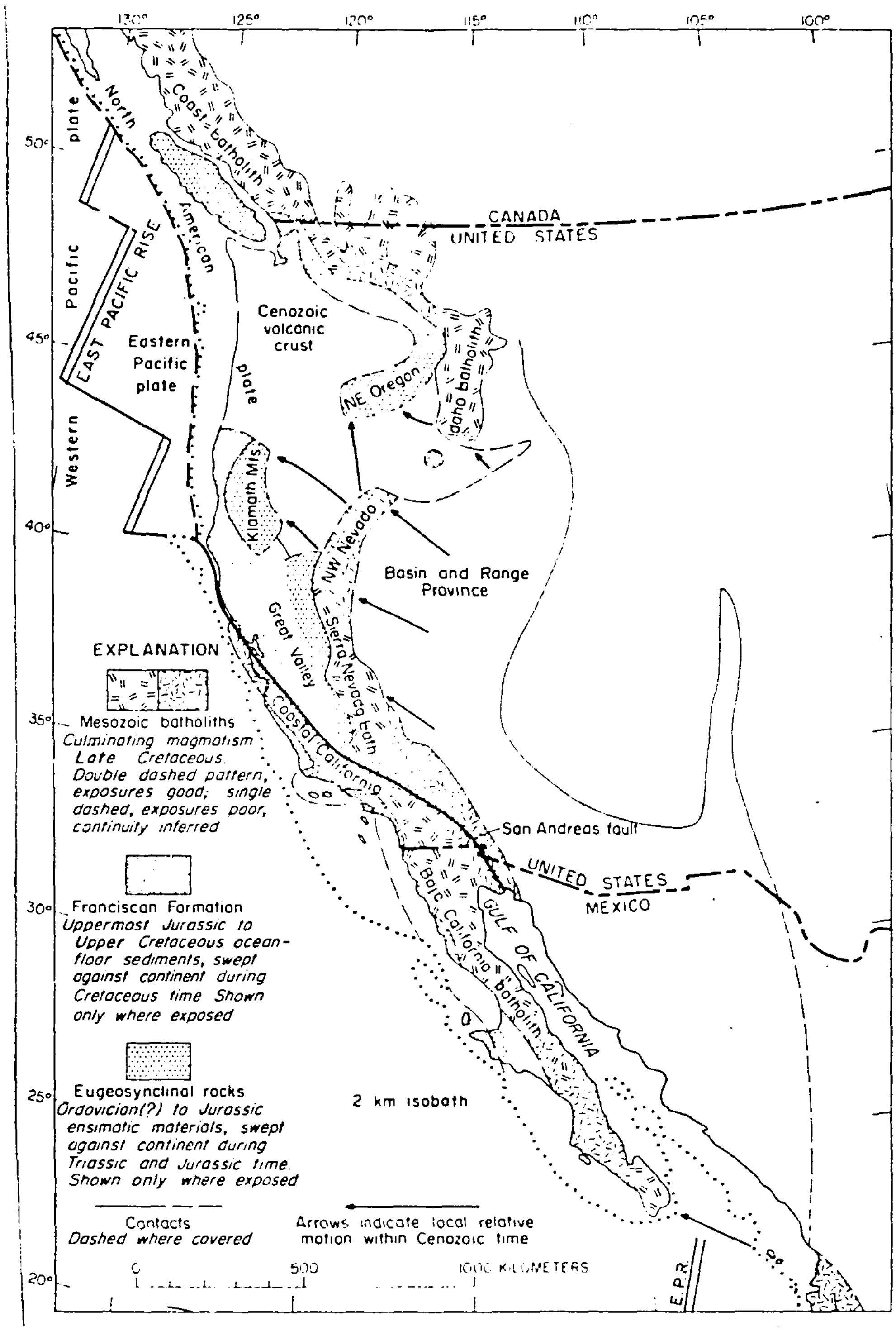



Figure I-6. Upper Mesozoic complexes of west-central North America showing inferred motion relative to the continental interior during Cenozoic time. Courtesy of Geological Society of America.

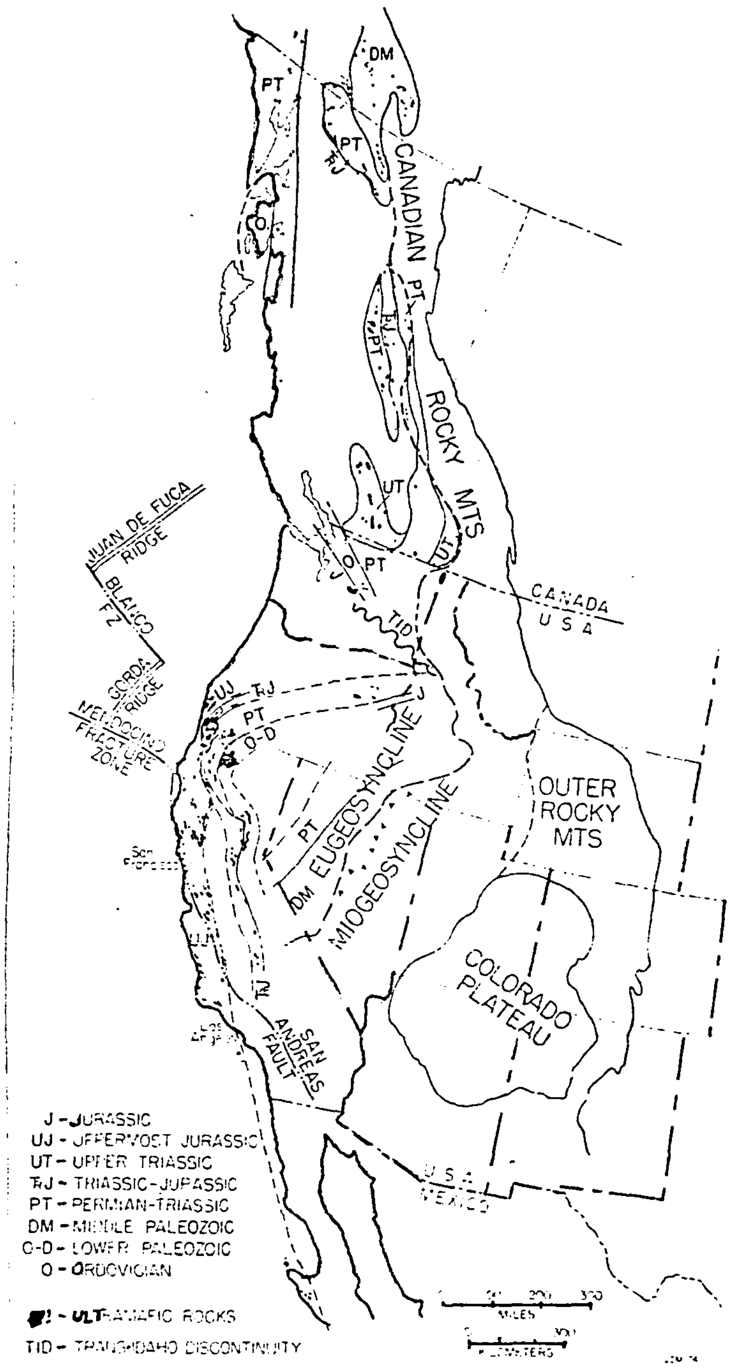



Figure I-7. Location and apparent ages of ultramafic rocks from Maxwell, 1974. Courtesy of Geological Society of America.

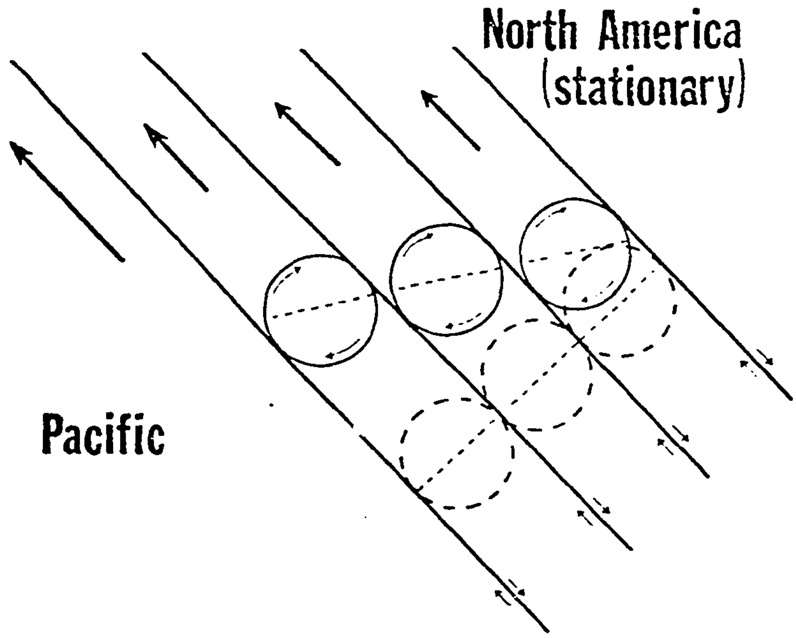
Discontinuity described by Taubeneck. This feature should be considered in any study of the Columbia Arc.

Rogers, et al (1974) suggest that the Columbia Arc is a primary feature rather than being the result of post-depositional rotation. They argue that the lithofacies distribution is indented into the continent and that the distribution reflects the original shape of the island arcs and basement compositional types.

Watkins and Baksi (1974) followed up Watkins' (1965) earlier work with careful K-Ar dating of the Miocene volcanics. They were able to compare sites with accuracies of .5 to 1.0 m.y. Data in eastern Oregon and Washington suggest clockwise rotation of about $15^{o}$ since Miocene. Data in central Oregon and Washington do not show rotation. They state, "At this time, the question of oroclinal rotation in the Pacific Northwest remains open."

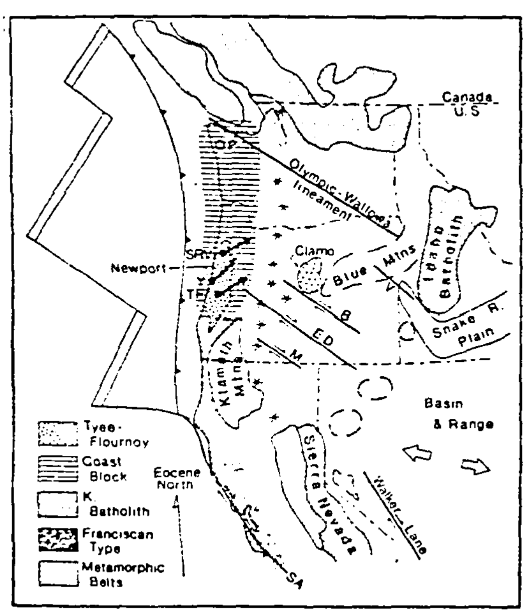
Beck (1976) argues that discordant paleomagnetic pole positions are evidence of regional shear in the western United States. Figure I-8 shows his explanation of translation and rotation of crustal blocks related to motion of the Pacific plate relative to the North American continent.

Simpson and Cox (1977) discuss Eocene volcanics and sediments from the Oregon Coast Range which show paleomagnetic directions $50^{o}$ to $70^{o}$ east of the expected Eocene direction (see Figure I-9). They believe that this suggests clockwise rotation of the crustal block and developed geologic models to accommodate the rotation.




Cartoon illustrating northwestward translation and clockwise rotation of rigid crustal blocks in a northwestward-trending right-lateral shear zone. Heavy diagonal lines represent individual faults in a zone of distributed shear. Crustal blocks (represented by circles) can rotate ball-bearing fashion or move northwestward without rotation. Coherent rotation of several blocks across adjacent faults is shown, but more complicated tectonic patterns might be expected to predominate.

Figure I-8. From Beck (1976). Courtesy of American Journal of Science.

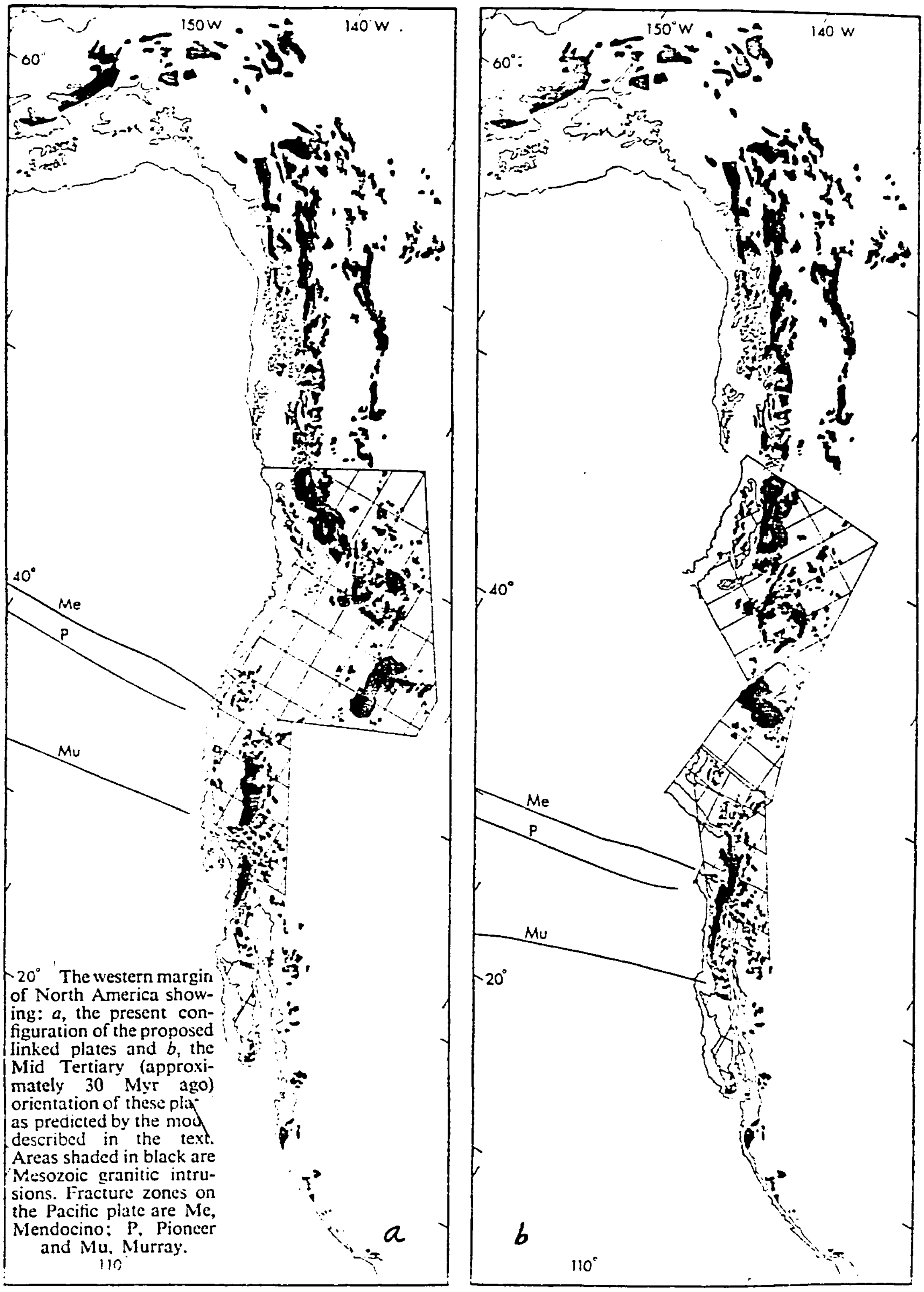



Generalized geologic and tectonic map of northwestern United States based in part on Hamilton (1969) and Lawrence (1976). SRV = Siletz River Volcanic Series, Y = Yachats basalt, TF = Tyee and Flournoy Formations, OP = Olympic Peninsula. Fault zones and lineaments: V = Vale, B = Brothers, ED = Eugene-Denio, M = McLoughlin, SA = San Andreas.

Figure I-9. From Simpson and Cox (1977). Courtesy of Geological Society of America.

Heptonstall (1977) proposes that the Columbia Arc can be "straightened" using the idea of three linked plates between the Canadian Cordillera and Mexico. He accepts the Columbia Arc as a series of three oroclines with hinge poles at Vancouver, east of the Idaho Batholith, and the Klamath Mountains (see Figure I-10). He suggests that deformation began during the Oligocene.

The above references indicate that the origin of the Columbia Arc remains controversial. The reconciliation of the geology and paleomagnetics should be a worthwhile goal. The more recent articles such as Beck (1976), Simpson and Cox (1977), and Heptonstall (1977) attempt to meld plate tectonics and continental geology. These latter articles depend heavily on the interpretations by Atwater (1970).




The western margin of North America showing: *a*, the present configuration of the proposed linked plates and *b*, the Mid Tertiary (approximately 30 Myr ago) orientation of these pla as predicted by the mod described in the text. Areas shaded in black are Mesozoic granitic intrusions. Fracture zones on the Pacific plate are Me, Mendocino; P, Pioneer and Mu, Murray.

Figure I-10. From Heptonstall (1977). Courtesy of Nature.

# CHAPTER II SUMMARY OF GEOLOGIC HISTORY

## Introduction

The geologic history of the Cordilleran area will be discussed regionally to show how parts of the Columbia Arc relate to each other. The approach is derived from Burchfiel and Davis (1972 and 1975) for California and Nevada but is extended into Oregon, Washington, and southern Canada following other authors.

## Eocambrian to Devonian

Rifting in Precambrian time is postulated as pre-Belt, about 1450 m.y.b.p. and pre-Wendemere, about 850 m.y.b.p. by Dickinson (1977). Thick Eocambrian rocks extending from southern California into British Columbia are believed to have then been deposited along an Atlantic-type plate margin in Late Precambrian time (see Figure II-1).

Early Paleozoic paleogeography of the western United States consisted of a thin cratonic sequence over the stable interior, a miogeosynclinal carbonate sequence extending from eastern Nevada into British Columbia, and an engeosynclinal sequence west of the miogeosyncline. Evidence of a Devonian island arc is found in the Klamath Mountains of California. Cambrian and Ordovician eugeosynclinal sediments and volcanics and Silurian and Devonian eugeosynclinal sediments are found in the Roberts Mountains thrust plate of Late Devonian-Early Mississippian age Antler orogeny.

Devonian shelf deposits are found at the west end of the Blue Mountains in Oregon (Vallier et al, 1977); these are the oldest

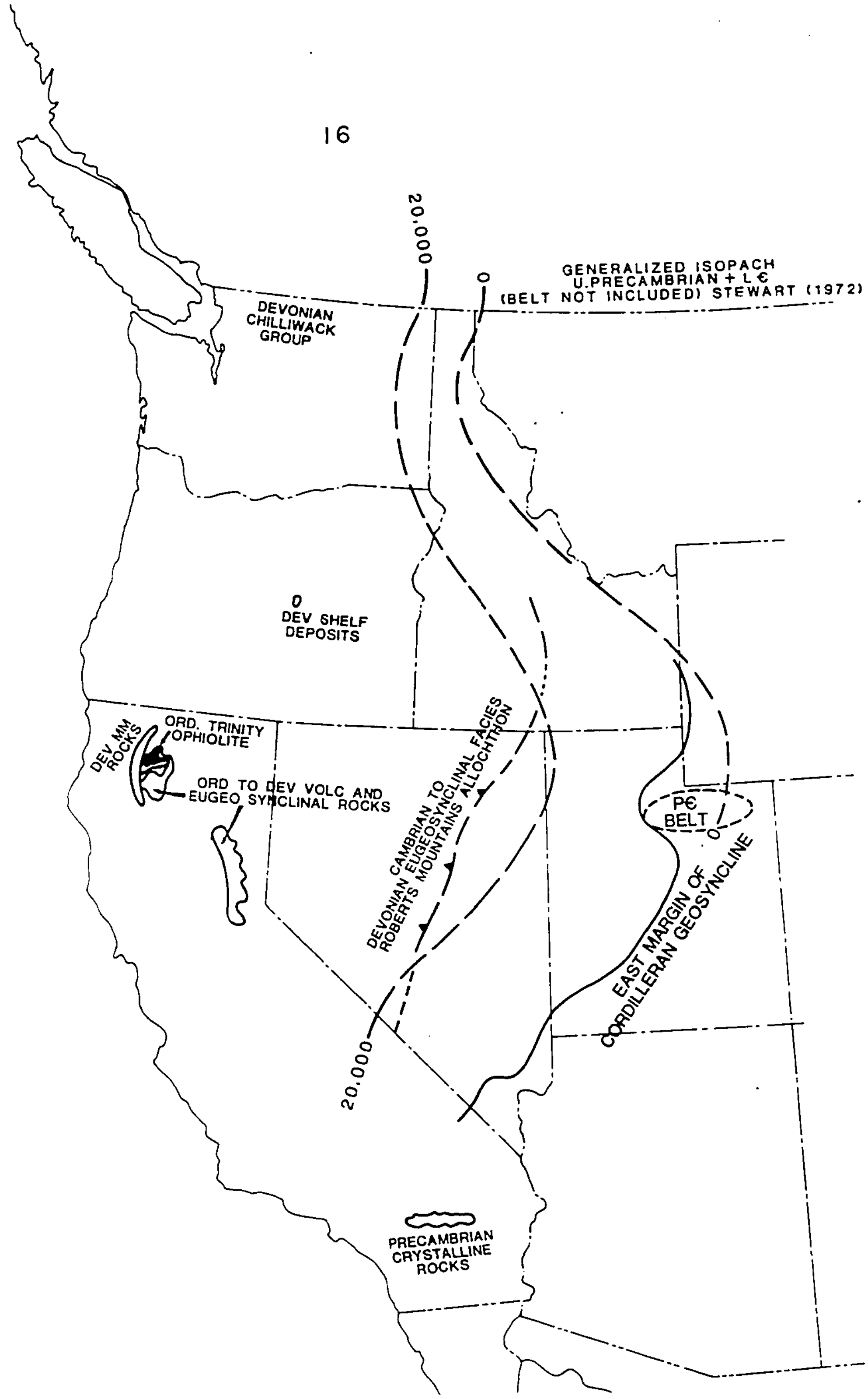



FIG. II-1 LATE PRECAMBRIAN TO DEVONIAN

ADAPTED FROM BUCHFIEL AND DAVIS (1972 AND 1975).

identified strata in Oregon. Devonian rocks of the Chilliwack group crop out in the northern Cascade Mountains of Washington. Fossiliferous limestone, graywacke, chert, greenstone, and volcanics are present in the Chilliwack group.

### Mississippian to Early Triassic

Figure II-2 shows suggested relationships of Mississippian - Early Triassic rocks in the western Cordillera based on present distribution. A true paleogeographic map would require removal of all post depositional movements such as faulting and consumption of plates in subduction zones.

The site of the Antler orogeny in Nevada (Roberts Mountain thrust) became a highland belt which shed clastics eastward into a shallow marine basin. To the west, a deep marine basin developed with thick chert, argillite, and turbidites being deposited (the Havillah Sequence). Further west was a volcanic arc terrain exemplified by the Happy Creek volcanics in northwest Nevada (Speed, 1977).

In the Sierra Nevada, the Calaveras Complex of volcanics, argillite, olistoliths of shallow water limestone, chert, and sandstones is thought to be at lease in part equivalent to the Havillah Sequence (Schweickert, et al, 1977).

The eastern part of the Klamath Mountains consists of Mississippian, Pennsylvanian, Permian, and Triassic volcanics, limestone, graywacke, and shale. These rocks suggest the continued presence of a volcanic arc in this region.

Three upper Paleozoic terranes are described by Vallier, et al (1977), in eastern Oregon. These are shelf, oceanic, and volcanic arc

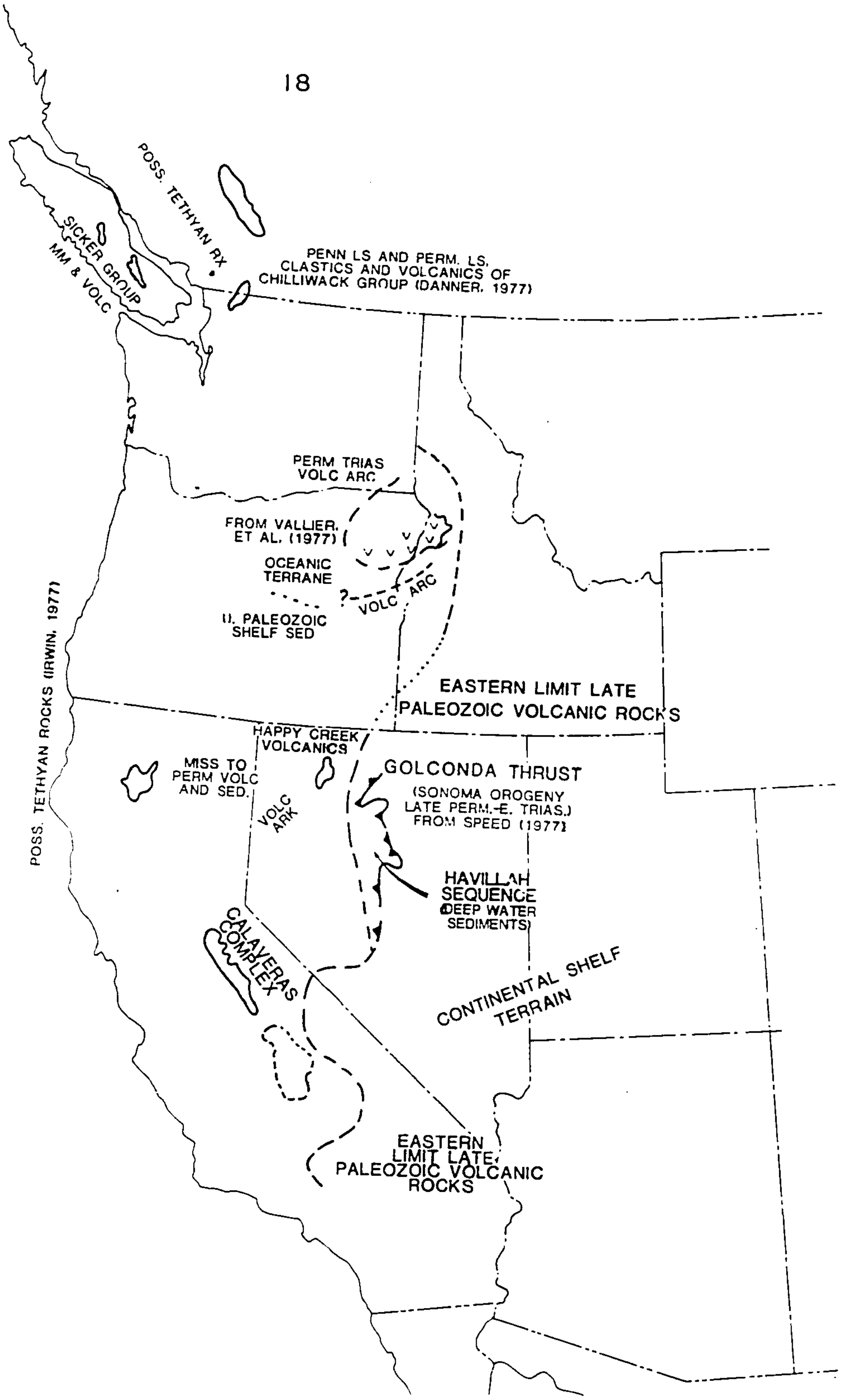



FIG. II-2 MISSISSIPPIAN TO EARLY TRIASSIC

ADAPTED FROM BURCHFIEL AND DAVIS (1972 AND 1975) (see Figure II-2). A larger scale map of eastern Oregon from Vallier is displayed (Figure II-3) because of the importance of the Blue Mountain area to the present thesis. The shelf reportedly has shallow water rocks of Devonian to Permian age. These apparently grade northerly into an oceanic terrane. The oceanic terrane contains serpentine, basalt, volcanoclastic rock, argillite, and scattered limestone broken into chaotic blocks. It is believed that these rocks represent a late Paleozoic and early Mesozoic oceanic floor of the ancestral Pacific. The volcanic arc terrane is exemplified by the Seven Devils Group of Permian and Triassic greenschist rocks in western Oregon and eastern Idaho. Stevens (1977) states that Permian rocks in eastern Oregon show many parallels with those in northern California and northwestern Nevada.

Pennsylvanian and Permian limestones, clastics, and volcanics are found in the northern Cascade Mountains (Danner, 1977). Correlation with the McCloud Limestone of the Klamath Mountains has been suggested.

Burchfield and Davis (1975) believe that the Devonian-Mississippian Antler and the Permian-Early Triassic Sonoma Orogenies were caused by similar mechanisms. The Havillah Sequence was thrust eastward across the continental shelf. This thrusting possibly was related to subduction activity thought to have been present in eastern Oregon, Washington and British Columbia. The significance of possible Tethyan faunas in the Klamath Mountains, the Blue Mountains and the Cascade Mountains is that plates may have been tectonically displaced into these areas in post-Permian time from distant Pacific sources by plate tectonic activity (Danner, 1977).

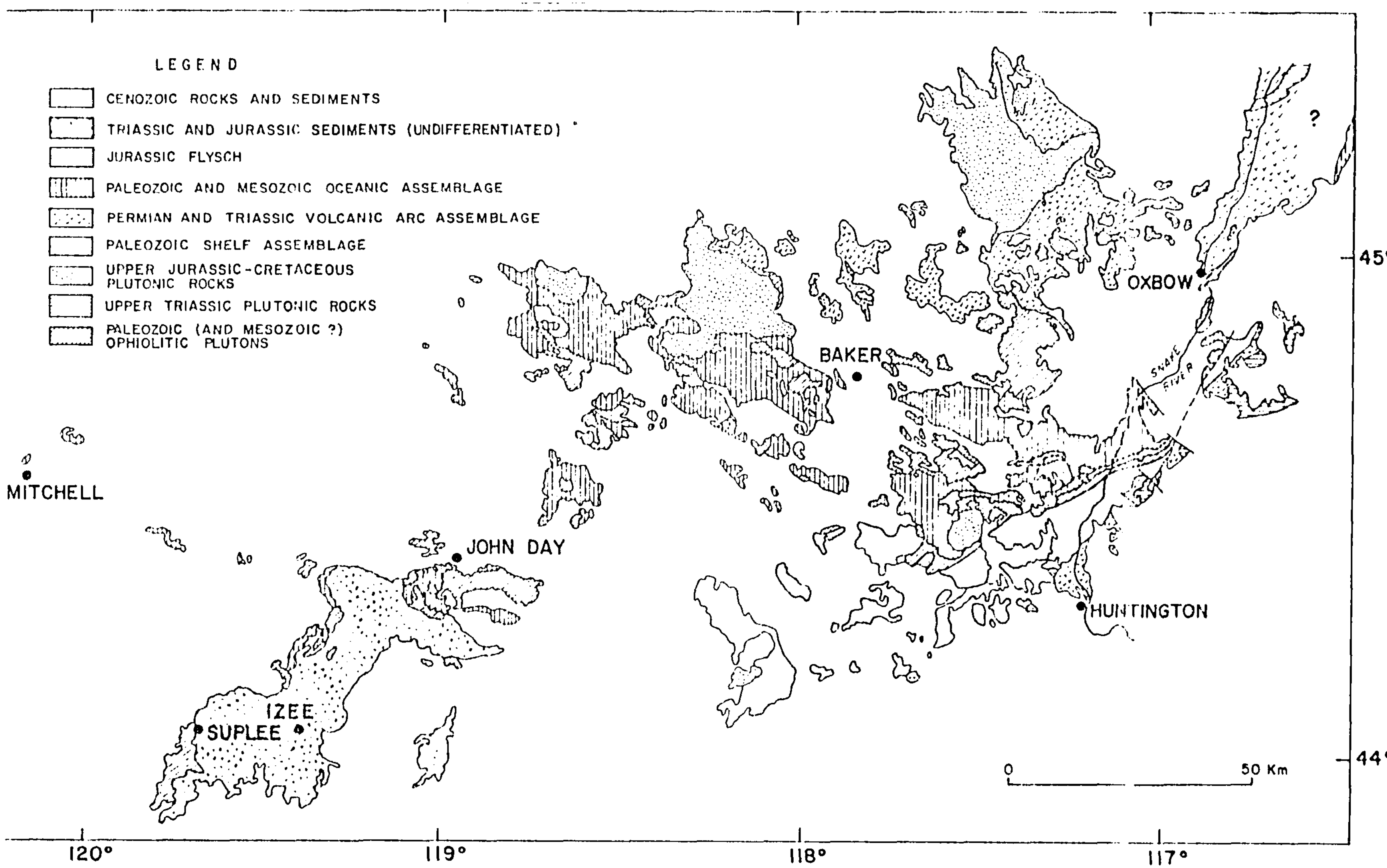



Figure II-3. Pre-Cenozoic geologic map of eastern Oregon and western Idaho (Vallier, et al, 1977). Courtesy of Pacific Section, Society of Economic Paleontologists and Mineralogists.

## Early Mesozoic through Jurassic

Early Mesozoic sedimentary, volcanic, and plutonic activity generally parallels the pre-middle Triassic trends in northern California, Washington, Oregon, and British Columbia. However, in the southern two-thirds of California, Triassic and later trends cut across the Antler and Sonoma belts and Cordilleran geosyncline (see Figure II-4). The southwestern part of the North American plate possibly was truncated in early Triassic time. Schweickert (1976) believes that the Melones and Trinity fault zones mark the truncation edge.

According to Burchfiel and Davis (1975), the Mesozoic volcanic-plutonic arc began to develop about middle Triasic time, after the truncation. This is thought to be the result of eastward subduction of the Pacific plate beneath the north American plate. Accompanying the subduction were Jurassic intrusives in southern California, the Sierra Nevada Mountains, the Klamath Mountains, the Blue Mountains of Oregon, Washington and British Columbia. Triassic blueschist localities are described by Hotz, et al (1977) in the Klamath Mountains and in the Blue Mountains. These are believed to have developed along a subduction zone. It thus seems likely that a volcanic arc setting existed during this period along the entire West Coast from southern California to British Columbia.

Easterly dipping thrusts associated with the subduction during Jurassic were accompanied with west dipping thrusting in Nevada, southern California, and early thrusts in Idaho. This is referred to as the "two sided" nature of the Cordilleran orogen by Burchfiel and Davis.

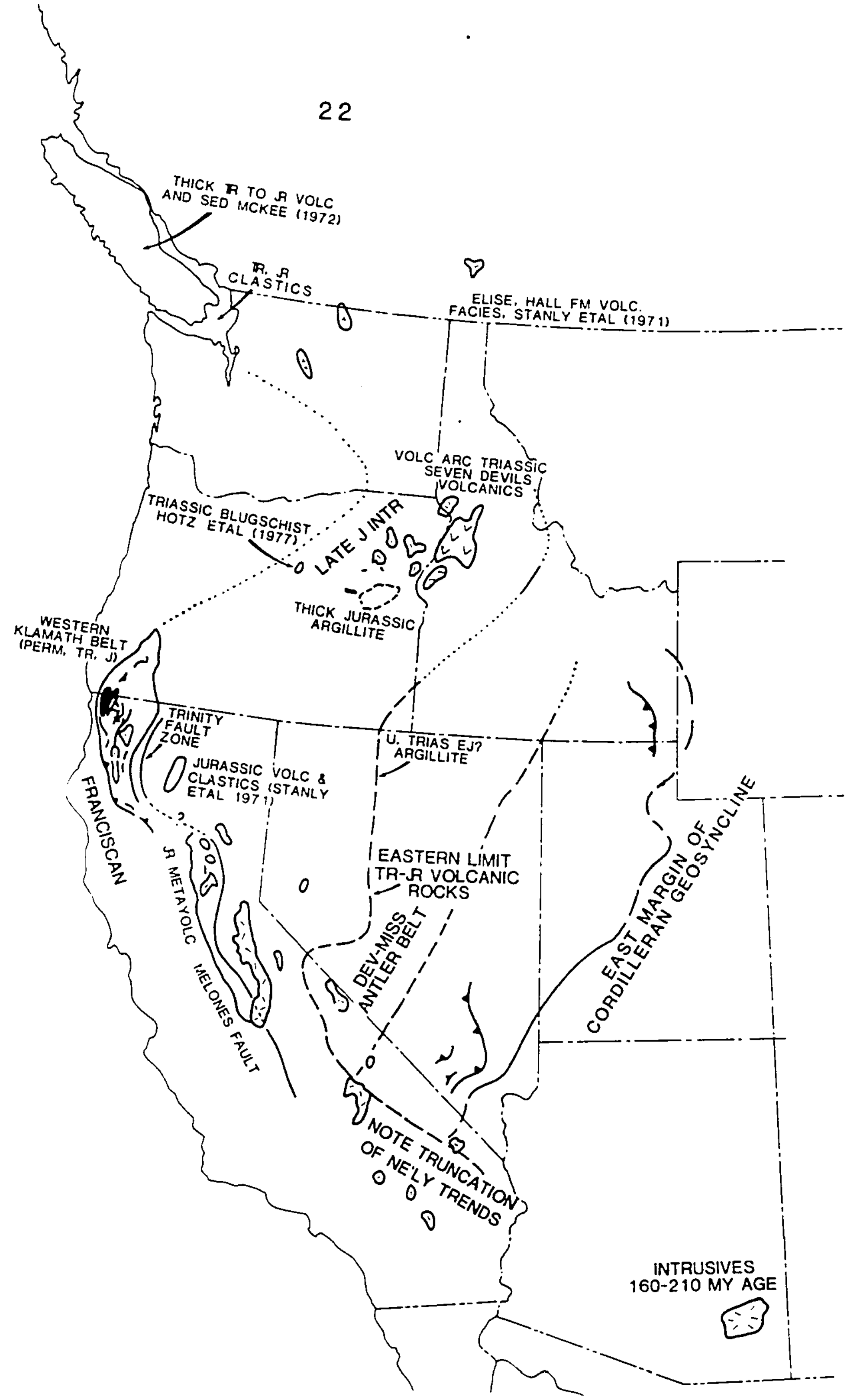



FIG. II-4 EARLY MESOZOIC THROUGH JURASSIC

ADAPTED FROM BURCHFIELD AND DAVIS (1972 AND 1975).

## Late Jurassic to Late Cretaceous

Referring to Figure II-5, rocks of the Great Valley sequence in California are Late Jurassic to Late Cretaceous in age. The Franciscan complex of the same age contains ultramafic rocks and are complicated structurally. Franciscan rocks lie to the west of the Great Valley sequence and possibly represent material thrust beneath the Great Valley sequence along a subduction zone (Hamilton, 1969; Maxwell, 1974; Burchfiel and Davis, 1975). This subduction is thought to have produced plutonism in the Klamath Mountains; related subduction probably caused extensive plutonism in the Sierra Nevada and southern California batholiths. Scattered Jurassic and Cretaceous intrusives are present in Nevada, Arizona, and Oregon (Armstrong and Suppe, 1973; Armstong et al, 1977).

About 10,000 feet of interfingering marine shales and nonmarine sands and conglomerates of Albian and later age are present in central Oregon (Wilkeson and Oles, 1968). In the northern Cascade Mountains, 40,000 feet of Lower Cretaceous marine volcanics and sediments are present as are 20,000 feet of Upper Cretaceous nonmarine rocks. The extensive Coast Range Batholith of British Columbia shows many Cretaceous age dates (Roddick, 1966).

It can be postulated that the subduction zone off California extended further north along the Pacific Coast and was also related to plutonism of the Idaho Batholith and batholiths of Oregon, Washington and British Columbia (Figure II-5).

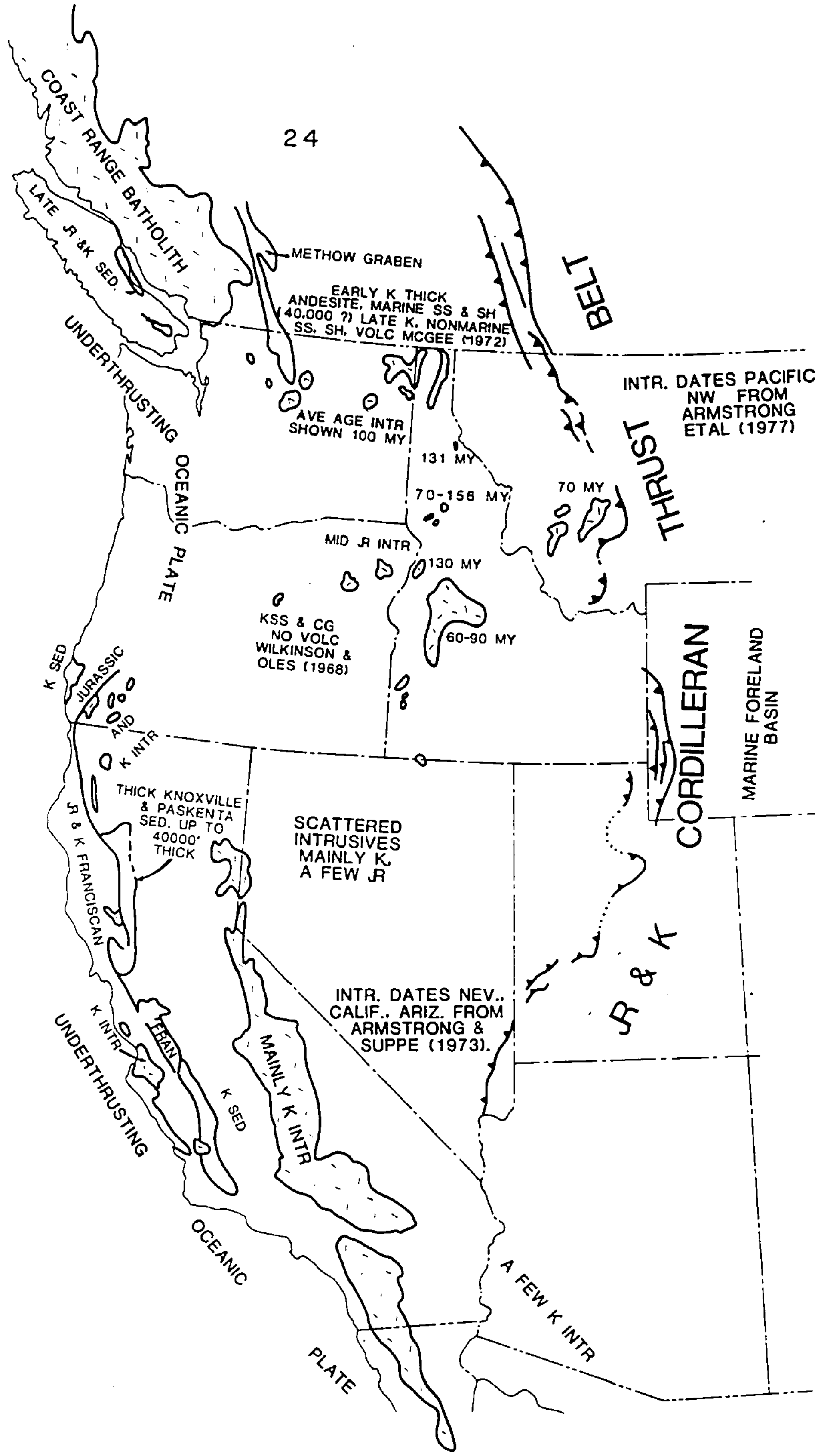



FIG. II-5 LATE JURASSIC TO LATE CRETACEOUS.

BURCHFIEL AND DAVIS (1972 AND 1975)

It should again be noted that the geologic history is based on present distribution of outcrops. We will later discuss how a more simple pattern may have been present in pre-Tertiary time.

## Paleocene to Oligocene

An important change took place in the Cordilleran thrust belt in Late Cretaceous according to Burchfiel and Davis (1975). At this time, thrusting ceased in central Utah and southeast California. To the north and south of this sector, however, thrusting continued until Late Eocene (see Figure II-6).

Igneous activity also changed during Late Cretaceous time. Igneous rocks of this period are rare in central and northern California, while extensive volcanism was present to the north in Oregon and Washington. Thick marine Eocene volcanics are present along the coast of Oregon and Washington (McKee, 1972). Eocene to Oligocene volcanics and volcanoclastics probably underlie southern Washington and Oregon (see Figure II-6). Eocene K-Ar age dates are found in many intrusives in northwestern Washington and in the Idaho Batholith (Armstrong et al, 1977). These areas represent areas of intense Eocene heating or actual Eocene instrusions. Armstrong (1974) states that the Eocene Challis volcanics in central Idaho probably are erosional remnants of formerly extensive flows. The Challis volcanics dates range from 55 to 40 m.y. The composition is primarily intermediate calk-alkalic. Eocene volcanism and instrusives are also present in southwest Montana, western Wyoming, southwest Colorado, Arizona, and southwest New Mexico. Noble (1972) points out that a strong period of volcanism began in the southwestern United States in earliest

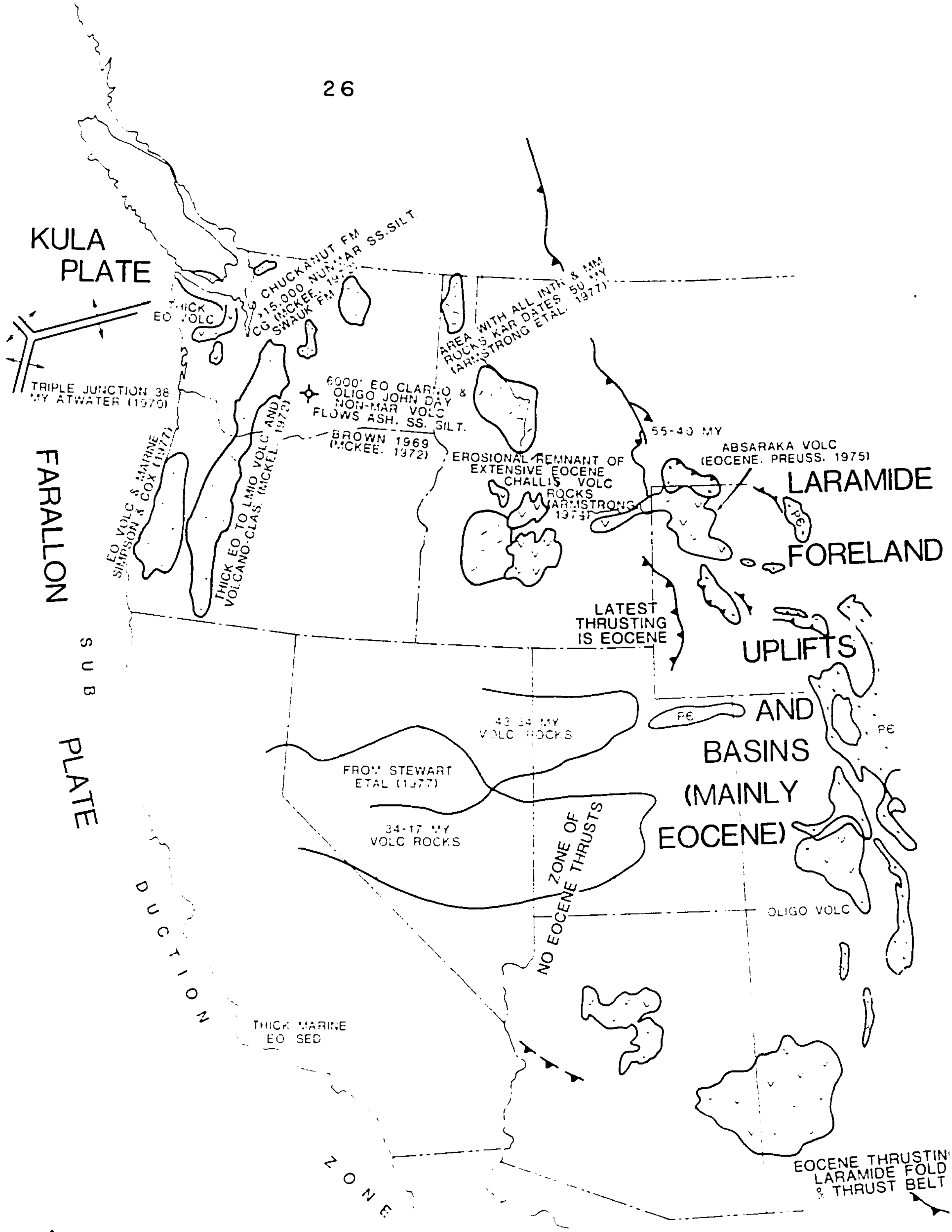



FIG. II-6 PALEOCENE TO OLIGOCENE

AFTER BURCHFIELD AND DAVIS (1975)

Oligocene, 37$\pm$1 m.y. This includes the Great Basin and Colorado San Juan and Mogollon - Datil volcanic fields in Arizona and New Mexico. In Nevada and western Utah, Eocene to Miocene volcanic and instrusive rocks tend to be aligned in east-west patterns (Stewart, et al, 1977), Figure II-6.

Laramide basement uplifts exposing Precambrian rocks occur in Montana, Wyoming, Utah, Colorado and New Mexico. These blocks display large vertical movements and are bounded by low to high angle reverse faults. Burchfiel and Davis point out that the basement uplifts mostly lie opposite to the portion of the thrust belt that ceased movement in Late Cretaceous. Continued thrusting occurred to the north and south, but the shortening in the central sector may have been transmitted to the area of foreland structures. Possible increase of ductility related to easterly shift of Laramide igneous activity is discussed.

Atwater (1970) shows evidence for presence of a spreading zone west of the continent during Eocene and a related subduction zone between the Farallon plate and the American plate. Burchfiel and Davis consider the possibility that a central shallow subduction plate extended easterly. The shallow subduction zone is postulated to have transferred the igneous activity eastward. Such a shallow subduction zone was also proposed by Lipman et al (1972). Steeper dipping subduction zones possibly existed to the north and south of the gently dipping zone and separated from it by tear faults. The east-west trend of the volcanism in Nevada and Utah could be related to the shallow dipping plate or to the tear faults.

Atwater (1970) shows the possibility that a triple ridge junction existed offshore 40 m.y. ago from the present position of Seattle. As shown on Figure II-6, the oceanic ridge between the Kula and Farallon plates could have directed a southwesterly force component onto the continent. The Paleocene to Oligocene history has a special bearing on the possible oroclinal bending in the Pacific Northwest as will be shown in a later section.

## Miocene to Quaternary

A broad summary of features of this time interval is shown on Figure II-7.

Atwater (1970) proposed that the present San Andreas fault was initiated about 30 m.y. ago. She shows that part of the oceanic rise may have come into contact with the American plate and the relative motion was taken up as right lateral strike slip faulting. She proposes that development of Basin and Range structure was related to plate tectonics and considers the western United States to be a wide, soft boundary between two rigid plates. Apparently she considers the analyses of Carey (1958) and Wise (1963) as reasonable.

McKee (1971) proposed that the continent overrode the East Pacific Rise. In Middle Miocene, basalt and rhyolite volcanism and Basin and Range faulting then commenced about 16 m.y. ago in response to the presence of the Rise beneath the Great Basin. He also shows that the nature of volcanism changed in the Great Basin from rhyolitic-andesitic to rhyolitic-basaltic at this time.

Noble (1972) suggested that inception of Basin and Range structure at about 17-15 m.y. was accompanied by crustal rifting in the Pacific Northwest with eruption of the Columbia River basalt volcanics. He believed that there is little evidence of time migration of deformation

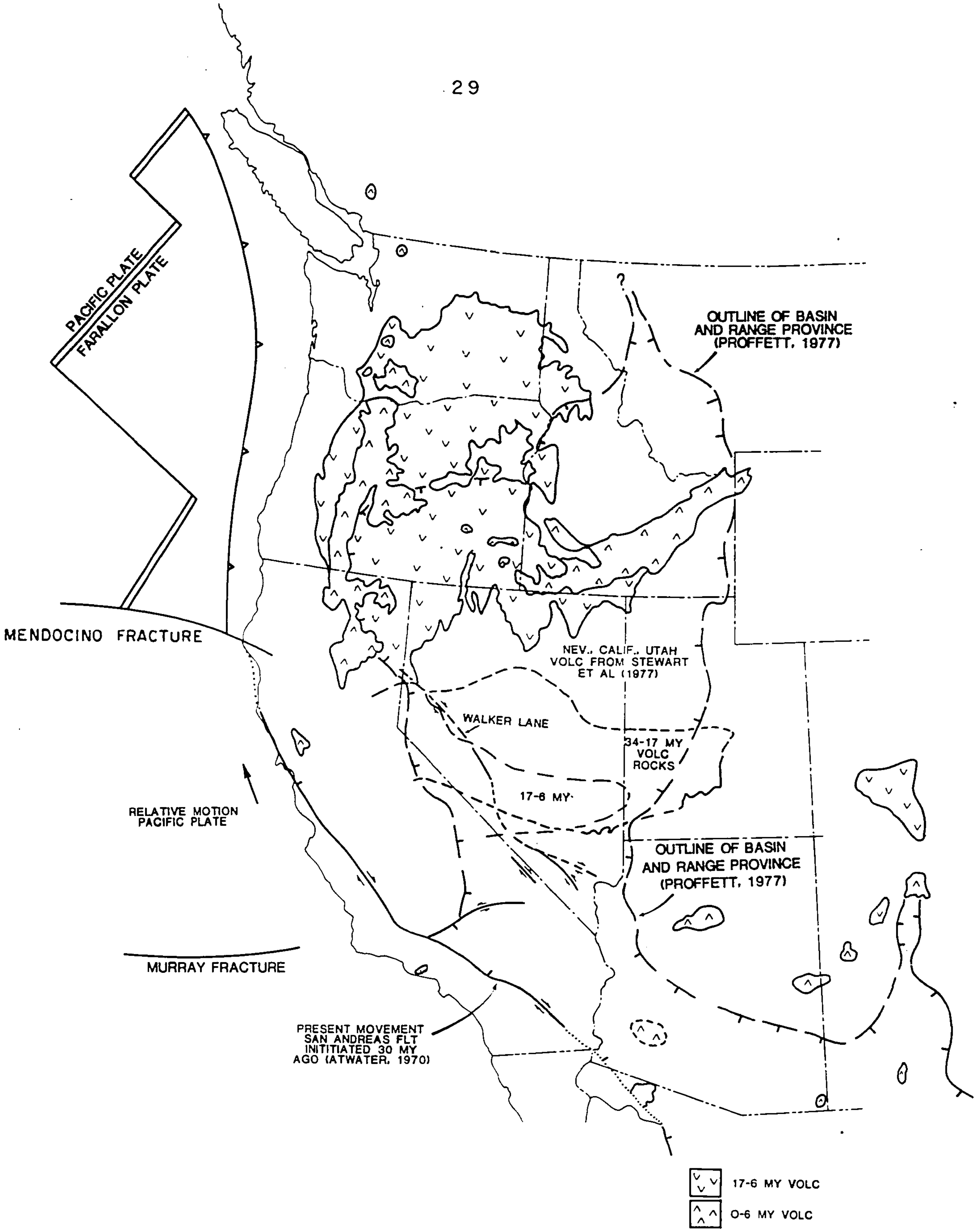



FIG. II-7 MIOCENE TO RECENT

but rather that faulting began at practically the same time over the entire Basin and Range area. He suggested that the Eocene to recent volcanics west of the Cascade Range are related to subduction. The Eocene to Oligocene andesites and rhyolites of Utah, Nevada, Arizona, Colorado, California, Arizona and New Mexico were likewise related to subduction.

Proffett (1977) suggests that Basin and Range extension may have begun in southern California 40-30 m.y. ago, moved northerly into southern Nevada 30-23 m.y. ago, into central Nevada 18-15 m.y. ago, then more recently into southeast Oregon and southern Idaho. He emphasizes the listric (normal faults which flatten with depth) nature of the Basin and Range faults. Figure II-8 shows his interpretation of the Great Basin. He believes symmetry is present, possibly about a spreading axis. The most severe faulting and rotation takes place near both boundaries of the Great Basin. Proffett believes that an overall extension of 30 to 35% is reasonable, or 160 to 180 kilometers across the Great Basin. This should have a bearing on possible clockwise rotation of volcanic rocks in the Basin and Range as will be discussed later.

Strike slip movement is important in the California and western Nevada portion of the Basin and Range province. Albers (1968) shows that right lateral structural bending occurred from Early Jurassic time to pre-Middle Miocene, along the Walker-Lane zone in western Nevada. Subsequent movement was strike slip faulting; total fault and bending movement may have been 80 to 100 miles. Lawrence (1976) proposes a series of northwest trending right lateral faults in Oregon and Washington which may in part terminate Basin and Range expansion to the north. Wright (1976) proposes a southerly zone of normal and strike slip faults and a northerly zone of mainly horst and graben structure.

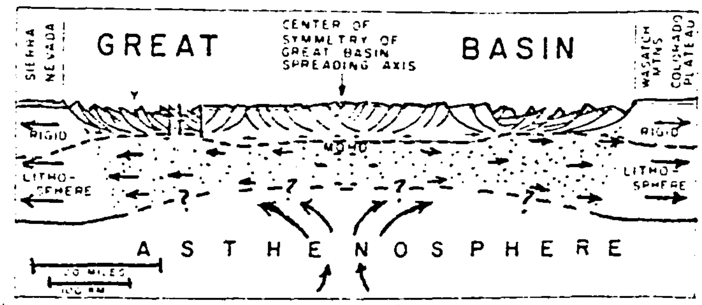



Figure II-8. East-west cross section across the Great Basin. From Proffett, Jr., J. M. (1977). Courtesy of Geological Society of America.

Quaternary volcanism of the Cascade Mountains probably is related to subduction (Noble, 1972 and Suppe, et al, 1975). According to Suppe et al, the Snake River volcanics become progressively older to the west, up to 15 m.y. at 400 km. west of Yellowstone Park. They suggest that the Snake River volcanics represent the track of a mantle hot spot at Yellowstone. The American plate may have moved westerly over the hot spot. The Snake River olivine tholeiites are chemically distinct from surrounding alkalic basalts. The Raton-trans New Mexico chain is suggested to be the track of a similar hot spot with strung-out volcanism related to western movement on the American plate.

# CHAPTER III
# APPLICATION OF PALEOMAGNETIC METHODS TO GEOLOGIC PROBLEM

## Uses of Paleomagnetism in Geology

Paleomagnetism has been used for many different purposes. Paleomagnetic "polar wandering" poles were clues to continental drift. Magnetic anomaly profiles of ocean floor "stripes" are important in sea floor spreading and plate tectonic studies. Paleomagnetic latitudes are useful in paleogeographic studies. A recent use of paleomagnetism is aid in correlation of terrestrial volcanic rocks. Archaeomagnetism has helped in age dating of prehistoric living sites. The present thesis depends on differences between measured paleomagnetic directions and expected directions.

## Detection of Structural Rotation

If the Columbia Arc is a secondary feature, created by regional bending deformation about vertical axes, paleomagnetics could be used to demonstrate this rotation. This is provided that the rocks acquired their magnetism prior to rotation. Paleomagnetic directions from similar times in the cratonic part of North America should be used for comparison to establish amount of rotation.

## Intrusive Rocks

The regional stratigraphic distribution suggests that rocks at least as young as Late Jurassic and Cretaceous are involved in the Columbia Arc.

Upper Jurassic and Cretaceous plutons ranging from gabbro to granite are present in the Blue Mountains of Oregon, the Idaho Batholith, and northern Nevada. If regional rotation occurred during Late Cretaceous or later, magnetic directions from these plutons should also demonstrate rotation. Rocks emplaced later than any regional binding would not show rotation of magnetic direction.

Eight intrusive localities were sampled in Nevada, fifteen in Idaho and twelve in Oregon. Sites of available radiometric age from the literature were given priority. Few radiometric dates were available in Oregon at the time of sampling (1972 and 1973) so undated plutons were also sampled there. As will be described in a later section, not all of the intrusive localities yielded useful results because of instability or weak magnetic response.

## Extrusive Volcanic Rocks

No field sampling of volcanic rocks was done by me. However, I was fortunate to obtain about 354 oriented samples and paleomagnetic data for an additional 170 samples from Chevron U.S.A. Inc. As mentioned in Chapter I, Watkins and Baksi (1974) state that eastern Oregon Miocene volcanics showed about $15^{\circ}$ of rotation. Simpson and Cox (1977) mention the possibility of rotation of Miocene volcanics near the Oregon coast. If rotation of Tertiary volcanics in the present study area can be confirmed, this would have a bearing on regional geology of the Basin and Range province in addition to that of the Columbia Arc.

## Examples from the Literature on Use of Paleomagnetic Data to Study Structural Rotation

Norris and Black (1961) studied paleomagnetics in the Canadian Rockies to show that the bend in the Lewis overthrust probably is due to erosion rather than later structural bending. Van Hilten (1962) showed that Permian volcanic rocks in northern Italy have magnetic directions that differ from other European Permian directions. Rotation of about $70^{\circ}$ is suggested. The use by Irving (1964) of Eocene data by Cox (1957) to suggest an oroclinal bend in the northwestern United States was mentioned in Chapter I. Kawai, et al (1961) show paleomagnetic and geologic evidence for early Tertiary bending of Japan. Mesozoic rocks are rotated $58^{\circ}$ counterclockwise whereas overlying early Tertiary rocks are unrotated. Irving and Opdyke (1965) suggest that the Appalachian geosyncline was rotated through an angle of about $40^{\circ}$ after Silurian time in the "Susqehanna Orocline". Narin and Westphal (1968) demonstrate Permo-Triassic rotation in Corsica of about $30^{\circ}$ by bathymetric contour fitting and sea floor anomaly results as well as paleomagnetics. Van der Voo (1969) confirmed previous suggestions of about $35^{\circ}$ of counterclockwise rotation of Spain between Late Triassic and Late Cretaceous. Larson, et al (1975) suggest that the south end of the Mariana Ridge and Trench system has been bent to the west (see Fig. III-1). This agrees with earthquake focal mechanisms and may be the result of major east-west lateral faulting.

The recent use of paleomagnetics by Simpson and Cox (1977) to suggest $50^{\circ}$ to $70^{\circ}$ of clockwise rotation of Eocene rocks in coastal Oregon was mentioned in Chapter I. Vandenberg, et al (1978) detailed both rotation and latitude change of the Italian Peninsula from Late Mesozoic to present. Counterclockwise rotation of about 70° and latitude shift of 10° southerly followed by 23° northerly shift are shown since Late Mesozoic time.

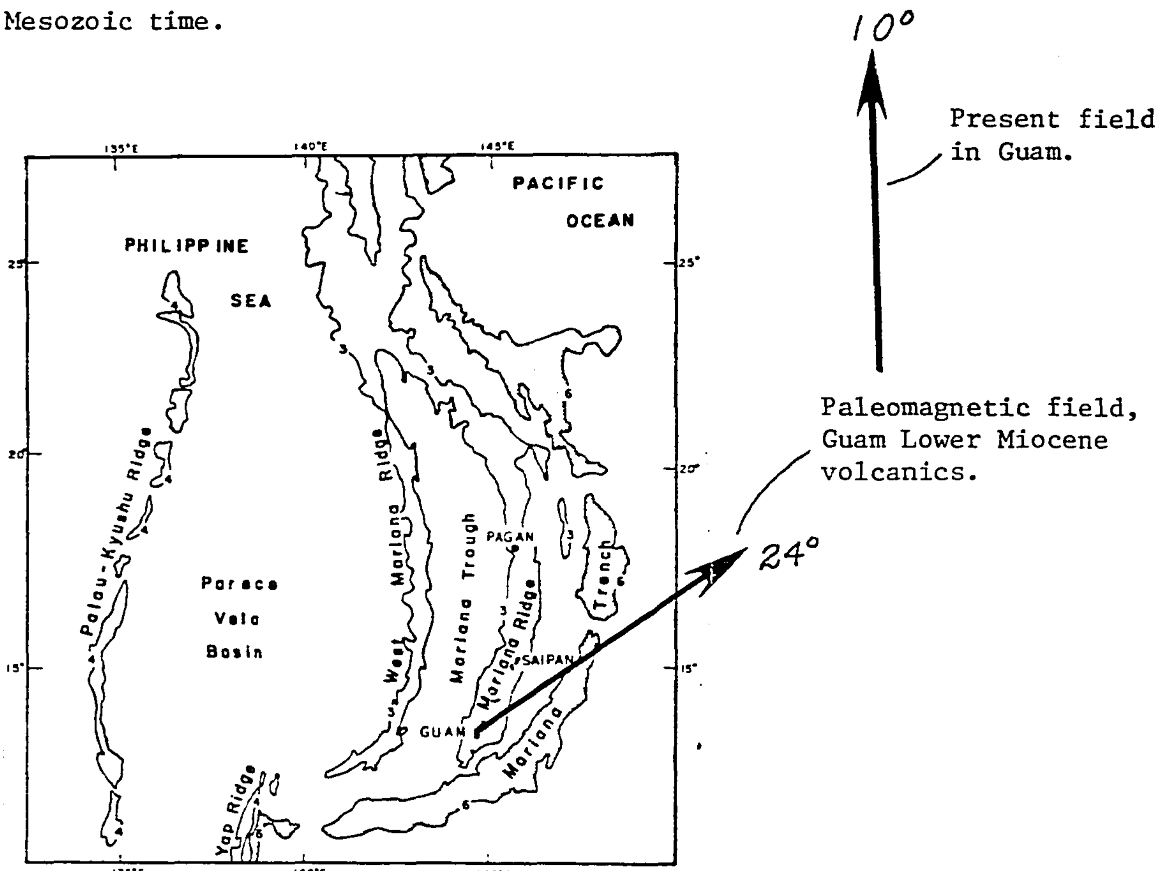



Figure III-1. Adapted from Larson et al (1975). Paleomagnetic data in Guam showing rotation. Courtesy of Geological Society of America.

## CHAPTER IV
## FIELD METHODS

### Sample Collection

#### Intrusives

Sampling was done during two 1-month intervals in 1972 and 1973. The primary targets for demonstrating possible rotation were the Blue Mountains of Oregon, the west edge of the Idaho Batholith, and northern Nevada. Sample locations are shown in Figure VI-3.

#### How Intrusive Sites Were Chosen

Sample localities were sought out wherever K-Ar dates were published. Smith, et al (1971) give age dates for sites in north central Nevada; McDowell (1966) provided dated localities in northwestern Nevada and the western part of the Idaho Batholith. W. H. Taubeneck (1972, pers. comm.) recommended localities I5, 01, 02, 03, and 04 and supplied general ages for them. Additional undated sites were sampled to fill in gaps in coverage, e.g. 07, 09, 010-12. Since the time of sampling, a considerable number of new age dates have become available (Armstrong, et al. 1977) in the Pacific Northwest. Sadness!

#### Sampling Procedures for Intrusives

Two gasoline powered drills were furnished by the University of Oklahoma for one month sampling periods in the summers of 1972 and 1973. Felker diamond tipped bits, 1-1/8" x 12" in size, were used for coring.

Water was provided for drilling by a hand pumped sprayer can. A Brunton Compass was used for orientation. Oriented block samples were taken when long hikes were required. Much time was consumed in the search for suitable sample sites. The field process of determining whether the outcrops were in place, looking for unweathered outcrops, and searching for attitudes of overlying volcanics took much more time than actual sampling.

## Strike and Dip of Volcanics Overlying Intrusives

The attitude of the overlying volcanics was recorded where possible to remove post-volcanic tilting from the measured paleomagnetic vector. In some cases, this measurement should be quite helpful, for example, at locality N6 in northern Nevada. A basalt ridge lies 3000' west of the diorite outcrop with N5$^{o}$E strike and dip of 16$^{o}$ west. In other cases, the volcanics might be located two miles away with 45$^{o}$ dip. Long distance extrapolation of steep dip to the intrusive sample site is risky.

## Number of Intrusive Samples

McElhinny (1973) states that the acceptable minimum number of specimens for reliability is eight, or rarely, seven. In some cases, fewer cores were taken when additional reliable outcrops were impossible to find, or where block samples had to be carried long distances. Eight sites were sampled in Nevada with 66 cores, 15 sites in Idaho with 121 cores, and 12 sites in Oregon with 79 cores. The total intrusive sites were 35 with 266 individual cores. It should be pointed out that for so large an area, the coverage is of reconnaissance nature. Unfortunately, several localities proved to be unreliable.

## Extrusives

Location of extrusive samples is shown in Figure VI-9.

One inch diameter oriented cores of volcanics were obtained from Chevron U.S.A. Inc. These samples were collected in the spring and summer of 1972 by Jack Cunningham, Keith Drummond, and Ralph Kraetsch. Azimuth on most samples was measured with a sun compass and dip of the core was measured by Brunton Compass.

## Strike and Dip of Volcanics

Strike and dip of the volcanic flows were measured with a Brunton Compass in most cases or estimated later on stereo photographs.

## Number of Volcanic Samples

Sampled sites were of two kinds. First, a series of flows were sampled in detail. An example of this is locality 28839 in Harney County, Oregon, where 47 cores were drilled in 2800' of Steens Mountain Basalt. The second type of sampling was reconnaissance, for example, north of the Harney Basin. Here a series of four cores were collected at different scattered stratigraphic and geographic sample sites.

Twenty-four extrusive sites were collected in Oregon with 282 cores. Ten sites were collected in Idaho with 242 cores. Total sites were 32 with 524 total oriented cores of volcanics.

# CHAPTER V
# LABORATORY METHODS

In paleomagnetic studies, the remanent magnetism's direction and strength are measured. Various "cleaning methods" are applied to remove soft components. We would ideally like to recover the TRM or thermoremanent magnetism that was acquired when the igneous rock cooled through the Curie point. This is in general a very difficult task to accomplish, particularly with coarse-grained intrusive rocks. The best that can be done is to try to achieve a stable magnetic moment and to compare it to other samples and other sites and attempt an interpretation. The age of the magnetization is considered to be the K-Ar age of the intrusives. However, later additive magnetization must be considered as a possibility.

## Intrusive Rocks

### Problem of Stability of Granitic Rocks

Coarse grained granitic rocks are commonly considered by workers in paleomagnetism to be magnetically less stable as compared to volcanics. For example, Hayes and Scharon (1956) described measurements on Precambrian granite in Missouri that were inconsistent and the magnetism too weak to give reliable directions, whereas associated Precambrian rhyolites gave consistent directions. However, if one wishes to work with western United State Cretaceous igneous rocks, he must try to use what is available, coarse grained granitic rocks in many areas. Inclusions are in many cases finer grained than the intrusive granitic rock. An attempt was made to sample inclusions for this reason.

Mineralogic Factors in Stability

The most common minerals of interest in paleomagnetism are the titanomagnetite and ilmenohematite series as shown in Figure V-1 adapted from Strangway (1970). Granitic rocks tend toward the magnetite and hematite ends of these series.

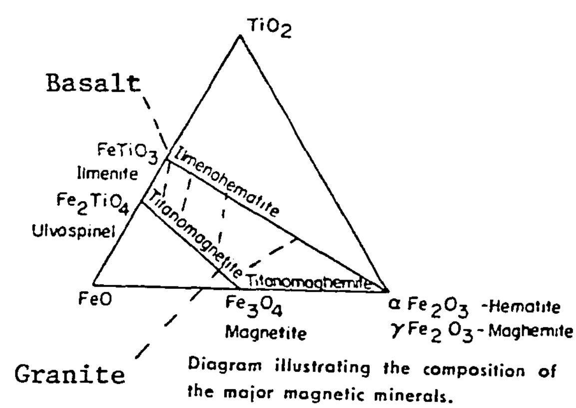
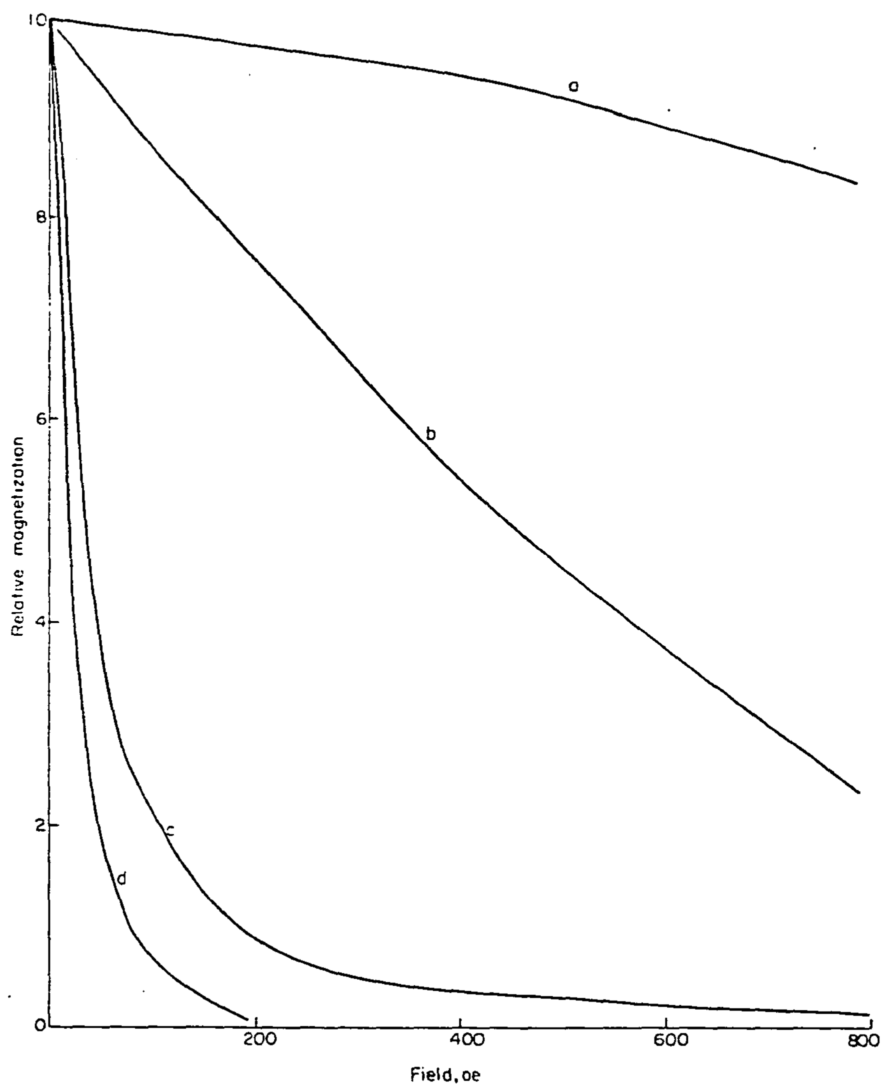



Fig. V-1. Modified from Strangway (1970). Courtesy of McGraw-Hill Book Company.

Verhoogan (1959) has experimentally established that finer ferrimagnetic grains in the rock produce a more stable TRM. Therefore, both texture and composition have important bearings on the magnetic stability of rocks.




Alternating field demagnetization.

*a* redbed with hematite as the magnetic mineral.
*b* basalt with magnetite as the main magnetic mineral, broken up into small grains by exsolution.
*c* basalt with magnetite as the main magnetic mineral without exsolution so that grains are around 20 microns in size.
*d* granite with very large grains of magnetite.

Figure V-2. Alternating field demagnetization. From Strangway (1970). Courtesy McGraw Hill Book Company.

Gromme and Merrill (1965) found that their granitic samples had a large soft component of magnetization. Large grains of pure magnetite comprised almost all of the ferromagnetic material. They attributed the large scatter to this mineralogy and texture. However, they believed they achieved a significant paleomagnetic direction by extensive averaging.

AF Demagnetization

One of the most easily applied and useful tests for stability is alternating field (AF) demagnetization in which the sample is tumbled in an A. C. generated field which is gradually reduced to 0. Figure V-2 from Strangway (1970) shows a comparison of AF demagnetization for red beds, two basalts of differing grain size and granite with large grains of magnetite. The granite sample is the least stable rock of those shown.

Coercivity is a useful concept for evaluating stability. Three considerations are 1) bulk coercivity, 2) remanent coercivity and 3) coercivity spectrum.

Bulk Coercivity

In the hysteresis loop, Figure V-3 modified from Irving (1964), the value -Hc is required to reduce the magnetization to 0. This is known as the bulk coercivity.

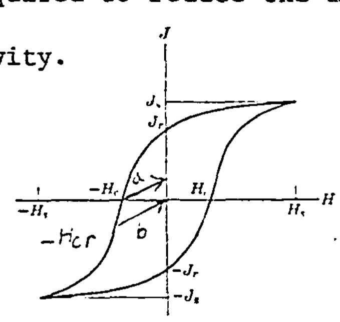



Fig. V-3 Hysteresis loop. Modified from Irving (1964).
-Hc=bulk coercivity
-Hcr=remanent coercivity

## Remanent Coercivity

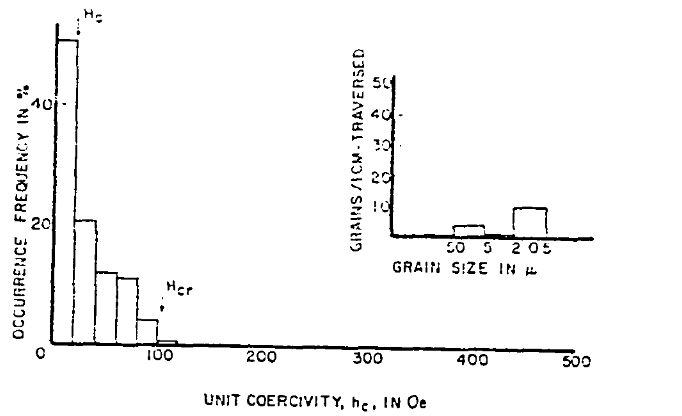
However, when the field Hc is removed often the material will rebound and reacquire a magnetization as shown by arrow a from Fig. V-3. To reduce the remanent magnetization to 0 requires a stronger field, -Hcr, to leave the magnetization at 0 when the field is removed; see arrow b.

## Coercivity Spectrum

A coercivity spectrum can be produced as described by Larson et al (1969). Figures V-4 and V-5 from Larson et al which show coercivity for fine and coarse grained granite. Note labels Hc and Hcr which are the bulk and remanent coercivities respectively. The fine grained granite is more stable than the coarse grained granite.

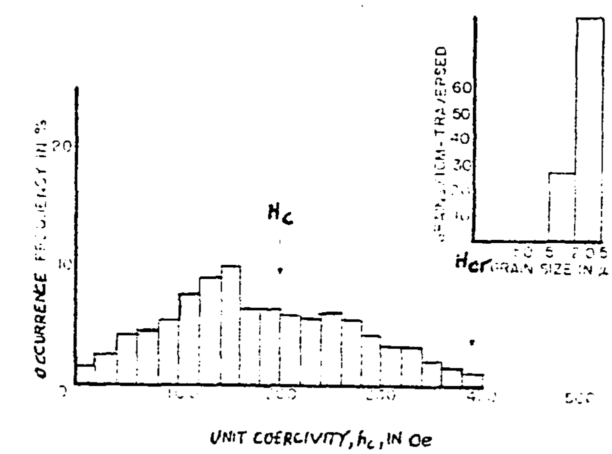
## AF Demagnetization Example, Intrusive Data

Fig. V-6 shows the magnetic intensity vs. demagnetization field plot for a 92.4 m.y. old diorite porphyry in north central Nevada (locality N6). This is not a simple demagnetization plot as comparison to Figure V-2 shows. The relative magnetization is higher at 50 oe. than at 0 field intensity. However, the direction is quite stable as shown in Figure V-6B. Some intrusive samples were run at 400 oe.; most were run at 0, 50, and 100 oe. However, all of the intrusive samples were thermally demagnetized to 580°C. as will be described in the next section.




Coercivity spectra and grain size distribution. Sample 32—coarse-grained granite.

Figure V-4. Coercivity spectra and grain size distribution for coarse grained granite. Unstable paleomagnetic behavior.




Coercivity spectra and grain size distribution. Sample 33—fine-grained granite.

Figure V-5. Coercivity spectra and grain size distribution for fine grained granite. Stable paleomagnetic behavior. Both figures from Larson, et al (1969). Courtesy of Journal of Geophysical Research.

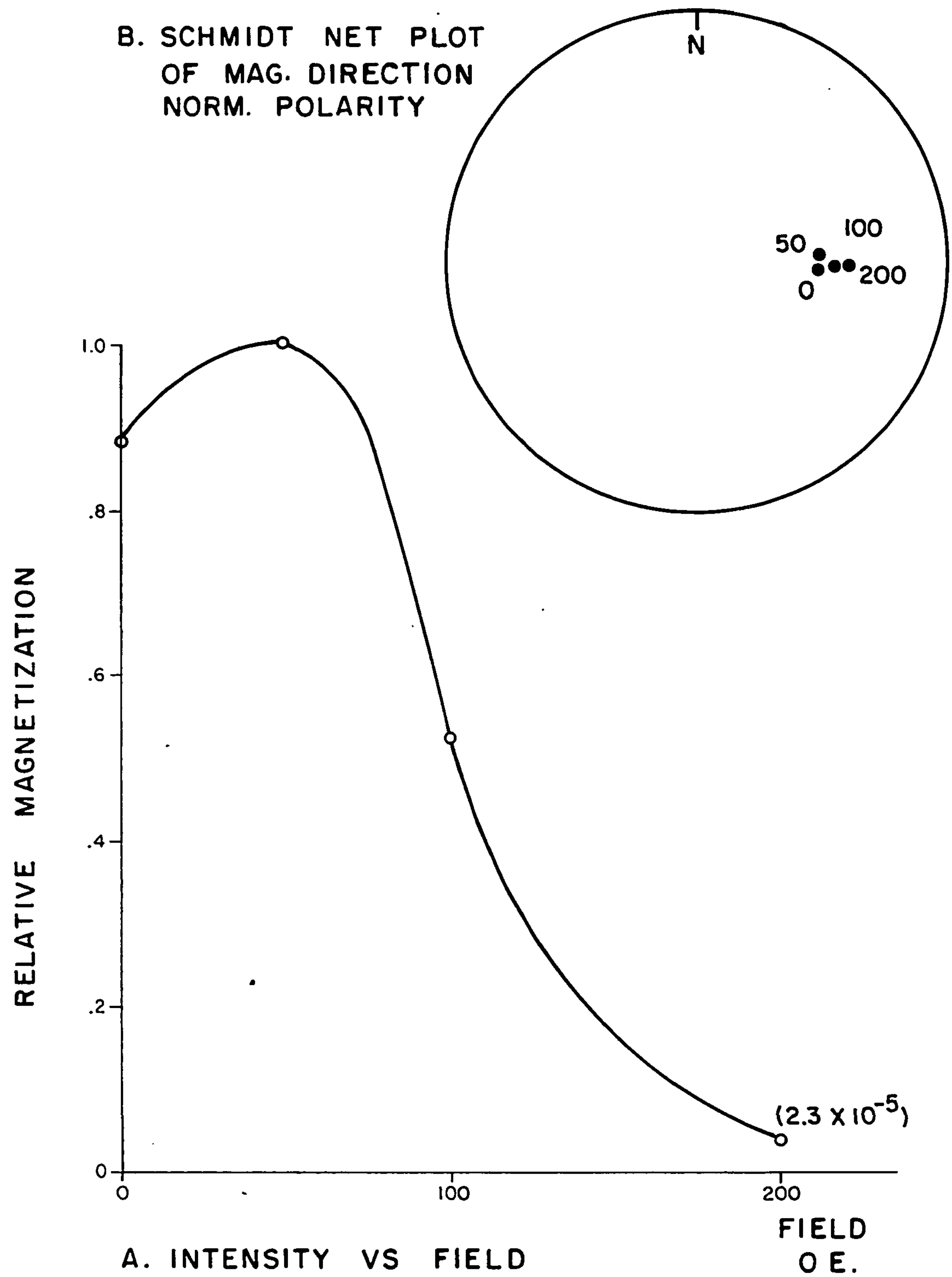



FIG. V-6 AF DEMAG. RESULTS, 92.4 m.y.
DIORITE PORPH., LOCALITY N6,
PUEBLO MT., NEV. SAMP. N6-2B.

Thermal Demagnetization of Intrusives

Thermal demagnetization is very useful as a means of removing soft components present in some of the rocks being investigated.

Thermal demagnetization is also useful for obtaining a suggestion of composition of the magnetic minerals present. Magnetite has a Curie point of 580$^{o}$ whereas titanomagnetite can have a much lower Curie temperature. It is reassuring if AF demagnetization and thermal demagnetization tend toward the same stable remanent direction. One danger of thermal demagnetization is that oxidation or other chemical changes can occur. One problem encountered in the present study is that some samples physically crumbled with high temperature.

Thermal Demagnetization Example, Intrusive Data

Figure V-7 shows thermal demagnetization results for the 92.4 m.y. diorite porphry, locality N6, in north central Nevada. This is from the same sample as displayed in Figure V-6. A similar early slight rise of intensity with demagnetization is noted in Figure V-6. The intensity falls off rapidly at temperatures higher than 300$^{o}$C. This intensity fall-off is presumably due to different size magnetic grains with different "blocking temperatures" (McElhinny, 1973).

In this case, the direction during AF and thermal demagnetization are not significantly different and do not change appreciably during demagnetization. This suggests that the direction is stable. It does not prove, unfortunately, that the final demagnetized direction is the original TRM.

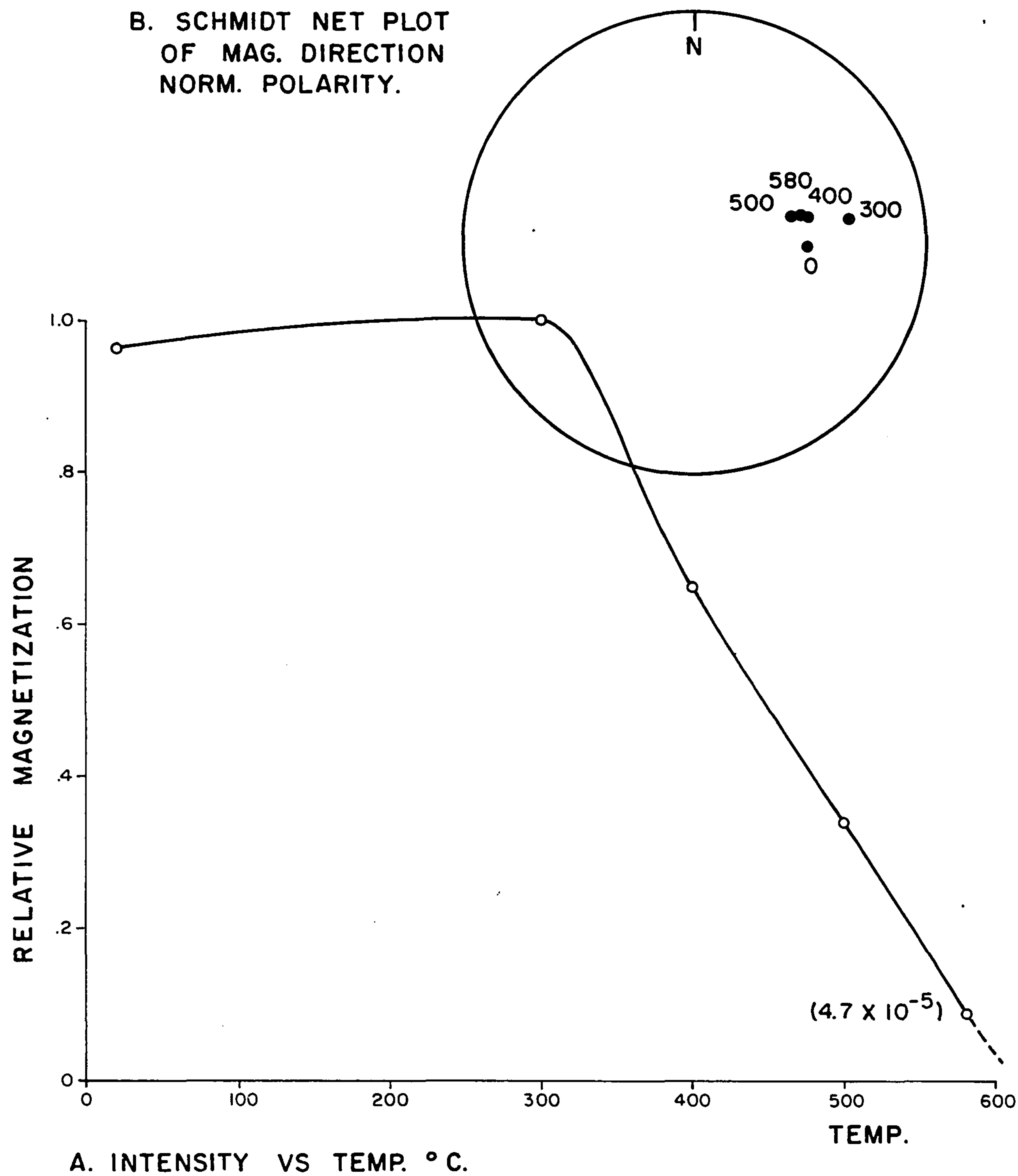


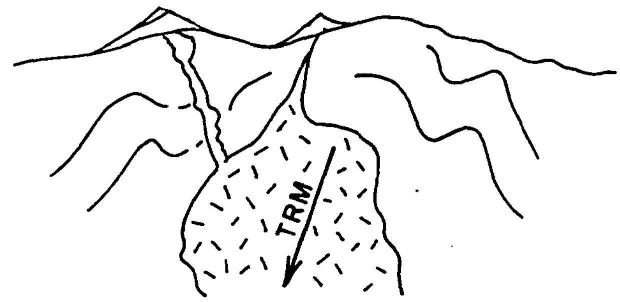

FIG. V-7 THERMAL DEMAG. RESULTS, 92.4 m.y. DIORITE PORPH., LOCALITY N6, PUEBLO MT., NEV. SAMP. N6-2B

All of the intrusive samples were thermally demagnetized to 580$^{o}$C, except those which crumbled at a lower temperature.

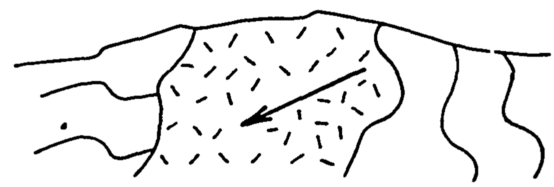
Problem of Post Intrusive Structural Movement

The intrusive rock obtains its TRM by cooling in the earth's magnetic field. Any later rotations will affect the paleomagnetic direction that is measured. Only those rotations revealed by tilting of overlapping younger beds on the intrusive can be detected and corrected. Previous post-cooling dislocations could not be corrected. One might picture an intrusive cooling through the Curie point of magnetite, or more properly, through the various blocking temperatures, and yet some portion of the intrusive might continue forcible emplacement with rotation of previously magnetized parts of the intrusion (see Figure V-8).

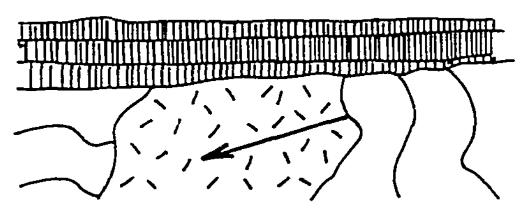
The Columbia River Basalts and other volcanics were deposited on an eroded surface of many of the sampled plutons. They are gently dipping in most areas, but have been strongly folded in some areas. Dips and strikes were measured wherever outcrops were available and the paleomagnetic directions were corrected by computation. Figure V-8 is suggestive that only relatively recent movements of intrusives can be properly accounted for. There will be some areas, such as interior parts of the Idaho batholith where volcanics have been eroded, where post intrusive rotation will be difficult to determine except possibly by paleomagnetic information.



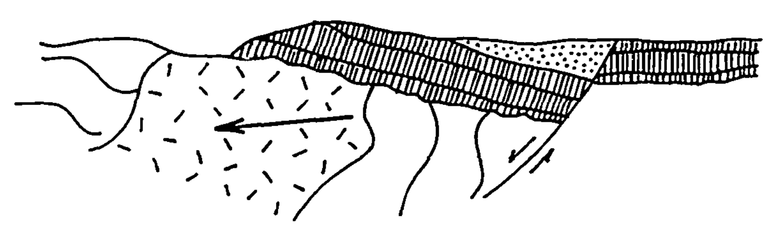

A. INTRUSIVE COOLS SLOWLY AND ACQUIRES TRM IN EARTHS FIELD



B. SUBSEQUENT UPLIFT, EROSION, AND POSSIBLE ROTATION



C. UNCONFORMABLE DEPOSITION OF VOLCANICS OR SEDIMENTS



D. POST VOLCANIC FAULTING AND/OR ROTATION

FIG. V-8 PROBLEM OF POST INTRUSIVE STRUCTURAL MOVEMENT

## Extrusive Rocks

### Stability of Extrusive Rocks

The previous discussion on intrusive rocks suggests that volcanics should display much better magnetic stability than coarse grained granitic rocks. Many of the extrusive localities measured appear to be stable. According to Watkins and Baksi (1974) the lavas of southern Oregon are very stable. However, the Columbia River Basalt is commonly maghemized, resulting in instability. This observation is confirmed by the present work. Samples from two different volcanic flows from the Columbia River Basalt at locality 29881 near Boise, Idaho, are shown in Figures V-9 and V-10.

### AF Demagnetization of Extrusive Volcanic Rocks

Figure V-9 shows rapid decline of intensity with increasing AF field to 1% of the initial NRM value at 300 oersteds. The Schmidt net plot shows reversed polarity, and successive directions vary considerably with different field values. Sample 14B is unstable.

Figure V-10 shows demagnetization results for sample 15D which is stratigraphically lower than 14B. The intensity falls only to 23% of its initial NRM value at 300 oersteds. The Schmidt net plot shows reverse polarity which varies little with increasing magnetization. Sample 15D is considered to be stable.

Most of the volcanic cores were demagnetized at 100 and 200 oersteds. No thermal demagnetization was done although it might prove helpful on unstable samples.

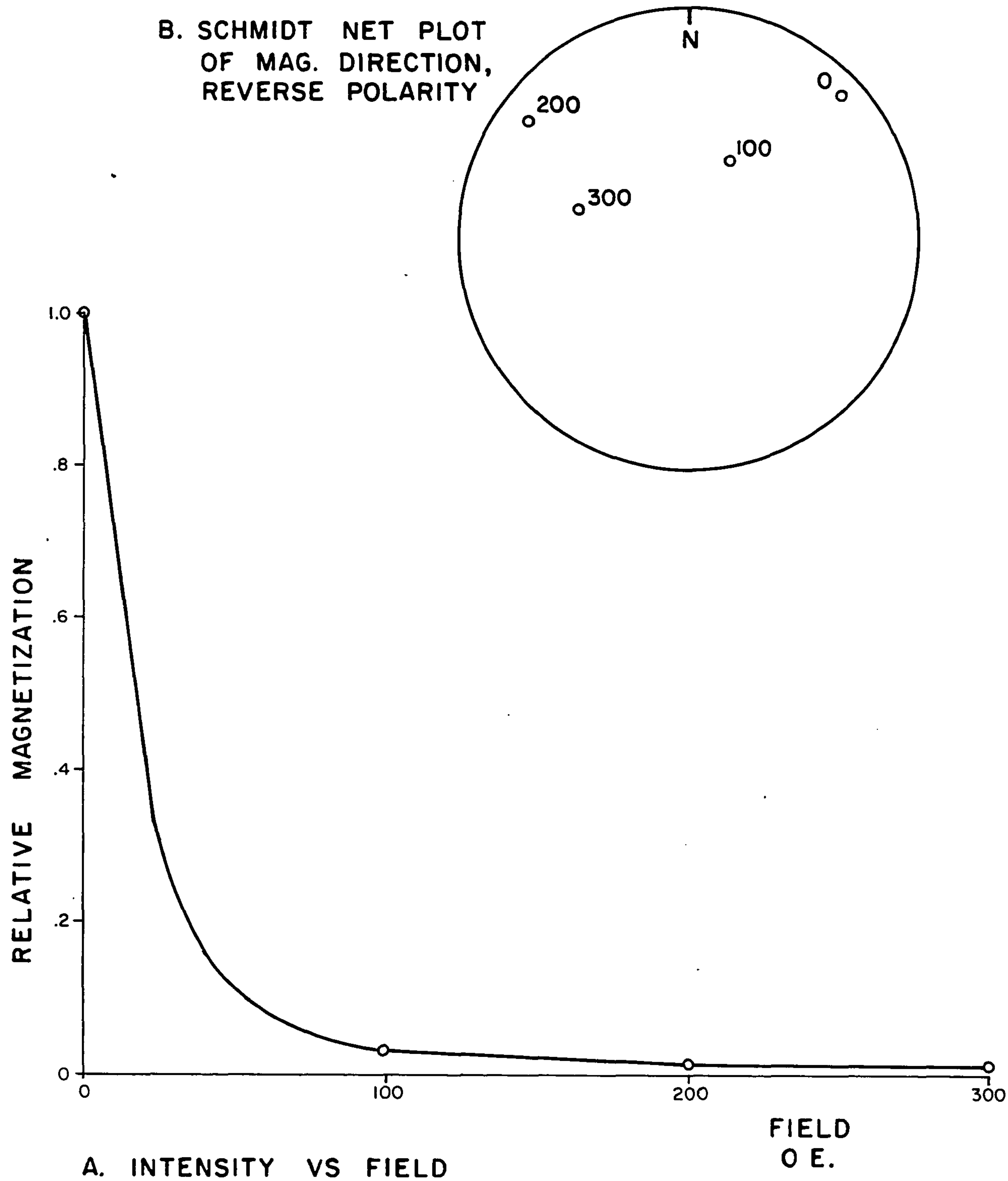



FIG. V-9 UNSTABLE AF DEMAG., 16 m.y. COLUMBIA RIVER BASALT. LOCALITY 29881, IDAHO. SAMP. 14 B

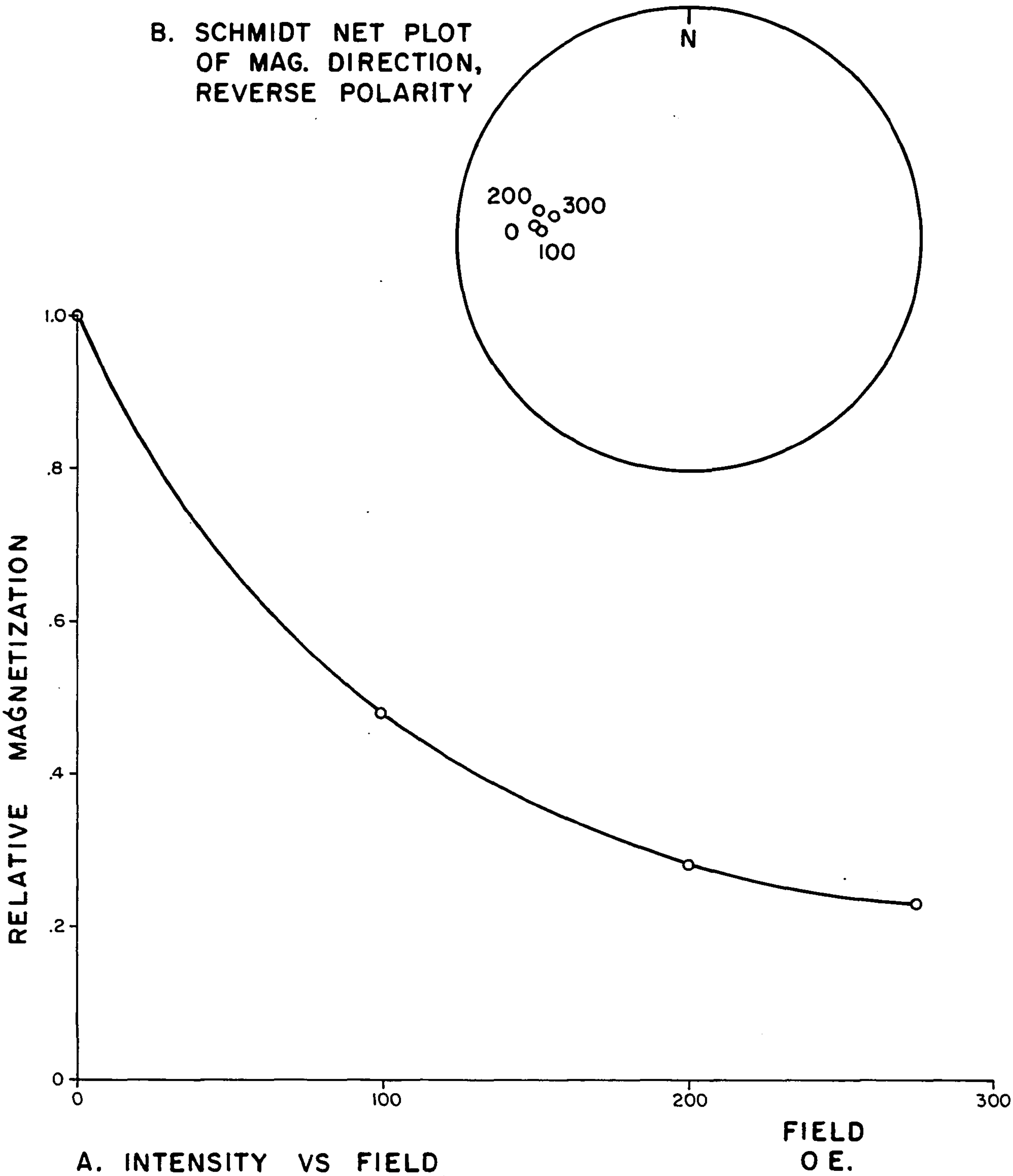



FIG. V-10 STABLE AF DEMAG., 16 m.y. COLUMBIA RIVER BASALT. LOCALITY 29881, IDAHO, SAMP. 15 D.

Significance of Paleomagnetic Directions in Volcanics

A single flow represents an instantaneous time in a geological sense. Because of secular variation of the magnetic field, successive measurements on many flows covering a sufficient time span should be made in order to obtain a useful paleomagnetic direction. Sample locality 28840 at Oregon Canyon Creek in the Trout Creek Mountains, Oregon, involves 1900' of volcanics probably correlative to the Steens Basalt. Nine reversals are noted in magnetic directions of the samples. This may suggest that sufficient time is represented at this locality so that an average direction would tend to smooth out secular variation. Larson (1965) and Watkins and Baksi (1974) have pertinent discussions of this problem.

A number of localities have been sampled with only a few cores (4 to 8). This is true for the localities north of the Harney Basin. The K-Ar ages vary from about 22 m.y. to 7 m.y. Each site would yield an instantaneous direction but an average of many localities should give a useful average Late Miocene paleomagnetic direction to test for rotation.

## Measurement of Paleomagnetic Data

Preparation of Samples

After a core was drilled in outcrop, the brass orienter was inserted and the cross bar leveled with the Brunton. The x-axis was scribed with a brass wire inserted into the slot. The azimuth and plunge were measured by Brunton and recorded (see Fig. V-11A). The orienter was removed and the core was broken loose with a brass wedge. The top of the core was marked.

Then, in the laboratory the core was drilled crosswise as shown in Figure V-11B, held in a special vise. The resultant core was then rotated and redrilled to yield an approximate sphere as shown in Figure V-11C. Oriented blocks were first core drilled in the laboratory.

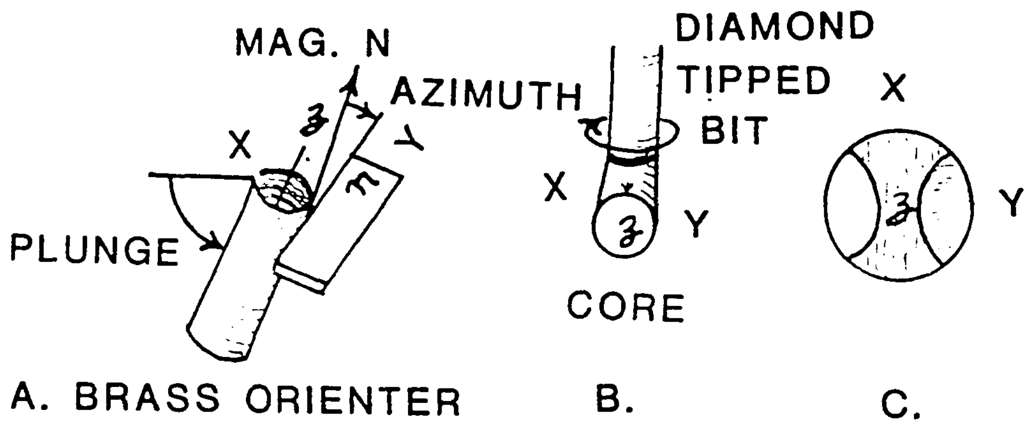



Figure V-11. Steps in preparation of sample.

<u>Spinner Magnetometers</u>

Three spinner magnetometers were used in the course of the work. The first was an electric motor driven modified Marathon spinner with a speed of 10 r.p.s. assembled by Dr. E. E. Larson. The maximum sensitivity was about $10^{-5}$ e.m.u.

The second spinner magnetometer was a compressed air driven 155 r.p.s. Marathon spinner in the laboratory of Dr. Don Watson of the U.S.G.S. Its accuracy was also about $10^{-5}$ e.m.u.

The third spinner magnetometer was a commercially built Schoenstedt electrically driven spinner, Model SSM-1A. Its maximum sensitivity is about $10^{-7}$ e.m.u. This spinner was used for all of the thermal demagnetization samples and all of the volcanic samples.

All three magnetometers involved spinning the samples about each axis in turn. In addition, for the weak or erratic samples, the specimen was reversed for each axis to give a total of six measurements per sample.

The natural remanent magnetism (NRM) of each specimen was measured. Both intrusive and extrusive samples were "cleaned" of unstable components by AF demagnetization and remeasured. The intrusive samples were then thermally treated, cooled, and measured.

## AF Demagnetizer

The equipment was constructed by Dr. E. E. Larson. During demagnetizing, the sample is rotated in a 3-axis tumbler at about five revolutions per second so that particles of all orientation will be statistically demagnetized along their axes of magnetization. The alternating field is reduced from a selected maximum to zero by means of an R-C circuit. As the field is slowly reduced, domains with lower coercive force are fixed in different orientations. All domains with coercive forces less than the initial selected maximum field should arrive at random directions. The demagnetizer is unshielded; the earth's field is small compared to the demagnetizing force.

## Thermal Demagnetizer

The thermal demagnetization equipment consists of a nichrome heating element inside a horizontal mumetal shield and a control panel. Water is circulated through the shield to keep it cool. The interior temperature is automatically monitored and kept at the desired temperature by a thermocouple and control circuit. The selected temperature was maintained for 30 minutes. The electricity was then turned off, and an air current was passed over the samples to hasten cooling. Only the intrusive samples were thermally treated.

## Computation by Computer

A computer program was adapted by Dr. E. E. Larson to reduce the raw data obtained from the spinner magnetometers. As shown for each locality in the Appendix, mean inclination and declination, N,R,K, alpha 95, and virtual pole latitude and longitude are calculated for the NRM and each demagnetization treatment. The terms will be defined in the following paragraphs. The computer program also plots the results as an equal area stereogram.

The sample localities all show various degrees of scatter as reference to the plots in the Appendix demonstrates. This scatter is to be expected as described by Larson (1965). Some of the reasons for scatter are: errors in orientation and measurement of the sample, anisotropism, unaccounted structural complications, movement of the geomagnetic field during intrusion or extrusion of the igneous rocks, and secondary magnetization.

Irving (1964) presents a review of the method of Fisher (1953) to calculate a mean direction of the scattered paleomagnetic directions. The best estimate of the true mean direction ($\ell$,m,n) is the vector sum of the N individual directions ($\ell$,m ,n ) each of which is given unit weight:

$$\ell = \frac{\sum_{n=1}^{N} \ell_i}{R}, \qquad m = \frac{\sum_{n=1}^{N} m_i}{R}, \qquad n = \frac{\sum_{n=1}^{N} n_i}{R}$$

$(\ell, m, n)$ are the direction cosines of the mean direction.

$$R^2 = \left(\sum_{n=1}^{N} \ell_i\right)^2 + \left(\sum_{n=1}^{N} m_i\right)^2 + \left(\sum_{n=1}^{N} n_i\right)^2$$

The declination, $D_m$, of the mean direction is

$$\tan D_m = \frac{\sum_{n=1}^{N} m_i}{\sum_{n=1}^{N} \ell_i}$$

and the inclination, $I_m$, is

$$\sin I_m = \frac{\sum_{n=1}^{N} n_i}{R}$$

Fisher showed that the best estimate of the precision is

$$k = \frac{N-1}{N-R}$$

k is small for large scatter and is large for small scatter. Another useful parameter, alpha 95, is given as

$$\cos \alpha 95 = 1 - \left(\frac{N-R}{R}\right)\left[\left(\frac{1}{.05}\right)^{\frac{1}{N-1}} - 1\right]$$

The value $\alpha 95$ is the radius of the circle of confidence about the mean. Circles of confidence can be used in the comparison of two different mean directions. If the two circles do not intersect, the two mean directions are significantly different at the 95% level of confidence.

## Age Measurement

Potassium-argon dates from the literature are used instead of lead-alpha dates because they are believed to more reliable (McDowell and Kulp, 1969). The potassium-argon dates are considered reliable if both hornblende and biotite dates agree. The biotite dates are more easily reset by later heating (Smith, et al, 1971). The source in the literature for the dates are given for the various sample sites in the Appendix.

Two sites, 02 in the Wallowa batholith, and 05 in the Bald Mountain batholith were dated by the fission track method in the Chevron U.S.A. Inc. laboratory in San Francisco. Apatite was used in sample 05; titanite and zircon were used in sample 02. One advantage of the fission track method is that it is not as sensitive to weathering as is the K-Ar technique.

K-Ar dating of some of the volcanic samples was performed by a commercial service. However, considerable scatter was present in some of the dates and certain dates are questioned.

In some intrusive or extrusive sites, no K-Ar dates are available. A general geologic date is then given from the literature wherever possible.

## Problem of Post-Intrusive and Post-Extrusive Disturbances

### Post Emplacement Reheating

As previously discussed, stable magnetism is not necessarily the original TRM of the rock. The original TRM could be changed by later heating. For example, extensive areas of the Idaho Batholith in Figure II-6 are shown to have K-Ar age dates of 50 m.y. or less. It is uncertain whether these are Mesozoic intrusives that were reheated during the Challis episode (50-40 m.y.) or true Eocene intrusives (Armstrong et al, 1977). If reheating is the correct interpretation, the earlier Mesozoic paleomagnetic direction probably was reset to that of Eocene time.

CRM, Chemical Remanent Magnetization

Later chemical alteration can produce stable or unstable magnetization which may not be parallel to the original magnetization. This is the method whereby many old rocks obtain magnetization parallel to the present field (E. E. Larson, personal communication). The problem of instability associated with maghemized Columbia River Basalt was discussed in Chapter V and illustrated in Figure V-9.

Effect of Lightning

Graham (1961) showed that IRM (isothermal remanent magnetism) resulting from lightning discharges can be very strong. R. L. DuBois (personal communication) showed that IRM could not be completely removed by demagnetization treatment in some cases. Sample site selection should be made in valleys or road cuts wherever possible to minimize the problem.

Post Emplacement Structural Rotation

The problem of post intrusive structural movements was discussed previously and shown in Figure V-8. The magnetization directions of sites listed in the appendix of both intrusives and extrusive volcanics have been corrected for dip wherever possible. This is satisfactory except in the case of steeply plunging fold axes in which case serious error can result from the simple tilt correction (Cox and Doell, 1960).

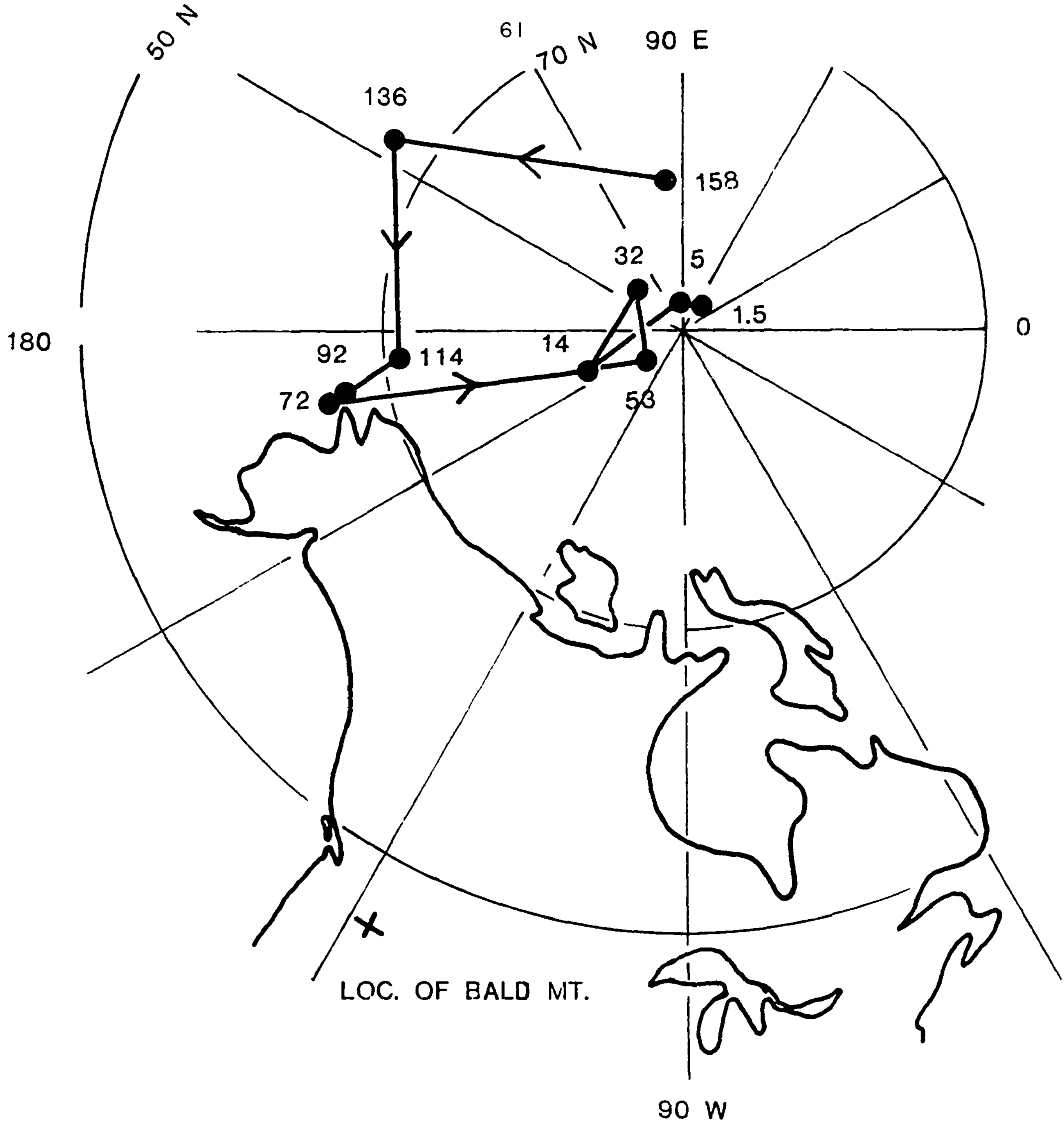



FIGURE VI-1. APPARENT POLAR WANDERING CURVE FOR NORTH AMERICA FROM 158 M. Y. TO 1.5 M. Y.

DATA FROM VAN ALSTINE AND DE BOER (1978).

AGES IN MILLIONS OF YEARS.

## CHAPTER VI
## PALEOMAGNETIC DATA PRESENTATION

### Reference Paleomagnetic Directions

Paleomagnetic directions must be compared with undisturbed paleomagnetic directions for the same geologic time in order to detect rotation as was discussed in Chapter III.

A recent article by Van Alstine and de Boer (1978) present a new method for constructing apparent polar wander paths using statistical analysis. Figure VI-1 was made from their data for Jurassic to Recent for North America. They attempted to use only reliable poles and have excluded poles for which (1) stability has not been demonstrated by A.C., thermal, or chemical cleaning techniques; (2) significant post-magnetization tectonic rotations have been suggested; (3) ages were in doubt more than a certain amount; or (4) the computed mean of at least five samples had an $\alpha 95$ larger than $15^{\circ}$.

Using pole positions as shown in Figure VI-1, the paleomagnetic directions were calculated for the position of Bald Mountain Batholith, Oregon. Results are shown in Figure VI-2 which uses formulas from Irving (1964), p. 42 and 43.

| Age | Pole Lat. | Long. | Calc. Incl. | Decl. |
|---|---|---|---|---|
| 100 m.y. | $69^{\circ}$ | $172^{\circ}$W | $70^{\circ}$ | $29.5^{\circ}$W |
| 53 m.y. | $87^{\circ}$ | $140^{\circ}$W | $65.5^{\circ}$ | $0^{\circ}$ |
| 12 m.y. | $86^{\circ}$ | $160^{\circ}$W | $65.5^{\circ}$ | $2^{\circ}$W |

Figure VI-2. Calculated paleomagnetic directions for region of Bald Mountain, Oregon (Lat. $45^{\circ}$N, Long. $118^{\circ}$W) from North American pole positions.

The data from Figure VI-2 are used to construct the reference directions displayed on the map, Figure VI-3.

## Intrusive Igneous Rocks

### Appendices 1, 2, and 3

Appendix 1 shows the paleomagnetic results for intrusive igneous rocks in Nevada. Appendices 2 and 3 are for intrusive igneous rocks in Idaho and Oregon. The location, age, rock description, overlying structure, and paleomagnetic results are given for each locality. The mean inclination and declination and statistics are listed for NRM and each demagnetization treatment. One treatment is chosen as the best interpretation of the paleomagnetic direction. Results for the treatment considered to yield the most representative of the stable paleomagnetic directions are displayed on an equal area stereonet. The choice for display is based partly on statistics, but in general for the intrusives the thermal demagnetization results are preferred over the AF. For example, the locality N4, the 400$^{o}$C. thermal demagnetization is displayed as probably the most stable direction. The direction for 400$^{o}$C. thermal demagnetization agrees in general with the AF results. The precision factor K is highest, 32.5, and alpha 95 scatter is smallest, 9.8$^{o}$, for all of the demagnetization treatments performed on locality N4. An attempt to evaluate reliability of the site is included under the "results" heading.

No stereonet plot is shown for those localities which were felt to be unreliable. For example, sites I1, I2, I8, and I9 in the Owyhee Mountains of Idaho all have undergone hydrothermal alteration and are too weak to measure reliably.

I collected and measured all of the intrusive sites listed in appendices, 1, 2, and 3.

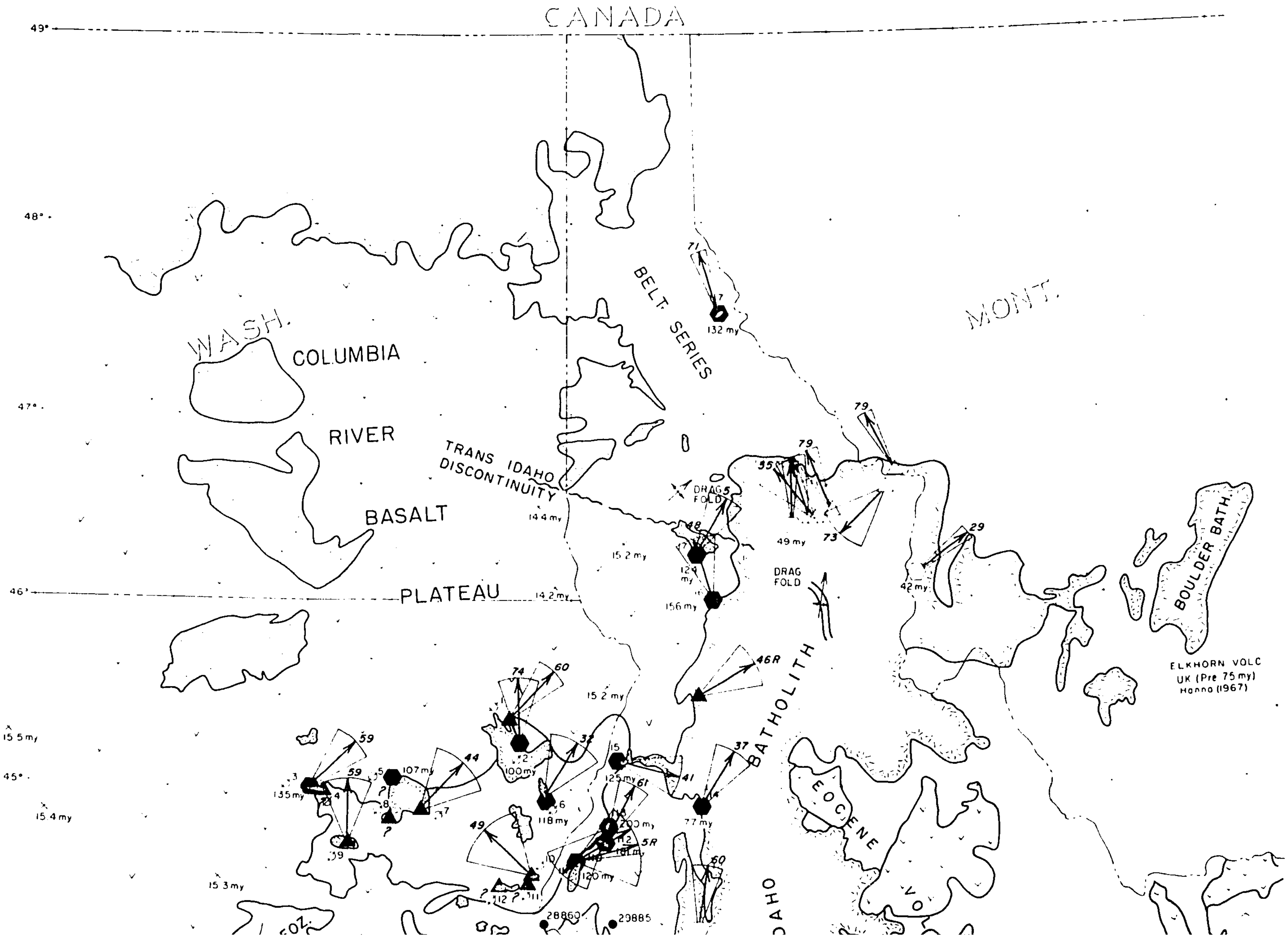
Some of the final displays of intrusive directions have circles of confidence which overlap the present direction of the earth's magnetic field. It cannot be said unequivocally that this direction is not related to recent magnetization. For example, site N4 direction is quite stable and overlaps the present field direction. If considerable clockwise rotation of a $330^{o}$ Cretaceous declination has occurred, we might expect some site directions to overlap the present $20^{o}$ declination. Many of the sites, however, do not overlap the present field, e.g. locality N1 and N6.

Map of Paleomagnetic Directions for Instrusive Granitic Rocks (Fig. VI-3)

The base map and regional geology for Figure VI-3 were taken from the A.A.P.G. Tectonic Map, Cohee, et al (1962). The Eocene Challis volcanic outline east of the Idaho Batholith was obtained from the Geologic Map of Idaho, Ross and Forrester (1947) and Armstrong (1974).

Dated intrusive granitic localities original in this report are shown as black hexagons in Figure VI-3. Undated localities are displayed as black triangles. All of these samples have been subjected to both AF and thermal demagnetization.

Data by Beck et al (1972) are shown as open hexagons and triangles. These samples were subjected only to AF demagnetization. In addition,



CANADA
49°
48°
47°
46°
45°
WASH.
MONT.
COLUMBIA
RIVER
BASALT
PLATEAU
BELT SERIES
TRANS IDAHO
DISCONTINUITY
DRAG FOLD
DRAG FOLD
BATHOLITH
IDAHO
EOCENE
BOULDER BATH.
ELKHORN VOLC
UK (Pre 75 my)
Hanna (1967)
132 my
14.4 my
15.2 my
14.2 my
156 my
49 my
42 my
15.2 my
15.5 my
15.4 my
15.3 my
135 my
107 my
100 my
118 my
125 my
100 my
120 my
77 my
28860
28885

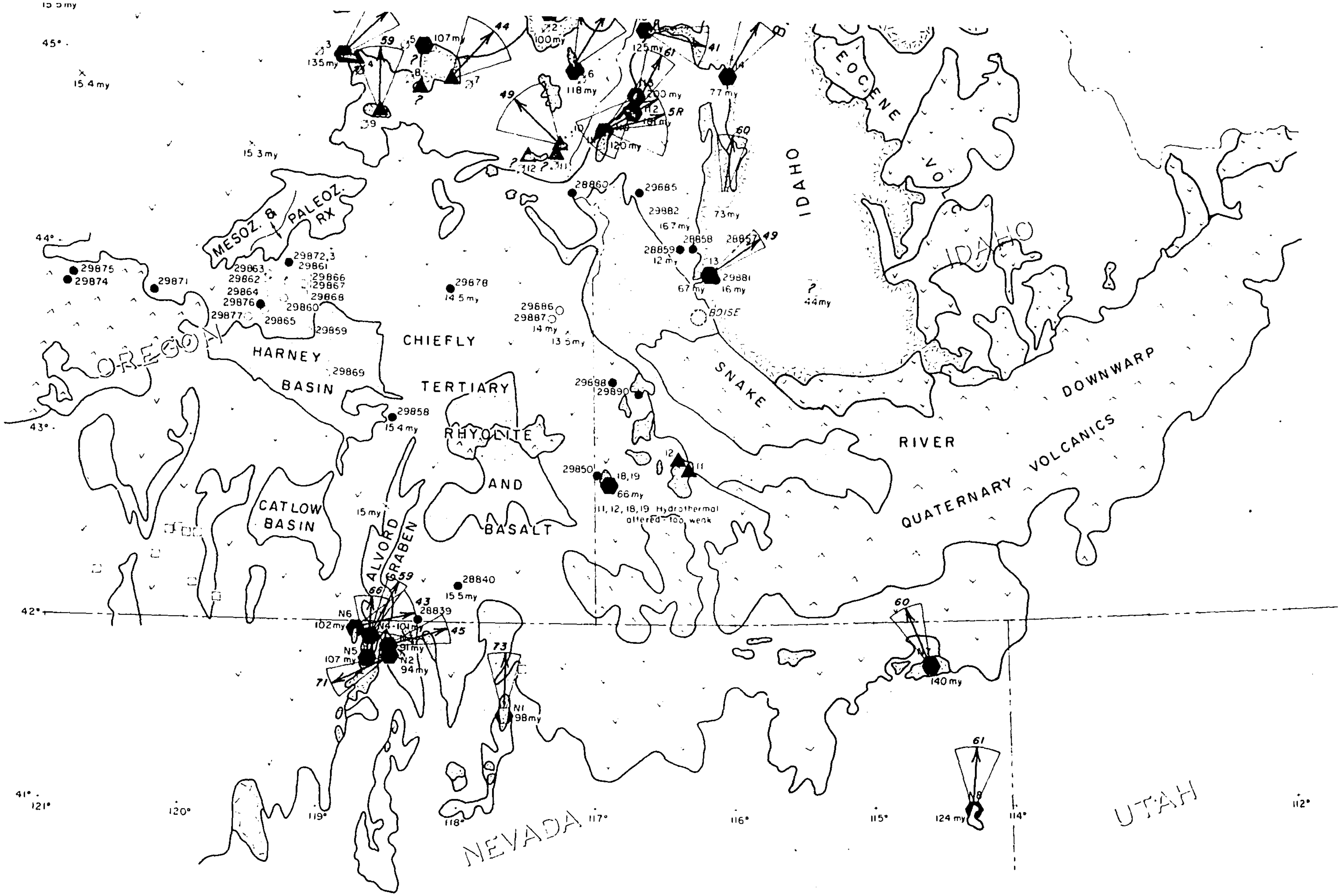
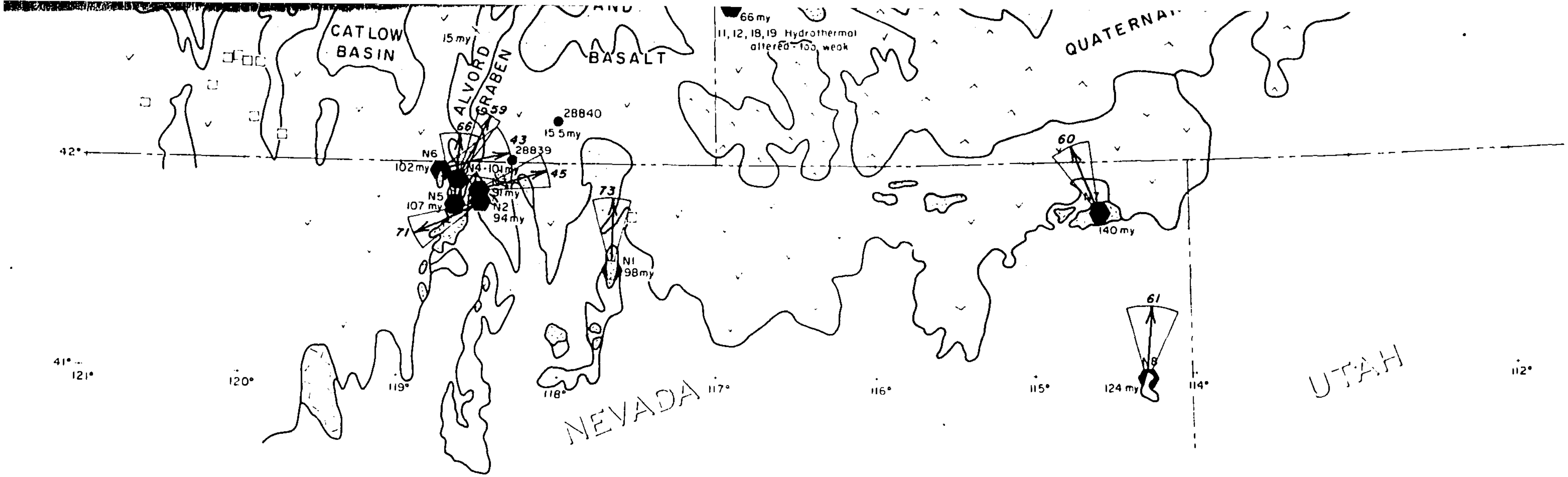



FIG. VI-3 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO
PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS

61° INCLINATION

α 95

ARROW SHOWS DIRECTION OF NORTH SEEKING POLARITY
DOWNWARD. α95 IS RADIUS OF CIRCLE CONTAINING 95%




# FIG. VI-3 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS

61° INCLINATION

α 95

ARROW SHOWS DIRECTION OF NORTH SEEKING POLARITY DOWNWARD. α95 IS RADIUS OF CIRCLE CONTAINING 95% OF INDIVIDUAL DIRECTIONS AT SITE.

AGE 124 my

## REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON

70° INC. N 29.5° CRETACEOUS 100 MY

65.5° INC. N EOCENE 53 MY

65.5° INC N 2° MIOCENE 16-10 MY

N 69.5° INC. 20° PRESENT

PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

### INTRUSIVES

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

- AGE DATED (MOSTLY LIT.) PALEOMAG. BY: W.L.B.
- NO AGE DATE. PALEOMAG. BY: W.L.B
- AGE DATED (FROM LITERATURE). PALEOMAG. BY BECK, ETAL (1972)
- NO AGE DATE. PALEOMAG. BY BECK, ETAL (1972)

### EXTRUSIVES

- PALEOMAG BY W.L.B.
- PALEOMAG BY HELSLEY
- PALEOMAG. BY WATKINS & BAKSI (1974)
- PALEOMAG. BY LARSON (1965) OR LARSON, ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

- INTRUSIVE ROCKS
- TERTIARY RHYOLITE & BASALT
- QUATERNARY VOLCANICS
- LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

W.L. BASHAM

MARCH 1978

an average pre-75 m.y. direction is shown in Montana for the Cretaceous Elkhorn Volcanics (Hanna, 1967).

The $\alpha 95^{o}$ radius of confidence is also shown on the map for the intrusive localities as arcs on either side of the central direction.

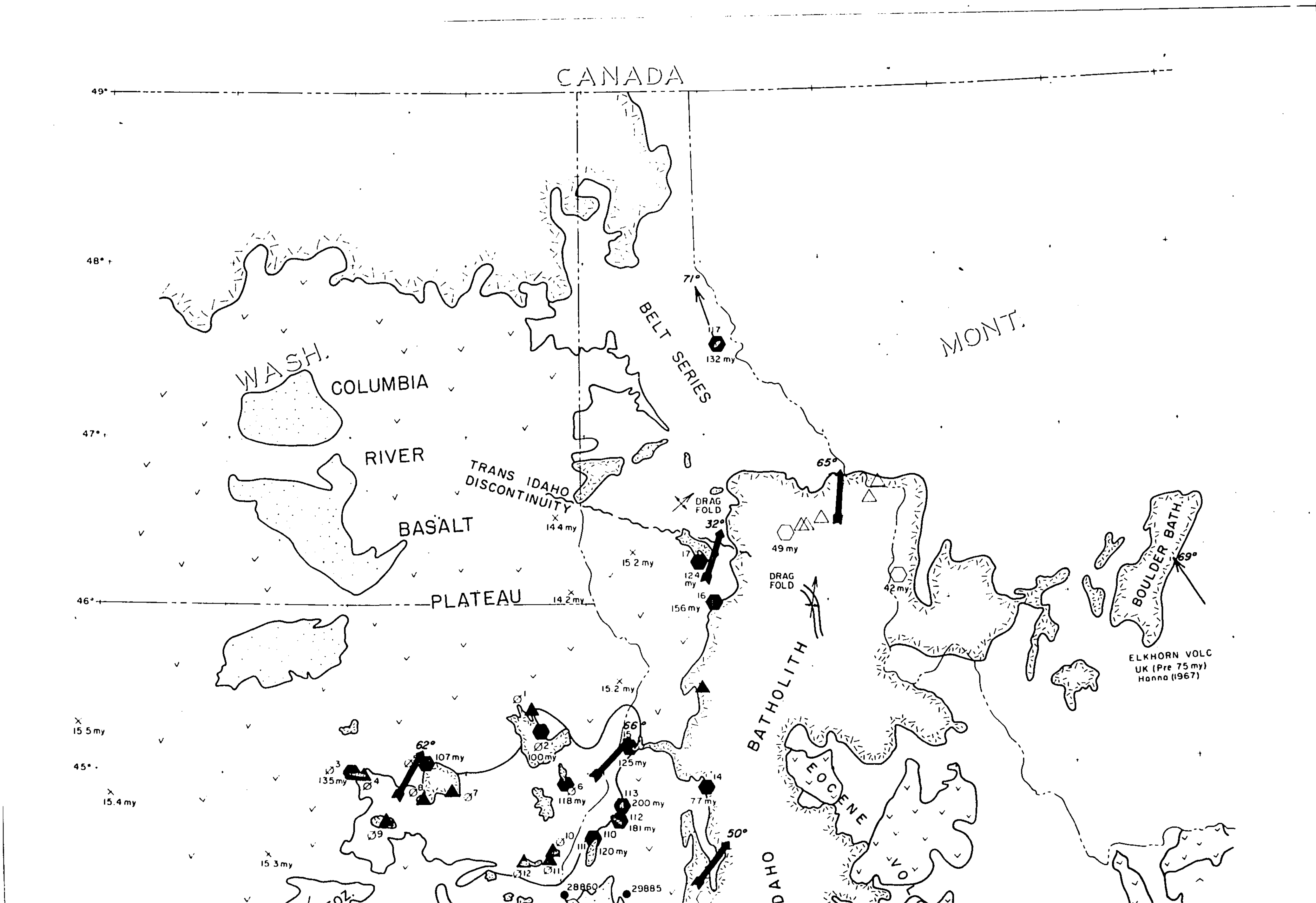
Considerable between site scatter is present for the various intrusive localities. Reason for within-site scatter was discussed in Chapter V. Reasons for between-site scatter probably are similar but accentuated. However, a northeasterly direction cominates in western Idaho, Oregon, and north central Nevada. A northwesterly trend may be present in northern Idaho, northeast Nevada and western Montana.

Map of Averaged Paleomagnetic Directions for Intrusive Igneous Rocks (Fig. VI-4)

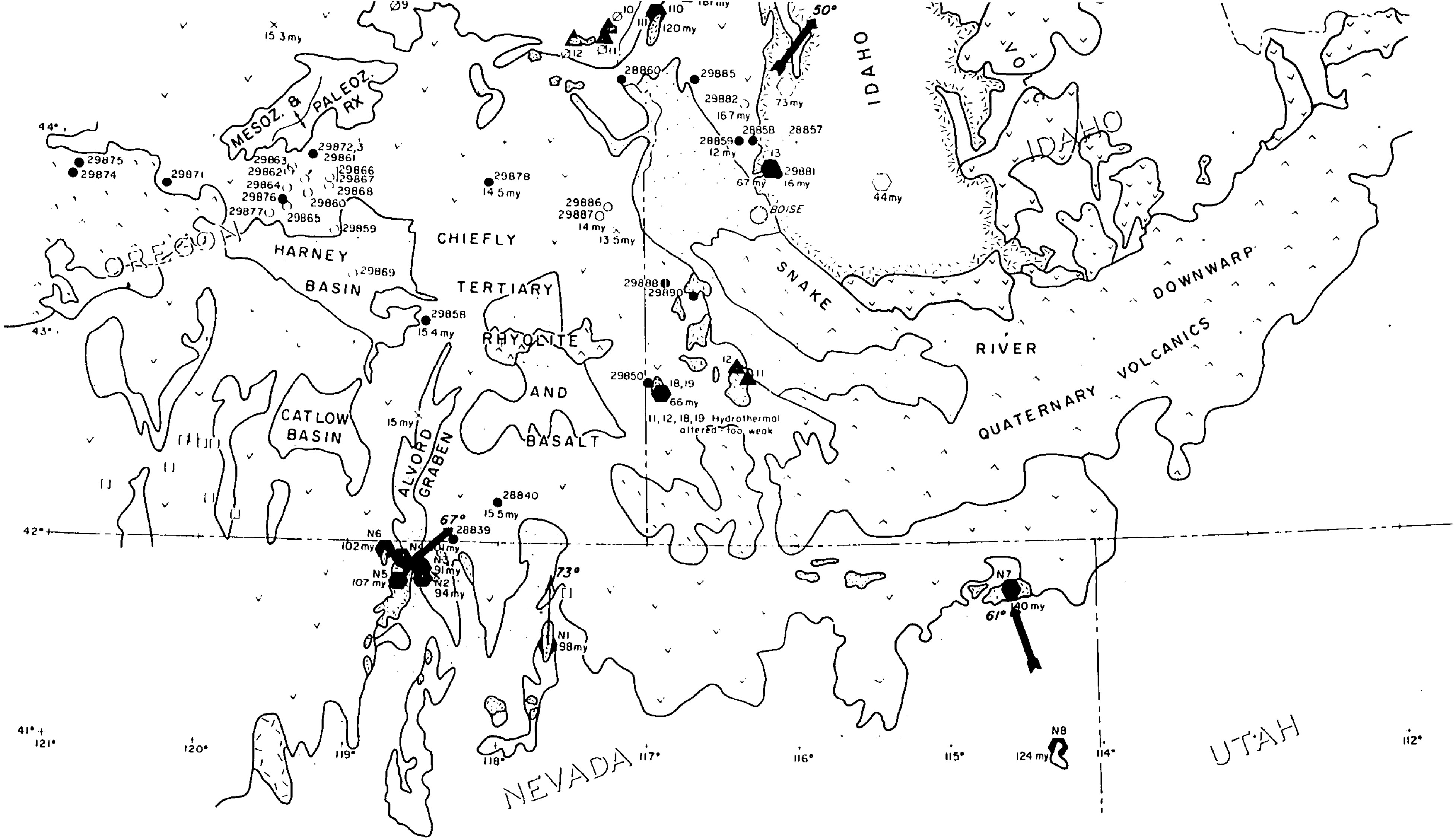
It is believed that averaged intrusive paleomagnetic directions by region produce a more reliable paleomagnetic direction to aid in estimating rotation. Figure VI-5A shows the Schmidt net plot of the localities in north central Nevada. This is the average paleomagnetic direction plotted in this region on the map, Figure VI-4.

No Schmidt net plot is shown for the average in northeast Nevada since the directions for N7 and N8 were simply averaged. N1 was not included in an average but is left by itself as a single locality. It appears to be intermediate in direction between directions for northeast and north central Nevada.

Figure VI-5A shows the average paleomagnetic direction for north central Nevada. N2 could perhaps be omitted but it was decided that no localities should be omitted from the averaging. The average age is



CANADA
49°
48°
47°
46°
45°
WASH.
COLUMBIA
RIVER
BASALT
PLATEAU
MONT.
BELT SERIES
TRANS IDAHO DISCONTINUITY
DRAG FOLD
DRAG FOLD
BATHOLITH
IDAHO
EOCENE
VOL
BOULDER BATH.
ELKHORN VOLC
UK (Pre 75 my)
Hanna (1967)
71°
65°
32°
62°
66°
50°
69°
117
132 my
14.4 my
15.2 my
17
124 my
16
156 my
49 my
42 my
14.2 my
15.2 my
15.5 my
15.4 my
15.3 my
Ø1
Ø2
100 my
Ø3
135 my
4
107 my
Ø7
Ø8
Ø9
6
118 my
15
125 my
14
77 my
113
200 my
112
181 my
110
111
120 my
Ø10
Ø11
Ø12
28860
29885




# FIG. VI-4 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO AVERAGED PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS

73° SINGLE ISOLATED SIGNIFICANT LOCALITY

AVERAGED LOCALITY
62° INCLINATION
DECLINATION SHOWN BY DIRECTION
LOCATION OF AVERAGE

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON


# FIG. VI-4 PALEOMAGNETIC STUDY - NEVADA, OREGON AND IDAHO
## AVERAGED PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS



73° SINGLE ISOLATED SIGNIFICANT LOCALITY

AVERAGED LOCALITY
62° INCLINATION
DECLINATION SHOWN BY DIRECTION
LOCATION OF AVERAGE

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON

70° INC. N 29.5° CRETACEOUS 100 MY

65.5° INC. N EOCENE 53 MY

65.5° INC N 2° MIOCENE 16-10 MY

N 69.5° INC. 20° PRESENT

PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

**INTRUSIVES**

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

- AGE DATED (MOSTLY LIT.) PALEOMAG. BY: W.L.B.
- NO AGE DATE, PALEOMAG. BY: W.L.B
- AGE DATED (FROM LITERATURE), PALEOMAG. BY BECK, ETAL (1972)
- NO AGE DATE, PALEOMAG. BY BECK, ETAL (1972)

**EXTRUSIVES**

- PALEOMAG BY: W.L.B.
- PALEOMAG BY: HELSLEY
- PALEOMAG. BY WATKINS & BAKSI (1974)
- PALEOMAG. BY LARSON (1965) OR LARSON, ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

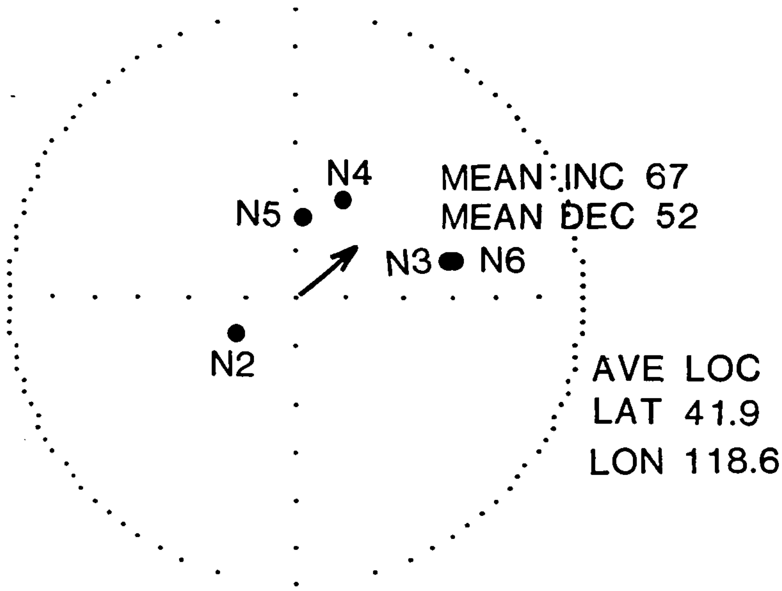
- INTRUSIVE ROCKS
- TERTIARY RHYOLITE & BASALT
- QUATERNARY VOLCANICS
- LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

W.L. BASHAM

MARCH 1978

A. HUMBOLDT COUNTY, NEVADA, SITES N2-N6




B. W IDAHO BATHOLTH, BOISE AND VALLEY CO., IDAHO, SITES I3, I4, BECK

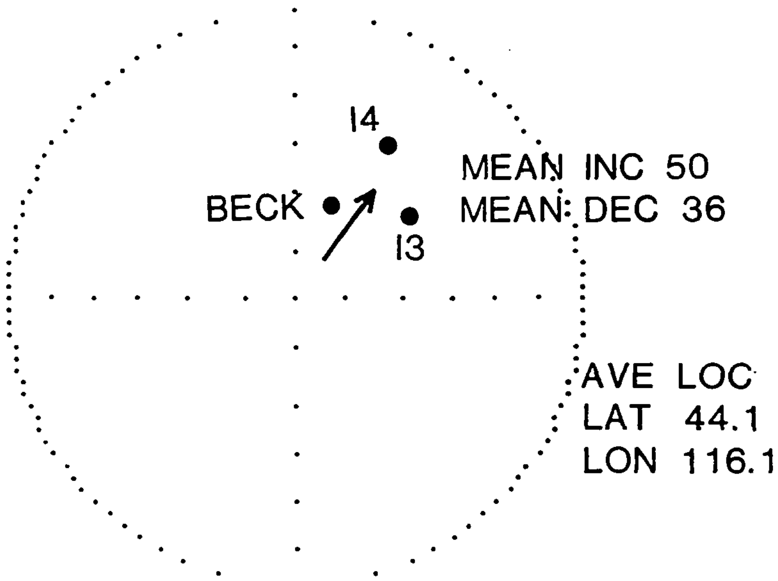



FIG. VI-5 CRETACEOUS INTRUSIVE ROCKS. AVERAGE OF MEAN N-SEEKING POINTS AND REFLECTED S-SEEKING PALEOMAGNETIC DIRECTIONS. SCHMIDT STEREONET DISPLAY. ●,⌖ NORTH SEEKING POLARITY DOWNWARD AND UPWARD RESPECTIVELY. TIP OF ARROW POSITION OF AVERAGE about 99 m.y.

Figure VI-5B shows the average direction for three localities, I3, I4, and the Beck, et al (1972) locality in the southwest side of the Idaho Batholith. The average age is about 72 m.y.

Figure VI-6A shows the averaged direction for the Bald Mountain area in Oregon. The average age of two dated samples in the area is 121 m.y. Figure VI-6B shows the average direction for eleven different localities in eastern Oregon and western Idaho. I13 possibly could be eliminated to make a more representative direction, but it was believed best to be completely objective in this averaging step. The average age is 120 m.y.

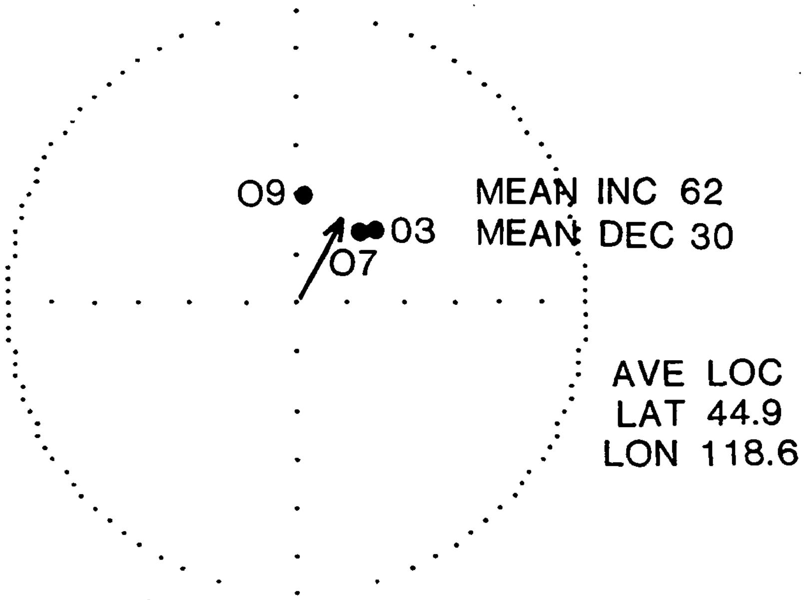
Figure VI-7 shows the averaged direction for the eight samples in northern Idaho described by Beck, et al (1972). Two localities are dated 49 and 42 m.y. and the rest are assumed also to be Eocene.

The map, Figure VI-4, shows northeasterly averaged directions in north central Nevada and northeast Oregon and west central Idaho. The map shows north-northwesterly paleomagnetic directions in northeast Nevada, Montana and northern Idaho.

## Map of Clockwise Rotation of Averaged Paleomagnetic Vectors for Intrusive Granitic Rocks (Fig. VI-8)

The assumption is made that the amount of structural rotation between two sites of about the same age is the angle between their paleomagnetic directions. This should be true if a, local structure is accounted for; b, if the earth's field was dipolar at the time of the intrusion; c, if secular variation was averaged out and the geographic and magnetic poles

A. BALD MT. AREA, GRANT AND BAKER CO., ORE.
SITES O3 07, 09.




B. WALLOWA MT. AREA, ORE., & W. IDAHO.
SITES O1, O2, 06, O10, I5, I10-14

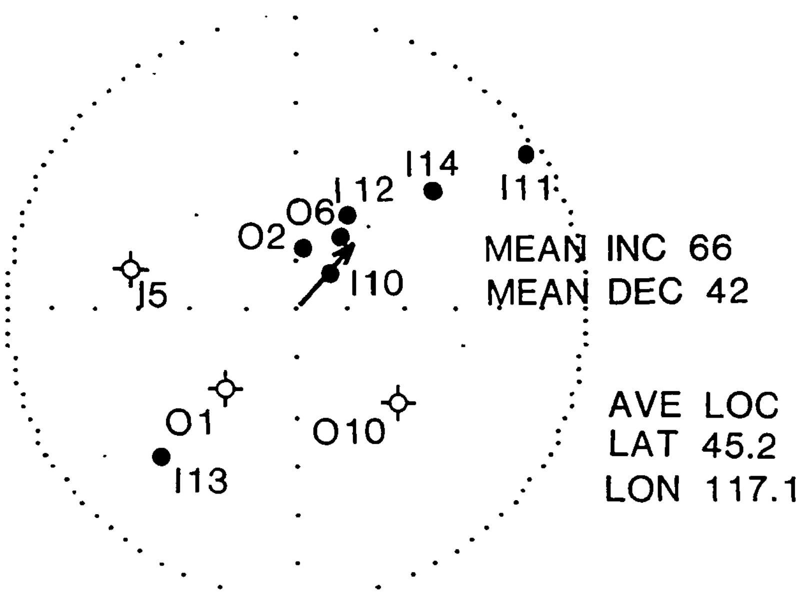



FIG. VI - 6 CRETACEOUS AND JURASSIC INTRUSIVE ROCKS.
AVERAGE OF PALEOMAGNETIC DIRECTIONS.

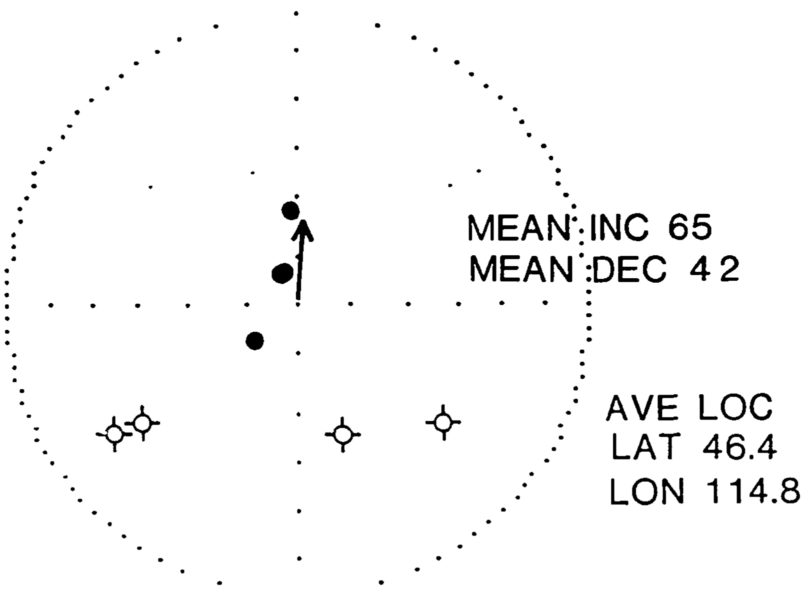
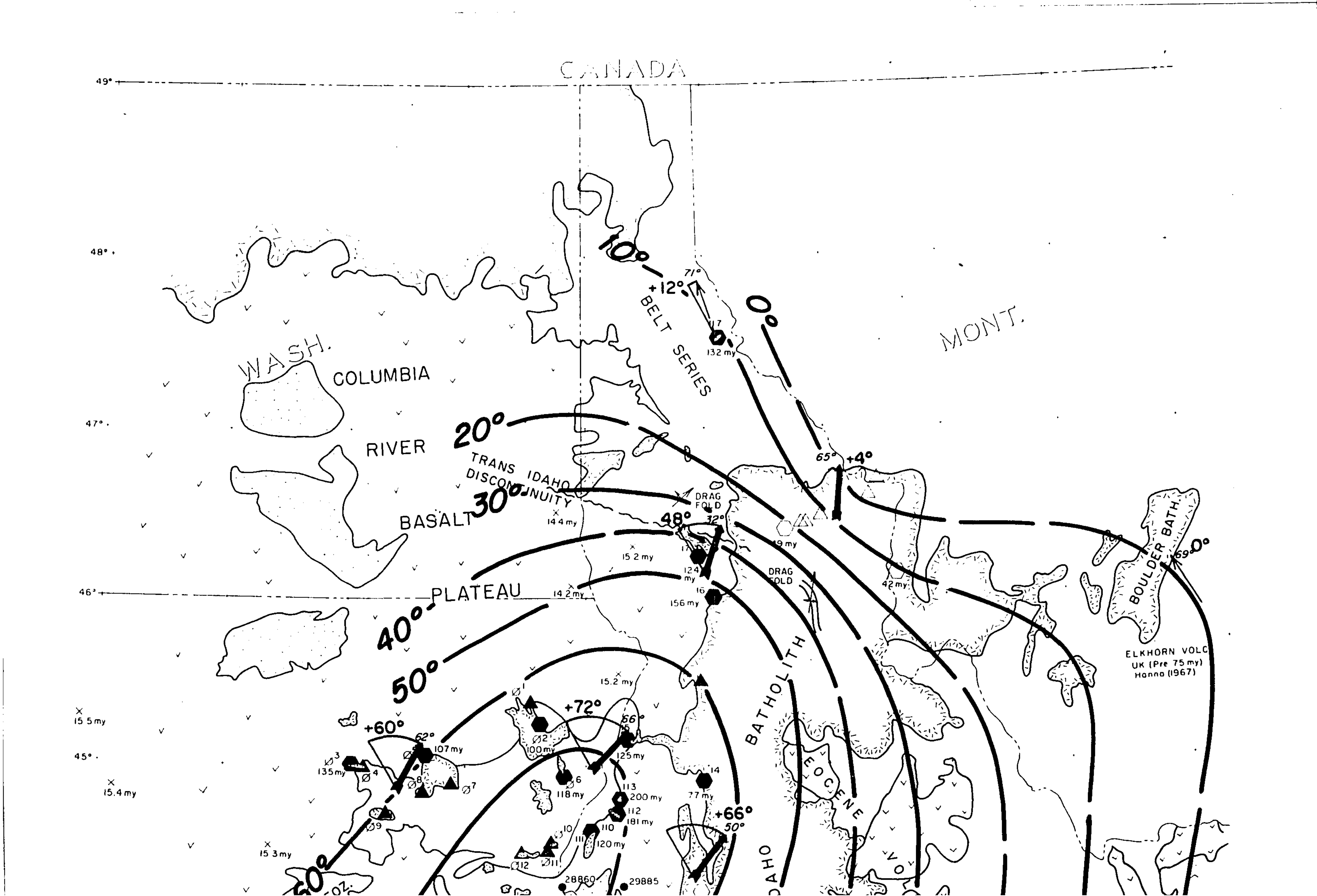
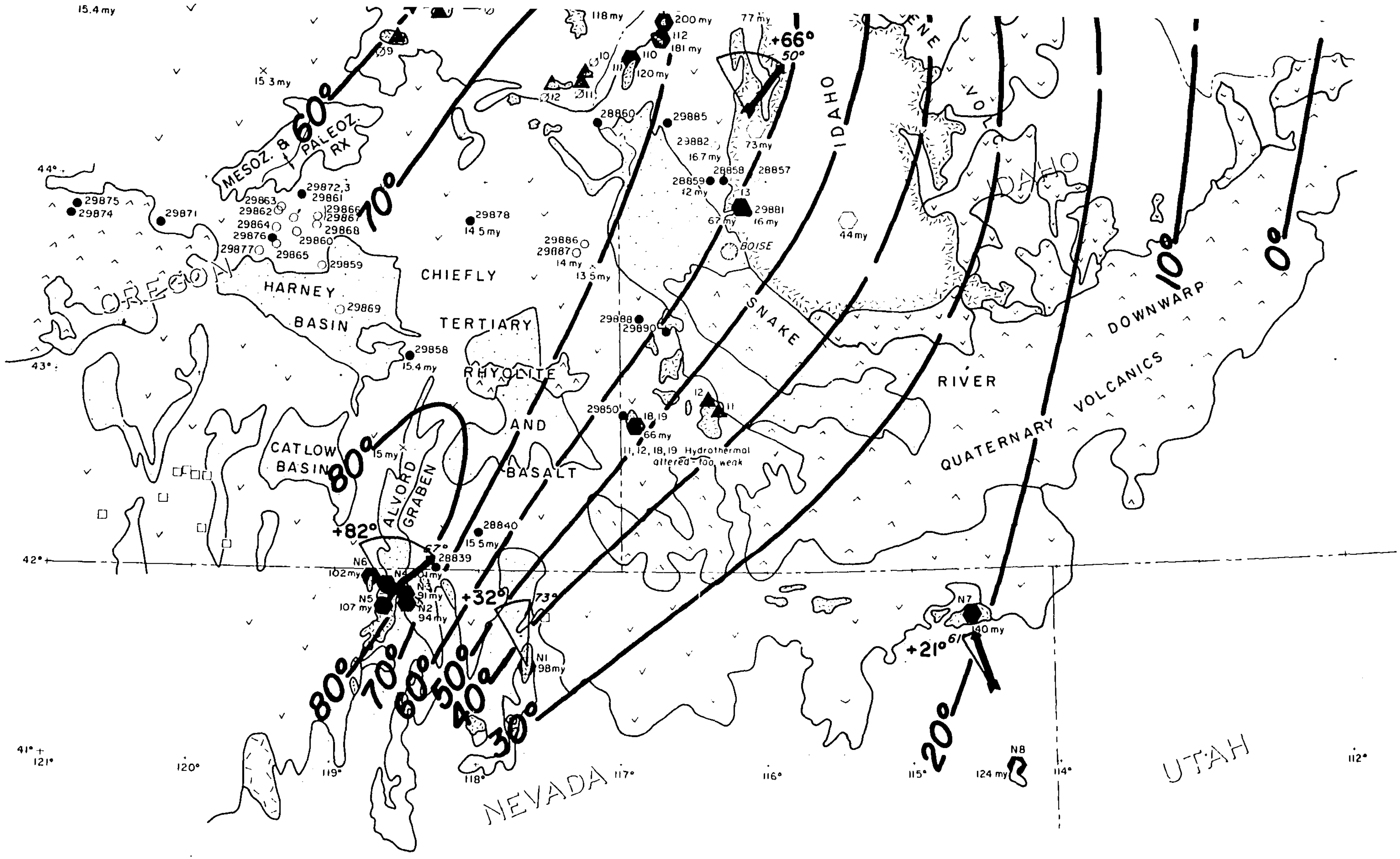



FIG. VI-7 EOCENE INTRUSIVE ROCKS. AVERAGE PALEOMAGNETIC DIRECTIONS, NORTHERN IDAHO BATHOLITH, BECK ET AL (1972)



CANADA
49°
48°
47°
46°
45°
WASH.
COLUMBIA
RIVER
BASALT
PLATEAU
MONT.
BELT SERIES
TRANS IDAHO DISCONTINUITY
DRAG FOLD
BATHOLITH
EOCENE
BOULDER BATH.
ELKHORN VOLC
UK (Pre 75 my)
Hanna (1967)
10°
+12°
71°
0°
20°
30°
40°
50°
60°
65°
+4°
48°
32°
+72°
+60°
62°
66°
+66°
50°
69°
0°
132 my
14.4 my
15.2 my
14.2 my
156 my
42 my
19 my
15.5 my
15.4 my
15.3 my
107 my
135 my
100 my
125 my
118 my
200 my
181 my
120 my
77 my
28860
29885




**CLOCKWISE ROTATION OF AVERAGED PALEOMAGNETIC VECTORS - INTRUSIVES**

**FIG. VI-8 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO**

**AVERAGED PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS**

73° SINGLE ISOLATED SIGNIFICANT LOCALITY

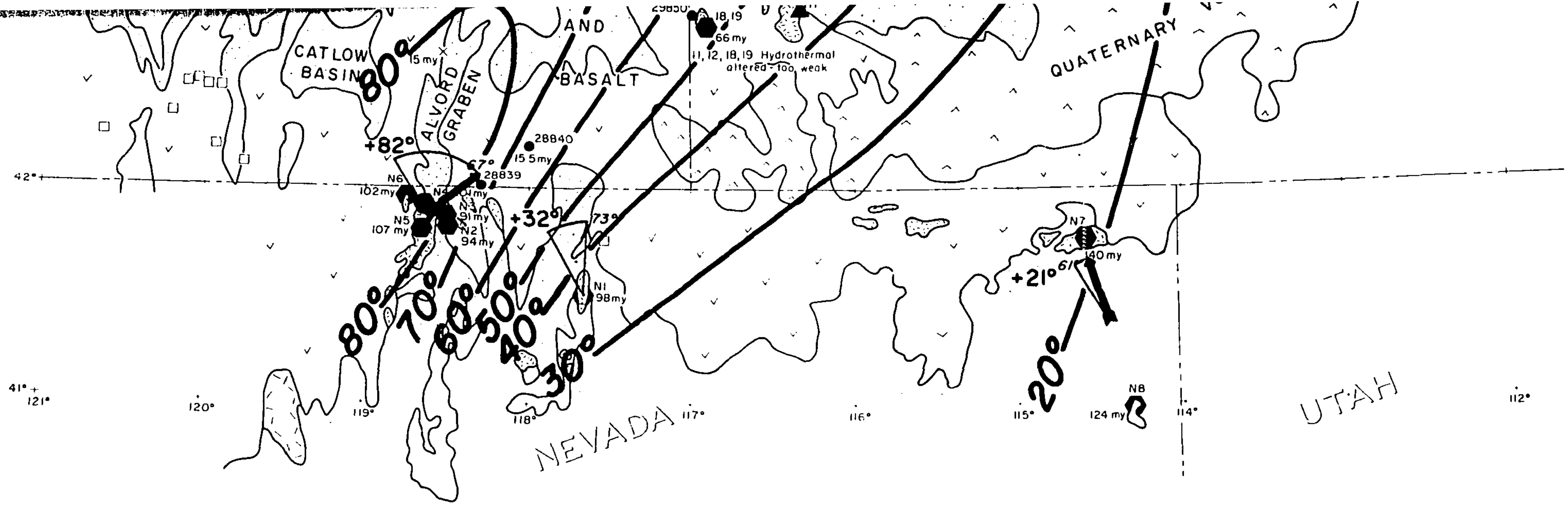
ROTATION 82° REFERENCE DIRECTION

AVERAGED LOCALITY 62° INCLINATION

DECLINATION SHOWN BY DIRECTION

LOCATION OF AVERAGE

C.I.=10°

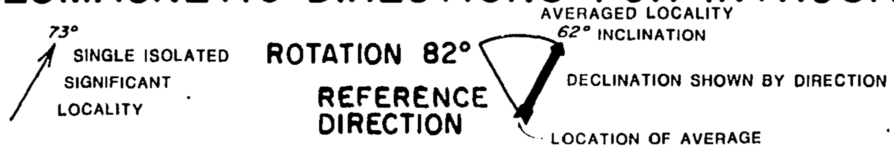



**CLOCKWISE ROTATION OF AVERAGED PALEOMAGNETIC VECTORS - INTRUSIVES**

FIG. VI-8 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO

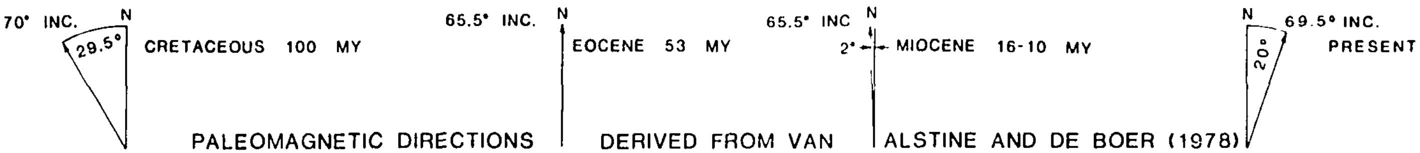
**AVERAGED PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS**

72




C.I.=10°

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON




PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

INTRUSIVES

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

- ⬣ AGE DATED (MOSTLY LIT.) PALEOMAG. BY: W.L.B.
- ▲ NO AGE DATE. PALEOMAG. BY: W.L B
- ⬡ AGE DATED (FROM LITERATURE). PALEOMAG. BY BECK, ETAL (1972)
- △ NO AGE DATE. PALEOMAG. BY BECK, ETAL (1972)

EXTRUSIVES

- ● PALEOMAG BY: W.L.B.
- PALEOMAG BY: HELSLEY
- × PALEOMAG. BY WATKINS & BAKSI (1974)
- PALEOMAG. BY LARSON (1965) OR LARSON, ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

- INTRUSIVE ROCKS
- TERTIARY RHYOLITE & BASALT
- QUATERNARY VOLCANICS
- LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

were in approximate agreement; and d, if the magnetic direction represents the field at the time the rock was formed. These are the usual assumptions implicit in paleomagnetic work. In the present case we are using reference directions computed from pole positions compared to the average of several site directions. The $\alpha 95^{\circ}$ confidence calculation was not carried into the average site directions. It is estimated to be of the order of $\pm 20^{\circ}$.

The Cretaceous reference direction (N29.5$^{\circ}$W) is drawn at each average paleomagnetic position. An exception is the northern Idaho Batholith with average age of 45.5 m.y. where the reference direction used is Eocene (N-S).

The rotation of the average paleomagnetic vector from the reference directions is shown as an arc and is plotted. (+) indicates clockwise rotation.

The amount of rotation is contoured at $10^{\circ}$ intervals. Although the control is sparse, a northeasterly trend of strong rotation extends from north central Nevada to the Blue Mountains and the west side of the Idaho Batholith. This map suggests that at least part of the Idaho Batholith has been rotated.

The maximum amount of average rotation is $82^{\circ}$ in north central Nevada. The amount of rotation is $4^{\circ}$ at the northern Idaho Batholith Eocene locality and at the Boulder Batholith is $0^{\circ}$.

The rotation in the most westerly localities of eastern Oregon is $60^{\circ}$. Therefore, the limit of strong rotation is defined to the north and east of the area of interest but not to the southwest or west.

## Extrusive Volcanic Rocks

Appendix 4

As mentioned in Chapter IV, all of the volcanic cores were collected by Chevron U.S.A. Inc. Dr. C. E. Helsley, then with the Institute of Advanced Studies, University of Texas at Dallas, Texas, processed about half of the cores on a consultant basis. I processed the other half. Each extrusive site is identified in Appendix 4 as to whether it was measured by Dr. Helsley or by me.

Appendix 4 shows the paleomagnetic results for all of the extrusive volcanic sites in eastern Oregon and western Idaho.

The location, age, rock description, dip and strike, and paleomagnetic results for AF demagnetization are shown. The interpretation of the significance of the site as to possible rotation is discussed in the results section.

The interpreted most stable direction is invariably that for the highest value AF demagnetization. The $\alpha 95$ radius of confidence is usually less than $10^{o}$ for the volcanic rock localities. Some points near the edge of the Schmidt net may be erratic and related to weak fields during a reversal (Watkins and Baksi, 1974). These points are marked "C" to denote they have been culled from the data before the statistics were computed. In addition, a few very erratic points were culled.

Some localities had only 4 or 5 samples. No Schmidt net display is shown for these localities because so few samples would not average out the secular variation. However, several of these localities were combined in a single average as will be discussed later.

Map of Paleomagnetic Directions for Tertiary Extrusives (Fig. VI-9)

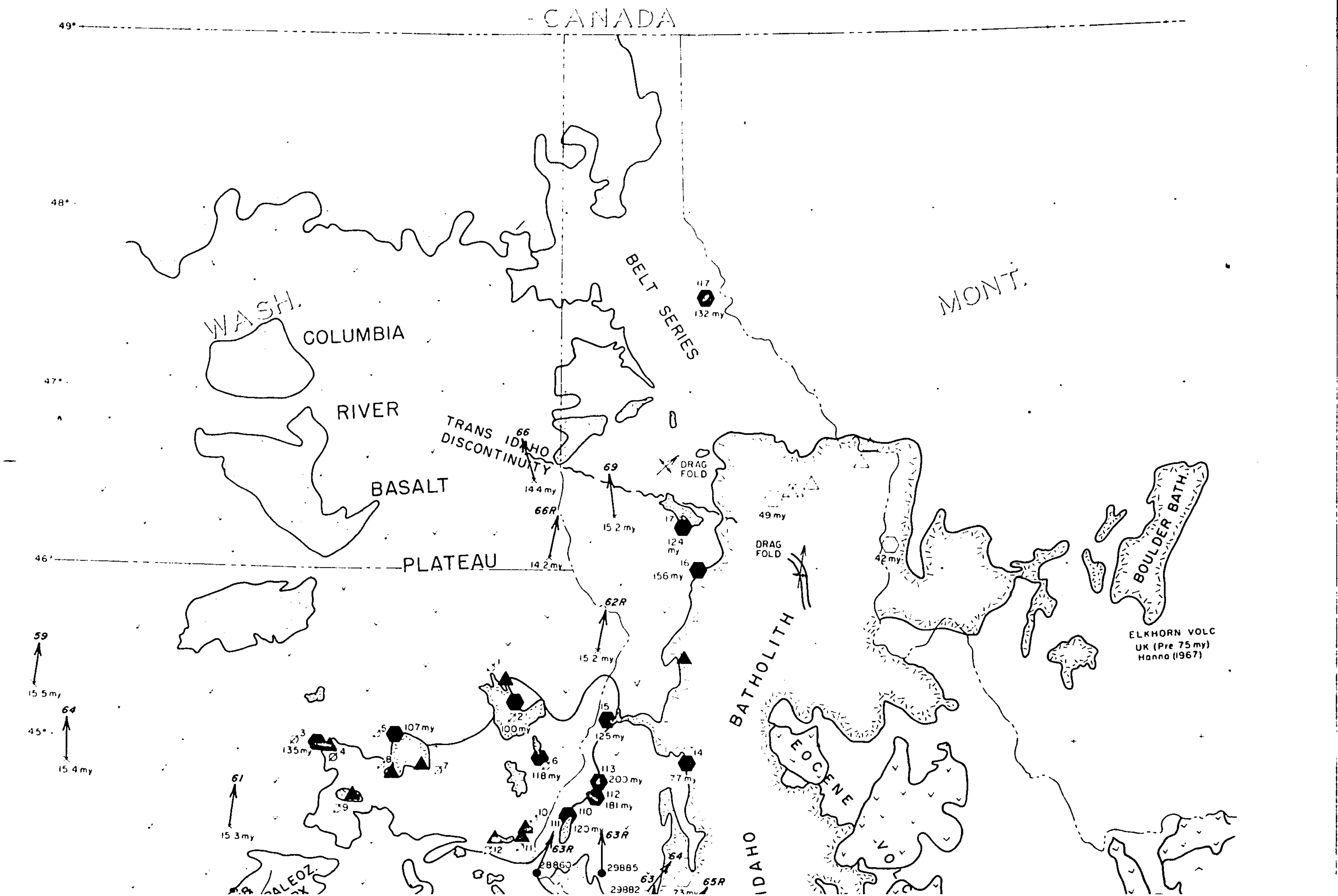
Referring to Figure VI-9, the solid black circles show extrusive localities measured by me. The open circles indicate those localities measured by Dr. Helsley. Both sets of data are original in this thesis.

The paleomagnetic data by Larson (1965) for southern Oregon volcanics is indicated by squares. Also a square shows the average position in north central Nevada of the Santa Rosa Mountain Miocene paleomagnetic data by Larson, et al (1971).

Localities from Watkins and Baksi (1974) in Oregon, Washington, and Idaho are indicated by "X".

Most of the declinations for the extrusive localities suggest a north-northeasterly direction not significantly different from the present field. However, several reversals are noted in many of the extrusive localities which suggests that the magnetization is related to original TRM rather than later alteration.

Some significant departures from the north-northeasterly trend are noted. The two most northerly localities from Watkins and Baksi (1974) which point north-northwesterly were interpreted by them to suggest oroclinal bending. Localities 28859 and 29881 just north of Boise, Idaho point east-northeasterly. However, locality 28859 contains only four samples which would not average out secular variation. Locality 29881 has 18 samples and the structural dip is $33^{\circ}$ northwest. The $\alpha_{95}$ is $18^{\circ}$



CANADA
49°
48°
47°
46°
45°
WASH.
MONT.
COLUMBIA
RIVER
BASALT
PLATEAU
BELT SERIES
TRANS IDAHO DISCONTINUITY
DRAG FOLD
DRAG FOLD
BATHOLITH
IDAHO
EOCENE
VO
BOULDER BATH.
ELKHORN VOLC
UK (Pre 75 my)
Hanna (1967)
PALEOZ.
117
132 my
66
14.4 my
69
15.2 my
66R
14.2 my
17
124 my
16
156 my
49 my
42 my
62R
15.2 my
59
15.5 my
64
15.4 my
61
15.3 my
3
135 my
4
5
107 my
8
7
9
2
100 my
6
118 my
15
125 my
14
77 my
113
200 my
112
181 my
110
120 my
111
10
11
12
63R
63R
28860
29885
29882
64
63
65R
73 my

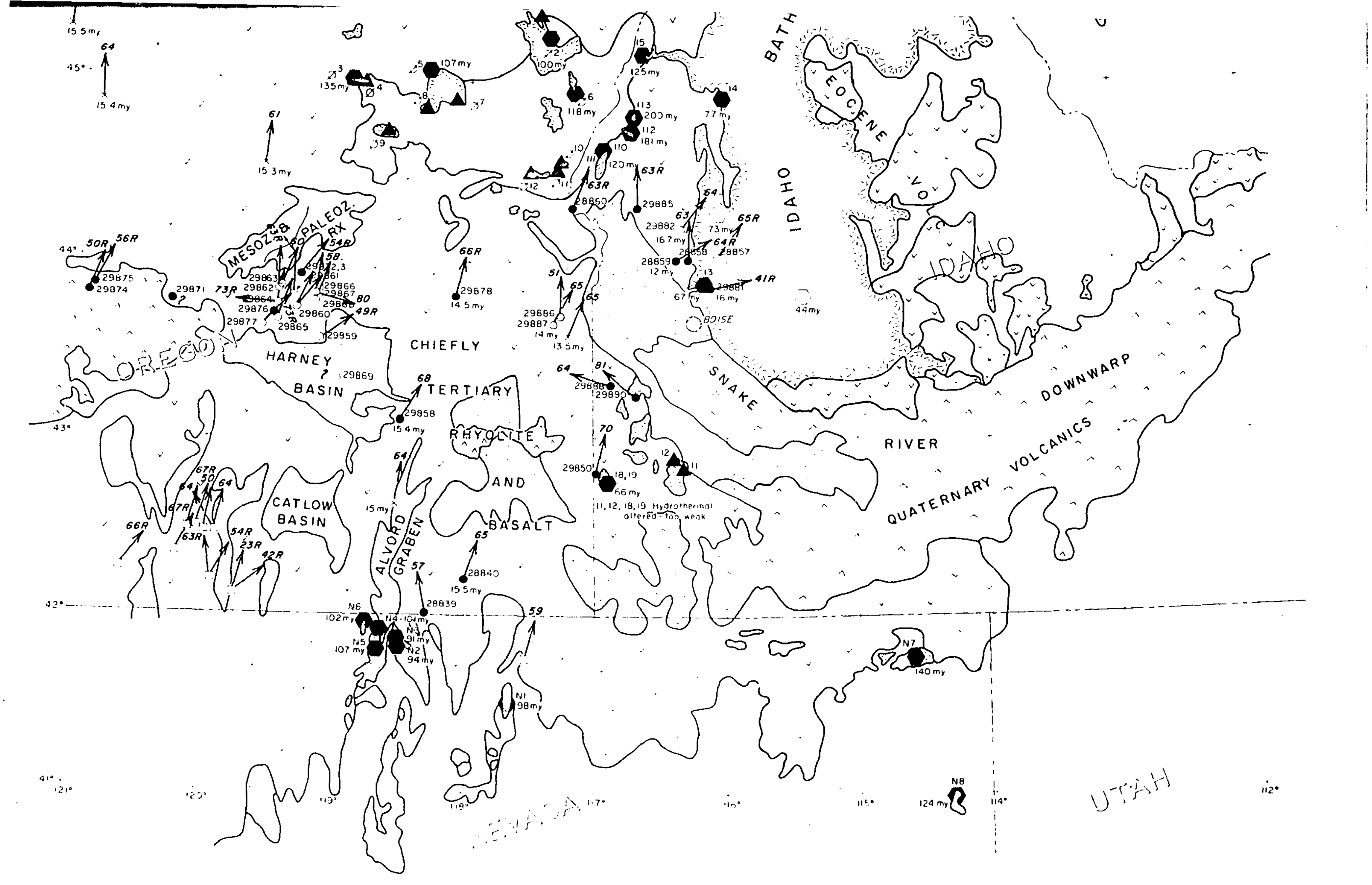
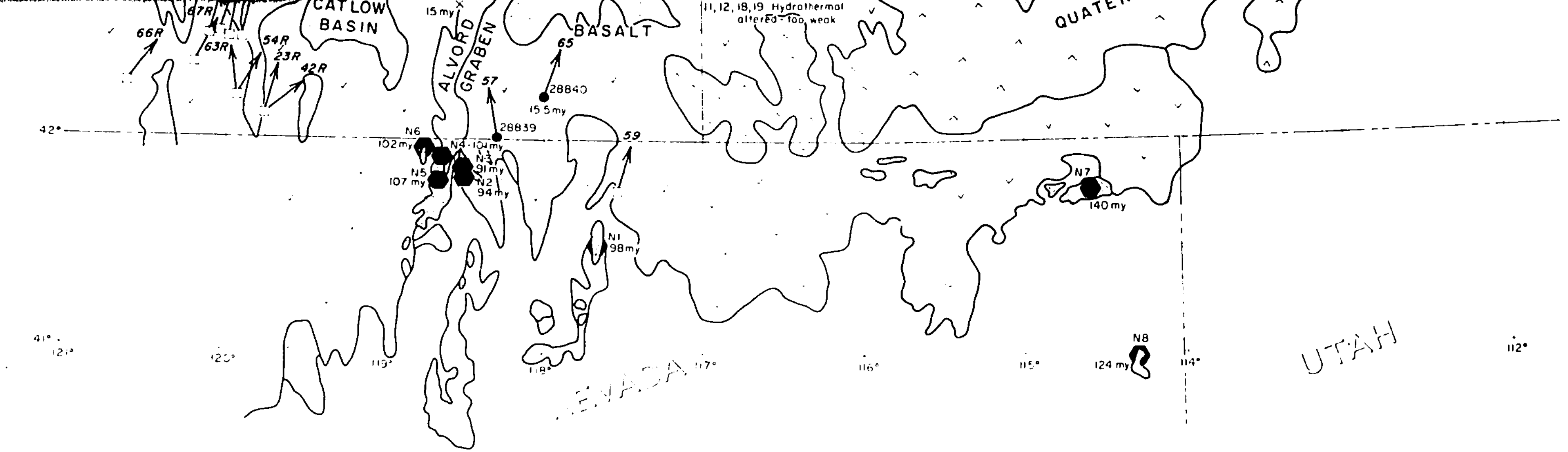


FIG. VI-9 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO
PALEOMAGNETIC DIRECTIONS FOR TERTIARY EXTRUSIVES






# FIG. VI-9 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO
## PALEOMAGNETIC DIRECTIONS FOR TERTIARY EXTRUSIVES

65° INCLINATION

ARROW SHOWS DIRECTION OF NORTH SEEKING POLARITY DOWNWARD. R INDICATES NORTH SEEKING POLARITY WAS UPWARD IN OPPOSITE DIRECTION.

AGE 15.5 my

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON

70° INC. N 29.5° CRETACEOUS 100 MY

65.5° INC N EOCENE 53 MY

65.5° INC N 2° MIOCENE 16-10 MY

N 69.5° INC. 20° PRESENT

PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

### INTRUSIVES

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

AGE DATED (MOSTLY LIT.) PALEOMAG BY W L B

AGE DATED (FROM LITERATURE) PALEOMAG BY BECK ETAL (1972)

NO AGE DATE PALEOMAG BY W L B

NO AGE DATE PALEOMAG BY BECK ETAL (1972)

### EXTRUSIVES

PALEOMAG BY W L B

PALEOMAG BY HELSLEY

PALEOMAG BY WATKINS & BAKSI (1974)

PALEOMAG BY LARSON (1965) OR LARSON ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

INTRUSIVE ROCKS

TERTIARY RHYOLITE & BASALT

QUATERNARY VOLCANICS

LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

W L BASHAM

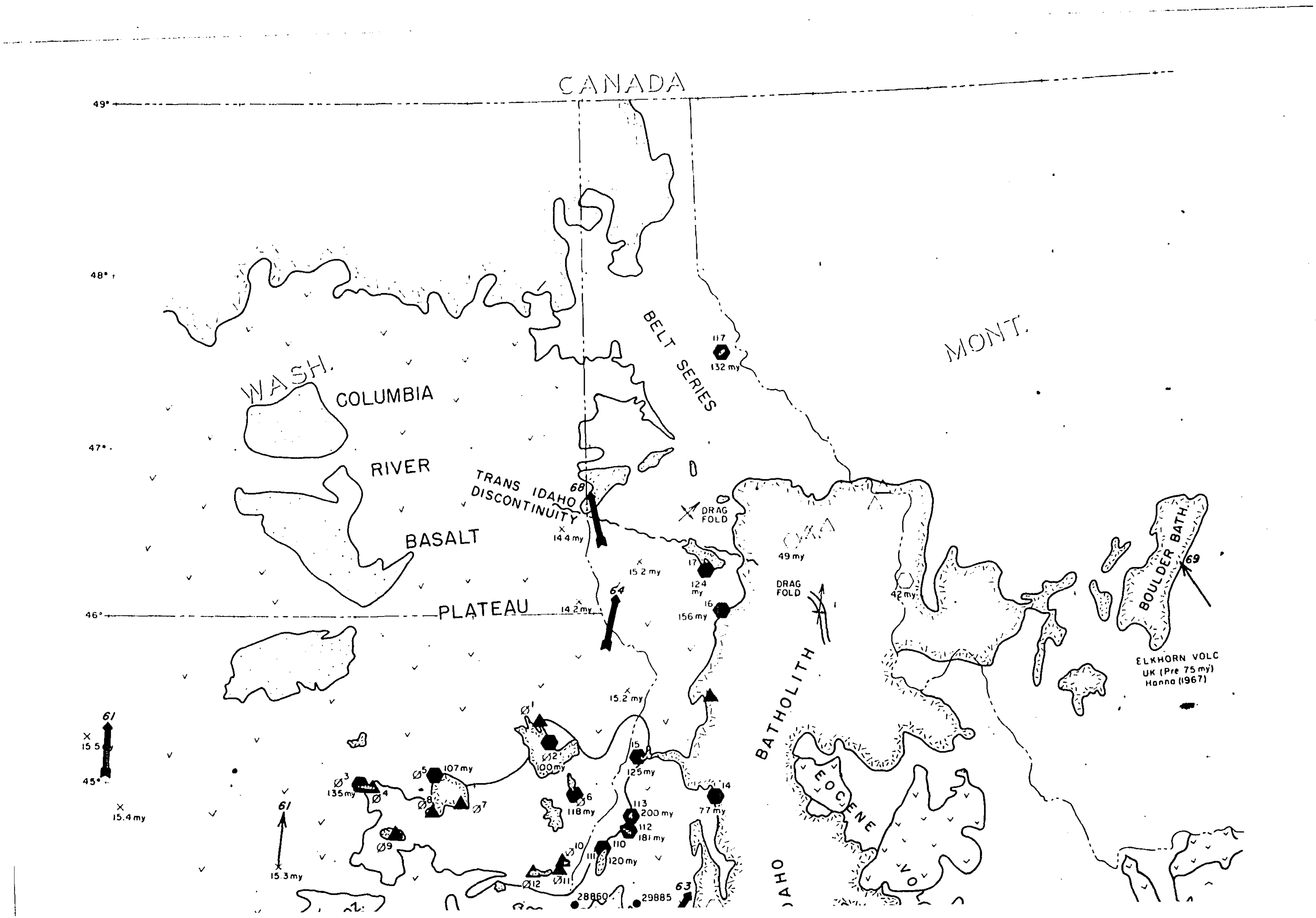
MARCH 1978

for 300 oe, which is considerable scatter as compared to most other localities. Perhaps complex folding or secondary alteration or both may explain the unusual paleomagnetic direction. In addition, two localities southwest of Boise in the Owyhee Mountains show west-northwest directions. Locality 29888 has 15 samples and the structural dip is only $5^{\circ}$. The $\alpha 95$ is $17^{\circ}$. Whether secondary alteration is responsible, the number of samples is insufficient, or whether counterclockwise rotation has occurred is not known. Locality 29890 has 27 samples, all reversed magnetically. The structural dip is $30^{\circ}$. Perhaps either complex folding or counterclockwise rotation is the best explanation here.

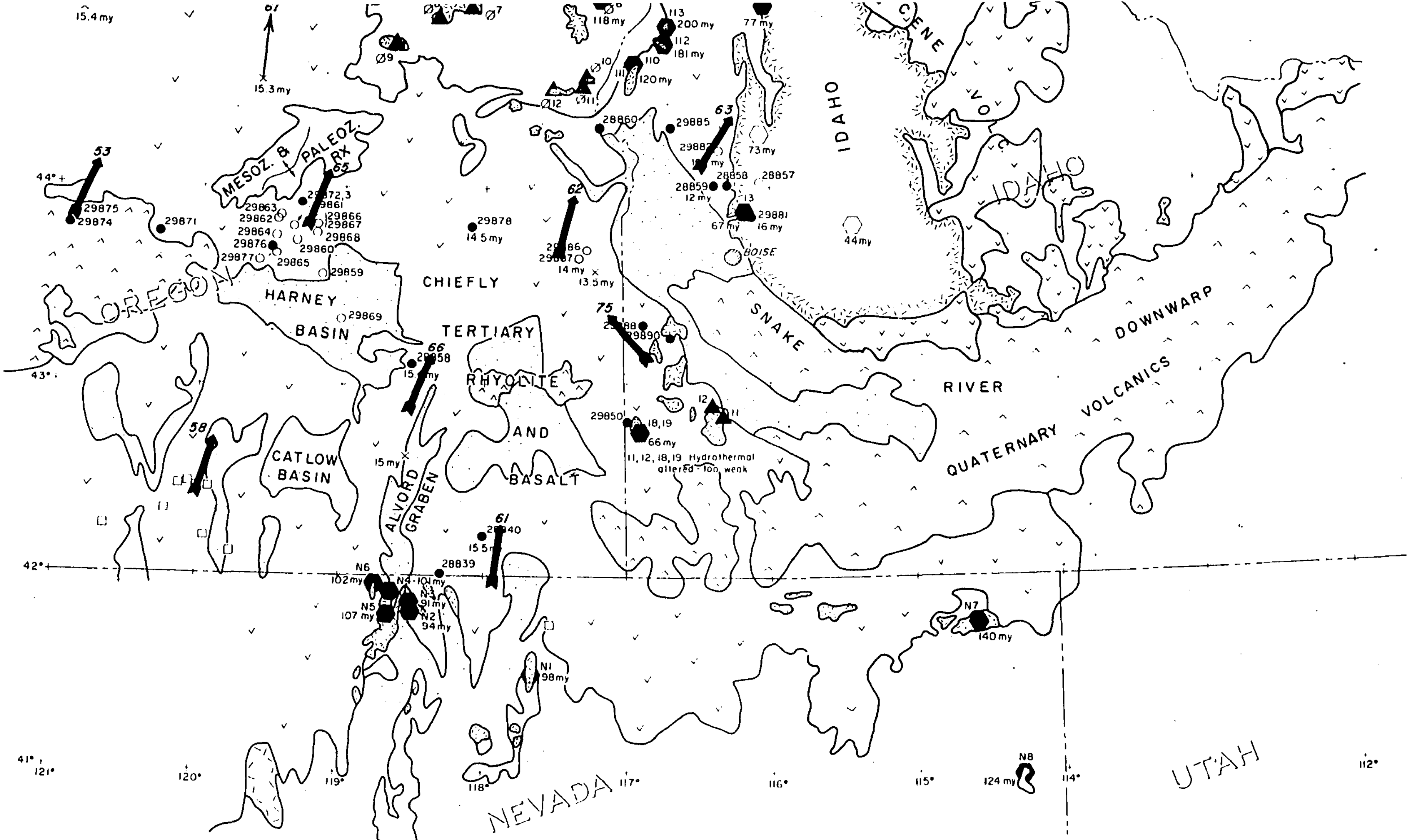
Map of Averaged Paleomagnetic Directions for Volcanic Rocks (Fig. VI-10)

Although the extrusive volcanic rock paleomagnetic directions (Figure VI-9) are considerably more regular than those for the older intrusive igneous rocks (Figure VI-3), it was considered worthwhile to also average the volcanic paleomagnetic directions areally (Figure VI-10).

Figure VI-11A shows the stereonet plot of sites in southeastern Oregon plus the Santa Rosa Mountains site described by Larson et al (1971). This average direction is plotted on Figure VI-10 on the Oregon-Nevada state line. Figure VI-11 shows the average and Schmidt net plot for 12 directions described by Larson (1965) in southeast Oregon. The only dating is locality 28840 which averages 15.75 m.y.



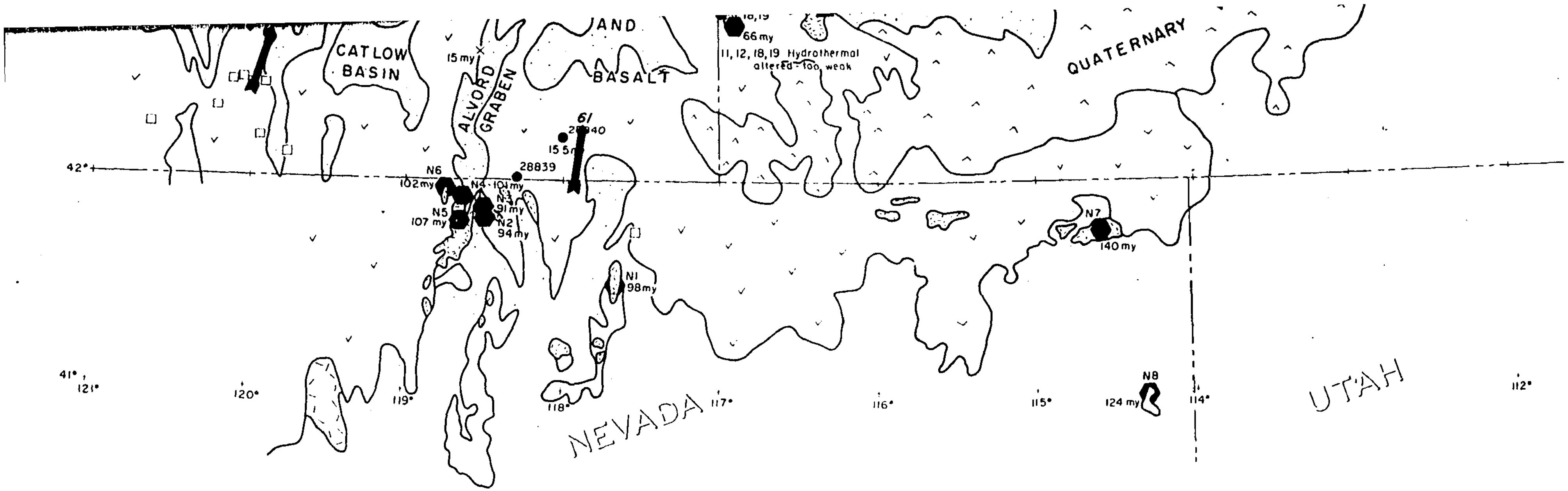
CANADA
49°
48°
47°
46°
45°
WASH.
MONT.
COLUMBIA
RIVER
BASALT
PLATEAU
BELT SERIES
TRANS IDAHO DISCONTINUITY
68
64
61
63
69
14.4 my
15.2 my
14.2 my
15.5 my
15.4 my
15.3 my
117
132 my
DRAG FOLD
49 my
42 my
17
124 my
16
156 my
BATHOLITH
BOULDER BATH.
ELKHORN VOLC
UK (Pre 75 my)
Hanna (1967)
EOCENE
15
125 my
14
77 my
113
200 my
112
181 my
110
111
120 my
107 my
100 my
118 my
135 my
28860
29885




# FIG. VI·10 PALEOMAGNETIC STUDY - NEVADA, OREGON AND IDAHO
# AVERAGED PALEOMAGNETIC DIRECTIONS FOR VOLCANIC ROCKS

61 SINGLE ISOLATED SIGNIFICANT LOCALITY

AVERAGED LOCALITY
62 INCLINATION
DECLINATION SHOWN BY DIRECTION
LOCATION OF AVERAGE




# FIG. VI·10 PALEOMAGNETIC STUDY - NEVADA, OREGON AND IDAHO
# AVERAGED PALEOMAGNETIC DIRECTIONS FOR VOLCANIC ROCKS

61 SINGLE ISOLATED SIGNIFICANT LOCALITY

AVERAGED LOCALITY
62 INCLINATION
DECLINATION SHOWN BY DIRECTION
LOCATION OF AVERAGE

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON

70° INC. N 29.5° CRETACEOUS 100 MY

65.5° INC. N EOCENE 53 MY

65.5° INC N 2° MIOCENE 16-10 MY

N 20° 69.5° INC. PRESENT

PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

## INTRUSIVES

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

- ⬢ AGE DATED (MOSTLY LIT.) PALEOMAG. BY: W.L.B.
- ⬡ AGE DATED (FROM LITERATURE), PALEOMAG. BY BECK, ETAL (1972)
- ▲ NO AGE DATE. PALEOMAG. BY W.L.B
- △ NO AGE DATE. PALEOMAG. BY BECK, ETAL (1972)

## EXTRUSIVES

- ● PALEOMAG BY W.L.B.
- PALEOMAG BY HELSLEY
- × PALEOMAG. BY WATKINS & BAKSI (1974)
- PALEOMAG. BY LARSON (1965) OR LARSON, ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

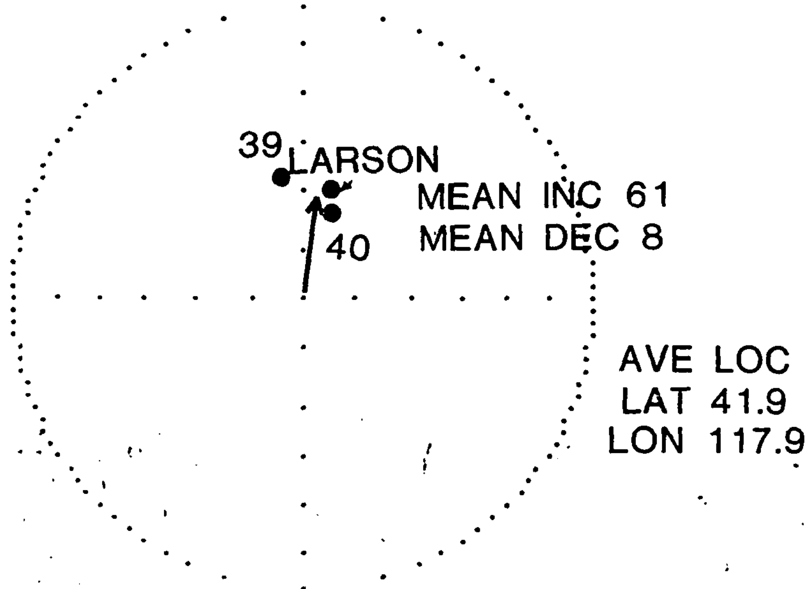
- INTRUSIVE ROCKS
- TERTIARY RHYOLITE & BASALT
- QUATERNARY VOLCANICS
- LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

W.L. BASHAM

MARCH 1978

A. MALHEUR AND HARNEY CO., ORE. HUMBOLDT CO.,NEV.
EXTRUSIVE SITES 28839, 28840, LARSON ET AL (1971).




B. LAKE CO., ORE. EXTRUSIVE SITES FROM
LARSON (1965).

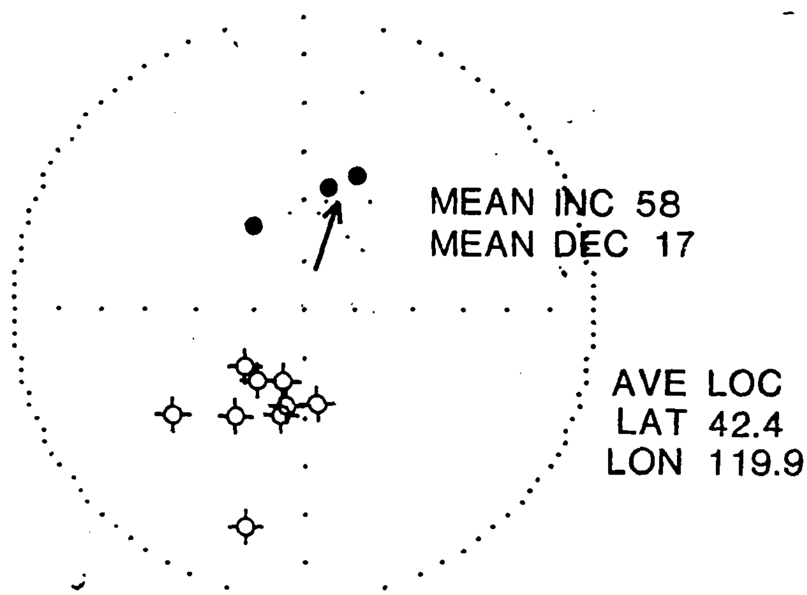
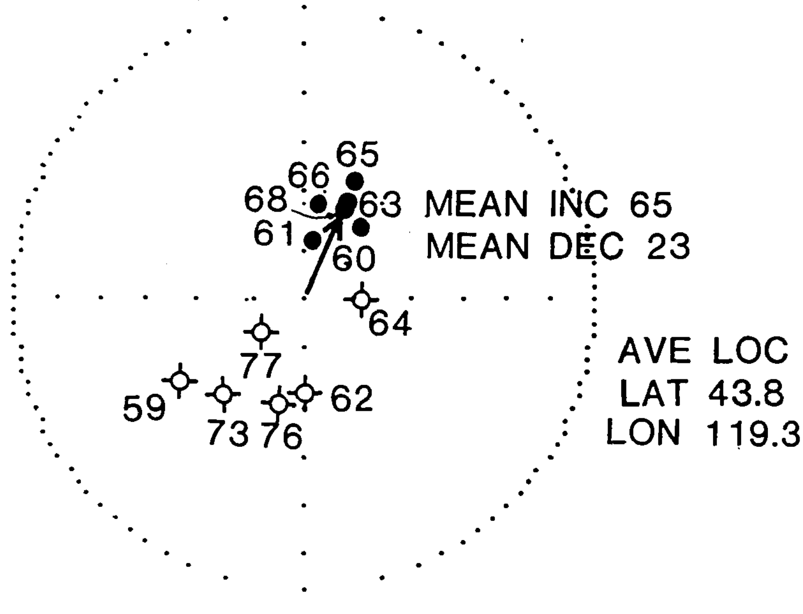



FIG. VI-11 MIOCENE VOLCANIC ROCKS AVERAGE OF
PALEOMAGNETIC DIRECTIONS

A. HARNEY CO., ORE. EXTRUSIVE SITES 29859-29866, 29868, 29873, 29876, 29877




B. OWYHEE CO., IDAHO EXTRUSIVE SITES 29850, 29888, 29890.

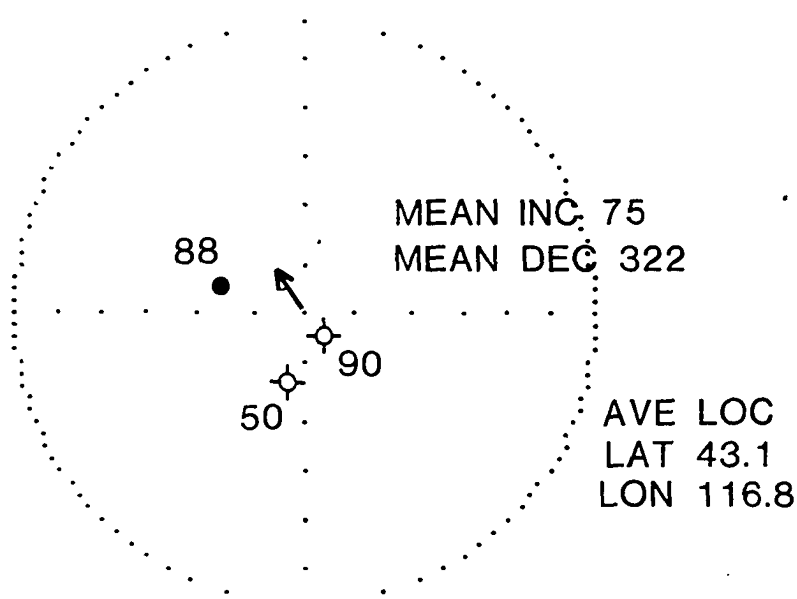
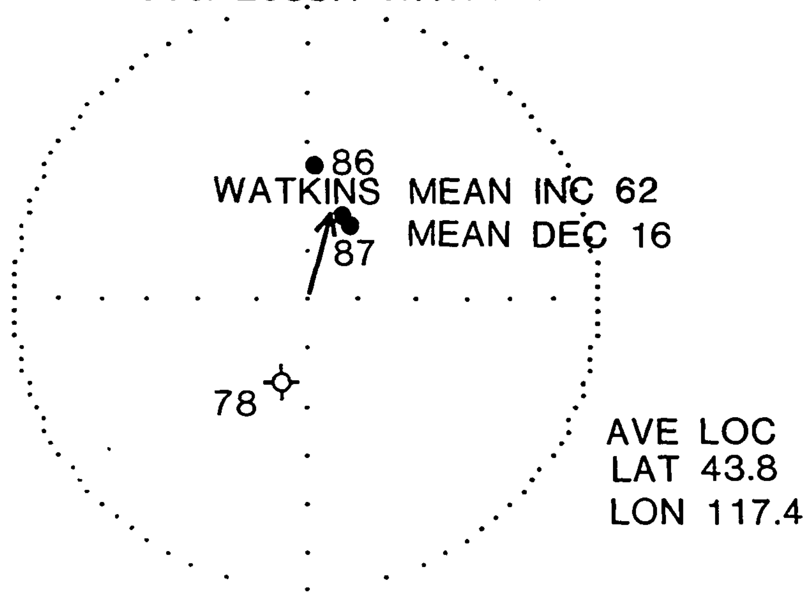



FIG. VI-12 MIOCENE VOLCANIC ROCKS
AVERAGE OF PALEOMAGNETIC DIRECTIONS

A. MALHEUR CO., ORE. EXTRUSIVE SITES 29878, 29886, 29887, WATKINS




B. BOISE CO., IDAHO EXTRUSIVE SITES 28857-28860, 29881, 29882, 29885

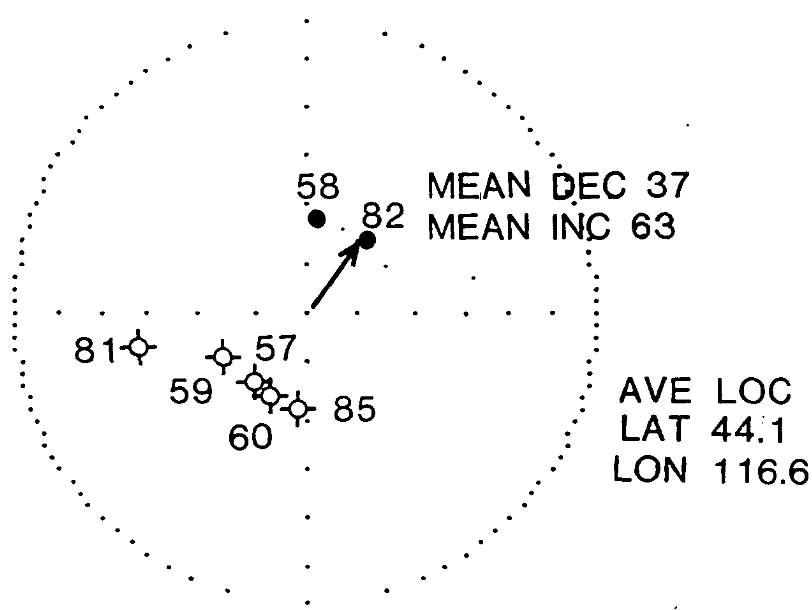



FIG. VI-13 MIOCENE VOLCANIC ROCKS
AVERAGE OF PALEOMAGNETIC DIRECTIONS

Localities 29874 and 29875 west of Harney Basin in Oregon are simply averaged. No age is known but the volcanics are described as Pliocene by Walker, et al (1967).

Ten sites north of Harney Basin, Oregon are shown averaged in Figure VI-12A. The average age of dated samples is 9 m.y. Several much older dates (Eocene to Oligocene) were discarded because of regional mapping by Walker. Figure VI-12B shows three Owyhee County, Idaho sites, two of which have anomalous west-northwesterly declinations.

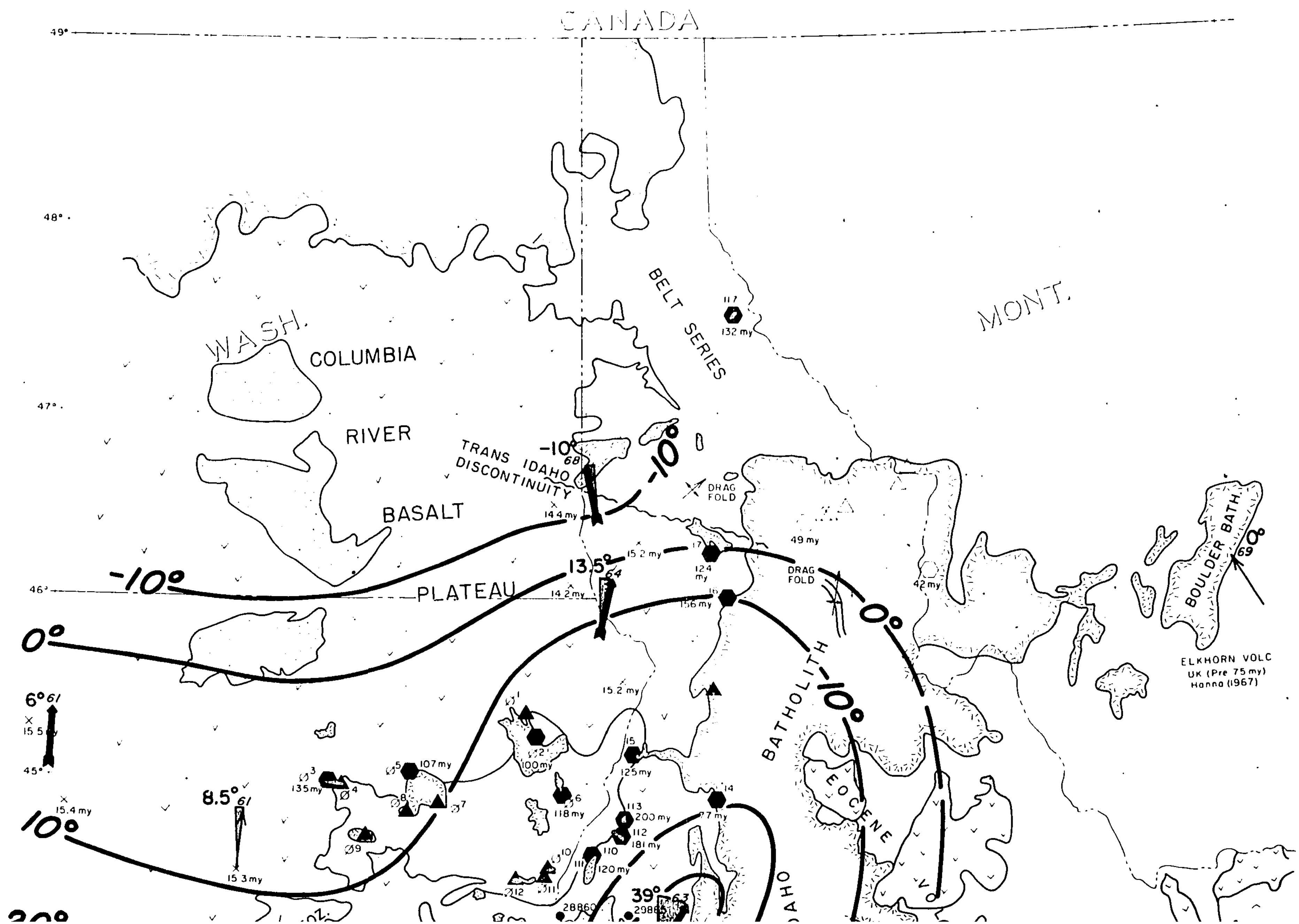
Figure VI-13A shows the average four sites in good agreement in east central Oregon near the Idaho border. The average age is about 14 m.y. Figure VI-13B shows the average of seven sites in western Idaho. These sites show the strongest suggestion of rotation (about $39^{o}$) of any of the volcanic averages. The average age is 21 m.y.; this may be too old because of two 30 m.y. ages.

Two pairs of paleodirections by Watkins and Baksi were averaged near the Oregon-Washington-Idaho border.

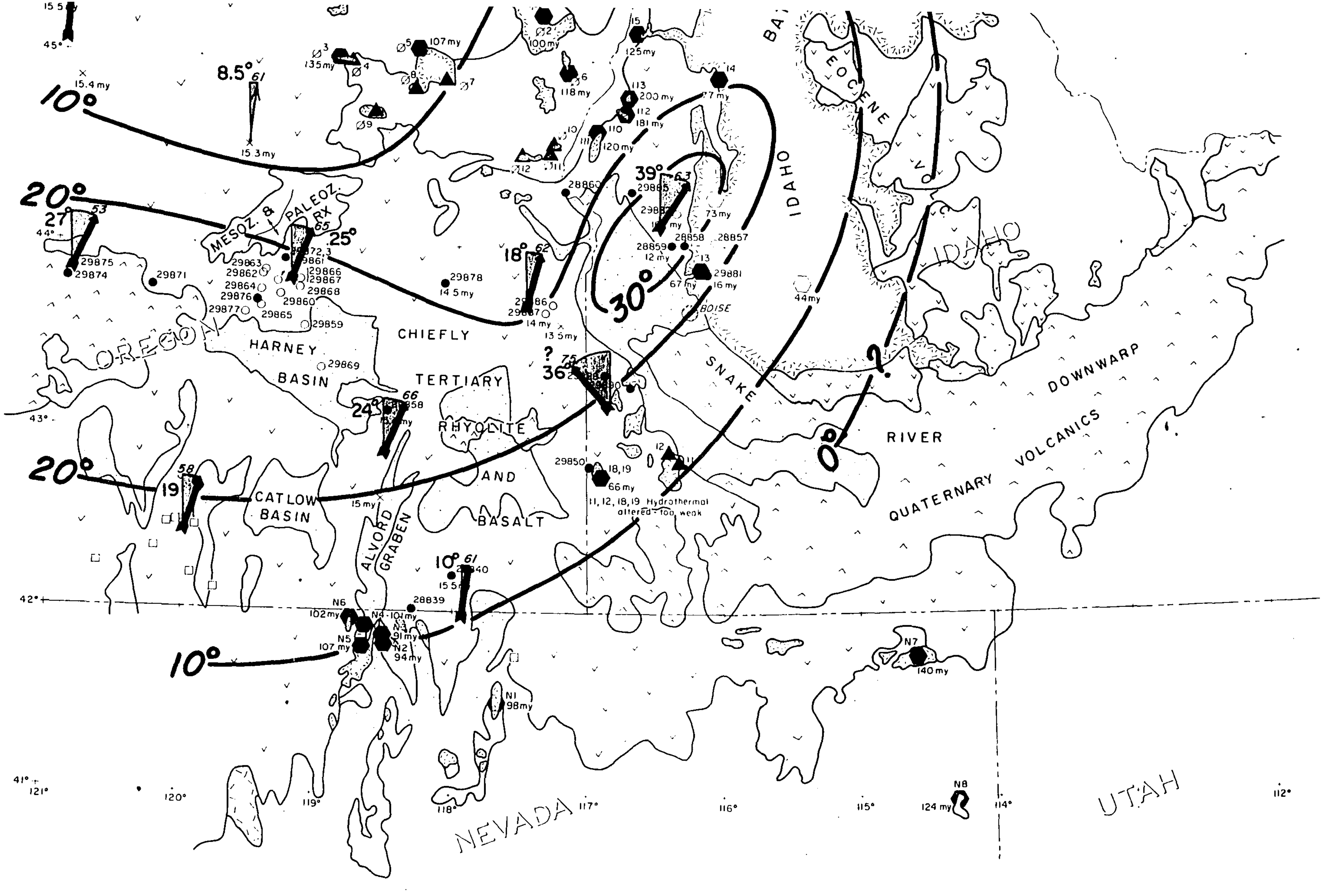
<u>Map of Clockwise Rotation of Averaged Paleomagnetic Vectors for Volcanic Rocks (Fig. VI-14)</u>

The reference direction ($N2^{o}W$) is plotted at each average paleomagnetic vector. The rotation of each average vector is shown as an arc. (+) shows clockwise and (-) denotes counterclockwise rotation. The 95 scatter probably is less than $10^{o}$ except for the high rotation vector ($39^{o}$) west of the Idaho Batholith where the $\alpha 95$ may be $\pm 20^{o}$.

Figure VI-14 should show the amount of rotation since Miocene (oldest reliable age about 20 m.y.). The contoured map suggests an



CANADA
49°
48°
47°
46°
45°
WASH.
COLUMBIA
RIVER
BASALT
PLATEAU
MONT.
BELT SERIES
TRANS IDAHO DISCONTINUITY
DRAG FOLD
BATHOLITH
EOCENE
BOULDER BATH.
ELKHORN VOLC
UK (Pre 75 my)
Hanna (1967)
-10°
0°
10°
13.5°
6°
8.5°
39°
15.2 my
14.4 my
14.2 my
15.5 my
15.4 my
15.3 my
124 my
156 my
49 my
42 my
132 my
107 my
100 my
135 my
125 my
118 my
200 my
181 my
120 my
77 my




CLOCKWISE ROTATION OF AVERAGED PALEOMAGNETIC VECTORS - VOLCANICS

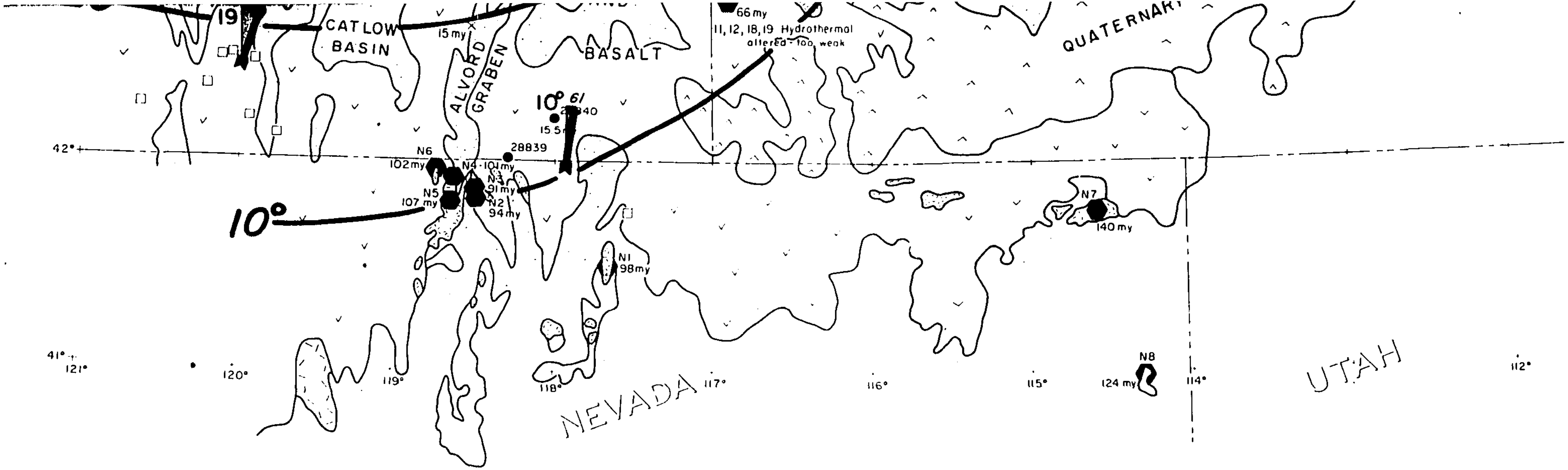
FIG. VI·14 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO

AVERAGED PALEOMAGNETIC DIRECTIONS FOR VOLCANIC ROCKS

ROTATION 22° AVERAGED LOCALITY 62 INCLINATION

61 SINGLE ISOLATED

C.I.=10°




# CLOCKWISE ROTATION OF AVERAGED PALEOMAGNETIC VECTORS – VOLCANICS

# FIG. VI·14 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO

# AVERAGED PALEOMAGNETIC DIRECTIONS FOR VOLCANIC ROCKS



ROTATION 22°

C.I.=10°

61 — SINGLE ISOLATED SIGNIFICANT LOCALITY

REFERENCE DIRECTION — AVERAGED LOCALITY 62 INCLINATION; DECLINATION SHOWN BY DIRECTION; LOCATION OF AVERAGE

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON

70° INC. N 29.5° CRETACEOUS 100 MY

65.5° INC. N EOCENE 53 MY

65.5° INC N 2° MIOCENE 16-10 MY

N 69.5° INC. 20° PRESENT

PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

## INTRUSIVES

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

- ⬢ AGE DATED (MOSTLY LIT.) PALEOMAG. BY W.L.B.
- ▲ NO AGE DATE. PALEOMAG. BY W.L.B.
- ⬡ AGE DATED (FROM LITERATURE). PALEOMAG. BY BECK, ETAL (1972)
- △ NO AGE DATE. PALEOMAG. BY BECK, ETAL (1972)

## EXTRUSIVES

- ● PALEOMAG BY W.L.B.
- PALEOMAG BY HELSLEY
- × PALEOMAG BY WATKINS & BAKSI (1974)
- PALEOMAG. BY LARSON (1965) OR LARSON, ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

- INTRUSIVE ROCKS
- TERTIARY RHYOLITE & BASALT
- QUATERNARY VOLCANICS
- LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

W.L. BASHAM

MARCH 1978

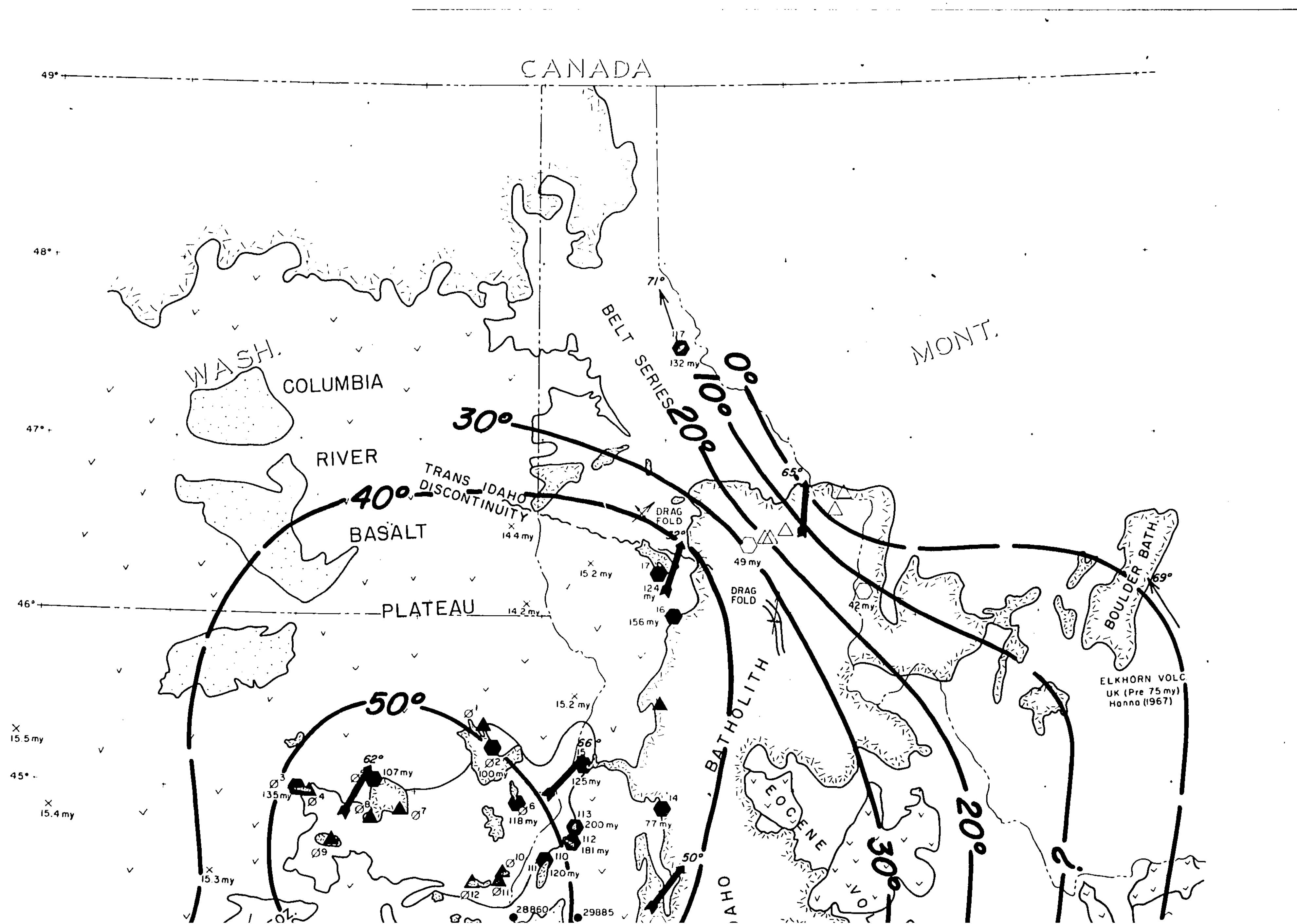
east-west pattern of maximum rotation which may terminate east of the Idaho Batholith. The only point suggesting termination is the "0" value of the Elkhorn Volcanics near the Boulder Batholith.

## Pre-Miocene Rotation of Intrusives
## Figure VI-15

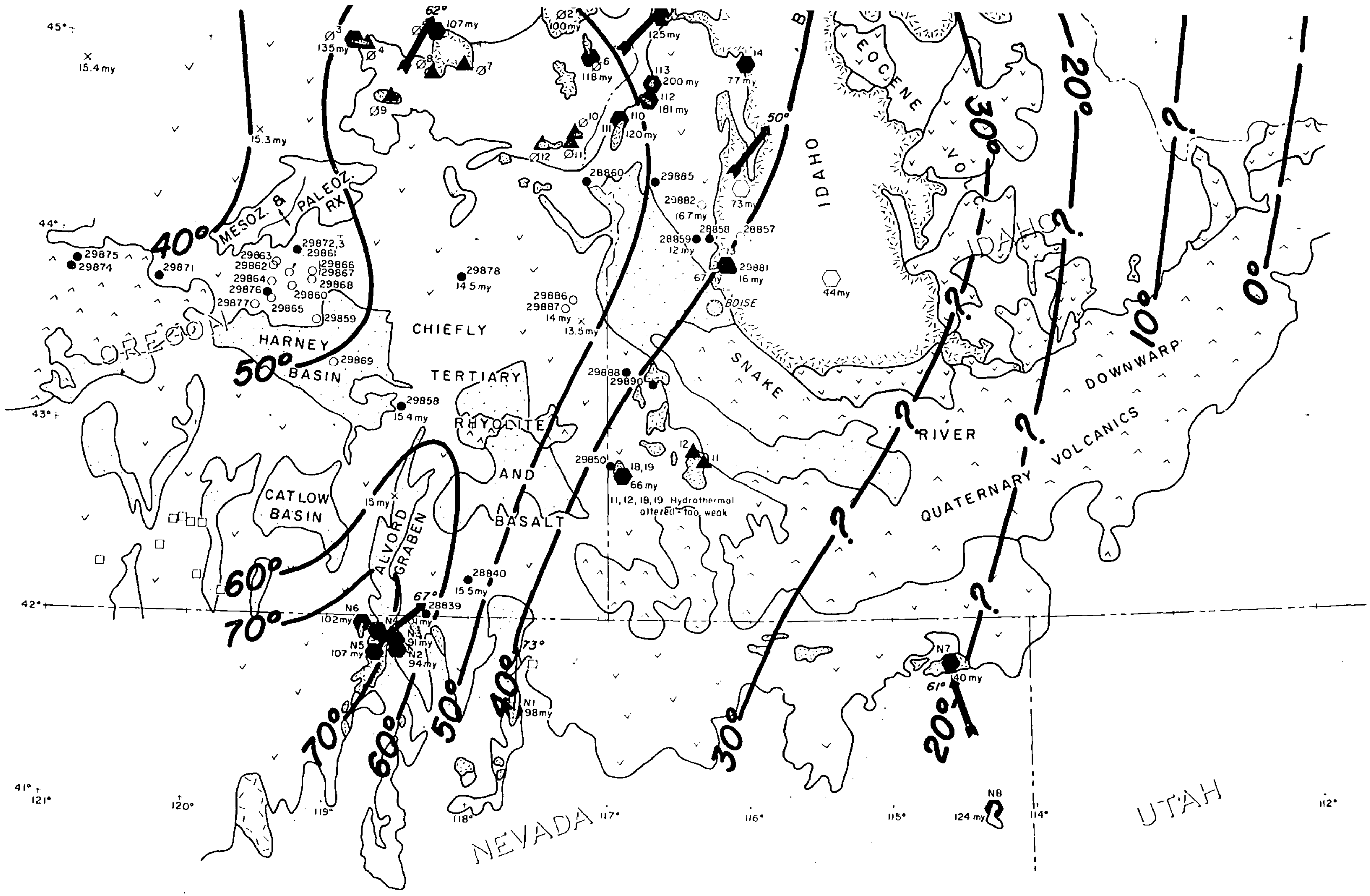
Figure VI-15 was constructed by subtracting Figure VI-14 from Figure VI-8. Figure VI-15 should show the amount of rotation of intrusive rocks that occurred in Pre-Miocene time. The $\alpha 95$ confidence limits are estimated to be of the order of $\pm 25^{\circ}$.

The locus of strong deformation in Figure VI-15 remains similar in position to that shown in the total rotation map of intrusives, Figure VI-8. The amount is of course decreased by the post-Miocene rotation. The contours between the Idaho and Boulder Batholiths are questionable because of lack of control.

The exact time of rotation suggested by Figure VI-15 cannot be stated precisely. The youngest intrusive locality suggesting clockwise rotation is one by Beck, et al (1972) dated 42 m.y. This is a single locality, however, and Eocene localities 50 miles northwest show counter-clockwise rotation. Whether this area represents the apex of bending or that the divergence represents local structural disturbance cannot be determined from the present data. The observation of $50^{\circ}$ to $70^{\circ}$ clockwise rotation in Eocene rocks in the Oregon Coast Range (Simpson and Cox, 1977) suggests the possibility of Late or Post-Eocene rotation in the present area if coastal Oregon and eastern Oregon were linked by the same deformation. The next youngest intrusive locality suggesting



CANADA
49°
48°
47°
46°
45°
WASH.
MONT.
COLUMBIA
RIVER
BASALT
PLATEAU
BELT SERIES
TRANS-IDAHO DISCONTINUITY
DRAG FOLD
DRAG FOLD
BATHOLITH
IDAHO
EOCENE
BOULDER BATH.
ELKHORN VOLC.
UK (Pre 75 my)
Hanna (1967)
0°
10°
20°
30°
40°
50°
20°
30°
71°
65°
69°
62°
66°
50°
132 my
49 my
42 my
14.4 my
15.2 my
14.2 my
15.2 my
15.5 my
15.4 my
15.3 my
124 my
156 my
135 my
107 my
100 my
118 my
125 my
200 my
181 my
120 my
77 my
28860
29885




PRE-MIOCENE CLOCKWISE ROTATION OF INTRUSIVES

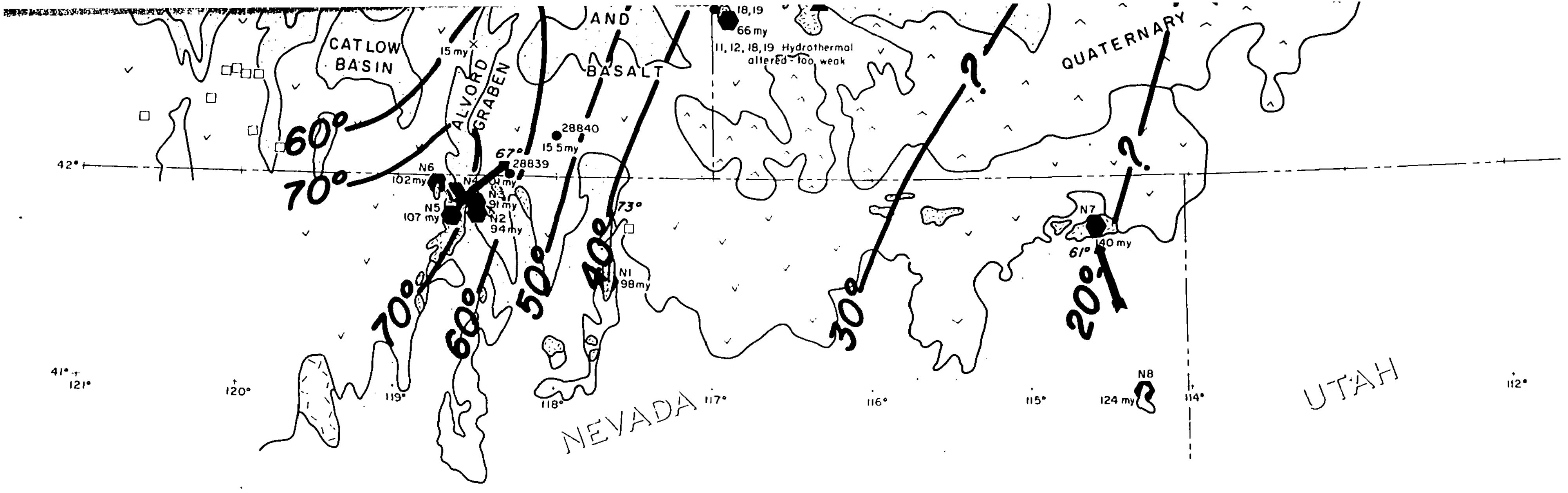
FIG. VI-15 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO

AVERAGED PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS

73° SINGLE ISOLATED

AVERAGED LOCALITY 62° INCLINATION

DECLINATION SHOWN BY DIRECTION




# PRE-MIOCENE CLOCKWISE ROTATION OF INTRUSIVES

## FIG. VI-15 PALEOMAGNETIC STUDY-NEVADA, OREGON AND IDAHO

## AVERAGED PALEOMAGNETIC DIRECTIONS FOR INTRUSIVE GRANITIC ROCKS



73° SINGLE ISOLATED SIGNIFICANT LOCALITY

AVERAGED LOCALITY 62° INCLINATION

DECLINATION SHOWN BY DIRECTION

LOCATION OF AVERAGE

C.I. = 10°

(MAP VI-8) - (MAP VI-14)

REFERENCE DIRECTIONS FOR LATITUDE AND LONGITUDE OF BALD MTN. BATH., OREGON

70° INC. N 29.5° CRETACEOUS 100 MY

65.5° INC. N EOCENE 53 MY

65.5° INC N 2° MIOCENE 16-10 MY

N 69.5° INC. 20° PRESENT

PALEOMAGNETIC DIRECTIONS DERIVED FROM VAN ALSTINE AND DE BOER (1978)

### INTRUSIVES

(AGE SHOWN IF AVAILABLE AND BELIEVED RELIABLE)

- AGE DATED (MOSTLY LIT.) PALEOMAG. BY: W.L.B.
- NO AGE DATE. PALEOMAG. BY: W.L B
- AGE DATED (FROM LITERATURE). PALEOMAG. BY BECK, ETAL (1972)
- NO AGE DATE. PALEOMAG. BY BECK, ETAL (1972)

### EXTRUSIVES

- PALEOMAG BY: W.L.B.
- PALEOMAG BY: HELSLEY
- × PALEOMAG. BY WATKINS & BAKSI (1974)
- PALEOMAG. BY LARSON (1965) OR LARSON, ETAL (1971)

GEOLOGY FROM A.A.P.G. TECTONIC MAP, COHEE, ET AL (1962)

- INTRUSIVE ROCKS
- TERTIARY RHYOLITE & BASALT
- QUATERNARY VOLCANICS
- LATE TERTIARY & QUATERNARY VALLEY FILL

SCALE 0 10 20 30 40 50 MILES

W.L. BASHAM

MARCH 1978

rotation is I3, 67 m.y., in the southwest portion of the Idaho Batholith. Thus the time of strong rotation is suggested to be from Early Paleocene or Eocene to Middle Miocene. Of course, the Miocene rocks also show post-Miocene rotation, possibly up to $39^{\circ}$ (Figure VI-14).

In hindsight, paleomagnetic samples from the Eocene Challis volcanics on the east side of the Idaho Batholith would be very useful to determine the amount and timing of the proposed rotation.

# CHAPTER VII
## INTERPRETATION OF PALEOMAGNETIC DATA

Ideas on the origin of the Columbia Arc were discussed in Chapter I. Two reconstructions of pre-Middle Tertiary were shown, those by Hamilton (1969) and Heptonstall (1977). These reconstructions will be compared to the paleomagnetic results as a basis of geologic interpretation.

### Interpretation by Hamilton (1969)

Figure VII-1 shows a portion of Hamilton's interpretation of present distribution of the Cretaceous batholiths and Ordovician to Jurassic eugeosynclinal rocks. He believed that the north end of the Sierra Nevada and the Klamath Mountains may be truncated against new volcanic crust.

The average paleomagnetic directions from Figure VI-4 are plotted on map VII-1. In addition, the paleomagnetic direction from Symons (1973) on Vancouver Island, the coastal Oregon Eocene directions from Simpson and Cox (1977), and a northern Sierra Nevada direction from Gromme, et al (1967) are shown on the map. An estimate of rotation can be made by comparison of the paleomagnetic directions. The Eocene and Oligocene averaged directions are identified; the remaining directions are Jurassic and Cretaceous.

Figure VII-2 shows Hamilton's interpretation of the western United States at the end of Cretaceous time. The indicated movements as shown by arrows in Figure VII-1 were reversed by Hamilton to produce this map.

The paleomagnetic directions in Figure VII-2 were rotated in accordance to Hamilton's reconstruction. If his ideas of reconstruction are correct, the resultant scatter of paleodirections should be considerably reduced

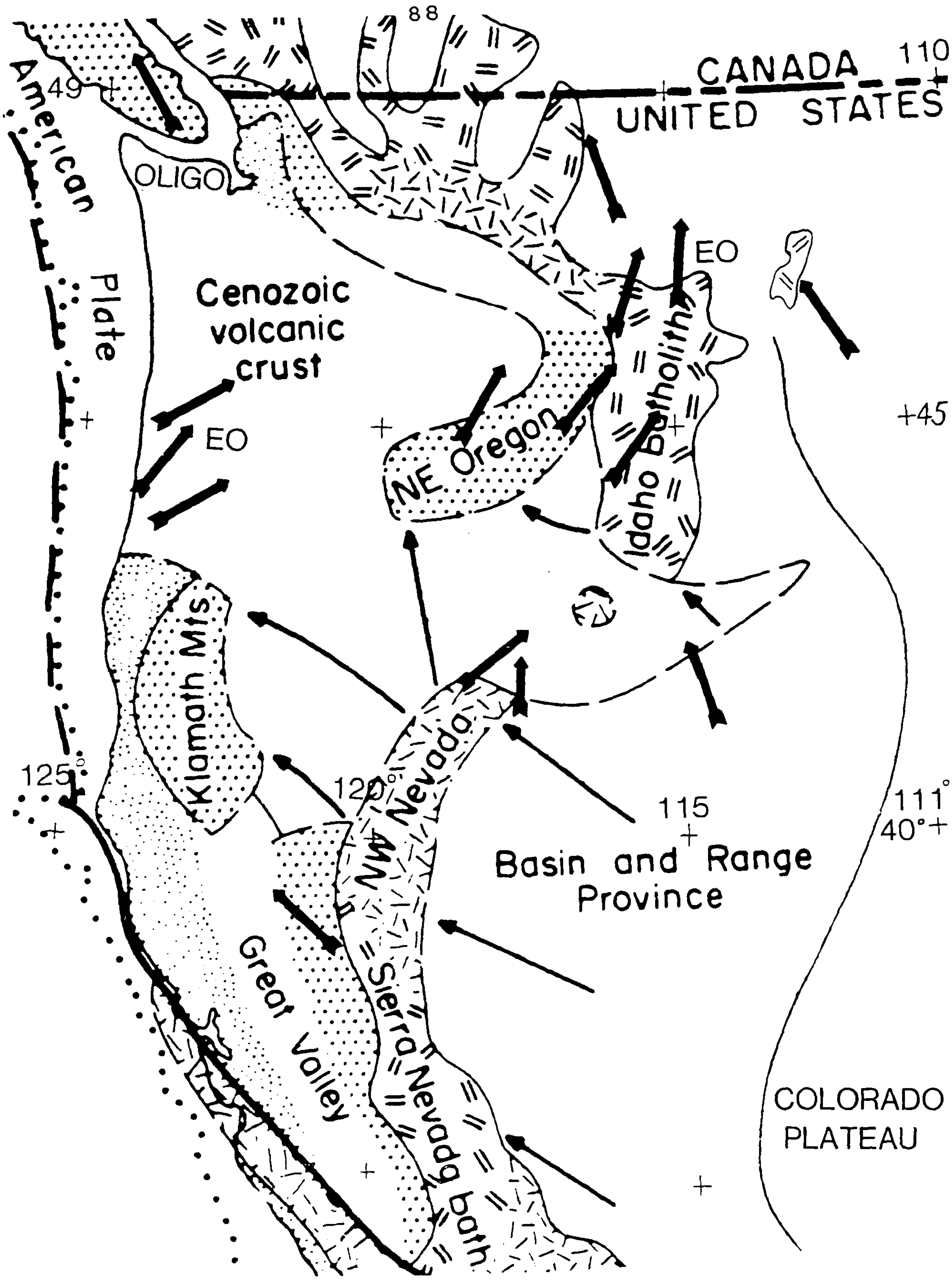



FIG. VII-1 AVERAGE PALEOMAGNETIC DIRECTIONS AND PRESENT STRUCTURE MODIFIED FROM HAMILTON (1969).

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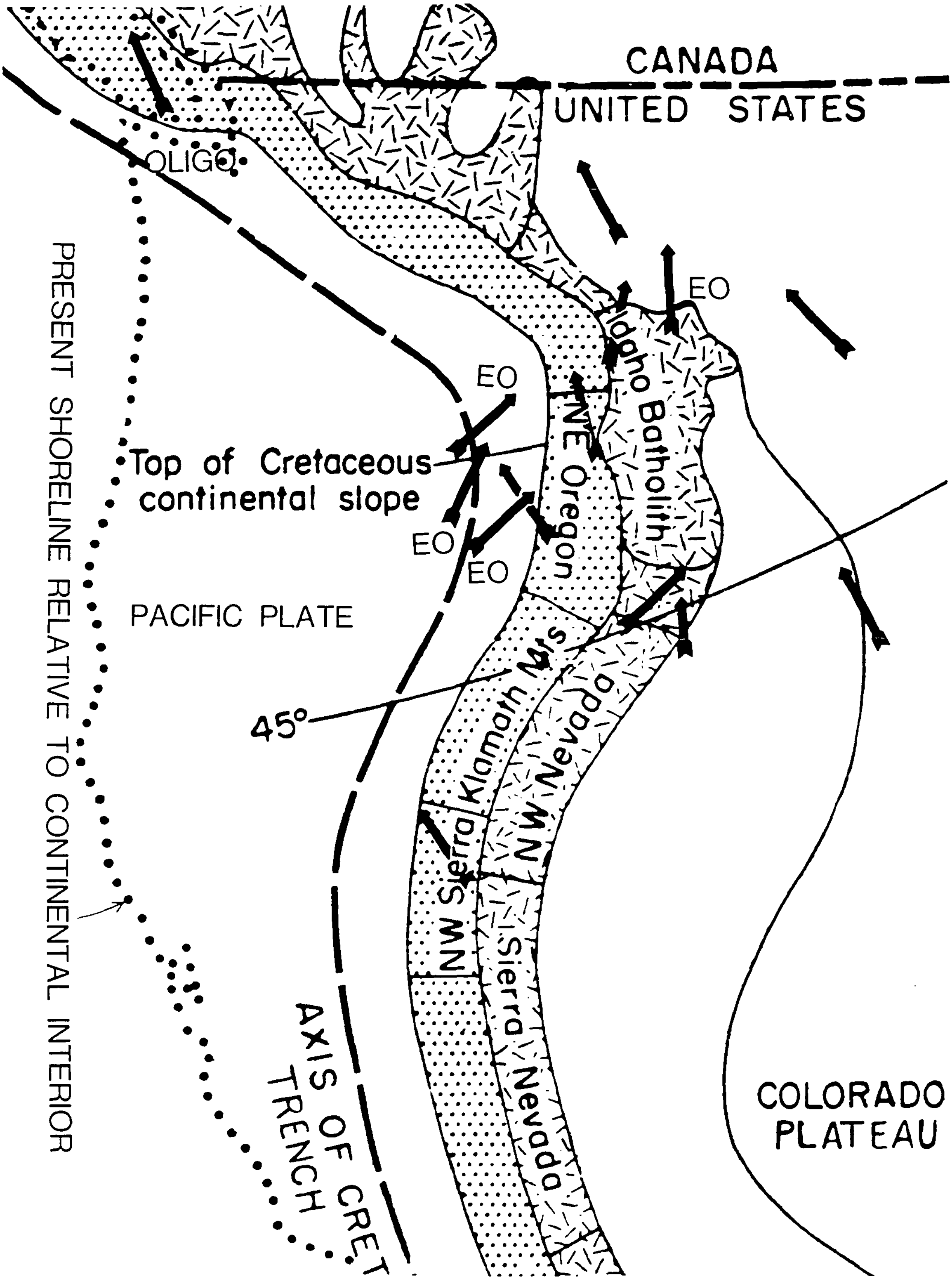


FIG. VII-2 RESTORED PALEOMAGNETIC DIRECTIONS AND STRUCTURE

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from the pre-reconstruction map. The resultant Jurassic and Cretaceous cirections should be approximately perpendicular to the 45$^{o}$ paleolatitude line and the Eocene paleomagnetic directions should be approximately north.

Northeastern Nevada, the Boulder Batholith, the northern Idaho Batholith, and the Sierra Nevada Mountains were not rotated in the reconstruction. Those paleomagnetic directions are approximately perpendicular to the 45$^{o}$ paleolatitude, and the Eocene direction shows no rotation.

The northeast Oregon paleomagnetic directions show remarkably good agreement with the reconstruction. This suggests that the Blue Mountains have indeed been rotated in the manner suggested by Hamilton.

There are two areas of serious disagreement with the reconstruction. (1) Northwest Nevada block. The northwest Nevada block was not rotated in Hamilton's reconstruction. If the northwest Nevada block were rotated in the past the same amount as the northeast Oregon block, the paleodirection would be about normal to the paleolatitude. This suggests that northwest Nevada and northeast Oregon behaved similarly in the post Cretaceous rotation. (2) Area north of the Klamath Mountains. The Eocene directions from Simpson and Cox (1977) were moved easterly with the Klamath block. These directions suggest up to 68$^{o}$ of clockwise rotation. Hamilton's reconstruction does not accommodate this rotation.

The Gromme, et al (1967) direction in the northern Sierra Nevada Batholith may suggest about 15$^{o}$ of counterclockwise rotation. This could be related to the Basin and Range expansion as will be discussed later.

Hamilton did not attempt reconstruction of the Cenozoic motion in British Columbia or Washington. Symons (1973) shows that the southern Vancouver Island block probably has rotated counterclockwise about $20^{\circ}$ since Oligocene. Judging from his paleomagnetic direction, the rotation probably is closer to $30^{\circ}$.

## Interpretation by Heptonstall (1977)

Figure I-10 shows Heptonstall's concept of linked plates which remain coupled to adjacent large plates. Figure VII-3 shows a portion of his map displaying present structure. The same averaged paleomagnetic vectors that were discussed in the previous section are plotted on Figure VII-3. They are lettered for identification. It is observed that vectors "O" and "N" differ markedly from directions to the northwest and are located south of the chosen boundary.

Figure VII-4 is the restored structure with the paleomagnetic directions rotated in accordance with the reconstruction. The "Washington Plate" was rotated $30^{\circ}$ CW (clockwise), the "Oregon Plate" $80^{\circ}$ CCW, and the "American Plate" $14^{\circ}$ CCW to achieve an approximate linearity of Mesozoic intrusives.

The Vancouver paleomagnetic vector A is perfectly aligned to the Eocene reference direction. Vectors B, C, and D from coastal Oregon point NNW'ly which suggests they have been rotated at least $25^{\circ}$ too much. Paleodirection E is now $25^{\circ}$ more westerly than the Cretaceous reference direction which may suggest that the "American Block" should have been rotated the opposite direction (CW instead of CCW).

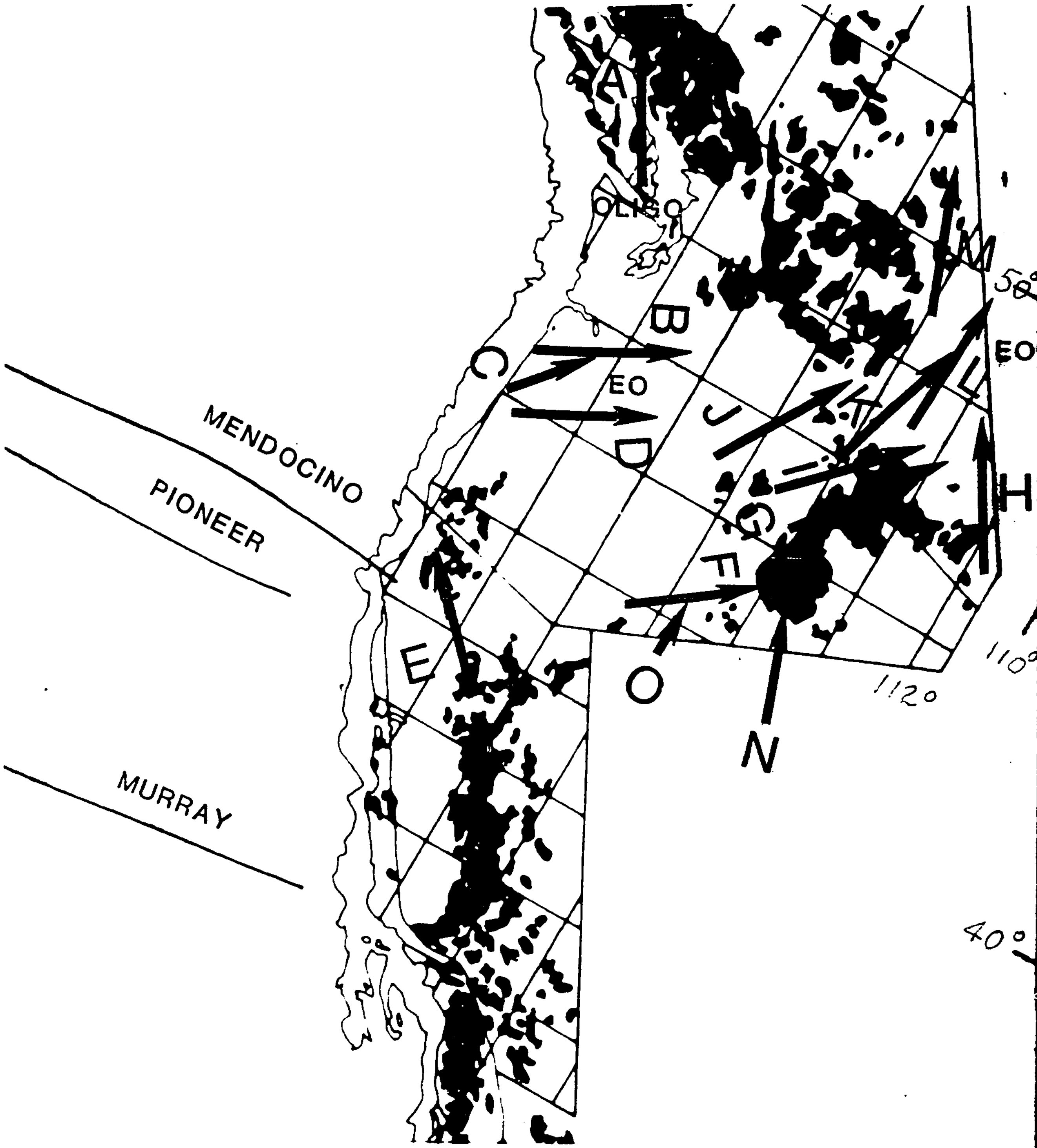
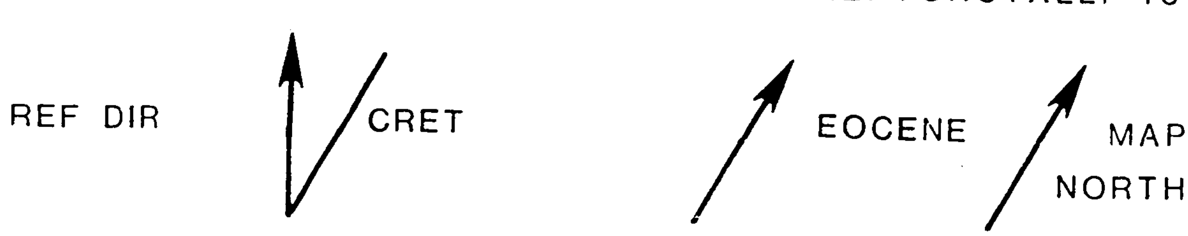



FIGURE VII-3 AVERAGE PALEOMAGNETIC DIRECTIONS AND PRESENT STRUCTURE (MODIFIED FROM HEPTONSTALL, 1977)



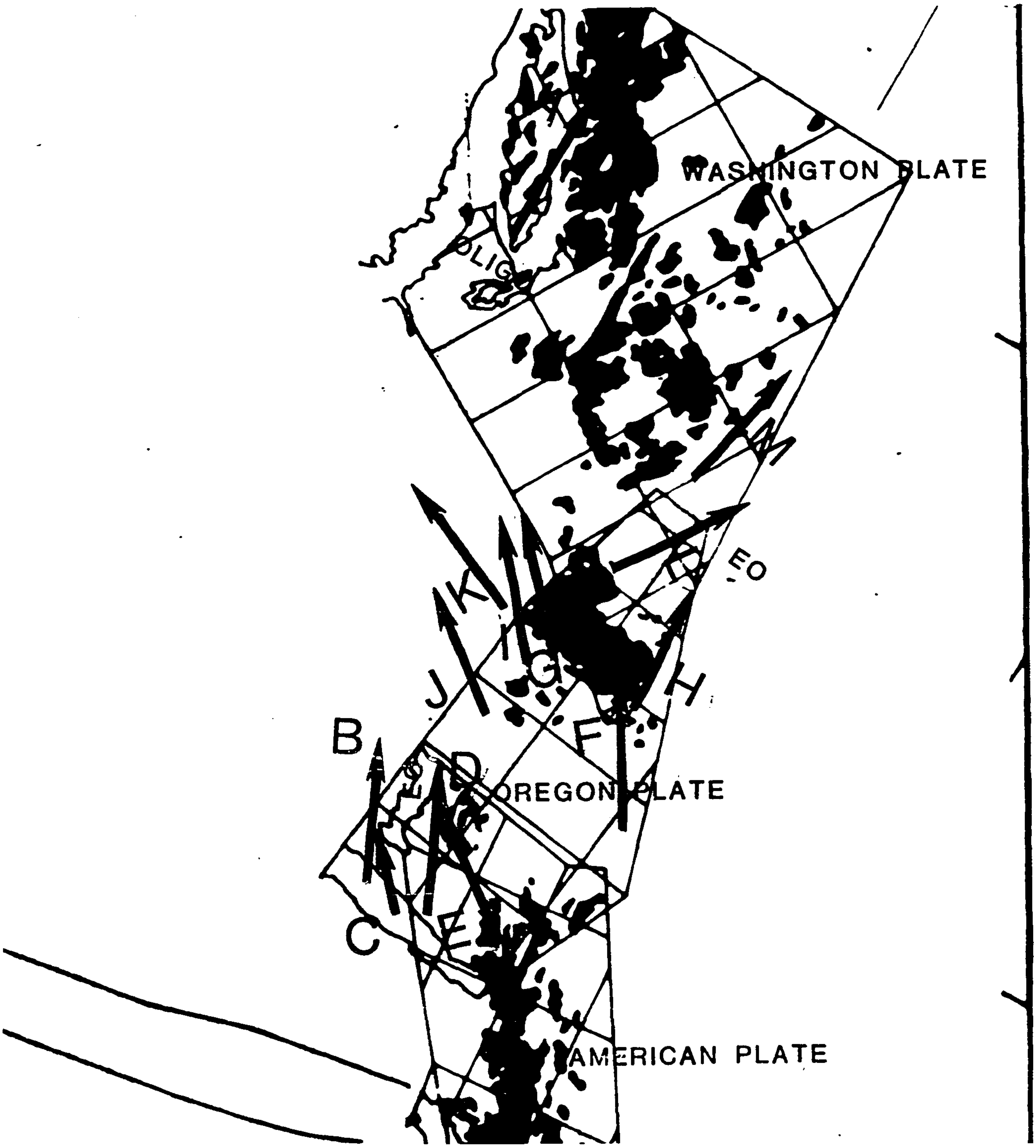



FIGURE VII-4 RESTORED PALEOMAGNETIC DIRECTIONS AND STRUCTURE (MODIFIED FROM HEPTONSTALL, 1977)

The north central Nevada, Blue Mountain, and Idaho Batholith vectors (F, G, I, and J) show reasonably good agreement with the Cretaceous reference direction. K is rotated about 35$^{o}$ too far and may be in the complex hinge area.

Vector H (near the Boulder Batholith) does not now agree with the Cretaceous direction; it was noted on maps V1-8 to have zero rotation. This suggests the boundary of the "Washington Plate" should be modified. Likewise, vectors H and M have been rotated clockwise out of alignment with their reference direction; the Washington Plate boundaries could be adjusted.

Heptonstall's idea is a variation of Carey's orocline hypothesis. In general it appears to have possibilities of reconciling the paleomagnetic data and Mesozoic intrusive distribution if the plate boundaries and rotations were modified.

## Comparison of Columbia River Basalt Dike Orientations to Volcanic Rock Paleomagnetic Directions (Figure VII-5)

Taubeneck (1969) presented dike orientation data for dikes cutting the Columbia River Basalt; this data is displayed in Figure VII-5 and shows at each locality the average dike direction and the range of directions. A minimum of 2 and a maximum of 31 measurements were made for each dike locality presented. The average dike direction is about N10$^{o}$W. Taubeneck believes that the dike trends are sufficiently long and straight to rule out post-Miocene oroclinal bending.

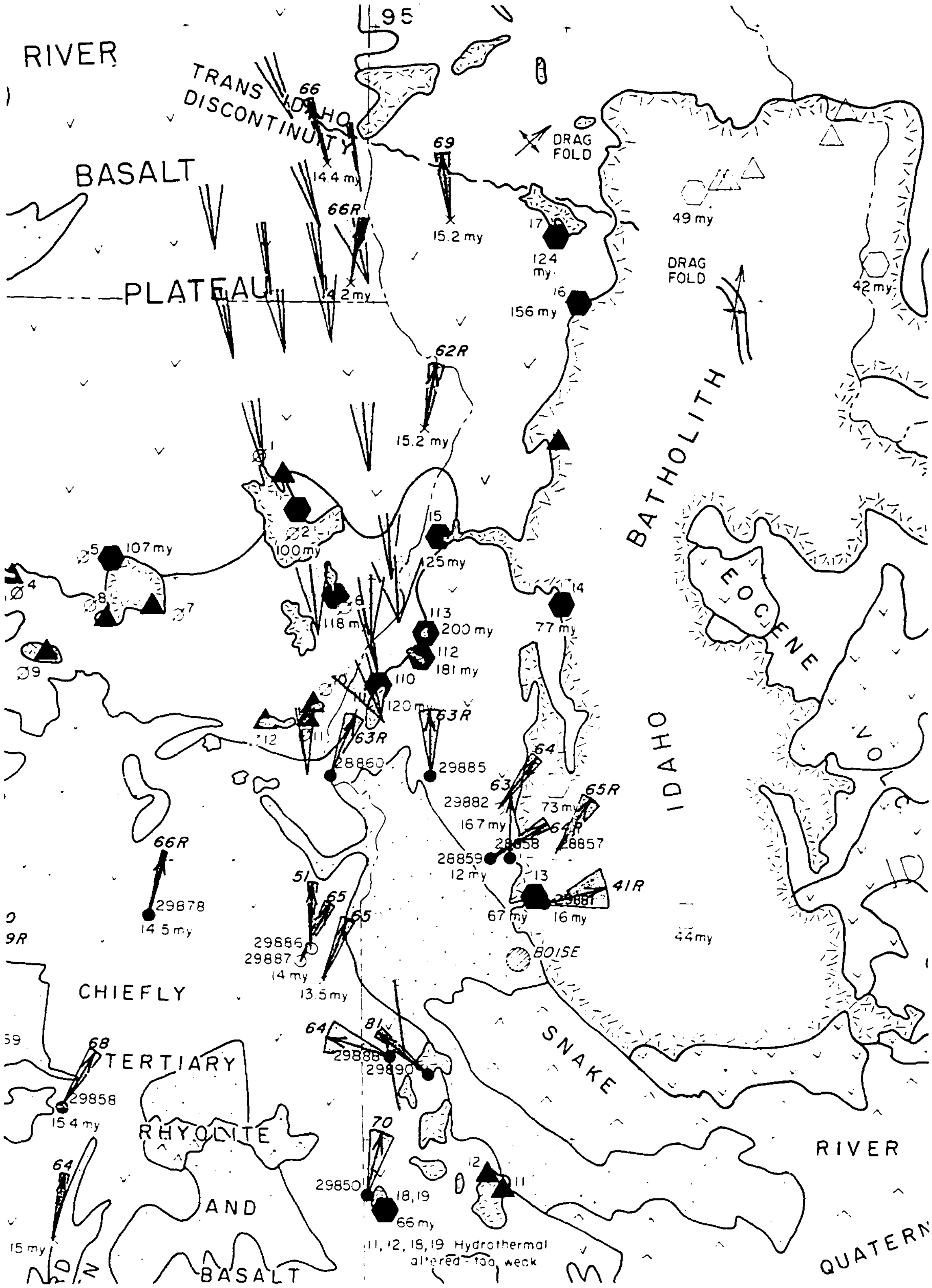
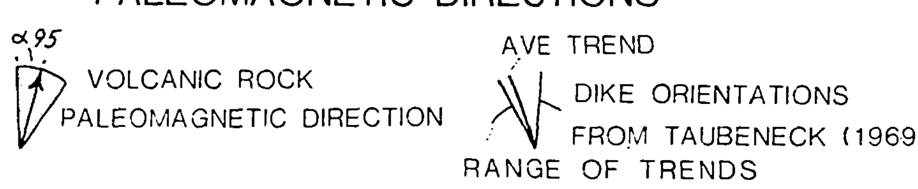



FIGURE VII-5 COMPARISON OF COLUMBIA RIVER BASALT DIKE ORIENTATIONS TO VOLCANIC ROCK PALEOMAONETIC DIRECTIONS



Paleomagnetic data for volcanic rocks are also presented in Figure VII-5. The average paleomagnetic direction is about N20°E. The paleomagnetic vectors appear more dispersive than the dikes. Westerly deviations from this trend occur in two localities in the Owyhee Mountains south of the Snake River Plains. This is an area of intense hydrothermal alteration of the granites; this alteration may be present also in the overlying volcanics. Locality 29888 has an unusually large $\alpha 95$ (17°) for volcanics. Locality 29890 has an unusually steep inclination (81.4°). The southwest Idaho Batholith shows at least one aberrant strong northeasterly trend (Locality 29881) with high (18°) $\alpha 95$. The dip is fairly steep (33°) and may not have been correctly accounted for. The northeasterly trend may swing to northwest just south of the Trans-Idaho discontinuity. The northerly change is from about N11°E to N12°W or about 23°.

It is noted that the dike directions may swing northwesterly in this area. The change in direction is from about N8°W to N25°, or a change of about 17°. Thus with the data at hand, I do not believe that a change in direction can be ruled out in this area. The paleomagnetic data suggest that a varying amount of rotation may be present (see Figure VI-14).

Two recent papers bear on this possible Miocene or post-Miocene rotation. Choiniere (1977) states that the average mean paleomagnetic declination of 48 flows of the Columbia River Basalt Group of southeast Washington show an average paleomagnetic direction of slightly west of north. This could very well be consistent with the paleomagnetic data from Watkins and Baksi (1974) as shown in Figure VI-14 in west central Idaho, approximately 46.5°N, 117°W. This area is north of the proposed Miocene rotation. On the other hand, the paper by Kienle, et al (1978) suggests that the western Oregon and western Washington Miocene NRM is virtually identical to the present field direction. The present author believes the evidence favors minor rotation of about $20^{o}$ in eastern Oregon which decreases to 0 rotation in southeast Washington.

## Great Basin Expansion As Possible Cause for Post-Miocene Rotation

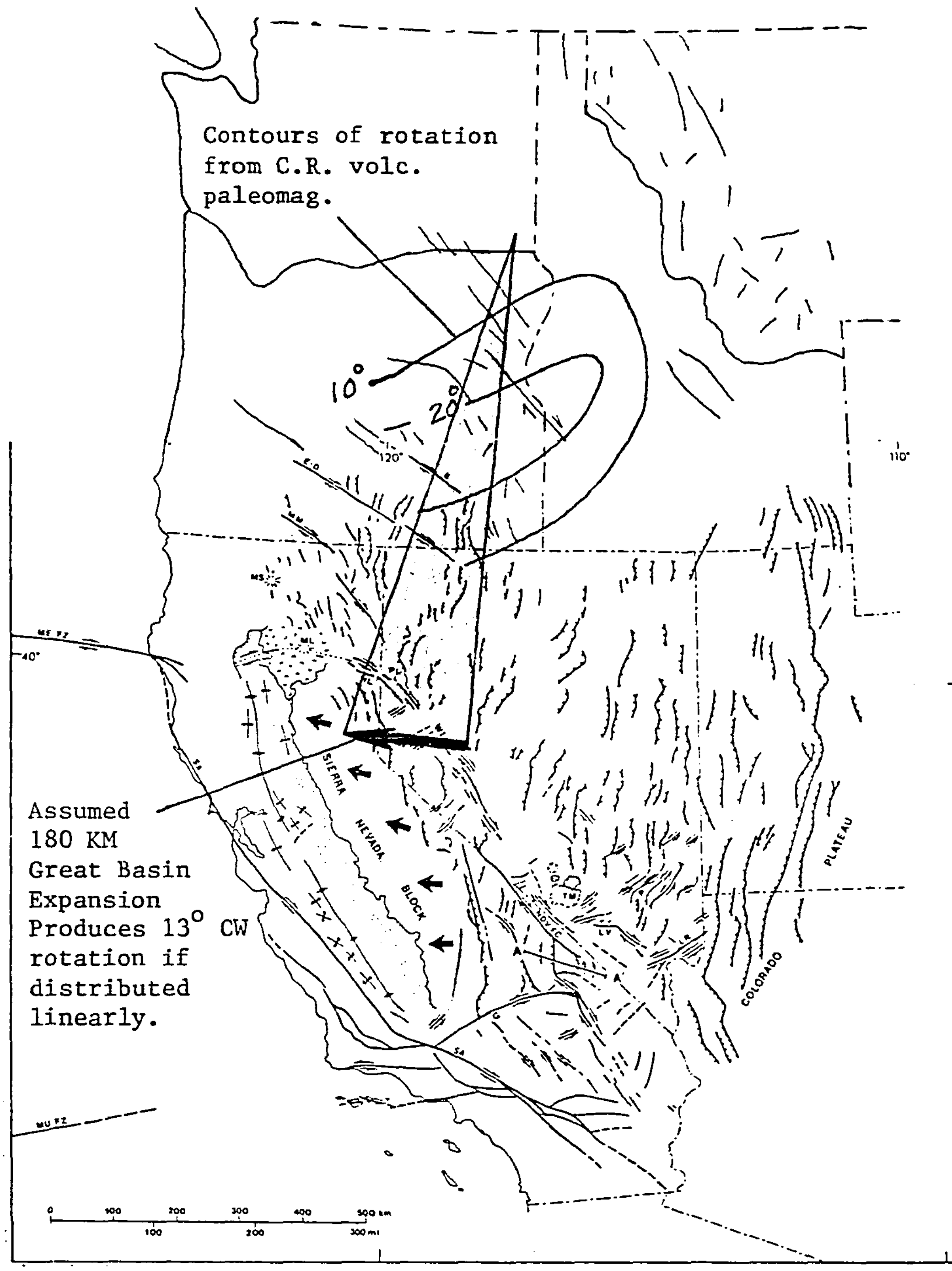
Proffett (1977) suggested possible Great Basin Expansion of 160 to 180 km. If this much expansion occurred, northerly termination of expansion might produce as much as $13^{o}$ if the decrease were linear as shown in Figure VII-6. If the decrease were more localized, much greater angles of rotation would be possible.

The paleomagnetic data suggests greater than $20^{o}$ of rotation in southeast Oregon as shown in Figures VI-14 and VII-6. The interpretation is complicated since right lateral faults may help terminate the Great Basin expansion northerly (Lawrence, 1976).

Similarly, southerly termination of expansion has been proposed along the left lateral Garlock Fault system. Possible paleomagnetic evidence of CCW rotation of the Sierra Nevada Mountains was mentioned previously. This rotation would be compatible with the idea of maximum east-west expansion through Central Nevada.

## Possible Explanation of Oroclinal Folding

Figure VII-7 shows Carey's (1976) recent explanation of the formation of the Columbia Arc. He states that A shows the prevailing shear, B shows simple offset, and C shows shear failure due to friction. A less brittle




Generalized map of late Cenozoic structural features of Great Basin and bordering regions, showing spatial relationship between Sierra Nevada block, distribution of normal (hachered) and strike-slip faults of Basin and Range province, and location of cross section in Figure 3. Synthesized and modified from Jennings (1973), King (1969), and Stewart and Carlson (1974). Stippled pattern west of Sierra Nevada represents Cenozoic sedimentary units; V-pattern north of Sierra Nevada represents Cenozoic volcanic rocks. Lettered features are as follows: (B) Brothers fault zone, (ED) Eugene-Denio fault zone, (G) Garlock fault zone, (HL) Honey Lake and Litchfield faults, (L) Likely fault, (LR) Lime Ridge and associated faults, (LV) Las Vegas shear zone, (ME FZ) Mendocino fracture zone, (ML) Mount Lassen, (MM) Mount McLaughlin fault zone, (MS) Mount Shasta, (MU FZ) Murray fracture zone, (NDV-FC) northern Death Valley-Furnace Creek fault zone, (P) Pahranagat shear system, (PL) Pyramid Lake, (SA) San Andreas fault, (TM) Timber Mountain and related calderas, and (WL) Walker Lane, northern part.

Figure VII-6. Possible relationship of Basin and Range expansion to post-Miocene paleomagnetic rotation. Modified from Wright (1976).

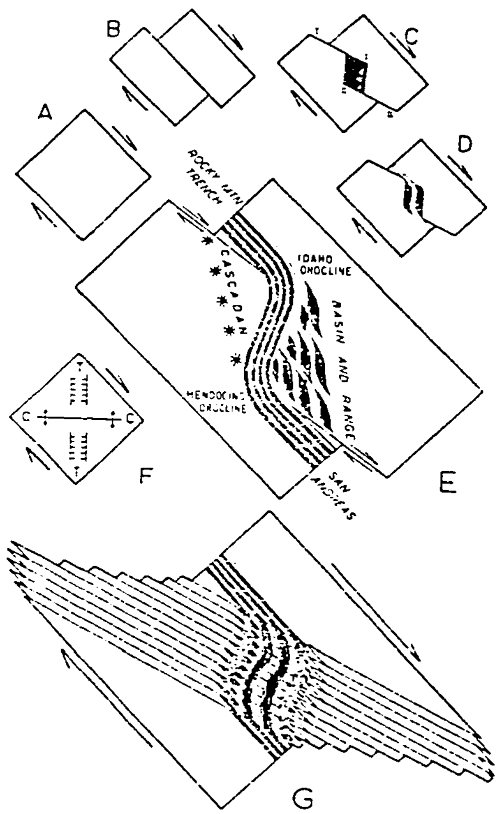



Figure VII-7. Mechanics of the Mendocino and Idaho Oroclines. From Carey (1976) Courtesy of North Holland Company.

belt such as an active orogenic belt associated with intrusives and extrusives might stretch rather than fracture as in D. This situation is thought to have existed at least in the area of the Idaho Batholith in Eocene (see Figure II-6). Figure E shows Carey's concept of the Columbia Arc. In G, transcurrent shears take up the movement. Carey believes both E and G apply to western North America. This appears reasonable to the author.

## Regional Comparison of Geologic Trends of the Columbia Arc to the Paleomagnetic Data

The Columbia Arc is shown in Figure VII-8 by the general shape of the Cretaceous and older rocks.

Averaged paleomagnetic directions from this thesis and also from the literature are shown. These are the same directions that were discussed in connection with the interpretations by Hamilton and Heptonstall. The amount of rotation can be estimated by comparing the paleomagnetic direction to the proper reference direction.

The rotation suggested by the averaged paleomagnetic directions in general parallels that suggested by the geological trends in the Klamath Mountains, northwestern Nevada, northeast Oregon, western Idaho, and Washington. The paleomagnetic data thus suggests that the Columbia Arc is compatible with the Orocline concept.

Simpson and Cox (1977) show that the bending in western Oregon is post-Eocene, probably Oligocene in age. In the eastern portion of the Columbia Arc, the timing of the strong bending at present only can be bracketed as post-Cretaceous - pre-Middle Miocene in age.

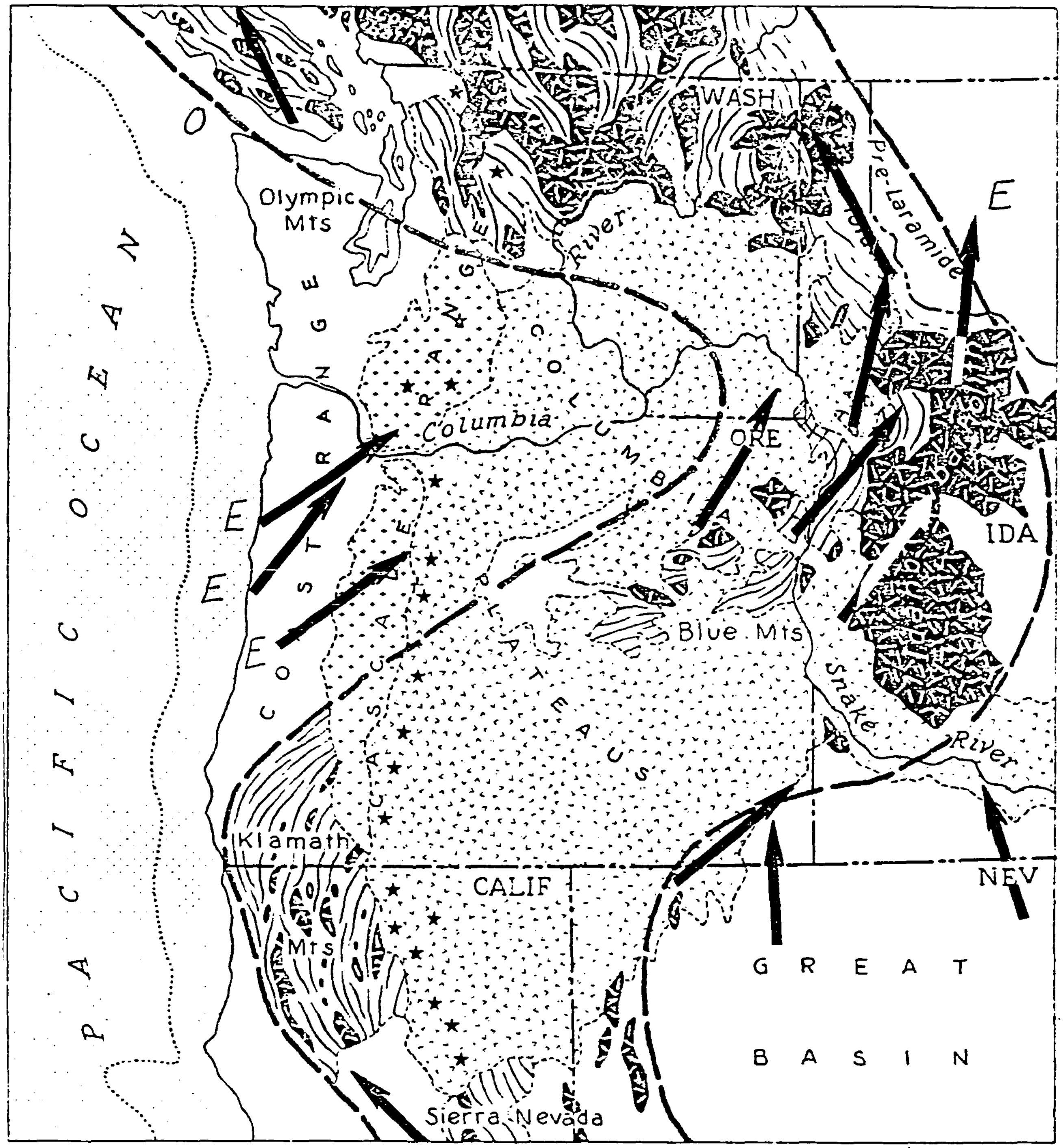



Figure VII-8. The Columbia Arc Compared to Paleomagnetic Directions. Modified from King (1977).

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# CHAPTER VIII
## CONCLUSIONS

1. A literature survey of the Cordilleran geologic history was useful in understanding that plate tectonics were important in the Cordilleran history from Precambrian to Recent time. Pre-Tertiary paleogeographic maps are difficult to construct because of the probability of major sea floor spreading movement, complex continental block to sea floor plate interactions, and intracontinental deformation.
2. Literature study showed that the origin of the Columbia Arc is controversial. One group of geologists believes that the arcuate pattern is a primary feature inherited from the Precambrian or that at least it is pre-Tertiary. Another group proposes post-Cretaceous movements that produced the arcuate pattern.
3. Paleomagnetic study of the pre-Tertiary igneous intrusives in eastern Oregon, western Idaho, and northern Nevada to determine possible confirmation of proposed large-scale rotation was complicated by reliability of the paleomagnetic results. Nine of thirty-four sites had to be rejected after A.C. and thermal demagnetization tests because of scatter and instability.
4. The remaining intrusive localities show considerable scatter but suggest a general northeasterly trend. Combination of sites produced averaged directions that are believed to be useful. Comparison to a Cretaceous reference direction from the stable part of the American continent allowed computation of rotation. A contour map shows a southwesterly trend of increasing rotation in southeastern Oregon.

5. Paleomagnetic data from extrusive volcanic cores largely Miocene in southeastern Idaho show less scatter than the older intrusive rocks. A. C. demagnetization appeared sufficient in most cases to reach a stable magnetic direction. Averaging of extrusive sites, including those from the literature, reduced scatter. A Miocene reference direction allowed contouring of rotation which suggests an east-west zone of rotation of more than 20° which terminates east of the Idaho Batholith.

6. A difference map of $R_I$-$R_V$ where $R_I$ is the paleomagnetic vector rotation for intrusive sites and $R_V$ is the paleomagnetic rotation from extrusive sites suggests that up to 70° rotation occurred in post-Cretaceous to pre-Miocene time.

7. Hamilton's interpretation that Cenozoic movements separated the pre-Tertiary structural elements of the western Cordillera into the present complex distribution was tested by paleomagnetic directions from this thesis and the literature. Clockwise rotation of the Blue Mountains in Oregon appears to be confirmed but several other proposed movements are contradicted by the paleomagnetic data.

8. Heptonstall's linked plate oroclinal construction reconciles more of the paleomagnetic data to the geology than does Hamilton's interpretation. However, different selections of plate boundaries and different rotations are suggested by some of the paleomagnetic data.

9. Comparison of Columbia River Basalt dike orientation to the volcanic rock paleomagnetic directions shows some suggestion of correlation. Additional data in adjoining areas would be helpful.

10. It is suggested that the post-Miocene clockwise rotation of $20^{\circ}$ or more shown by paleomagnetics in southeast Oregon is related to northerly cessation of the Great Basin expansion.

11. Intense heating occurred in the Idaho Batholith area during Eocene. Contempory development of Eocene foreland structures in the Rocky Mountain area, the east-west pattern of volcanics in Nevada, the intense heating in Idaho, possible presence of a triple rise junction off the Pacific Northwest, and the possible oroclinal bending of the Columbia Arc may all be related responses to plate tectonic interaction between the North American plate and several oceanic plates to the west.

12. The regional paleomagnetic data suggests that the Columbia Arc is compatible with the orocline concept. The time of major bending in northeast Oregon, western Idaho, and northwest Nevada is post-Cretaceous - pre-Middle Miocene.

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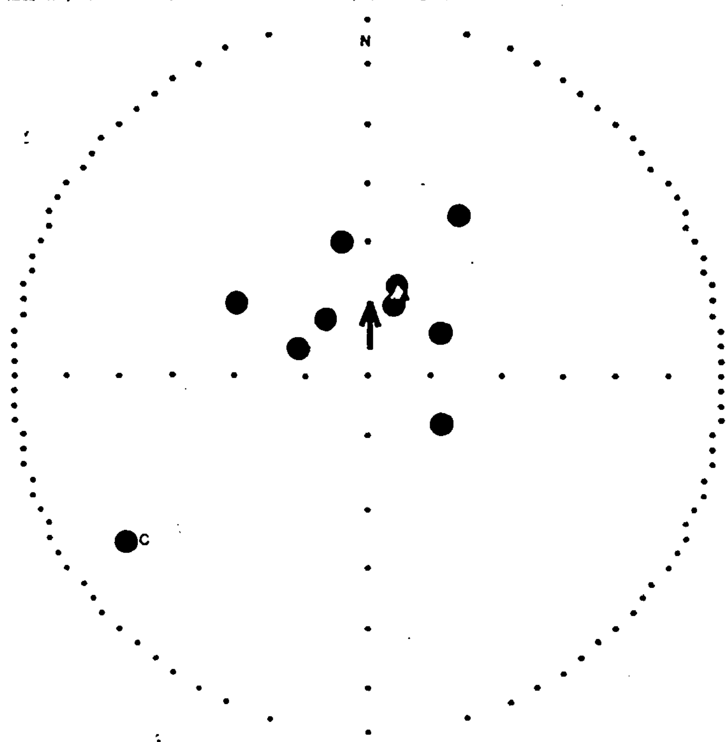
# APPENDIX 1

Intrusive Igneous Sample Localities From Nevada. See Chapter VI for general discussion of intrusive locality information.

SAMPLE LOCALITY N1: Santa Rosa Mt., Humboldt Co., Nevada. Paradise Valley Quadrangle, T42N R38E, Singus Creek, 41°29.5'N., 117°38.75'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 97.8 m.y. ±3.5 biotite, 99.5 ±5.0 hornblende (Sample 1, Smith et al. [1971]).

ROCK DESCRIPTION: Light grey leucogranodiorite with 1 to 5 mm. hornblende and biotite crystals. Fresh exposure in creek beds. Dark minerals about 5% of rock.

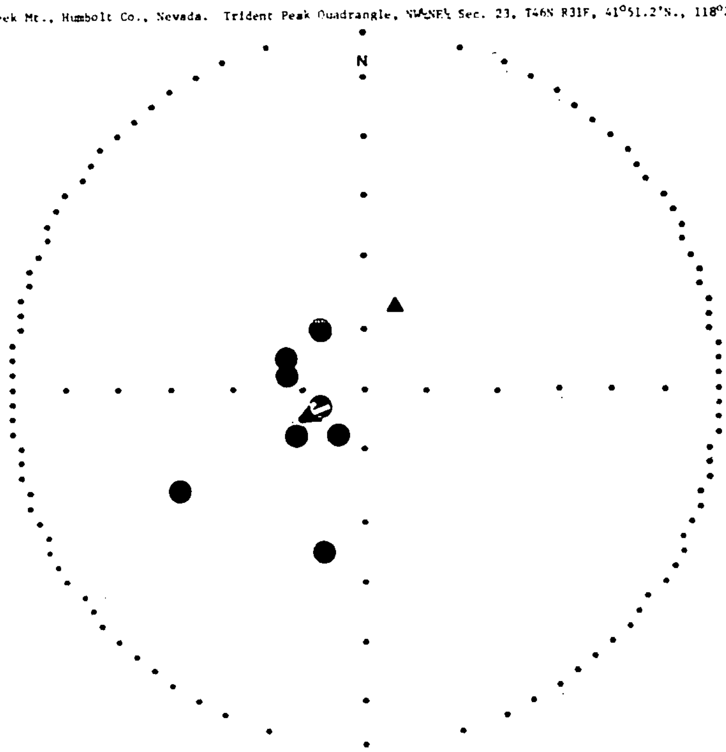
OVERLYING STRUCTURE: Steens Mt. Basalt 2 miles east, strike N [illegible]E dipping 8° east. Santa Rosa stock forcibly intruded into steeply dipping Upper Triassic metamorphic rocks (Crompton, 1960).

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (k) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 78.3 | 15.4 | 10 | 8.1 | 4.8 | 24.8 | 62.8N | 104.8W | N |
| 50 Oe. A.C. | 73.7 | 6.3 | 9 | 8.6 | 22.7 | 11.1 | 71.3N | 107.7W | N |
| 100 Oe. A.C. | 63 | 4 | 9 | 8.6 | 22.6 | 11.1 | 86.2N | 71.8W | N |
| 400°C Therm. | 73.3 | 1.8 | 9 | 8.4 | 13.8 | 14.4 | 72.5N | 114.7W | N (Display) |
| 500°C Therm. | 63.4 | 322.8 | 9 | 7.4 | 5.01 | 25.6 | 62.9N | 172.4E | N |
| 580°C Therm. | Scattered | Directions | - | Unreliable | | | | | |

RESULTS: 400° thermal demag. believed the most reliable. Santa Rosa locality would suggest C.W. rotation of about 32° since 98 m.y.b.p.

SAMPLE LOCALITY N2: Bilk Creek Mt., Humbolt Co., Nevada. Trident Peak Quadrangle, NW¼NE¼ Sec. 23, T46N R31E, 41°51.2'N., 118°28.3'W.




Schmidt stereonet display, direction of magnetization after 50 Oe. A.C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 94.2 ±3.7 m.y. biotite (1200' W. of Sample B, Smith et al (1971)).

ROCK DESCRIPTION: Leucogranodiorite, coarse grained biotite and hornblende apparent under hand lens. Dark minerals estimated 5% of rocks. Considerable alteration of feldspar to clay.

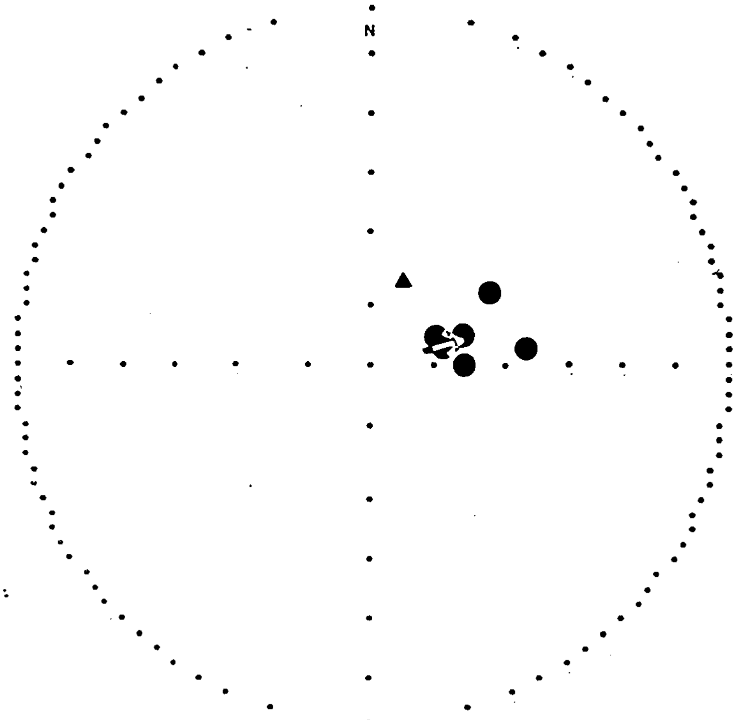
OVERLYING STRUCTURE: Volcanics probably correlative to Steens Mt. Basalt 1200' to S.W., N.47°W, dipping 18°S.W.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 73.8 | 249.4 | 8 | 6.9 | 6.1 | 24.4 | 23.2N | 146.8W | N |
| 50 Oe. A.C. | 71.3 | 244.4 | 8 | 7.6 | 17.2 | 13.7 | 21.3N | 151.6W | N (Display) |
| 100 Oe. A.C. | 76.3 | 271.7 | 9 | 7.9 | 7.2 | 20.6 | 37.6N | 152W | N |
| 400°C Therm. | Samples crumbled on heating. | | | | | | | | |

RESULTS: 50 Oe. A.C. the most reliable, but no thermal results could be obtained. W.S.W. direction of magnetization not confirmed by any other localities in area.

SAMPLE LOCALITY N3: Bilk Creek Mt., Humboldt Co., Nevada. Denio Quadrangle, SE¼NE¼, Sec. 9, T46N R31E, 41°52.8'N, 118°30.2'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

ROCK DESCRIPTION: Leucogranodiorite, light grey, coarse grained, quartz, plagioclase biotite, and hornblende visible under hand lens. Dark minerals about 5% of rock. Outcrop in stream bed less weathered than nearby outcrops; also less weathered than N2.

AGE: 90.6 ±3.2 m.y. biotite (Sample 9, Smith et al. [1971]).

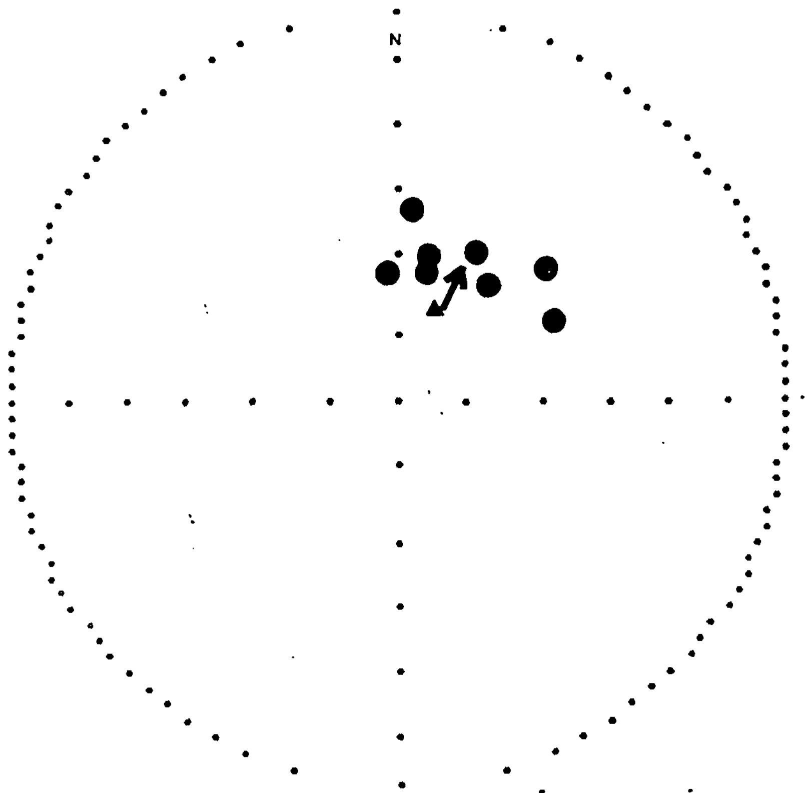
OVERLYING STRUCTURE: Volcanics 2 miles S.W., N.47°W, dipping 18°S.W. Volcanics are closer (1700' to S.W.) but reliable dip strike could not be measured accurately due to poor outcrops.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 63.8 | [illegible] | 6 | 5.7 | 17.0 | 16.7 | 29.6N | 68.2W | N |
| 50 Oe. A.C. | 67.2 | 74.4 | 6 | 5.9 | 69.2 | 8.1 | 39.6N | 64.7W | N |
| 100 Oe. A.C. | 68.2 | 77.1 | 6 | 4.9 | 4.6 | 35.3 | 38.7N | 67.3W | N |
| 400°C. Therm. | 45.3 | 73.4 | 5 | 4.9 | 34.6 | 13.2 | 29.4N | 39.5W | N (Display) |
| 500°C. Therm. | 40.8 | 84.5 | 5 | 4.6 | 9.0 | 26.9 | 13.3N | 43.0W | N |
| 580°C. Therm. | Scattered directions - unreliable. | | | | | | | | |

RESULTS: 400°C. therm. demag. considered the most reliable. Approximately 100° clockwise rotation suggested since 91 m.y.b.p.

SAMPLE LOCALITY N4: Black Mt., north end of Pine Forest Range, Humboldt County, Nevada. Denio Quadrangle, C W½SW¼, Section 21, T47N R30E, 41°56.1'N, 118°38.3'W.




Schmidt stereonet display, direction of magnetization after 400° C. therm. demag. ●, ○, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points, C denotes culled or rejected points deleted from final statistics.

AGE: 101± 2.0 m.y. (Sample #YU-PF-2, Harrold /1972/).

ROCK DESCRIPTION:[5] Quartz diorite. Equigranular rounded crystals of microcline and plagioclase. Some outcrops are black; this intrusive has increased biotite and hornblende content (about 30% dark minerals).

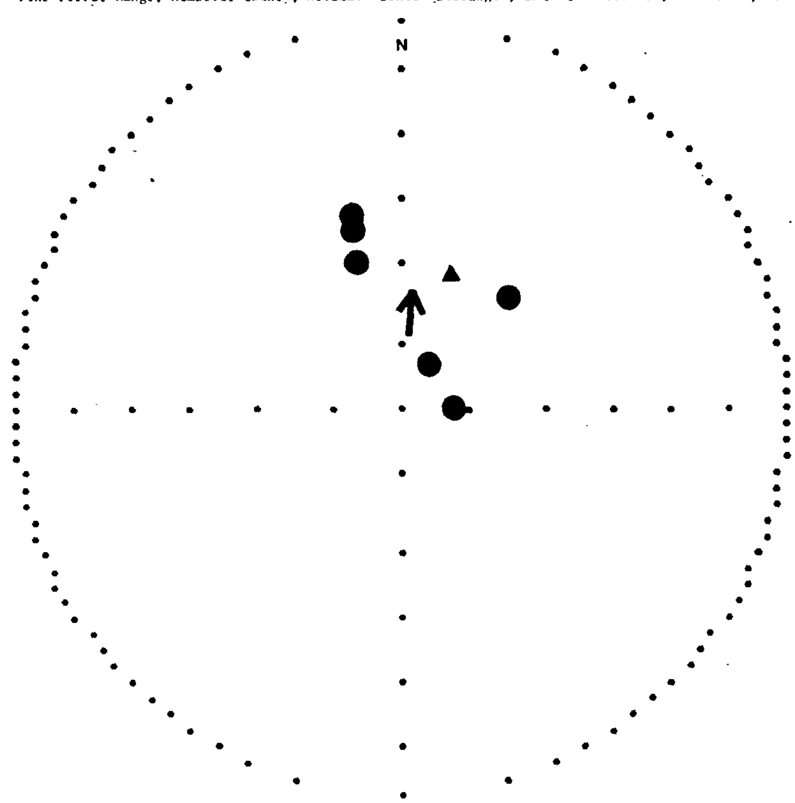
OVERLYING STRUCTURE: Volcanics three miles to southwest, N10°E., 23°W. This structural correction was applied to N4.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 66.0 | 13.3 | 8 | 7.6 | 29.0 | 10.5 | 78.6N | 67.7W | N |
| 50 Oe. A.C. | 48.9 | 32.3 | 9 | 7.7 | 6.0 | 22.9 | 61.4N | 14.1W | N |
| 100 Oe. A.C. | 56.0 | 24.4 | 9 | 8.5 | 16.3 | 13.2 | 70.4N | 20.9W | N |
| 400°C. Therm. | 56.5 | 26.4 | 8 | 7.8 | 32.9 | 9.8 | 69.8N | 29.7W | N (Display) |
| 500°C. Therm. | 53.0 | 37.5 | 7 | 6.5 | 12.2 | 18.0 | 59.5N | 25.2W | N |
| 580°C. Therm. | Samples crumbled. | | | | | | | | |

* RESULTS: 400°C. therm. demag. believed to be the most reliable. About 56° clockwise motion suggested since 101 m.y.b.p.

SAMPLE LOCALITY N5: Pine Forest Range, Humboldt County, Nevada. Denio Quadrangle, SE¼SW¼ Section 30, T46N R30E, 41°49.8'N, 118°40.3'W.




Schmidt stereonet display, direction of magnetization after demag. , , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 93.6± 1.5 m.y. (1-1/2 miles southwest of sample #YF-PF-1, Harrold /1972/).

ROCK DESCRIPTION: Leucogranodiorite, extensively weathered. Light gray, about 8% biotite and hornblende 1-4 mm in size. Biotitized hornblende or pyroxene crystals up to 15 mm long.

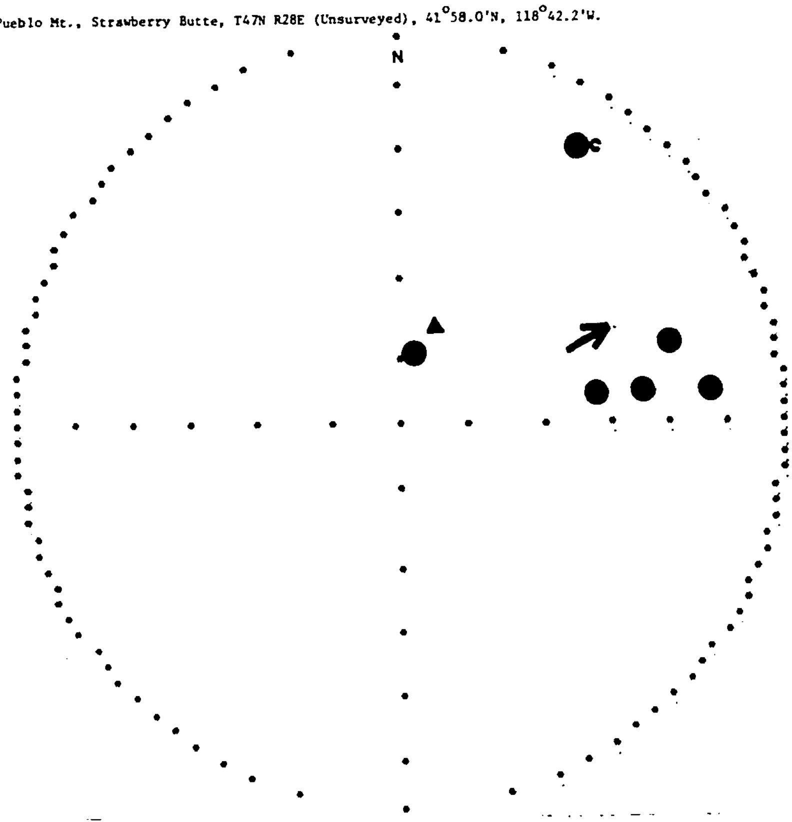
OVERLYING STRUCTURE: Volcanics 1-1/2 miles west are north-south with 43°W. dip. This structural correction was applied to N5.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 68.4 | 358.4 | 6 | 5.0 | 4.8 | 34.1 | 80.1N | 124.5W | N |
| 50 Oe. A.C. | 67.7 | 322.2 | 6 | 5.9 | 76.8 | 7.7 | 62.8N | 176.8W | N |
| 100 Oe. A.C. | 65.7 | 4.2 | 6 | 5.7 | 15.6 | 17.5 | 83.2N | 94.1W | N (Display) |
| 400°C. Therm. | Samples crumbled. | | | | | | | | |

RESULTS: About 34° clockwise rotation is suggested since 94 m.y.b.p. These results are somewhat questionable in view of weathered condition of rocks and the steep west dip correction applied.

SAMPLE LOCALITY N6: Pueblo Mt., Strawberry Butte, T47N R28E (Unsurveyed), 41°58.0'N, 118°42.2'W.




Schmidt stereonet display, direction of magnetization after 400° C. therm. demag. ●, ⊕, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 92.4 ±1.3 m.y. (Sample #YI-P-2, Harrold /1972/).

ROCK DESCRIPTION: Dark grey diorite porphry. Rounded, resorbed feldspar crystals up to 8 mm. in size set in finer ground mass of feldspar and biotite. Diorite is intrusive into steeply dipping metasomatized quartzite. Biotite schist and gneiss were observed five miles to east.

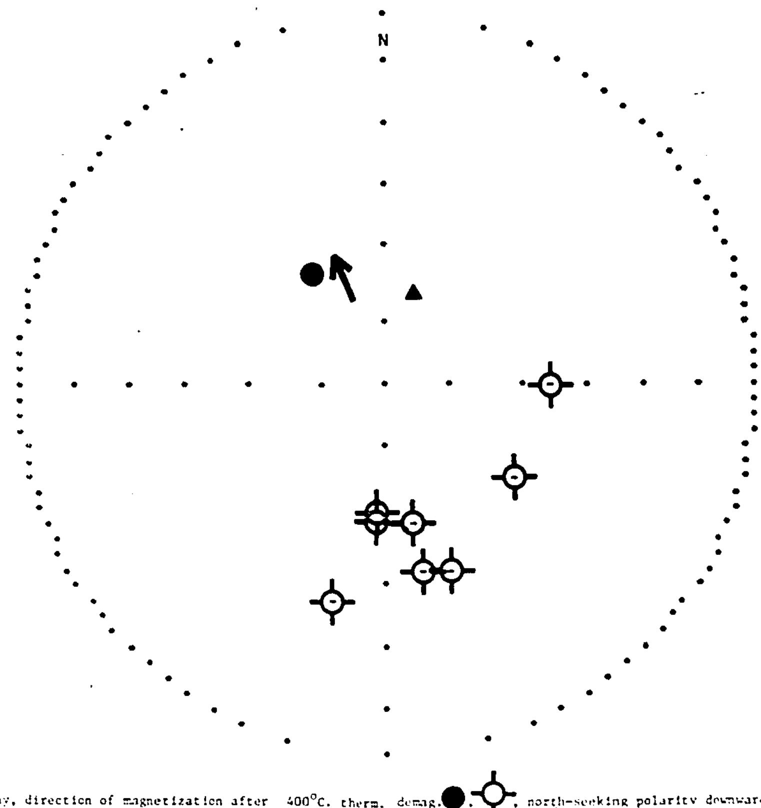
OVERLYING STRUCTURE: Basalt ridge 3000' west of diorite outcrop, N5°E dipping 16°W.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 41.3 | 40.9 | 5 | 4.1 | 4.4 | 41.2 | 51.6N | 13.4W | N |
| 50 Oe. A.C. | 57.1 | 45.5 | 6 | 5.2 | 6.3 | 29.0 | 55.2N | 37.1W | N |
| 100 Oe. A.C. | 58.7 | 38.0 | 6 | 4.6 | 3.7 | 40.6 | 61.3N | 36.4W | N |
| 200 Oe. A.C. | 50.7 | 69.8 | 6 | 3.9 | 2.5 | 54.6 | 34.6N | 42.1W | M |
| 300°C. Therm. | 36.5 | 55.0 | 6 | 5 | 5.2 | 32.7 | 39.2N | 21.1W | M |
| 400°C. Therm. | 42.9 | 76.3 | 5 | 4.6 | 10.9 | 24.3 | 26.2N | 39.6W | N (Display) |
| 500°C. Therm. | 42.3 | 62.0 | 6 | 5.1 | 5.8 | 30.4 | 36.5N | 30.2W | N |
| 580°C. Therm. | 64.6 | 32.3 | 6 | 3.2 | 1.8 | 73.9 | 66.6N | 50.8W | N |

RESULTS: 400° thermal demag. gives the most reliable results. Approximately 106° C.W. rotation is suggested since 92 m.y.b.p.

SAMPLE LOCALITY N7: 1.8 miles north of Contact, Elko County, Nevada. T12N R64E, 41°47.5'N, 114°44.6'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. , , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 140 ±5 m.y. (Sample L-1040, from hornblende, McDowell /1970/).

ROCK DESCRIPTION: Grey, fresh, unweathered coarse grained granodiorite, Plagioclase crystals up to 12 mm. in size. Dark minerals (biotite and hornblende) about 10% of rock.

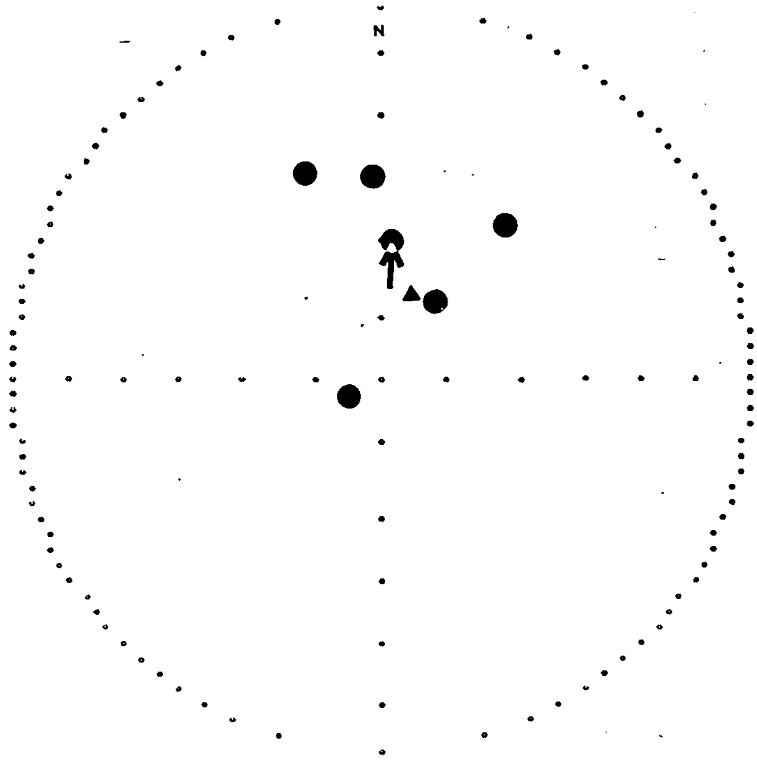
OVERLYING STRUCTURE: Volcanics less than 5° dip.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 58.0 | 108.9 | 10 | 6.8 | 2.8 | 35.3 | 13.2N | 65.5W | N |
| 50 Oe. A.C. | 21.0 | 112.7 | 9 | 4.8 | 1.9 | 53.0 | 19.0N | 130.8E | R |
| 100 Oe. A.C. | 62.6 | 121.5 | 7 | 2.2 | 1.3 | 113 | 48.0N | 178.7E | R |
| 400°C. Therm. | 60.0 | 338.6 | 8 | 7.5 | 14.0 | 15.4 | 73.9N | 159.3E | R (Display) |
| 500°C. Therm. | 47.0 | 343.8 | 7 | 4.4 | 2.3 | 52.6 | 71.0N | 145.4W | R |
| 580°C. Therm. | Scattered - Weak - Unreliable | | | | | | | | |

RESULTS: Sample locality chosen 2.8 miles north of McDowell's age determination because rock was not as weathered. 400°C. chosen as best indicator of paleomagnetic direction. Only about 10° of rotation is suggested. Reverse magnetism is unusual in Cretaceous rocks (Larson, Pers. Comm.).

SAMPLE LOCALITY N8: Silver Zone Pass, Toana Range, Elko County, Nevada. T2N R68E, 40°54.7'N, 114°18.7'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 124 ±5 m.y. (Sample L-1042, from biotite, McDowell /1966/).

ROCK DESCRIPTION: Grey equigranular granite with about 10% biotite and hornblende. Many dark inclusions present which were also sampled. Inclusions have about 50% biotite and hornblende.

OVERLYING STRUCTURE: Tertiary Humboldt Formation with gentle dips crops out two miles to west.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 60.6 | 5.2 | 10 | 9.8 | 36.1 | 8.2 | 86.0N | 36.3W | N |
| 50 Oe. A.C. | 58.5 | 2.1 | 8 | 7.8 | 40.7 | 8.8 | 87.7N | 21.5E | N |
| 100 Oe. A.C. | 57.6 | 354.6 | 8 | 7.5 | 13.0 | 16.0 | 85.1S | 65.8E | N |
| 400°C. Therm. | 60.5 | 4.6 | 6 | 5.6 | 11.9 | 20.3 | 86.5N | 35.9W | N (Display) |
| 500°C. Therm. | 82.0 | 108.6 | 6 | 4.6 | 3.5 | 42.0 | 24.4N | 96.1W | N |
| 580°C. Therm. | 53.0 | 8.8 | 4 | 3.6 | 6.8 | 38 | 22.2N | 49.5W | N |

RESULTS: 400°C. thermal demag. chosen as possibly the most reliable results. About 35° rotation suggested since 124 m.y.b.p. The 500° and 580° heating results suggest considerably more rotation, so some uncertainty is present for this location.

# APPENDIX 2

## Intrusive Igneous Sample Localities From Idaho

SAMPLE LOCALITY I1: Owyhee Mt., Owyhee County, Idaho. T6S R1E, 42°50.0'N, 116°19.7'W.

AGE: Cretaceous on Idaho State Geologic Map.

ROCK DESCRIPTION: Fine-grained, schistose weathered granite.

OVERLYING STRUCTURE: Part of three township-sized outlier of granite surrounded by Tertiary volcanics.

RESULTS: Magnetization very weak ($10^{-8}$ e.m.u./cc.), directions scattered. Possibly altered by hydrothermal action from volcanics. No useful results.

SAMPLE LOCALITY I2: Owyhee Mt., Owyhee County, Idaho. T6S R1E, 42°52.5'N, 116°22.5'W.

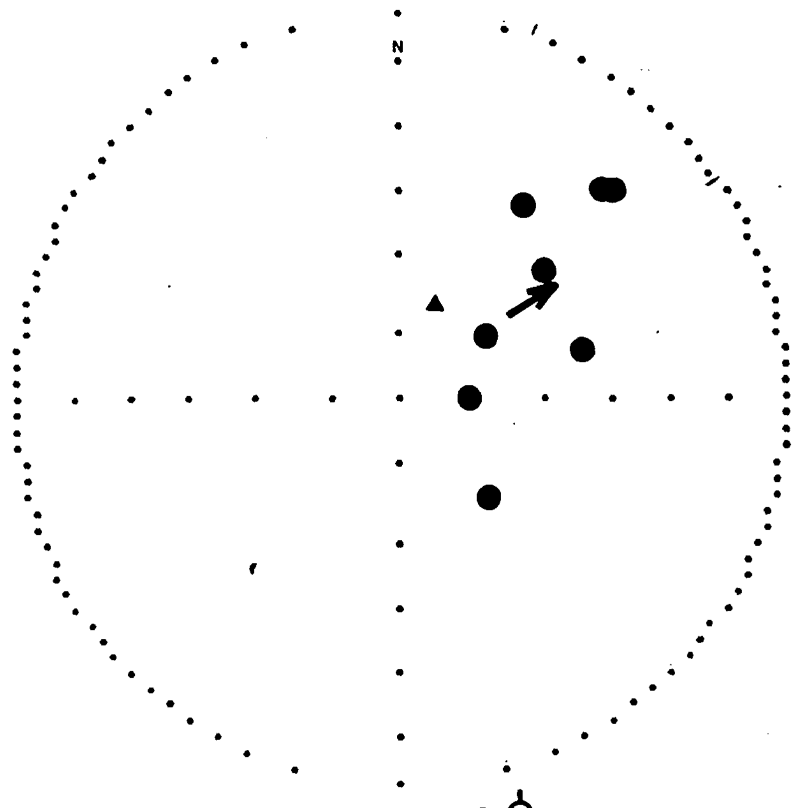
AGE: Cretaceous on Idaho State Geologic Map.

ROCK DESCRIPTION: Coarse-grained, white, weathered granite.

OVERLYING STRUCTURE: Part of three township-sized outlier of granite surrounded by Tertiary volcanics. Intrusive into black biotite schist with schistosity of N55°E and dip of 33°SE.

RESULTS: Magnetization very weak ($10^{-8}$ e.m.u./cc.), directions scattered. No useful results.

SAMPLE LOCALITY L3: Horseshoe Bend, Boise County, Idaho. T6N R2E, 43°53.0'N, 116°10.5'W.




Schmidt stereonet display, direction of magnetization after 400° C. therm. demag. ●, ⊕, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Eight miles east of YU-WT 242, 64 ±2 m.y. and nine miles northeast of YU-WT 236, 69 ±2 m.y., Armstrong (1975).

ROCK DESCRIPTION: Porphyritic biotite granodiorite with feldspar crystals up to 10 x 30 mm. Prominent system of joints N80°W, dipping 53° east. Tremendous fresh outcrops exposed in canyon.

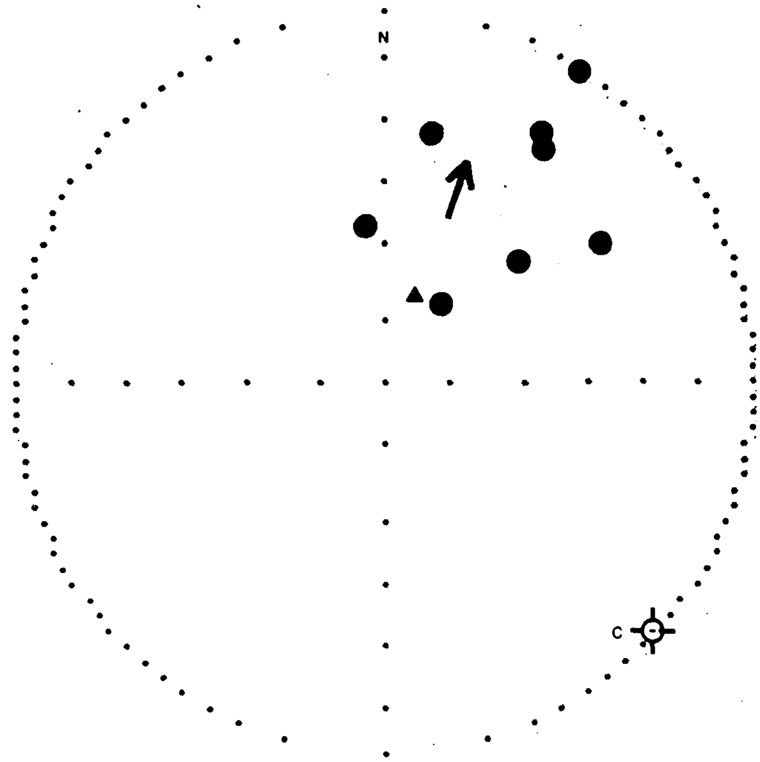
OVERLYING STRUCTURE: Volcanics strike S51°W, dipping 33° northwest 4 miles to southeast (locality #29881).

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 43.8 | 336.2 | 7 | 6.0 | 5.8 | 27.3 | 71.4N | 74.5E | N |
| 50 Oe. A.C. | 40.5 | 17.8 | 7 | 5.6 | 4.2 | 33.6 | 64.6N | 22.8E | M |
| 100 Oe. A.C. | 43.4 | 21.8 | 7 | 6.5 | 11.7 | 18.4 | 60.4N | 73.5W | N |
| 400°C. Therm. | 49.2 | 55.4 | 7 | 6.3 | 9.1 | 21.1 | 44.6N | 27.8W | N (Display) |
| 500°C. Therm. | 29.9 | 73.6 | 7 | 4.5 | 2.5 | 49.4 | 22.8N | 26.9W | M |
| 580°C. Therm. | 53.2 | 341.9 | 7 | 2.4 | 1.3 | 106.0 | 72.7N | 124.1E | M |

RESULTS: About 85° rotation suggested since 67 m.y.b.p. This may be excessive; it may be that the structural attitude of the volcanic is too far away to be used here.

SAMPLE LOCALITY 14: West edge of Idaho Batholith, Little Payette Lake, Valley Co., Idaho. W½ Cor. 1, T18N R3E, 44°54.9'N, 116°1.0'W.




Schmidt stereonet display, direction of magnetization after 500° Therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 77 ±2.5 m.y., biotite (Sample L-1028, McDowell [1966]). There is some question whether this is original intrusive age or is related to reheating, McDowell and Kulp (1969).

ROCK DESCRIPTION: Light grey, fresh medium-grained granite. Biotite about 2% of rock.

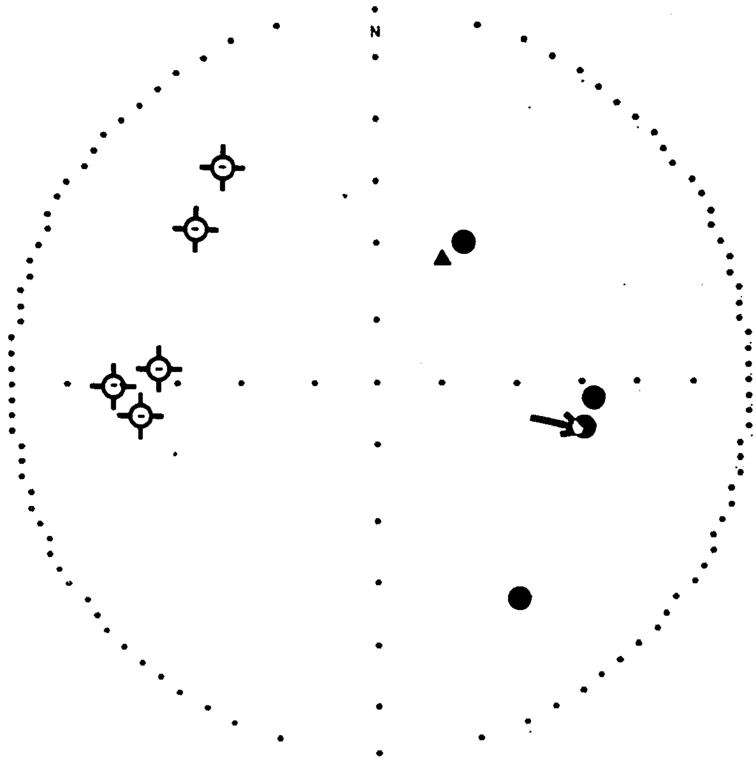
OVERLYING STRUCTURE: Volcanics gently folded six miles to west.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 29.6 | 62.6 | 8 | 4.8 | 2.2 | 50.4 | 6.9N | 4.7E | M |
| 50 Oe. A.C. | 14.8 | 47.0 | 8 | 4.5 | 2.0 | 53.8 | 34.8N | 1.9E | M |
| 100 Oe. A.C. | 16.0 | 26.2 | 8 | 3.7 | 1.6 | 68.2 | 46.9N | 24. E | M |
| 400°C Therm. | 30.3 | 38.9 | 8 | 7.4 | 10.8 | 17.7 | 46.7N | 3.6E | N |
| 500°C. Therm. | 37.2 | 31.1 | 8 | 7.3 | 10.0 | 18.4 | 54.8N | 7.0E | N (Display) |
| 580°C. Therm. | Scattered directions. | | | | | | | | |

RESULTS: Thermal heating apparently produces a stable paleomagnetic direction whereas A.C. does not. 500° thermal results are displayed. If this is true paleomagnetic direction, a rotation of 69° is suggested for this portion of the Idaho batholith since Late Cretaceous time.

SAMPLE LOCALITY 15: Deep Creek Stock, Seven Devils Mountains, Adams County, Idaho. NW¼ Section 13, T21N R3W, 45°9.6'N., 116°39.2'W.




Schmidt stereonet display, direction of magnetization after 50 Oe. A.C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 121 m.y., biotite; 127 m.y., hornblende (White, 1973).

ROCK DESCRIPTION: Light grey quartz hornblende diorite. Three inclusions also measured. Inclusions are fine grained and are about 50% hornblende.

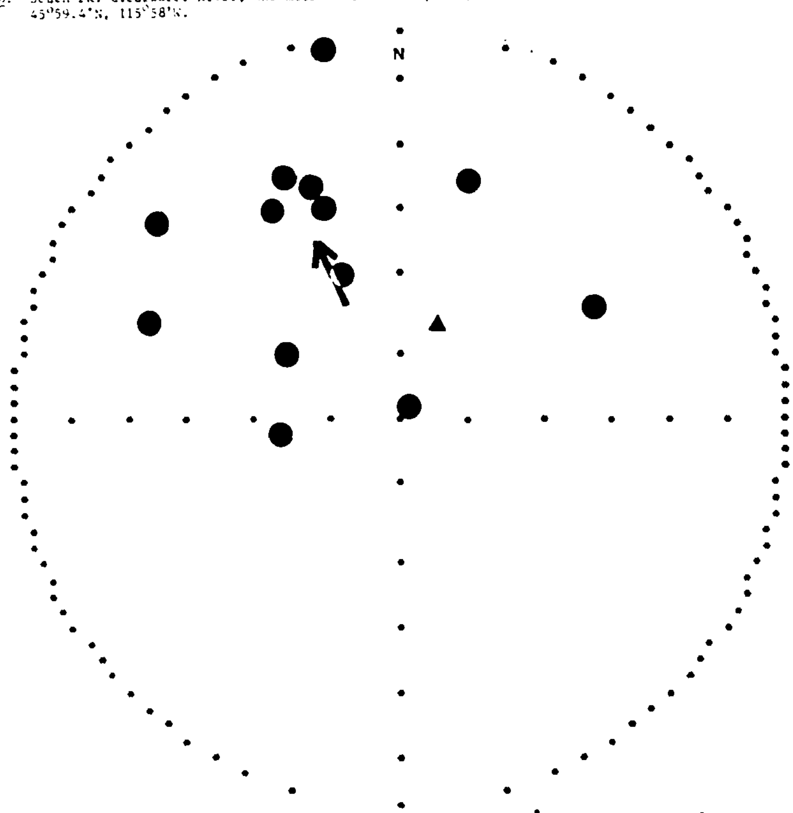
OVERLYING STRUCTURE: Deep Creek stock, intruded into Permo-Triassic Seven Devils Volcanics. Overlying Columbia River basalt gently folded, crops out three miles south.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 40.0 | 100.6 | 9 | 8.2 | 9.5 | 17.6 | 8.9N | 50.1W | M |
| 50 Oe. A.C. | 41.2 | 104.0 | 9 | 8.0 | 8.6 | 18.7 | 7.4N | 53.0W | M (Display) |
| 100 Oe. A.C. | 50.0 | 106.9 | 8 | 6.5 | 4.5 | 29.3 | 10.8N | 59.9W | M |
| 400°C. Therm. | 47.9 | 102.1 | 9 | 7.0 | 4.0 | 29.6 | 12.4N | 55.5W | M |
| 500°C. Therm. | 30.1 | 118.7 | 9 | 4.0 | 1.6 | 65.0 | 31.5N | 144.5E | M |
| 580°C. Therm. | 47.8 | 107.6 | 8 | 6.6 | 5.2 | 27.0 | 9.0N | 59.0W | M |

RESULTS: Three of the samples have $10^{-5}$ e.m.u./cc. or stronger magnetization after 580°C. thermal treatment which suggests presence of hematite. Samples are half normal and half reversed polarity. This is difficult to explain for an intrusive rock unless a self-reversing process is present. Since both A.C. and heating give similar results, 50 O.e. A.C. is displayed because it yields good K and alpha 95. 134°CW rotation suggested since 121 m.y.b.p.

SAMPLE LOCALITY I6: South Fk. Clearwater River, one mile north of Harpster, Idaho County, Idaho. NW¼SW¼ Section 28, T30N R4E, 45°59.4'N, 115°58'W.




Schmidt stereonet display, direction of magnetization after 580° C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 156± 6 m.y., hornblende (sample L-1122, McDowell (1966)).

ROCK DESCRIPTION: Dark grey fine-grained quartz gabbro with swarm of mafic elongate inclusions 1 to 12 inches in size. West edge of Idaho Batholith. Several inclusions sampled. Hornblende ranges from 25% of gabbro to 75% of inclusions.

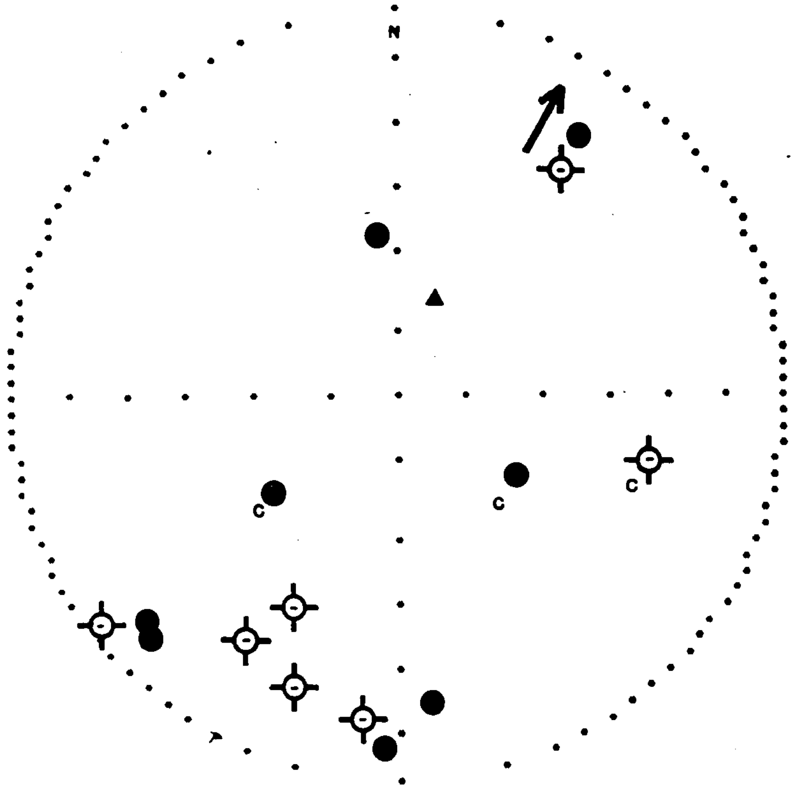
OVERLYING STRUCTURE: Late Jurassic rocks exposed in an erosional window in the gently folded Columbia River Basalt.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 61.9 | .6 | 17 | 16.4 | 24.8 | 7.3 | 87.1N | 55.0E | N |
| 50 Oe. A.C. | 61.9 | 13.4 | 17 | 16.2 | 20.6 | 8.9 | 80.0N | 14.3W | N |
| 100 Oe. A.C. | 65.3 | 10.3 | 17 | 15.8 | 13.4 | 10.1 | 82.8N | 41.2W | N |
| 400°C. Therm. | 69.6 | 302.9 | 17 | 10.9 | 2.6 | 27.9 | 53.4N | 172.7W | N |
| 500°C. Therm. | 55.8 | 308.3 | 15 | 10.3 | 3.0 | 27.0 | 50.7N | 158.8E | N |
| 580°C. Therm. | 48.0 | 334.6 | 13 | 11.0 | 6.0 | 18.5 | 63.9N | 122.3E | N (Display) |

RESULTS: Samples still strong ($10^{-3}$ e.m.u./cc) after 580° thermal demag. which suggests magnetic mineral is hematite. 580° thermal demag. results are believed to be the most reliable. Results suggest minor rotation since Late Jurassic time. Beck et al (1972) report I=63°, D=78° after A.C. demag. for same locality.

SAMPLE LOCALITY I7: Clearwater River, 3.5 miles northwest of Kamiah, Lewis County, Idaho. NE¼SE¼ Section 28, T34N R3E, Woodland Quadrangle, 46°15.4'N, 116°4.5'W.




Schmidt stereonet display, direction of magnetization after 580° C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Biotite 115± 3 m.y., hornblende 124± 4 m.y., sample #L-1027, McDowell (1966).

ROCK DESCRIPTION: Tonalite, gneissic, dark mineral mostly biotite. Some fine-grained dark inclusions and dikes or remnants of country rock. Granitic and aplitic dikes present.

OVERLYING STRUCTURE: Columbia River volcanics on ridges gently folded. Gneissic and schistose structure is N30° to 35°E, very steep.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 76.8 | 73 | 17 | 13.6 | 4.8 | 18.3 | 47.7N | 78.9W | N |
| 50 Oe. A.C. | 78.1 | 144.1 | 15 | 12.9 | 6.6 | 16.1 | 26.6N | 101.4W | N |
| 100 Oe. A.C. | 87.9 | 28.0 | 15 | 10.9 | 3.4 | 24.4 | 49.8N | 113.1W | N |
| 400°C. Therm. | 60.0 | 123.8 | 12 | 10.1 | 5.7 | 19.9 | 10.5N | 76.4W | N |
| 500°C. Therm. | 68.1 | 127.6 | 12 | 9.7 | 4.8 | 22.2 | 17.3N | 84.8W | N |
| 580°C. Therm. | -5.4 | 208.5 | 11 | 8.2 | 5.9 | 17.0 | 39.9S | 154.5W | M (Display) |

RESULTS: Samples still strong ($10^{-5}$ e.m.u./cc) after 580° thermal demag. which suggests magnetic mineral is hematite. 580° thermal demag. results are believed to be the most reliable, although there is considerable change between 500 and 580° results. About 59° clockwise rotation is suggested since 115 m.y.b.p., in comparison with little rotation suggested by locality I6. Beck et al (1972) report I=64°, D=231.5° after A.C. demag. for same locality.

SAMPLE LOCALITY I8: Owyhee Mts., Owyhee County, Idaho. Silver City Quadrangle, SW¼ Section 5, T5S R3W, 43°8'N, 116°42.7'W.

AGE: 66.8 ± 1.3 m.y., muscovite, sample YU-PZ (A56), Panze (1972).

ROCK DESCRIPTION: Granodiorite, medium to coarse grained, fairly soft, altered by hydrothermal action.

OVERLYING STRUCTURE: Owyhee Mts. are anticlinal with volcanics dipping away from uplifted and exposed Cretaceous intrusives.

PALEOMAGNETIC RESULTS: Very weak and scattered results. Hydrothermal and weathering action has destroyed original paleomagnetism. Similar to conditions of samples I1 and I2.

SAMPLE LOCALITY I9: Owyhee Mts., Owyhee County, Idaho. Silver City Quadrangle, C N½ Section 5, T5S R3W, 43°1.3'N, 116°43.1'W.

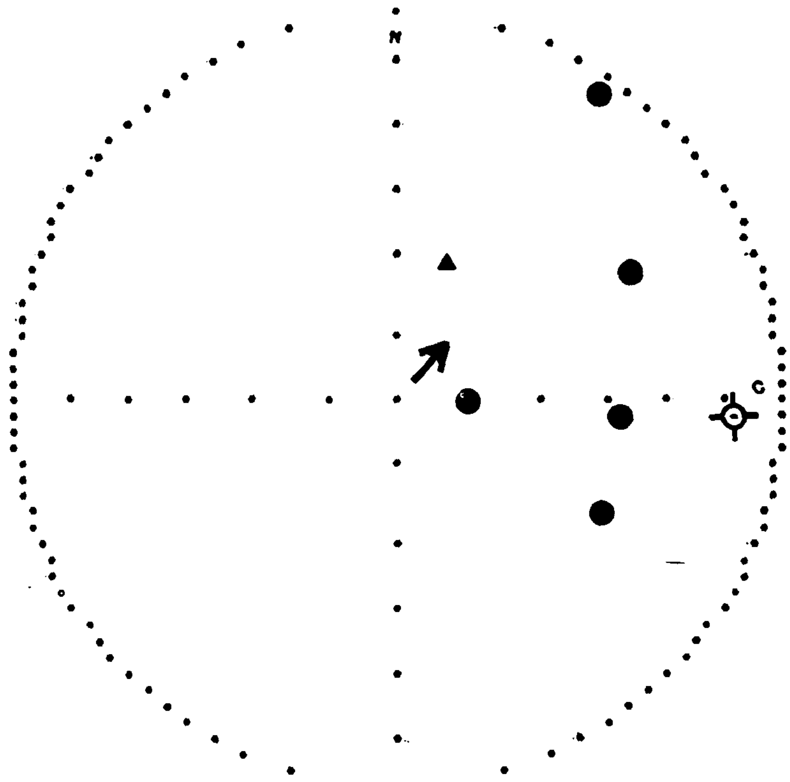
AGE: 65.6 ± 2 m.y., musovite, sample G-M1416 (A384), Panze (1972).

ROCK DESCRIPTION: Same as I8.

OVERLYING STRUCTURE: Same as I8.

PALEOMAGNETIC RESULTS: Same as I8.

SAMPLE LOCALITY 110: Mann Creek, Hitt Mountains, Washington County, Idaho. N½NE¼ Section 33, T15N R5W, 44°36.8'N, 116°56.6'W.




Schmidt stereonet display, direction of magnetization after 500° C. therm. demag. , , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 120± 2.4 m.y., biotite, .3 miles west of sample #YU-SS-60-A, Henricksen et al (1972).

ROCK DESCRIPTION: Granodiorite, very fractured. Biotite and hornblende about 20% of rock.

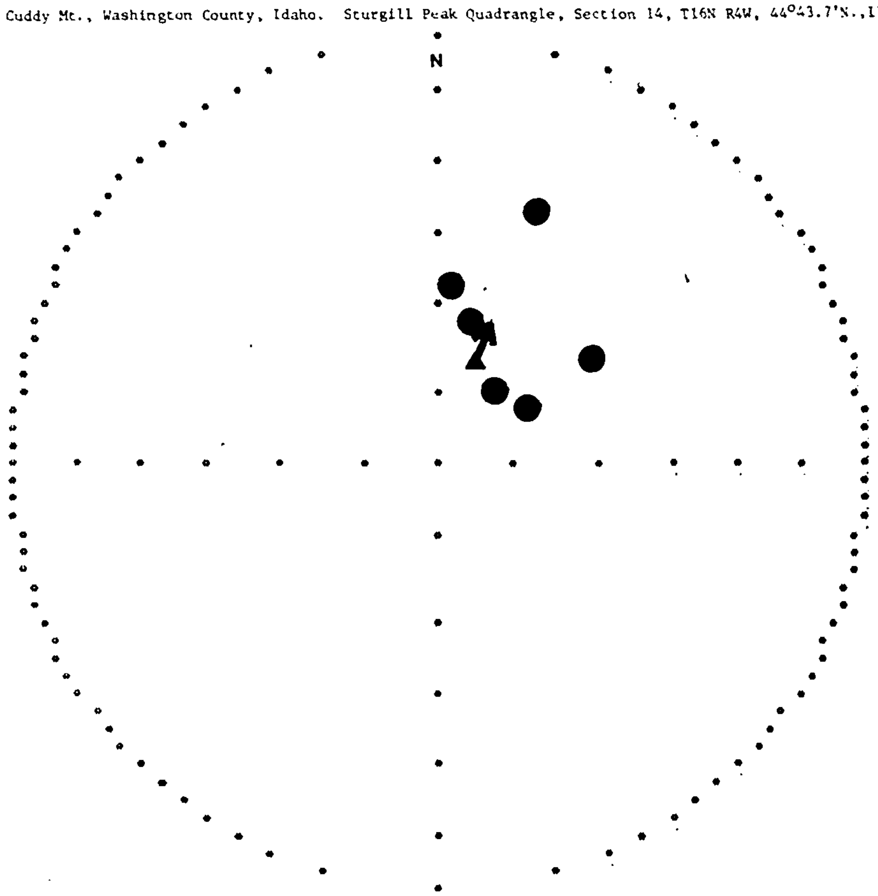
OVERLYING STRUCTURE: One mile to east, volcanics with N-S strike, 15° east dip.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 72.0 | 75.9 | 6 | 5.4 | 8.7 | 24.1 | 43.1N | 70.6W | N |
| 50 Oe. A.C. | 78.8 | 22.0 | 6 | 5.5 | 10.1 | 22.2 | 63.7N | 98.8W | N |
| 100 Oe. A.C. | 77.0 | 62.1 | 6 | 5.0 | 5.2 | 32.4 | 51.0N | 81.0W | N |
| 400°C. Therm. | 53.8 | 83.4 | 6 | 4.8 | 4.3 | 36.9 | 27.6N | 49.3W | N |
| 500°C. Therm. | 44.0 | 74.8 | 5 | 4.2 | 5.1 | 37.7 | 28.3N | 33.2W | M (Display) |
| 580°C. Therm. | 24.9 | 226.9 | 3 | 2.9 | 35.0 | 21.2 | 18.3N | 165.5W | N |

RESULTS: About 100° clockwise rotation is suggested since 120 m.y.b.p.

SAMPLE LOCALITY I12: Cuddy Mt., Washington County, Idaho. Sturgill Peak Quadrangle, Section 14, T16N R4W, 44°43.7'N., 116°47.8'W.




Schmidt stereonet display, direction of magnetization after 50 Oe. A.C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 181± 5 m.y. (chloritized biotite), 201± 6 m.y. (hornblende). (.5 mi. NE of Sample YU-979, Armstrong and Besancon /1970/).

ROCK DESCRIPTION: Coarse grained (5 mm) hornblende granodiorite. Exposure near stream bottom.

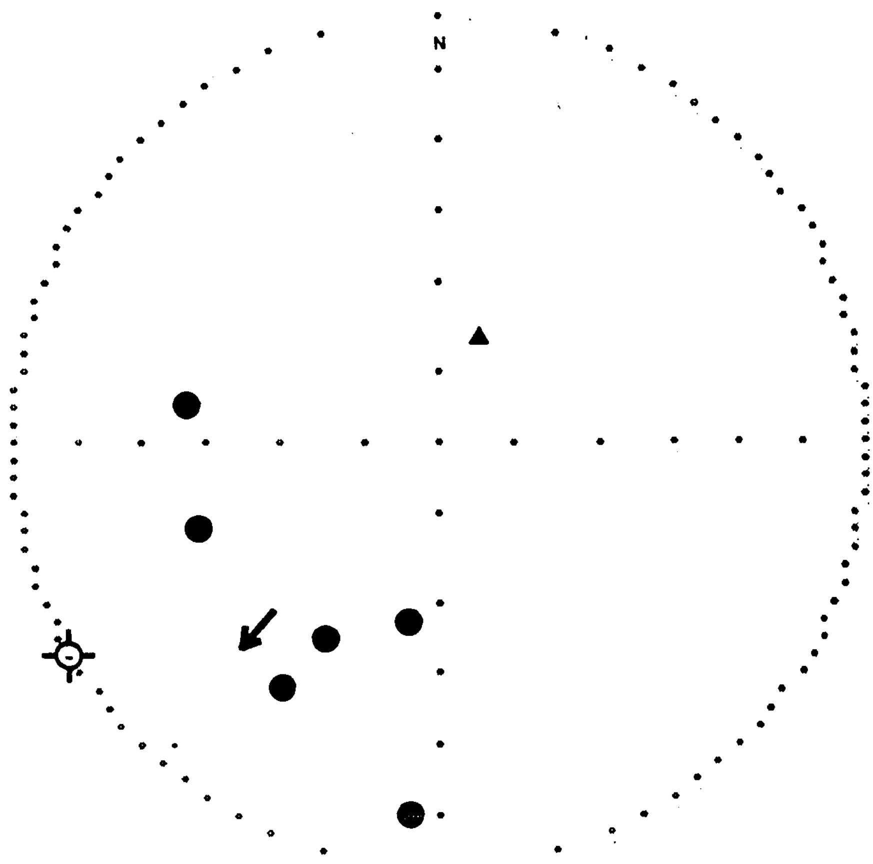
OVERLYING STRUCTURE: Columbia River Volcanics, gentle attitude, surrounding 9 square mile intrusive exposure. Intrusive into Permo-Triassic volcanics on NW.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 58.8 | 35.1 | 6 | 5.7 | 18.5 | 16.0 | 63.7N | 27.9W | N |
| 50 Oe. A.C. | 60.5 | 27.9 | 6 | 5.8 | 23.5 | 14.1 | 69.5N | 27.6W | N (Display) |
| 100 Oe. A.C. | 62.3 | 91.8 | 6 | 3.8 | 2.3 | 57.7 | 28.0N | 61.8W | N |
| 400°C. therm. | 60.2 | 70.0 | 5 | 4.1 | 4.4 | 41.4 | 40.2N | 48.8W | N |
| 500°C. therm. | 68.3 | 43.7 | 5 | 4.1 | 4.6 | 40.3 | 60.5N | 55.8W | N |
| 580°C. therm. | 54.3 | 35.6 | 4 | 2.8 | 2.5 | 75.9 | 61.2N | 19.1W | N |

RESULTS: Intensities $10^{-4}$ to $10^{-6}$ even after 580°C. thermal demag suggest hematite. 50 Oe. A.C. demag chosen as best indication of paleo direction because of best statistics and general agreement of heating results. About 58° of rotation suggested since 181 m.y.b.p.

SAMPLE LOCALITY I13: Cuddy Mt., Washington County, Idaho. Hornet Quadrangle, NE¼SW¼ Section 18, T17N R3W, 44°48.6'N,116°44.8'W.




Schmidt stereonet display, direction of magnetization after 580°C. therm. demag. , , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 200± 6 m.y., chloritized biotite, 217± 7 m.y., hornblende (3/4 mile NE of Sample YU-984, Armstrong and Besancon /1970/).

ROCK DESCRIPTION: Dark grey, fine-grained quartz diorite. Hornblende and biotite 40% of rock.

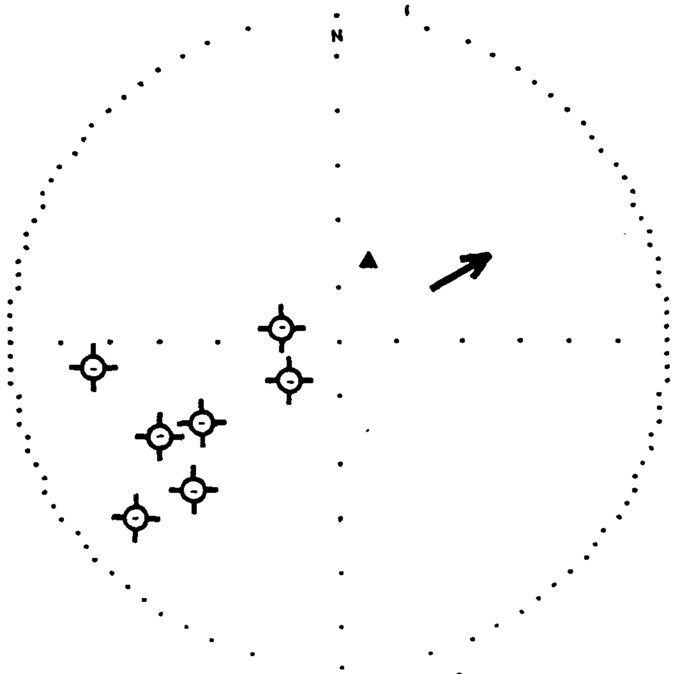
OVERLYING STRUCTURE: Intrusive into Permo-Triassic on west side of 12 square mile exposure. Surrounded by gently dipping Columbia River volcanics.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 DEG. | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 77.7 | 254.2 | 7 | 4.9 | 2.9 | 43.5 | 34.7N | 35.3E | N |
| 50 Oe. A.C. | 78.7 | 80.1 | 7 | 5.0 | 3.0 | 42.5 | 44.4N | 86.1W | N |
| 100 Oe. A.C. | 65.9 | 251.9 | 6 | 4.1 | 2.6 | 52.0 | 22.2N | 160.0W | N |
| 400°C. therm. | 58.8 | 172.3 | 8 | 3.9 | 1.7 | 63.1 | 5.4S | 110.8W | N |
| 500°C. therm. | 26.7 | 134.0 | 8 | 4.9 | 2.3 | 47.9 | 17.8S | 69.6W | M |
| 580°C. therm. | 32.3 | 223.7 | 8 | 6.9 | 6.3 | 24.0 | 16.1N | 160.1W | N (Display |

RESULTS: $10^{-5}$ e.m.u./c.c. strength after 580°C. thermal treatment suggests presence of hematite. Direction (223.7°) suggest extreme rotation or structural disturbances in pre-volcanics time.

SAMPLE LOCALITY I14: Clearwater Mountains, Idaho County, Idaho. NW Section 27, T24N R3E, Riggins Quadrangle, 45°29.7'N, 116°3.4'W.




Schmidt stereonet display, direction of magnetization after 580° C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Youngest intrusion in Riggins Quadrangle, mgd, probably of Cretaceous age (Hamilton, 1969).

ROCK DESCRIPTION: Medium-grained (1-2 mm) biotite granodiorite. Outcrop in old Florence (ghost town) mining area extensively kaolinized. Sample site is in hillside west of Florence, not certainly in place but judged to be.

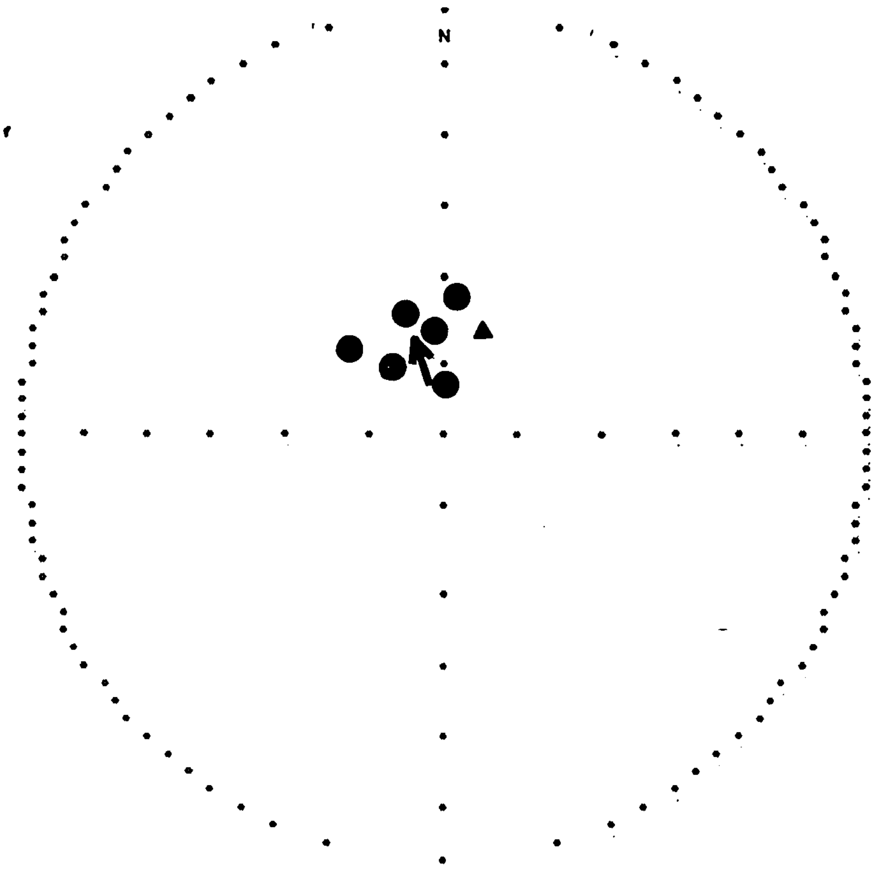
OVERLYING STRUCTURE: Twelve miles to west, Columbia River volcanics average north-south strike, 10° west dip.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 1.5 | 314.3 | 8 | 2.3 | 1.2 | 107.4 | 29.9N | 119.6E | M |
| 50 Oe. A.C. | -21.7 | 301.9 | 8 | 5.3 | 2.6 | 42.7 | 12.9N | 122.6E | M |
| 100 Oe. A.C. | -30.4 | 289.6 | 8 | 5.9 | 3.4 | 35.6 | 1.5N | 128.6E | M |
| 400°C. Heat | -37.6 | 280.3 | 8 | 6.9 | 6.5 | 23.5 | 8.0S | 131.9E | R |
| 500°C. Heat | -35.8 | 278.2 | 8 | 7.4 | 13.0 | 16.0 | 8.5S | 134.2E | R |
| 580°C. Heat | -46.2 | 241.8 | 7 | 6.4 | 10.1 | 20.0 | 38.6S | 152.0E | R (Display) |

RESULTS: 580° heating results plotted on map. About 90° rotation suggested since Cretaceous.

SAMPLE LOCALITY I17: Gem, Shoshone County, Idaho. T48N R5E, 47°30.9'N.,115°52.1'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 131± 4 m.y., hornblende (Sample L-955, McDowell /1966/).

ROCK DESCRIPTION: Light grey hornblende monzonite with foliation.

OVERLYING STRUCTURE: Small stock intrusive into Precambrian rocks. No overlying volcanics.

PALEOMAGNETIC RESULTS:

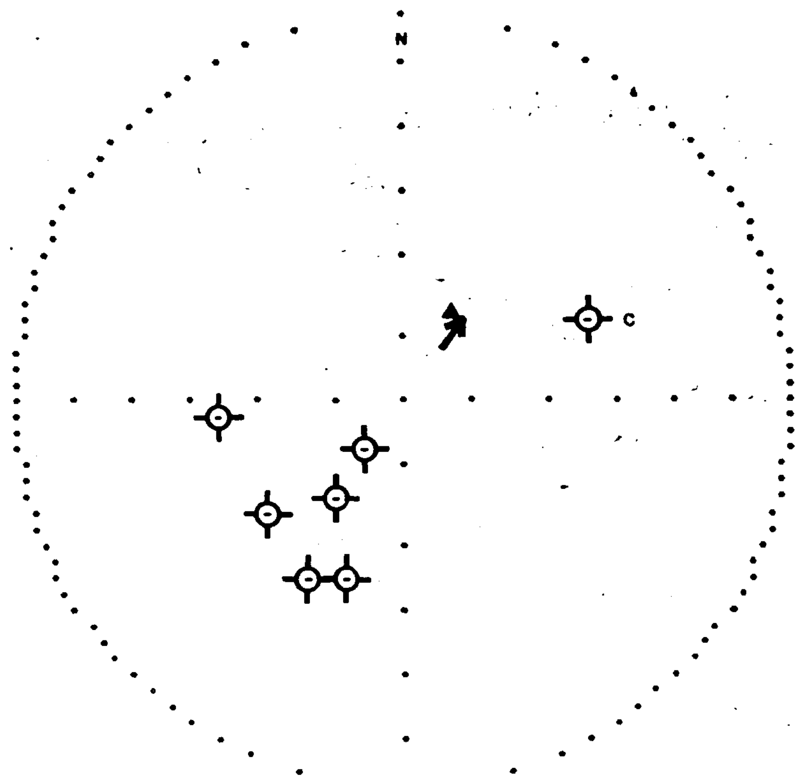
| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 78.9 | .8 | 6 | 5.9 | 65.0 | 8.4 | 69.0N | 115.1W | N |
| 50 Oe. A.C. | 73.0 | .8 | 6 | 5.9 | 56.3 | 9.0 | 79.0N | 113.6W | N |
| 100 Oe. A.C. | 72.2 | 1.0 | 6 | 5.9 | 88.4 | 7.2 | 80.2N | 112.9W | N |
| 400°C. therm. | 70.9 | 342.3 | 6 | 4.9 | 74.4 | 7.8 | 76.6N | 164.2W | N (Display) |
| 500°C. therm. | 79.5 | 311.2 | 6 | 4.9 | 4.5 | 35.7 | 57.8N | 145.1W | N |
| 580°C. therm. | 84.3 | 156.7 | 6 | 4.1 | 2.6 | 52.7 | 36.9N | 110.3W | N |

RESULTS: $10^{-5}$ to $10^{-6}$ e.m.u./c.c. after 580°C. thermal treatment suggests presence of hematite. 400°C. thermal treatment selected as most probable direction of paleomagnetic direction. This suggests little rotation since 131 m.y.b.p.

# APPENDIX 3

## Intrusive Igneous Sample Localities From Oregon

SAMPLE LOCALITY 01: Wallowa Mts., Wallowa County, Oregon. Enterprise Quadrangle, NWSE Section 15, T2S R43E, 45°23.0'N., 117°28.2'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Late Jurassic (Taubeneck, personal communication).

ROCK DESCRIPTION: Grey hornblende-biotite diorite with gneissic texture, dark minerals 20% of rock. Black fine-grained inclusions up to 17 inches long.

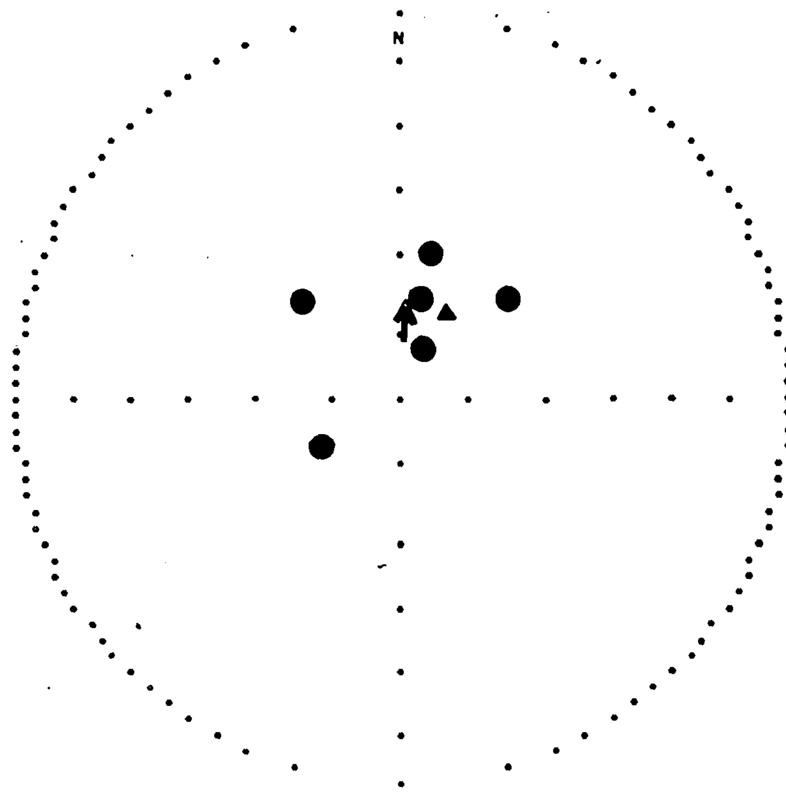
OVERLYING STRUCTURE: Gently folded Miocene volcanics. Diorite intrusive into Triassic metamorphosed sediments on NE side.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 33.1 | 38.9 | 7 | 6.7 | 20.6 | 13.6 | 47.8N | 1.4E | N |
| 50 Oe. A.C. | -10.5 | 39.2 | 7 | 4.7 | 2.6 | 46.9 | 28.6N | 16.7E | M |
| 100 Oe. A. C. | -61.0 | 283.1 | 7 | 3.1 | 1.5 | 80.1 | 20.9N | 66.8W | R |
| 400°C. therm. | -50.8 | 216.7 | 7 | 5.5 | 3.9 | 35.2 | 58.5N | 14.6W | R (Display) |
| 500°C. therm. | -59.5 | 223.3 | 6 | 5.8 | 22.7 | 14.4 | 58.2N | 34.3W | R |
| 580°C therm. | Scattered results but still fairly strong ($10^{-5}$ to $10^{-6}$ e.m.u./c.c.). | | | | | | | | |

RESULTS: Consistent results with 100 Oe. A.C. demag and heating suggest rotation of about 67° since late Jurassic time. Reversed magnetization is fortunate because if not reversed we could not distinguish paleomagnetic direction from present magnetic direction.

SAMPLE LOCALITY 02: Wallowa Mt., Wallowa County, Oregon. Wallowa Quadrangle, NENE Section 1, T2S R43E (unsurveyed).




Schmidt stereonet display, direction of magnetization after 500°C. therm. demag. ●, ⊕, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 102± 10 m.y. fission track (Chevron U.S.A. lab in Richmond, California).

ROCK DESCRIPTION: Fresh hornblende biotite granodiorite in exposures in valley floor of glaciated valley.

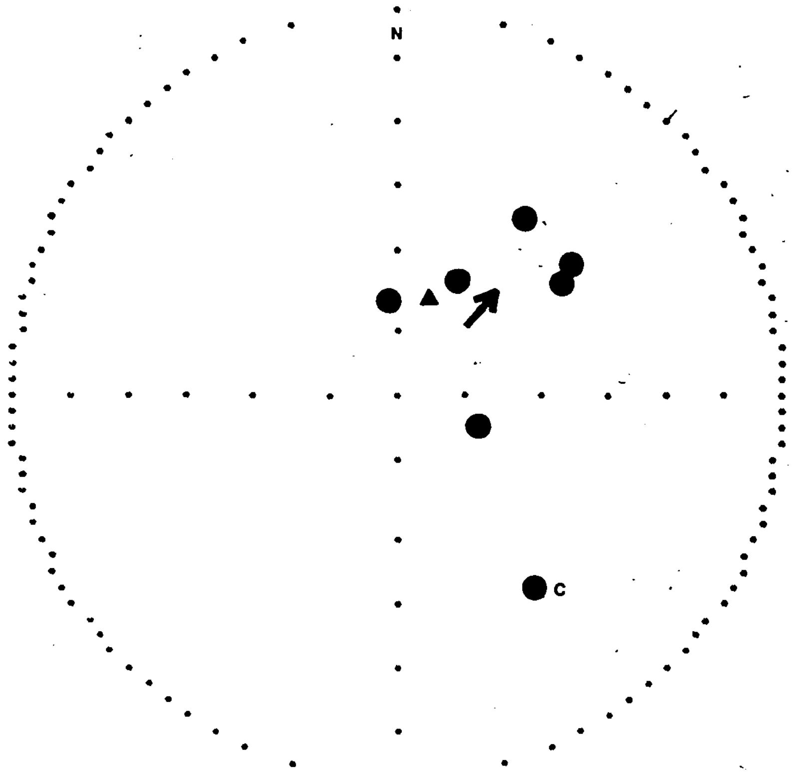
OVERLYING STRUCTURE: Intrusive into Triassic sediments Wallowa Batholith in over 200 square miles in size. Wallowa Mts. surrounded by gently folded Tertiary volcanics.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 71.0 | 7.0 | 7 | 6.9 | 72.2 | 7.2 | 78.8N | 96.5W | N |
| 50 Oe. A.C. | 74.9 | 8.3 | 9 | 9.0 | 163.4 | 4.0 | 72.8N | 104.0W | N |
| 100 Oe. A.C. | 76.9 | 25.4 | 9 | 8.8 | 34.0 | 9.0 | 65.8N | 91.9W | N |
| 400°C. therm. | 69.3 | 3.9 | 8 | 6.5 | 4.5 | 29.2 | 81.9N | 100.4W | N |
| 500°C. therm. | 73.8 | 0.0 | 6 | 5.7 | 15.0 | 17.9 | 75.4N | 118.1W | N (Display) |
| 580°C. therm. | Samples crumbled. | | | | | | | | |

RESULTS: 400°C. thermal demag with 3.9° declination chosen as the most reliable results. About 34° of clockwise rotation is suggested since 102 m.y.b.p. The paleomagnetic direction almost overlaps the present field direction but the locality is believed to be significant.

SAMPLE LOCALITY 03: N. Fork John Day River, Oriental Creek, approx. Section 10, T7S R33E, 44°58.4'N, 118°42.9'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 135 m.y. (W. H. Taubeneck, 1972, Personal Communication).

ROCK DESCRIPTION: Large black, basic inclusions (many square feet in size) with small (1 mm) plagioclase crystals. These inclusions probably are related to Permo-Triassic volcanics noted on regional map by Walker (1973). Intrusive is coarse-grained hornblende - biotite diorite.

OVERLYING STRUCTURE: Volcanics with gentle dip. Diorite body is about 25 square miles and is intrusive into Permo-Triassic volcanics (map by Walker [1973]).

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LONG. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 80.3 | 89.8 | 7 | 5.8 | 5.0 | 30.0 | 42.1N | 93.1W | N |
| 50 Oe. A.C. | 54.6 | 29.3 | 7 | 6.3 | 8.12 | 22.5 | 65.6N | 15.2W | N |
| 100 Oe. A.C. | 61.0 | 24.9 | 8 | 7.3 | 9.9 | 18.5 | 71.8N | 28.3W | N |
| 400°C. thermal | 59.4 | 45.2 | 6 | 5.7 | 14.8 | 18.0 | 56.9N | 37.0W | N (Display) |
| 500°C. thermal | 78.8 | 100.8 | 7 | 6.0 | 6.0 | 26.9 | 37.5N | 91.7W | N |
| 580°C. thermal | 45.0 | 156.3 | 6 | 3.2 | 1.8 | 72.5 | 15.2N | 97.1W | N |

RESULTS: Strength of $10^{-5}$ to $10^{-6}$ after 580° thermal demag. suggests presence of hematite. 400°C. thermal results chosen as best representation of paleomag field. About 75° of clockwise rotation suggested since 135 m.y.b.p. Lack of agreement with 500° and 580° thermal heating results casts some doubt on results.

SAMPLE LOCALITY 05: Grande Ronde River, Union County, Oregon. T6S R36E, 45°3.3'N, 118°18.6'W.

AGE: 105± 5 m.y., fission track determination.

ROCK DESCRIPTION: Bald Mountain Batholith, coarse grained tonalite (Tanbeneck /1957/). Intrusive into Permian argillite and Triassic metagabbro. Somewhat weathered at this locality.

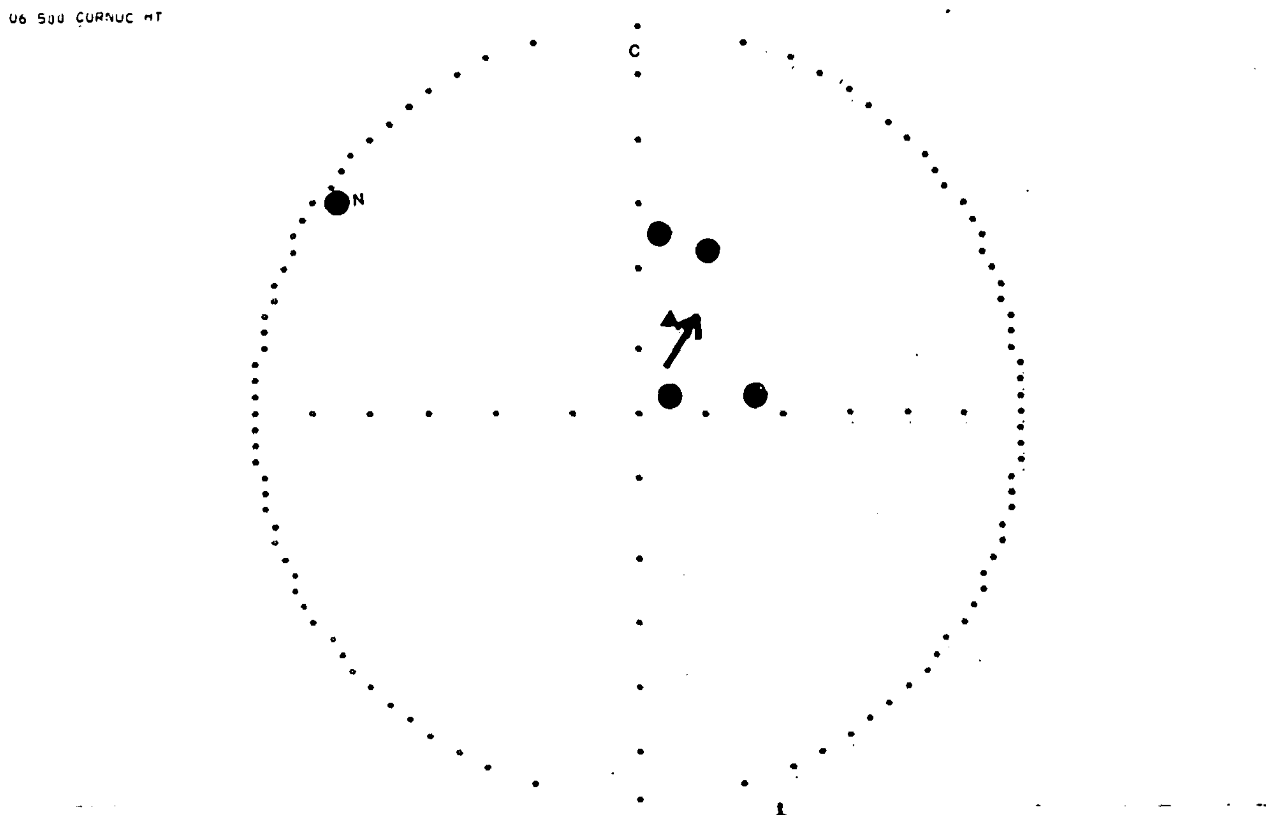
OVERLYING STRUCTURE: Overlying volcanic clastics 1-1/2 miles to west, strike N40°E, dip 12° to northwest.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 55.3 | 17.9 | 7 | 4.9 | 2.8 | 44.3 | 73.6N | 0.4W | N |
| 50 Oe. A.C. | 69.4 | 13.6 | 6 | 4.1 | 2.7 | 51.2 | 70.0N | 75.5W | N |
| 100 Oe. A.C. | 53.9 | 11.4 | 7 | 4.8 | 2.8 | 44.8 | 76.3N | 18.2E | N |
| 400°C. Therm. | -44.3 | 323.2 | 6 | 3.3 | 1.8 | 72.1 | 11.5N | 95.0E | M |
| 500°C. Therm. | -44.4 | 306.2 | 6 | 3.8 | 2.2 | 59.4 | 3.7N | 108.2E | R (Display) |
| 580°C. Therm. | 51.4 | 163.2 | 6 | 4.4 | 3.06 | 46.2 | 11.5S | 103.8W | N |

RESULTS: Differences between A.C. demag and thermal demag results and large scatter suggest questioning results. No direction is shown on map.

SAMPLE LOCALITY 06: Wallowa Mountains, Cornucopia Area, Baker County, Oregon. S½SW¼ Section 16, T6S R45E, 45°E, 45°2.3'N, 117°13.2'W.




Schmidt stereonet display, direction of magnetization after 500° C. therm. demag. ●, ○, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ⟶, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Late Jurassic to Early Cretaceous (Taubeneck/1964/).

ROCK DESCRIPTION: Tramway trondhjemite (Taubeneck, ibid). Underhand lens, appears to be fairly coarse monzonite, (grains about 5 mm in size), about 10% hornblende. A few rare argillite inclusions (oriented sample taken).

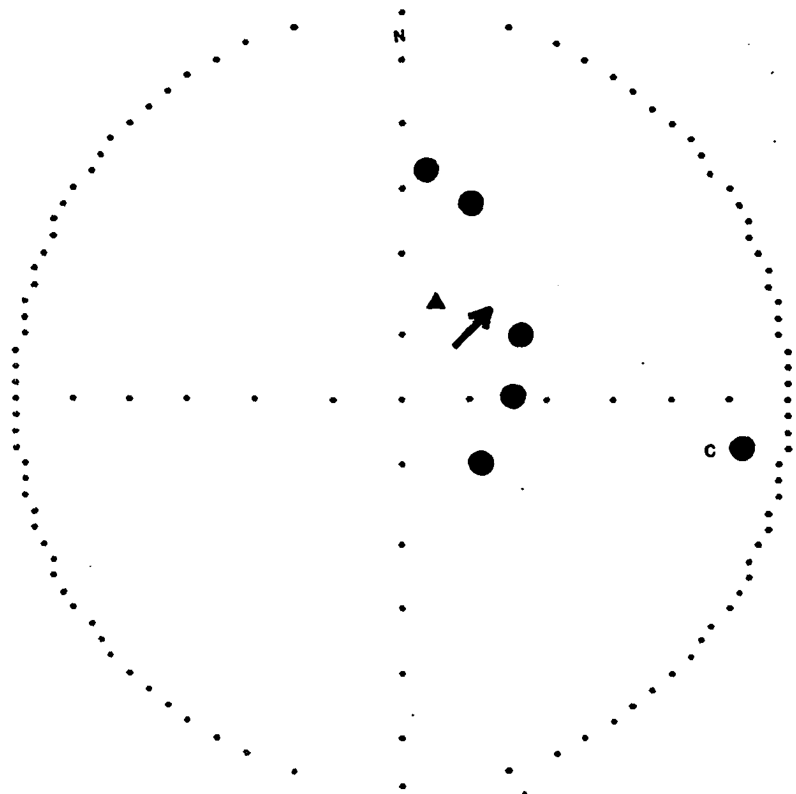
OVERLYING STRUCTURE: Gently folded Columbia River Basalt 1-1/2 miles south but separated by fault. No structure correction used in calculations as it cannot be predicted.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 77.2 | 68.2 | 5 | 4.5 | 6.9 | 27.2 | 48.8N | 81.4W | N |
| 50 Oe. A.C. | 83.8 | 174.1 | 5 | 3.7 | 3.1 | 52.5 | 32.8N | 115.7W | N |
| 100 Oe. A.C. | 65.9 | 56.1 | 5 | 4.8 | 17.9 | 18.6 | 52.2N | 52.8W | N |
| 200 Oe. A.C. | 70.4 | 13.6 | 5 | 4.8 | 21.1 | 17.0 | 77.1N | 79.4W | N |
| 300 Oe. A.C. | 80.0 | 41.4 | 5 | 4.7 | 14.0 | 21.2 | 57.5N | 112.9W | N |
| 400 Oe. A.C. | 80.7 | 112.8 | 5 | 4.7 | 12.4 | 22.6 | 35.9N | 96.4W | N |
| 400°C. Therm. | 67.6 | 98.0 | 5 | 4.9 | 45.7 | 11.4 | 28.9N | 71.2W | N |
| 500°C. Therm. | 66.0 | 31.7 | 4 | 3.8 | 15.3 | 24.3 | 68.8N | 84.5E | N (Display) |
| 580°C. Therm. | 50.3 | 225.5 | 5 | 3.4 | 2.4 | 62.9 | 3.4S | 155.0W | N |

RESULTS: $10^{-5}$ to $10^{-6}$ e.m.u./cc after 580°C. suggests presence of hematite. Smallest 95 results from 400°C. but 500°C. results used because they agree better with other localities. Clockwise rotation of about 62 degrees since Early Cretaceous.

SAMPLE LOCALITY 07: Elkhorn Mt., Bald Mt. Batholith, Barker County, Oregon. Approx. Sec. 8, T8S R38E, 44°52.3'N, 118°7.0'W.




Schmidt stereonet display, direction of magnetization after 500° C. therm. demag. ●, ⊕, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Early Cretaceous (Taubeneck /1957/). Ø5 is 105±5 m.y.

ROCK DESCRIPTION: Fresh exposure in deep glacial valley. Light grey, medium grained (3 mm) hornblend-biotite granodiorite.

OVERLYING STRUCTURE: Volcanics 12 miles to west have gentle dip. Bald Mt. batholith is intrusive into Permian sediments and Triassic metagabbro (Taubeneck /1957/).

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 71.6 | 69.9 | 6 | 5.8 | 23.3 | 14.2 | 46.3N | 69.3W | N |
| 50 Oe. A.C. | 75.5 | 72.3 | 6 | 5.8 | 22.7 | 14.4 | 46.6N | 78.7W | N |
| 100 Oe. A.C. | 62.4 | 93.9 | 6 | 5.6 | 11.3 | 20.8 | 26.9N | 64.1W | M |
| 400°C. therm. | 61.7 | 161.7 | 5 | 2.3 | 1.5 | 107.7 | .7S | 104.8W | M |
| 500°C. therm. | 64 | 43.6 | 5 | 4.5 | 8.6 | 27.7 | 59.7N | 45.5W | M (Display) |
| 580°C. therm. | Most samples crumbled. | | | | | | | | |

RESULTS: Not significantly different from present magnetic direction. May be valid, however, since lower heating and A.C. demag results do not overlap present field direction. About 74° clockwise rotation may be suggested since early Cretaceous.

SAMPLE LOCALITY 08: Elkhorn Mt., Bald Mt. batholith, Baker County, Oregon. Approx. Section 14, T8S R36E, 44°51.7'W, 118°16.0'W.

AGE: Early Cretaceous (Taubeneck /1957/).

ROCK DESCRIPTION: Extensively fractured, somewhat weathered exposures along mining road. Light grey coarse-grained granodiorite. Hornblende and biotite crystals up to 10 mm.

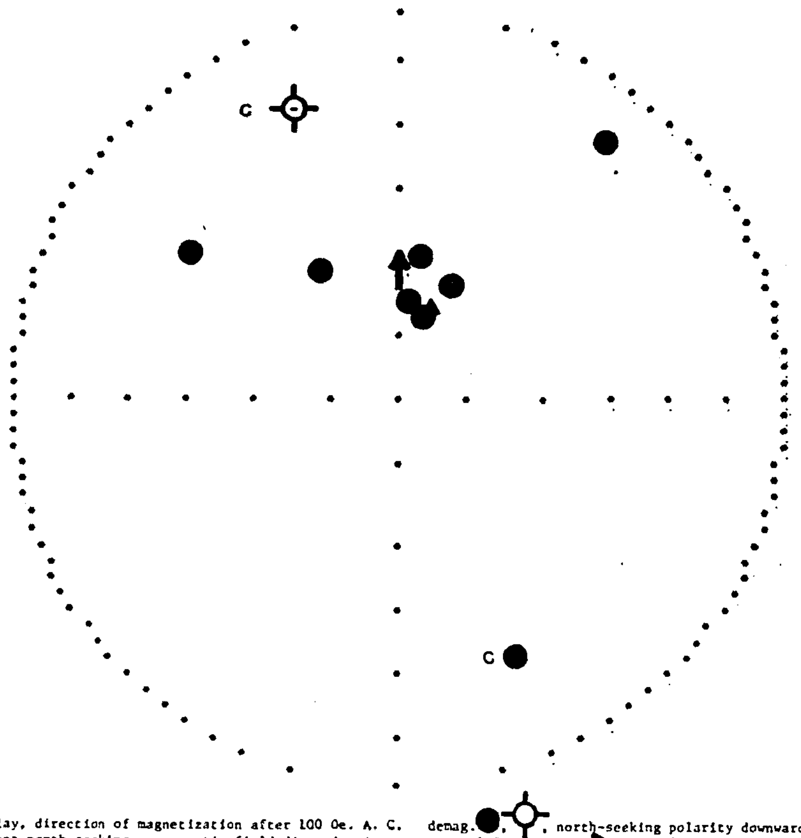
OVERLYING STRUCTURE: Gently dipping volcanics 8 miles to west.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 73.2 | 90.8 | 9 | 4.7 | 1.9 | 53.6 | 36.9N | 78.2W | M |
| 50 Oe. A.C. | 68.0 | 253.7 | 7 | 3.6 | 1.8 | 68.0 | 25.1N | 160.0W | M |
| 100 Oe. A.C. | 55.4 | 262.9 | 7 | 3.1 | 1.5 | 80.6 | 20.1N | 177.1W | M |
| 400°C. therm. | 82.8 | 151.5 | 8 | 4.5 | 2.0 | 54.3 | 32.2N | 110.4W | M |
| 500°C. therm. | 43.0 | 323.1 | 7 | 3.7 | 1.8 | 64.6 | 54.2N | 130.4E | M |
| 580°C. therm. | 72.9 | 268.1 | 7 | 4.0 | 2.0 | 58.6 | 36.1N | 158.6W | M |

RESULTS: Unstable results in that little consistency occurs between various methods of treatment. K factors are low and Alpha 95 values are large. No display is shown; paleomagnetic direction is not used on maps.

SAMPLE LOCALITY 09: Blue Mt., Ben Harrison Peak, Grant County, Oregon. Bates Quadrangle, NW¼ Section 2, T10S R34E, 44°44.0'N, 118°35.5'W.




Schmidt stereonet display, direction of magnetization after 100 Oe. A. C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Cretaceous (Thayer and Brown, 1963).

ROCK DESCRIPTION: Light grey, fine-grained granodiorite. Many felsic dikes. Inclusions of dark grey crystalline rock.

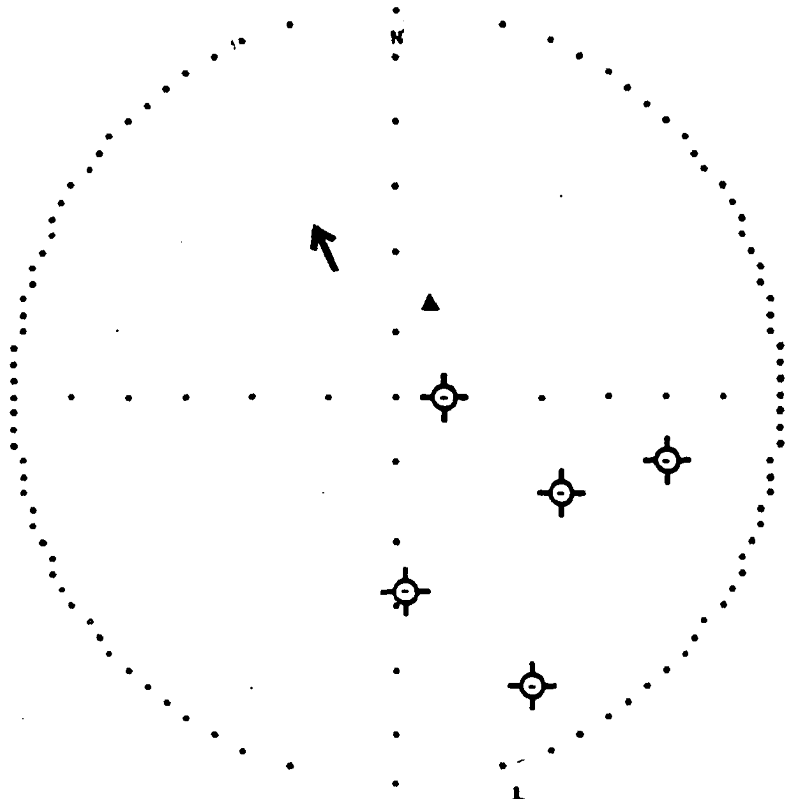
OVERLYING STRUCTURE: Volcanics with gentle southerly dip. Cretaceous intrusive into Permo-Triassic sediments and Triassic ultramafic rocks (Walker, 1973).

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 52.0 | 338.4 | 9 | 5.4 | 2.3 | 45.3 | 69.3N | 122.9E | N |
| 50 Oe. A.C. | 57.8 | 358.2 | 9 | 5.9 | 2.6 | 39.9 | 83.6N | 74.3E | N |
| 100 Oe. A.C. | 59.1 | 0.0 | 7 | 6.2 | 7.7 | 23.3 | 85.1N | 62.1E | N (Display) |
| 400°C. therm. | 82.5 | 328.0 | 8 | 5.3 | 2.6 | 43.0 | 56.4N | 132.6W | N |
| 500°C. therm. | 40.7 | 15.1 | 8 | 2.3 | 1.2 | 111.3 | 65.3N | 26.6E | M |
| 580°C. therm. | 58.7 | 263.2 | 8 | 3.7 | 1.6 | 67.6 | 22.4N | 174.7W | M |

RESULTS: 100 Oe. A.C. demag results show N orientation with 59° dip. These results are questioned as they are not confirmed by heating results. The direction is shown on the map but is questionable.

SAMPLE LOCALITY 010: Big Lookout Mt., Baker County, Oregon. Durkee Quadrangle, C. Section 13, T11S R44E, 44°36.6'N, 117°16.5'W.




Schmidt stereonet display, direction of magnetization after 400°C. therm. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Cretaceous (Thayer and Brown, 1963).

ROCK DESCRIPTION: Grey biotite-hornblende schistose quartz monzonite. High on Lookout Mt. near forest lookout.

OVERLYING STRUCTURE: Gentle volcanics two miles north. Cretaceous intrusive (about 18 sq. miles in size) flanked by Triassic metamorphosed sediments on north and east side.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -65.7 | 162.7 | 5 | 4.5 | 8.0 | 28.9 | 77.6S | 5.5W | R |
| 50 Oe. A.C. | -56.4 | 167.8 | 5 | 4.7 | 11.7 | 23.4 | 78.1S | 62.7W | R |
| 100 Oe. A.C. | -64.9 | 134.8 | 5 | 4.6 | 10.4 | 24.9 | 58.8S | 6.8W | R |
| 400°C. therm. | -49.3 | 134.8 | 5 | 4.4 | 6.5 | 32.4 | 51.9S | 13.7W | R (Display) |
| 500°C. therm. | -37.1 | 129.1 | 5 | 3.4 | 2.6 | 60.2 | 41.9S | 39.9W | M |
| 580°C. therm. | 32.0 | 69.3 | 5 | 2.6 | 1.7 | 91.3 | 26.7N | 25.7W | M |

RESULTS: 400°C. therm. demag. chosen as most representative of paleomag. direction, although statistics are not quite as good as for 50 and 100 Oe. A.C. This locality, differing from most others in eastern Oregon, suggests little rotation since Cretaceous time.

SAMPLE LOCALITY 011: Big Lookout Mt., Baker County, Oregon. Durkee Quadrangle, NW¼NW¼ Section 36, T11S R44E, 44°34.3'N, 117°34.3'W.

AGE: Cretaceous (Thayer and Brown, 1963).

ROCK DESCRIPTION: Very coarse (up to 10 mm) grained biotite granite or quartz monzonite. Biotite about 10% of granite. Maybe kaolinized since rock drills fairly easily.

OVERLYING STRUCTURE: Near overlap of gently dipping volcanics. Near intrusion into Triassic gabbro.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -53.0 | 310.0 | 6 | .7 | .9 | Data too scattered | | | M |
| 50 Oe. A.C. | -13.7 | 289.7 | 6 | 1.1 | 1.0 | " " " | | | M |
| 100 Oe. A.C. | 2.0 | 322.8 | 6 | .9 | 1.0 | " " " | | | M |
| 125 Oe. A.C. | 17.7 | 314.9 | 6 | 1.4 | 1.1 | " " " | | | M |
| 400°C. Therm. | | | | | | | | | |

RESULTS: The data is too scattered for meaningful interpretation. NO direction is shown on map.

SAMPLE LOCALITY 012: Pedro Mt., Malheur County, Oregon. Bridgeport Quadrangle, NENE Section 11, T13S R42E, 44°27.4'N., 117°34.3'W.

AGE: Cretaceous (Thayer and Brown, 1963).

ROCK DESCRIPTION: Hornblende granodiorite. Large crystals of hornblende 9up to 15 x 5 mm. in size), dark minerals 25% of rock. Rock somewhat altered or weathered.

OVERLYING STRUCTURE: Intrusive into Permo-Triassic volcanic rocks. Tertiary volcanics are gently folded.

PALEOMAGNETIC RESULTS:

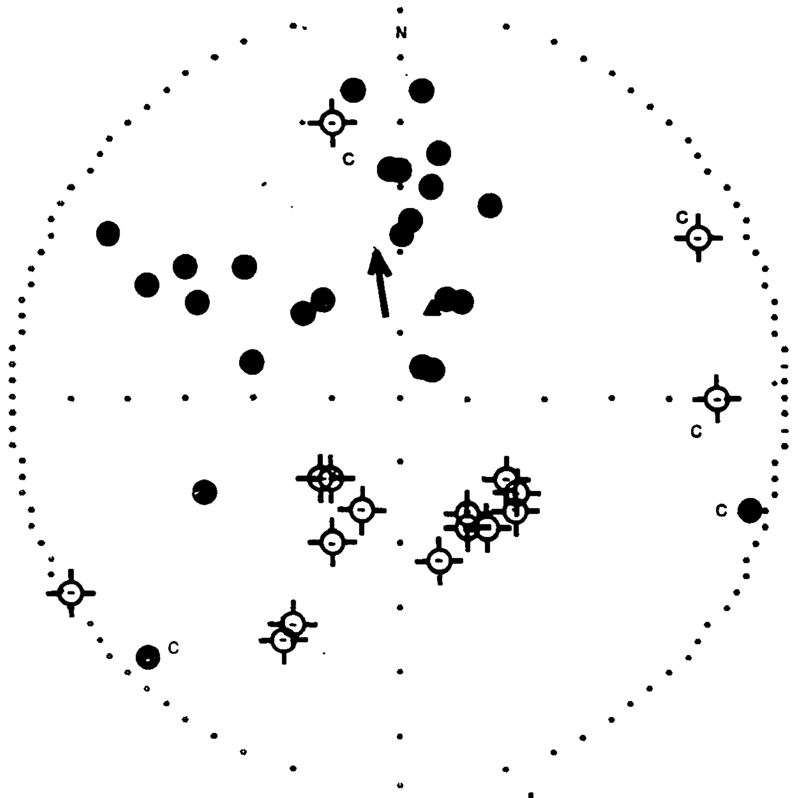
| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -47.7 | 338.2 | 8 | 3.8 | 1.7 | 65.1 | 18.7N | 83.5E | M |
| 50 Oe. A.C. | -22.3 | 276.1 | 8 | 3.8 | 1.7 | 66 | 3.8S | 140.0E | M |
| 100 Oe. A.C. | -34.7 | 275.9 | 8 | 4.5 | 2.0 | 54.8 | 9.2S | 144.7E | M |
| 400°C. therm. | -36.0 | 276.5 | 7 | 4.7 | 2.6 | 47.1 | 9.4S | 133.7E | M |
| 500°C. therm. | -33.6 | 270.5 | 5 | 2.8 | 1.8 | 83.0 | 12.4S | 138.8E | M |

RESULTS: 400°C. therm. gives best statistics; results show reversed polarity with 96° declination. Although this direction is reasonable considering scatter and surrounding localities, the α95 is too high (47.1°) to be reliable. No direction is shown on map for this locality.

# APPENDIX 4

Extrusive volcanic sample localities from Oregon and Idaho. Samples are listed in order of increasing sample locality number.

SAMPLE LOCALITY 28839: Cottonwood Creek, west side of Trout Creek Mt., Harney County, Oregon. Sections 1 and 2, T41S R37E, 42°3'N, 118°19.6'W.




Schmidt stereonet display, direction of magnetization after 200 Oe. A.C. demag. ●, ○, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: No radiometric age at this locality, but probable stratigraphic equivalent 20 miles to northeast is 15.5 m.y.

ROCK DESCRIPTION: Steens Mt. Basalt. 2800' of section, 47 cores. Fine grained to vesicular basalt and andesite flows.

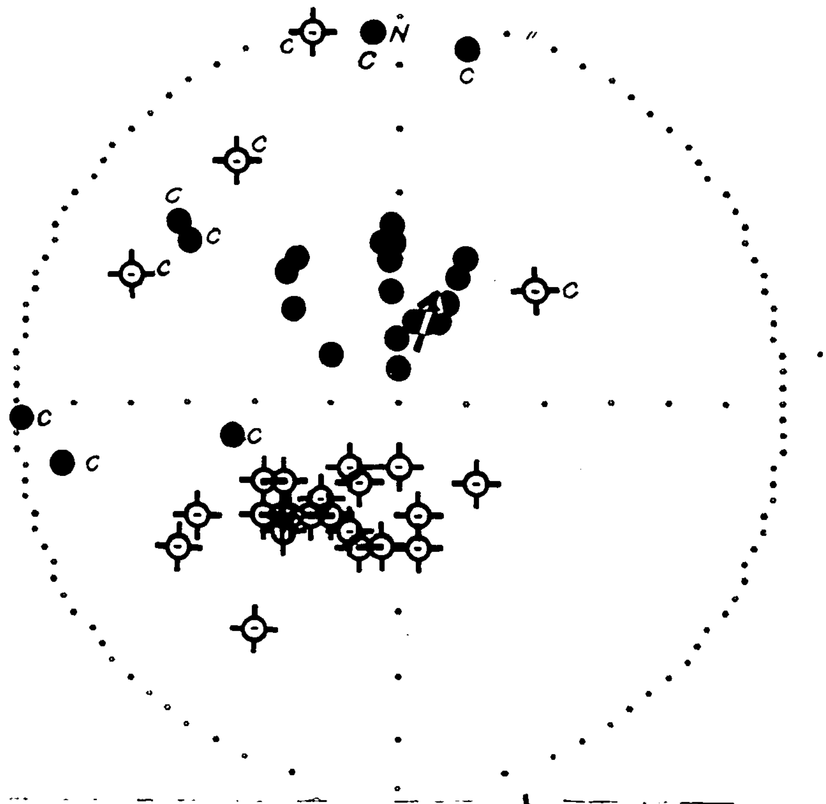
ATTITUDE: Strike N45°W dipping 2° to 5° to northeast.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -23.8 | 338.0 | 42 | 1.5 | 1.0 | Too scattered | | | M |
| 100 Oe. A.C. | 2.6 | 315.9 | 42 | 2.5 | 1.0 | 102.5 | 33.3N | 118.0E | M |
| 200 Oe. A.C. | 57.3 | 351.0 | 40 | 32.8 | 5.4 | 10.8 | 79.4N | 133.2E | M (Display) |

RESULTS: This locality shows little or no rotation since Miocene time. Sequence in 2800' of section, top to bottom, is N,N,N,N,N,N,N,N,N, N,N,N,N,N,R,R,R,N,N,R,N,N,N,N,N,N,N,N,N,R,R,N,R,R,R,R,R,R,R,R,R,R.

SAMPLE LOCALITY 28840: Oregon Canyon Creek, Trout Creek Mountains, Malheur County, Oregon. Sections 2 and 3, T39S R40E, 42°13.0'N, 118°.7'W.




Schmidt stereonet display, direction of magnetization after 200 Oe. A.C. demag. , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 15.5 and 16.0 m.y. K-Ar.

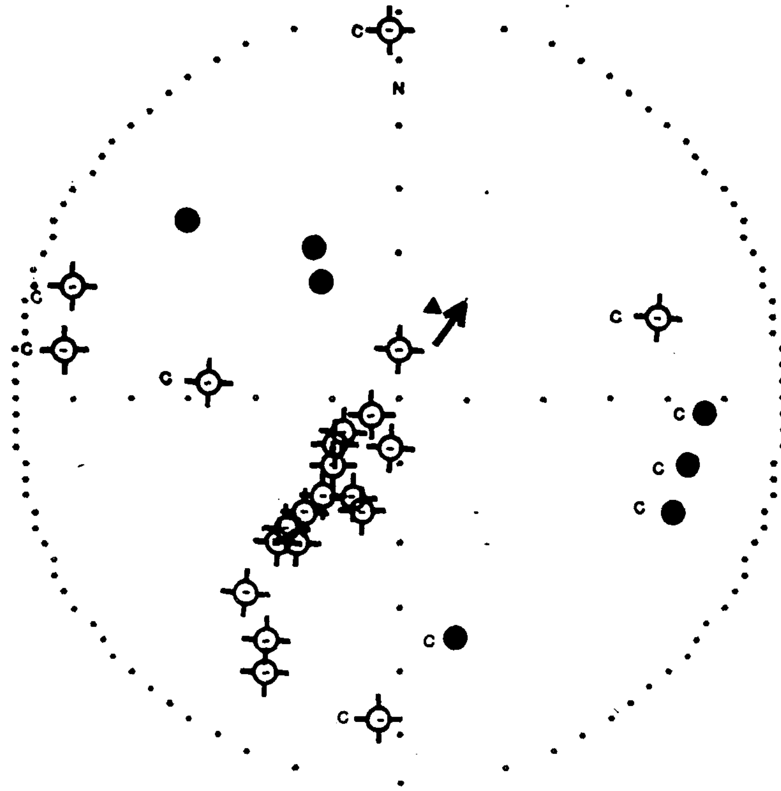
ROCK DESCRIPTION: Interlayered andesite, dacite, and basalt flows, individual units up to 300 feet thick, total measured section 1900'. Probably correlative to Steens Basalt.

OVERLYING STRUCTURE: Attitude is strike S10°E, dipping 3° west.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL -REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 6 | 279 | 54 | 12.5 | 1.3 | 36 | 8.7N | 168.2E | M |
| 100 Oe. A.C. | -14.7 | 277.2 | 54 | 14 | 1.3 | 33.5 | .3N | 141.6E | M |
| 200 Oe. A.C. | -65 | 199.4 | 43 | 40.9 | 19.8 | 5.0 | 75.4S | 126.3E | M (Display) |

RESULTS: 19° clockwise rotation is suggested since Miocene. From to to bottom, sequence is N,N,N,N,N,N,R,N,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,R,N,R,N,R,R,N,R,R,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N, SAMPLE LOCALITY #28857: Hill Creek, Horseshoe Bend, Boise County, Idaho. Sections 23 and 25, T8N R3E, 44°N, 116°3.8'W.




Schmidt stereonet display, direction of magnetization after 175 Oe. A.C. demag., north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 29.9± 2.6 m.y. K-Ar. (Sample #28753A measured by Geochron.) Osr on state geologic map, Ross and Forrester (1959) but this is in error.

ROCK DESCRIPTION: Fine grained basalt. Lower half of section has scattered thin tuff interbeds throughout section. Lowest unit is porphryitic with plagioclase crystals 5-10%.

STRUCTURE: Strike S17°W, dipping 31° west. Locally overlies tuff breccia and granite. At top of section, basalt interfingers with Horseshoe Bend sediments.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 32.2 | 345.5 | 29 | 6.2 | 1.2 | 54.5 | 60.8N | 93.3E | M |
| 175 Oe. A.C. | -65.4 | 215.1 | 18 | 16.8 | 13.8 | 9.7 | 65.5S | 133.1E | M (Display) |

RESULTS: 35° clockwise rotation suggested since 30 m.y.b.p. Polarity from top to bottom is 13R,4N,8R,N,R,2N.

SAMPLE LOCALITY 28858: East side Squaw Butte, Gem County, Idaho. Section 26, T8N R1E, 44°1.2'N, 116°20.2'W.

AGE: 22.5 m.y. K-Ar (possibly too old by comparison to nearby localities?).

ROCK DESCRIPTION: Porphyritic, vesicular andesite(?) with large laths (6 x 15 mm) of plagioclase. Base of Columbia River Basalt.

STRUCTURE: Dip N18°W, 20°W.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 33.3 | 312.7 | 4 | 3.3 | 4.4 | 49.5 | 42.8N | 136.0E | M |
| 200 Oe. A.C. | 63.3 | 2.6 | 4 | 3.4 | 5.2 | 44.7 | 88.0N | 51.0W | M |

RESULTS: Not much rotation suggested since Miocene. Too few points to average out secular variation. Direction is plotted on map, but no display shown here because only four samples.

SAMPLE LOCALITY 28859: Roystone Spring, Gem County, Idaho. Section 17, T7N R1E, 43°56.6'N, 116°21.6'W.

AGE: 12.1± 1.4 m.y. K-Ar, Geochron. Tcr on Idaho State Map, Ross and Forrester (1959).

ROCK DESCRIPTION: Black, massive fine-grained basalt.

STRUCTURE: Attitude is strike S10°E, 35°W dip.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -62.4 | 235.6 | 4 | 4.0 | 700.3 | 3.5 | 50.7S | 133.8E | R |
| 100 Oe. A.C. | -64.2 | 237.3 | 4 | 4.0 | 205.7 | 6.4 | 50.3S | 129.9E | R |
| 200 Oe. A.C. | -63.8 | 239.1 | 4 | 4.0 | 275.3 | 5.6 | 49.0S | 130.0E | R |

RESULTS: Rotation of 59° suggested since Miocene. However, small number of samples may not represent a reliable direction with secular variation averaged out. No sample shown here because of small N.

<u>SAMPLE LOCALITY 28860</u>: Coal Mine Gulch, Dead Indian Ridge, Washington County, Idaho. Sections 22 and 23, T11N R7W, 44°12.2'N, 117°10.5'W.


Schmidt stereonet display, direction of magnetization after 200 Oe. A.C. demag. , , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

<u>AGE</u>: 30 m.y. K-A but this date is believed to be in error. More probable age 12 to 16 m.y. judging from ages 40 miles to east.

<u>ROCK DESCRIPTION</u>: Columbia River Basalt. Black, uniformly textured fine grained basalt with a few small ( 1 mm.) plagioclase laths.

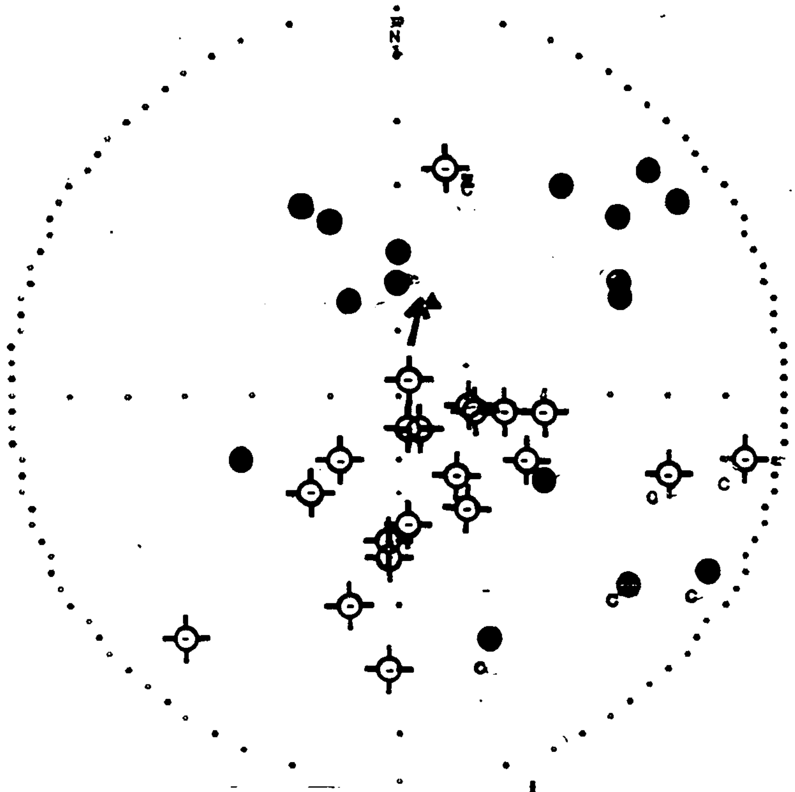
<u>STRUCTURE</u>: N5E strike, dip 28° east, volcanics overlap Permo-Triassic volcanics four miles to west. Pliocene Payette Formation overlaps volcanics six miles to east.

<u>PALEOMAGNETIC RESULTS</u>: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 54.5 | 46.5 | 35 | 24.2 | 3.1 | 16.5 | 53.6N | 28.8W | N |
| 100 Oe. A.C. | -49.6 | 200.9 | 35 | 8.5 | 1.3 | 44.6 | 68.5S | 174.2W | M |
| 200 Oe. A.C. | -62.9 | 202.8 | 28 | 25.6 | 11.3 | 8.5 | 73.8S | 144.7E | M (Display) |

<u>RESULTS</u>: 23° clockwise rotation suggested by this locality since Miocene. From top to bottom, sequence for 200 Oe. A.C. demag. is R,N,N, R,R,R,R,R,R,R,R,R,N,N,N,R,R,R,R,R,N,N,N,N,N,N,N,R,R,R,R,R,R,R,R. N.R.M. showed all normal orientation which probably indicates secondary magnetization superimposed on the true remanent magnetism. This behavior was noted by Watkins and Baksi (1974).

SAMPLE LOCALITY 29850: South Mountain, Owyhee Range, Owyhee County, Idaho. Section 33, T7S R5W, 42°46.4'N, 116°54.5'W.




Schmidt stereonet display, direction of magnetization after 200 Oe. A.C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Thought to be correlative to Columbia River or Steens Mountain Basalt, Tcr on Idaho State Geologic map, Ross and Forrester (1959). Twenty miles to southwest, age 16.6± 4 m.y. for lower basalt unit (Panze /1972/).

ROCK DESCRIPTION: Upper 16 samples vesicular basalt; balance of section is massive, fine-grained. Lowest bed has small (2 mm) patches of lighter material set in dark ground mass.

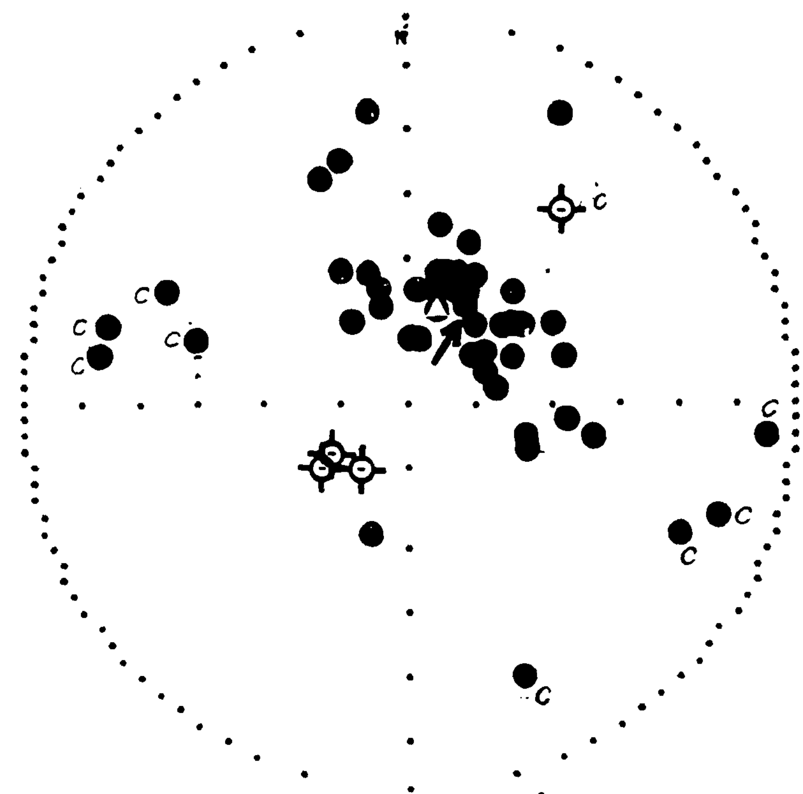
STRUCTURE: Strike is N6°W, dip 35° to east. Probable fault contact with Cretaceous intrusive.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -71.8 | 91.1 | 40 | 26.4 | 2.9 | 16.5 | 35.9S | 20.4E | M |
| 100 Oe. A.C. | -79.4 | 109.9 | 40 | 27.8 | 3.2 | 15.1 | 47.3S | 34.0E | M |
| 200 Oe. A.C. | -69.5 | 194.4 | 34 | 29.5 | 7.3 | 9.8 | 75.9S | 100.7E | M (Display) |

RESULTS: 14° clockwise motion suggested since Miocene time. Direction similar to present field but reverse directions of many samples suggest the direction is a paleomagnetic and is valid. Polarity from top to bottom is 19 samples with normal direction and 21 samples with reverse direction.

SAMPLE LOCALITY 29858: Riddle Mountain, Harney County, Oregon. Section 31, T28S R35E, 43°5.6'N, 118°27.2'W.




Schmidt stereonet display, direction of magnetization after 200 Oe. A.C. demag. ●, ⊕, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 15.4 m.y. K-Ar (measured by Geochron).

ROCK DESCRIPTION: Dark grey basalt, mostly massive but some vesicular. Near base of section, unit with large laths (4x20 mm.) of plagioclase. Believed correlative with Steens Mountain Basalt.

STRUCTURE: Approximately flat dip. Region of northwesterly trending normal faults.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 51.0 | 34.7 | 56 | 33.5 | 2.4 | 15.8 | 60.5N | 17.4W | N |
| 100 Oe. A.C. | 57.6 | 35.2 | 56 | 36.8 | 2.9 | 13.9 | 63.1N | 30.1W | N |
| 200 Oe. A.C. | 67.8 | 32.3 | 46 | 43.0 | 14.9 | 5.6 | 66.8N | 59.2W | N (Display) |

RESULTS: Site is mostly normal magnetization except lowest unit which is reversed. About 32° clockwise rotation is suggested since 15.4 m.y.b.p. Fairly close to present field but reverse readings on three samples may suggest direction is valid paleomagnetic direction. Also, scattered low inclination points may be related to field changes.

SAMPLE LOCALITY 29859: Burns Butte, Harney County, Oregon. Section 21, T23S R30E, 43°34.1'N, 119°7.0'W.

AGE: 7.3± .5 m.y. K-Ar. Tr, early Pliocene, on Burns quadrangle map, Greene, et al. (1972). (This is #29511 measured by Geodron in 1971.)

ROCK DESCRIPTION: Basalt flow.

STRUCTURE: Approximately flat.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -9.7 | 267.3 | 3 | 2.9 | 23.8 | 25.9 | 5.3S | 149.2E | M |
| 175 Oe. A.C. | -48.7 | 235.2 | 3 | 3.0 | 393.1 | 6.2 | 44.5S | 149.6E | R |

RESULTS: About 55° clockwise possible rotation since 7 m.y.b.p. However, only three samples which would not average out secular variation.

SAMPLE LOCALITY 29860: Sawtooth Creek, Harney County, Oregon. Section 24, T21S R28E, 43°44.1'N, 119°18.5'W.

AGE: Tdo, Pliocene, on Burns quadrangle map, Greene et al (1972), probable age by comparison with nearby localities, 7 to 10 m.y.

ROCK DESCRIPTION: Basalt.

STRUCTURE: Strike N60°W, dip 9° east.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 65.4 | 36.3 | 5 | 4.7 | 12.6 | 22.4 | 64.5N | 50.8W | N |
| 175 Oe. A.C. | 63.9 | 39.2 | 5 | 4.7 | 12.7 | 22.3 | 62.3N | 47.0W | N |

RESULTS: 39° clockwise rotation possible since Pliocene(?). However, only five samples which would not average out secular variation.

SAMPLE LOCALITY 29861: Butte Creek, Harney County, Oregon. Section 27, T20S R28E, 43°48.4'N, 119°20.9'W.

AGE: 47.6± 2.8 m.y. K-Ar, but age probably is much too old. Tdo, considered to be Pliocene, on Burns quadrangle map, Greene et al (1972). This is #29255 measured by Geochron in 1971.

ROCK DESCRIPTION: Basalt.

STRUCTURE: Strike is S1°W, dip 10° west.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 61.4 | 359.1 | 3 | 3.0 | 45.3 | 18.5 | 88.5N | 86.3E | N |
| 175 Oe. A.C. | 72.4 | 3.5 | 3 | 3.0 | 905.0 | 4.1 | 76.1N | 111.5W | N |

RESULTS: Very little rotation since Pliocene(?) time. However, only three samples which would not average out secular variation.

SAMPLE LOCALITY 29862: Little Emigrant Creek, Harney County, Oregon. Section 24, T20S R27E, 43°49.3'N, 119°25.6'W.

AGE: 32.7± 4.8 m.y. K-Ar, but this probably is too old. Tba, late Miocene, on Burns quadrangle map, Greene, et al (1972). (This is #29506 by Geochron in 1971.)

ROCK DESCRIPTION: Basalt.

STRUCTURE: Approximately flat.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -44.0 | 182.7 | 4 | 3.1 | 3.5 | 57.7 | 71.8S | 127.3W | M |
| 175 Oe. A.C. | -63.0 | 180.8 | 4 | 4.0 | 3957.2 | 1.5 | 89.1S | 104.1E | R |

RESULTS: No rotation since Miocene. Only four samples which would not average out secular variation.

SAMPLE LOCALITY 29863: Little Emigrant Creek, Harney County, Oregon. Section 25, T20S R27E, 43°48.4'N, 119°25.6'W.

AGE: 10.3± .5 m.y. K-Ar. Tdo considered to be Pliocene on Burns quadrangle map, Greene, et al (1972). This is #29500 measured by Geochron in 1971

ROCK DESCRIPTION: Felsic volcanic ash.

STRUCTURE: Gentle dip.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE (LAT.) | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 73.2 | 32.9 | 3 | 2.0 | 1.9 | 144.9 | 64.9N | 77.8W | N |
| 175 Oe. A.C. | 59.5 | 22.9 | 3 | 2.3 | 3.0 | 88.9 | 72.7N | 25.7W | N |

RESULTS: Scatter to great to be useful. Not shown on map.

SAMPLE LOCALITY 29864: Little Emigrant Creek, Harney County, Oregon. Section 34, T20S R27E, 43°47.6'N, 119°27.7'W.

AGE: 9.5± .6 m.y. K-Ar. Tdo considered Pliocene on Burns quadrangle map, Greene et al (1972). This is #29599 measured by Geochron in 1971.

ROCK DESCRIPTION: Basalt.

STRUCTURE: Very gentle dip, 3°.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 38.4 | 17.1 | 4 | 4.0 | 84.4 | 10.1 | 63.7N | 22.3E | N |
| 175 Oe. A.C. | -72.5 | 92.7 | 3 | 3.0 | 96.3 | 12.6 | 37.1S | 18.5E | R |

RESULTS: Unusual direction compared to other localities in Harney Basin. Suggests 87° of counterclockwise rotation. Shown on map but is anomalous. Only three samples used in computation; not enough to average out secular variation.

SAMPLE LOCALITY 29865: Fine Spring Basin, Harney County, Oregon. Section 2, T23S R28E, 43°36.4'N, 119°19.7'W.

AGE: 9.1± .6 m.y. K-Ar. Tdo considered Pliocene on Burns quadrangle map, Greene et al (1972). (This is #29505 measured by Geochron in 1971).

ROCK DESCRIPTION: Basalt.

STRUCTURE: Gentle

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 53.3 | 20.7 | 5 | 5 | 2449.8 | 1.6 | 71.2N | 5.0W | N |
| 175 Oe. A.C. | 52.7 | 21 | 5 | 5 | 1920.9 | 1.8 | 70.7N | 3.9W | N |

RESULTS: 21° clockwise rotation suggested since 9 m.y.b.p. Insufficient samples (5) to average out secular variation.

SAMPLE LOCALITY 29866: Silvies River, Harney County, Oregon. Section 24, T20S R29E, 43°49.4'N, 119°11.3'W.

AGE: Tdo, listed as Pliocene age on Burns quadrangle map, Greene et al. (1972). By comparison to other ages in area for this unit, probable age is 7 to 9 m.y.

ROCK DESCRIPTION: Basalt.

STRUCTURE: Gentle dips.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 22.3 | 23.4 | 4 | 3.8 | 12.0 | 27.7 | 52.0N | 21.6E | N |
| 175 Oe. A.C. | 61.1 | 9.2 | 4 | 3.9 | 27.7 | 17.8 | 83.1N | 18.3W | N |

RESULTS: 9° clockwise rotation since 7 to 9 m.y.b.p. Insufficient samples (4) to average out secular variation.

SAMPLE LOCALITY 29867: Silvies River, Harney County, Oregon. Section 24, T20S R29E, 43°49.4'N, 119°11.3'W.

AGE: 22.1 m.y. ±1.9, K-Ar, Geochron, but this may be too old. In ledge below locality 29866. Below Devine Canyon tuff.

ROCK DESCRIPTION: Basalt.

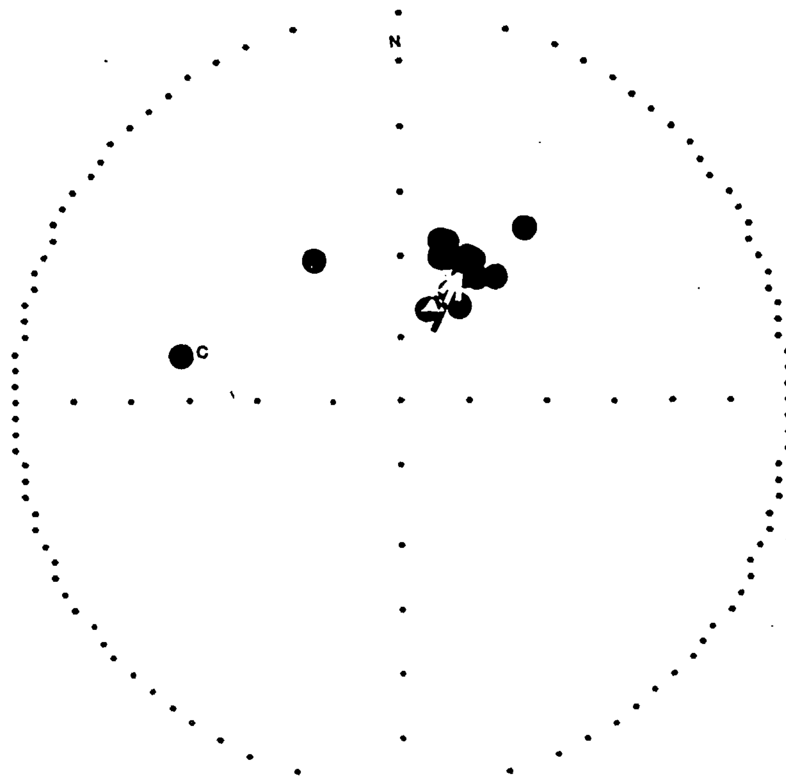
STRUCTURE: Gentle dips.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 74.8 | 95.5 | 4 | 3.9 | 38.6 | 15.0 | 35.1N | 83.6W | N |
| 175 Oe. A.C. | 76.9 | 105.0 | 4 | 4.0 | 244.7 | 5.9 | 33.3N | 90.1W | N |

RESULTS: No display shown because there are only four samples. Direction is shown on map. Excessive rotation (105° clockwise)* is suggested but samples too few to average out secular variation.

SAMPLE LOCALITY 29868: Silvies River, Harney County, Oregon. Section 2, T21S R29E; 43°46.7'N, 119°11.9'W.




Schmidt stereonet display, direction of magnetization after 175 Oe. A.C. demag. ●, ○, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Thought to be equivalent to basalt below Devine Canyon tuff at locality 29867 which has K-Ar age of 22.1 ±1.9 m.y.b.p. This may be too old.

ROCK DESCRIPTION: Andesite or basalt flows.

STRUCTURE: Gentle.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 50.7 | 0.0 | 13 | 9.3 | 3.3 | 27.4 | 77.6N | 60.7E | N |
| 175 Oe. A.C. | 57.5 | 21.0 | 12 | 11.8 | 53.4 | 6.0 | 73.2N | 16.7E | N |

RESULTS: About 21° rotation since 22 m.y.b.p.

SAMPLE LOCALITY 29869: Canyon Creek, Grant County, Oregon. Section 25, T14S R31E, 44°20.7'N, 118°11.6'W.

AGE: Triassic, Brown and Thayer (1966).

ROCK DESCRIPTION: Gabbro from Canyon Mountain complex.

STRUCTURE: Complex but overlying volcanics fairly gentle.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 55.5 | 291.6 | 4 | 3.0 | 3.0 | 64.3 | 38.6N | 66.8E | N |
| 175 Oe. A.C. | 40.5 | 264.9 | 4 | 2.8 | 2.5 | 75.2 | 12.4N | 171.3E | M |

RESULTS: Too scattered for meaningful results.

SAMPLE LOCALITY 29871: Hampton Butte, Deschutes County, Oregon. Section 2, T21S R20E, 43°46.9'N, 120°16.9'W.

AGE: QTsv, Pliocene and Pleistocene(?), Walker, et al. (1967).

ROCK DESCRIPTION: Grey porphyritic dacite. Probably an intrusive dome.

STRUCTURE: Massive, not certain of bedding.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -14.4 | 1.0 | 4 | 3.8 | 12.8 | 26.8 | 38.9N | 58.4E | R |
| 100 Oe. A.C. | -73.6 | 208.1 | 4 | 3.6 | 8.2 | 34.1 | 66.8S | 97.0E | R |
| 200 Oe. A.C. | -76.0 | 95.2 | 4 | 3.6 | 7.5 | 36.0 | 40.5S | 24.1E | R |

RESULTS: Results appear to be unstable. Not plotted on map.

SAMPLE LOCALITY 29872: Middle Fork Camp Creek, Deschutes County, Oregon. Section 22, T19S R20E, 43°54.8'N, 119°18.8'W.

AGE: Eocene or Oligocene, Walker et al (1967).

ROCK DESCRIPTION: Samples from basalt blocks in Clarno flow breccia.

STRUCTURE: Uncertain - fairly gentle.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham).

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 19.8 | 29.9 | 4 | 3.2 | 3.8 | 54.3 | 47.5N | 13.1E | M |
| 100 Oe. A.C. | 22.6 | 58.8 | 4 | 2.2 | 1.7 | 109.9 | 30.4N | 16.6W | M |
| 200 Oe. A.C. | -12.4 | 71.4 | 4 | 1.8 | 1.4 | Too scattered. | | | M |

RESULTS: Too scattered for meaningful results. Blocks may have been tumbled after cooling through Curie point. No direction shown on map.

SAMPLE LOCALITY 29873: Middle Fork Camp Creek, Deschutes County, Oregon. Section 27, T19S R20E, 43°54'N, 119°18.8'W.

AGE: Eocene or Oligocene, Walker et al (1967).

ROCK DESCRIPTION: Basalt flow in Clarno formation.

STRUCTURE: Poor 5 to 10° east component of dip.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -11.0 | 216.1 | 3 | 2.8 | 10.4 | 40.5 | 40.3S | 170.6W | M |
| 100 Oe. A.C. | -42.0 | 216.1 | 3 | 2.8 | 10.5 | 40.1 | 54.7S | 171.5E | R |
| 200 Oe. A.C. | -54.1 | 219.2 | 3 | 2.9 | 22.4 | 26.7 | 58.6S | 153.3E | R |

RESULTS: 39° clockeise rotation is suggested since Eocene or Oligocene. Samples too few to average out secular variation. Direction is shown on map but no display shown here because N is small.

SAMPLE LOCALITY 29874: Pine Mountain, Deschutes County, Oregon. Section 28, T20S R15E, 43°48.5'N, 120°56.2'W.

AGE: Unknown. Tvs, Miocene or Pliocene on map by Walker (1973).

ROCK DESCRIPTION: Vesicular basalt.

STRUCTURE: Approximately flat.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -27.0 | 219.6 | 3 | 2.4 | 3.5 | 79.7 | 45.2S | 177.8E | M |
| 100 Oe. A.C. | -40.5 | 211.1 | 3 | 2.9 | 19.4 | 28.7 | 57.2S | 177.9E | R |
| 200 Oe. A.C. | -49.8 | 201.4 | 3 | 3.0 | 89.0 | 13.1 | 68.5S | 179.7E | R |

RESULTS: About 21° of clockwise rotation since Miocene or Pliocene(?). Only three samples probably would not average out secular variation. Agrees fairly well with locality 29875 in paleomagnetic direction.

SAMPLE LOCALITY 29875: Pine Mountain, Deschutes County, Oregon. Section 14, T20S R15E, 43°50.2'N, 120°53.6'W.

AGE: Tob, Pliocene, Walker, G. W., et al. (1967).

ROCK DESCRIPTION: Dense black basalt.

STRUCTURE: Approximately flat.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -43.0 | 221.1 | 4 | 3.9 | 25.0 | 18.7 | 51.8S | 164.8E | R |
| 100 Oe. A.C. | -50.6 | 207.7 | 4 | 4.0 | 207.6 | 6.4 | 64.9S | 169.5E | R |
| 200 Oe. A.C. | -56.3 | 208.8 | 4 | 4.0 | 245.3 | 5.9 | 67.1S | 156.8E | R |

RESULTS: A few degrees of clockwise rotation possibly are indicated. 200 Oe. A.C. demag results are shown on map. Only four samples probably would not average out secular variation.

SAMPLE LOCALITY 29876: Gum Boot Canyon, Harney County, Oregon. Section 22, T22S R27E, 43°37.2'N, 119°28.0'W.

AGE: Tdo considered Pliocene on Burns quadrangle map, Greene et al (1972). However, most consistent K-Ar dates appear to be about 9 m.y. (late Miocene).

ROCK DESCRIPTION: White banded rhyolite flow.

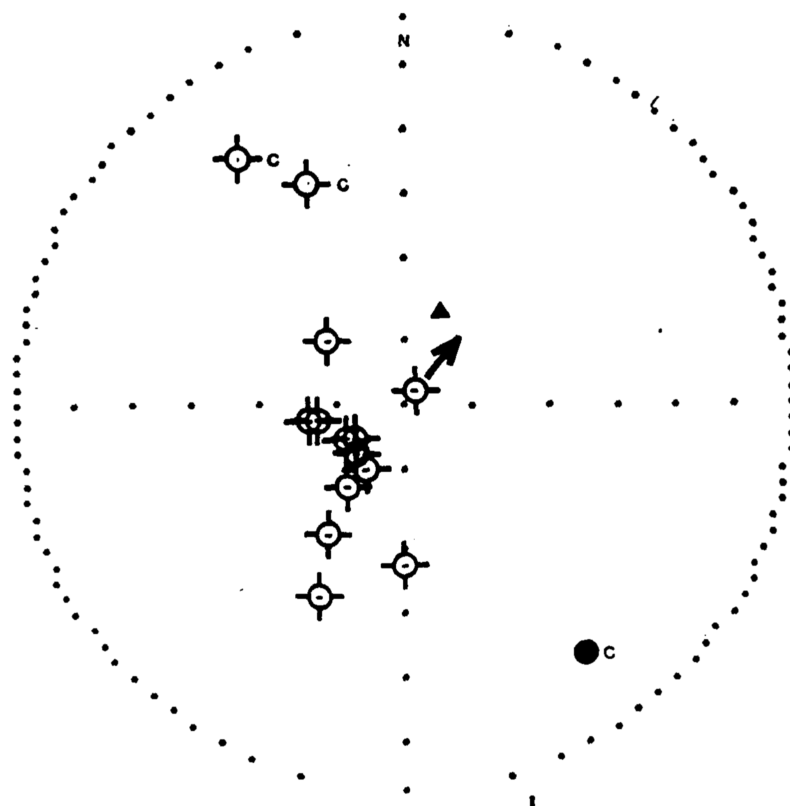
STRUCTURE: Near horizontal.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -58.4 | 217.9 | 5 | 3.3 | 2.4 | 64.1 | 61.5S | 146.4E | R |
| 100 Oe. A.C. | -62.0 | 117.9 | 5 | 4.6 | 10.1 | 25.3 | 88.4S | 46.4W | R |
| 200 Oe. A.C. | -59.8 | 191.8 | 4 | 4.0 | 352.9 | 4.9 | 80.8S | 164.3E | R |

RESULTS: About 12° clockwise rotation is suggested since late Miocene. Only four samples which might not average out secular variation.

SAMPLE LOCALITY 29877: Dry Mountain, Harney County, Oregon. Sections 11 and 14, T22S R26E, 43°40.0'N, 119°45.9'W.




Schmidt stereonet display, direction of magnetization after 175 Oe. A.C. demag. ● . ⌖ , north-seeking polarity downward and upward, respectively; ▲ , present north-seeking geomagnetic field direction in east-central Oregon; ➡ , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: 8.6± .5 m.y. K-Ar age from upper unit. Tha on Burns quadrangle map, by Greene et al (1972), listed as Miocene and Pliocene andesite.

ROCK DESCRIPTION: Blocky, dense to vesicular, fine-grained basalt or andesite. 430 feet of section measured, eight apparent flow units, average thickness about 55 feet.

STRUCTURE: Strike east-west, 5 to 10 degrees north dip.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -32.9 | 304.1 | 15 | 5.5 | 1.5 | 53.9 | 10.0N | 113.5E | M |
| 175 Oe. A.C. | -72.7 | 223.7 | 12 | 11.5 | 22.7 | 9.3 | 59.6S | 106.6E | R |

RESULTS: All except one sample are reversed paleomagnetism. About 44° clockwise rotation suggested since 9 m.y.b.p.

SAMPLE LOCALITY 29878: Juntura, Malheur County, Oregon. Section 9, T21S R38E, 43°45.5'N, 118°4.2'W.

AGE: 14.5 m.y. K-Ar, Geochron. Tba, Miocene, on Burns Quadrangle Map, Greene et al (1972).

ROCK DESCRIPTION: Dark grey aphanitic basalt or andesite.

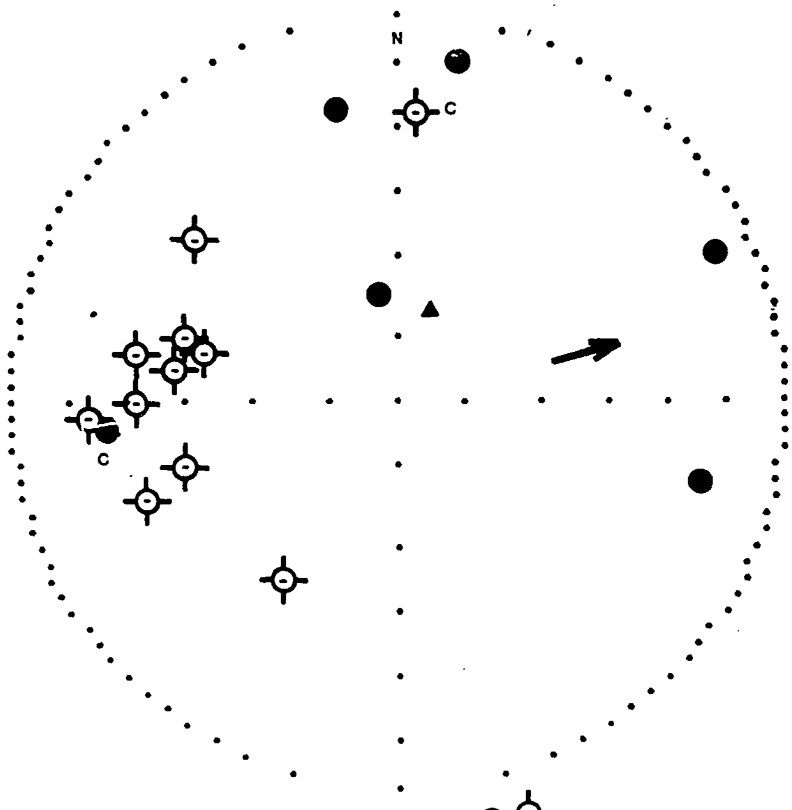
STRUCTURE: Approximately east-west strike, 12° north dip.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -64.9 | 195.4 | 4 | 4.0 | 534.4 | 3.2 | 78.8S | 130.9E | R |
| 100 Oe. A.C. | -41.0 | 182.5 | 4 | 3.5 | 5.7 | 42.4 | 69.6S | 124.6E | R |
| 200 Oe. A.C. | -65.5 | 194.9 | 3 | 3.0 | 424.32 | 1.9 | 78.9S | 146.4E | R |

RESULTS: About 15° clockwise rotation since 15 m.y.b.p. Shown on map. Too few samples to average out secular variation. Not shown here because of small N.

SAMPLE LOCALITY #29881: Cartwright Canyon, Boise County, Idaho. Section 29, T6N R3E, 43°50.1'N, 116°7.4°W.




[illegible] stereonet display, [illegible] 300 Oe. A.C. [illegible]

AGE: 41.5 m.y., 16 m.y. (both are K-Ar dates but are from different laboratories; second date is more reasonable).

ROCK DESCRIPTION: Black aphanitic basalt with small (.2 mm) plagioclase phenocrysts. Thought to be equivalent to sample locality 2985[illegible].

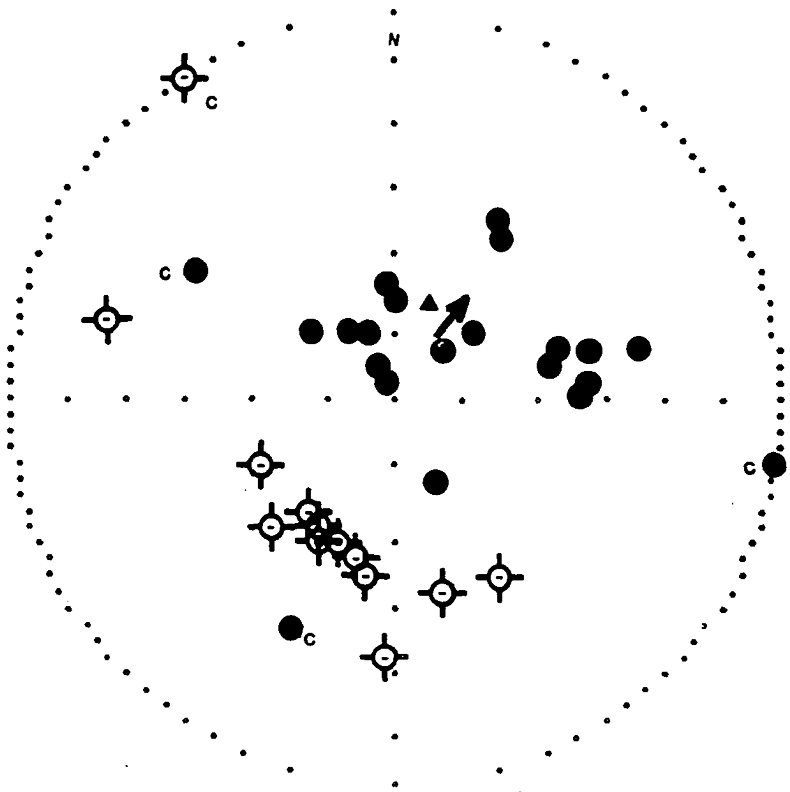
STRUCTURE: Average strike north 51°east, dipping 31° northwest.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -21.6 | 9.8 | 18 | 8.4 | 1.8 | 38.6 | 30.4N | 52.7E | M |
| 100 Oe. A.C. | -50.5 | 314.4 | 18 | 9.8 | 2.1 | 32.9 | 1.0N | 109.6E | M |
| 200 Oe. A.C. | -55.6 | 299.9 | 18 | 11.7 | 2.7 | 26.3 | 9.6S | 109.1E | M |
| 300 Oe. A.C. | -40.9 | 256.1 | 16 | 13.0 | 5.1 | 18.2 | 26.3S | 147.3E | M (Display) |

RESULTS: Paleomagnetic results suggest clockwise motion of 76° since 16 m.y.b.p. This is greater than surrounding localities and may suggest insufficient samples to average out secular variation or complicated folding.

SAMPLE LOCALITY 29882: Squaw Creek, Gem County, Idaho. NE¼ Section 33, T11N R1E, 44°14.7'N, 116°18.3'W.




Schmidt stereonet display, direction of magnetization after 175 Oe. A.C. demag. ●, ⊕, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Upper unit is 15.9± .9 m.y. K-Ar (sample 29884, Geochron Lab., measured 1972). 16.7± 2.5 m.y. in section equivalent to lower unit (sample 29451, Geochron Lab., measured 1970).

ROCK DESCRIPTION: 900' of section measured but base not exposed. 13 flow units, thickest is 110'. Alternating dense and vesicular basalt or andesite.

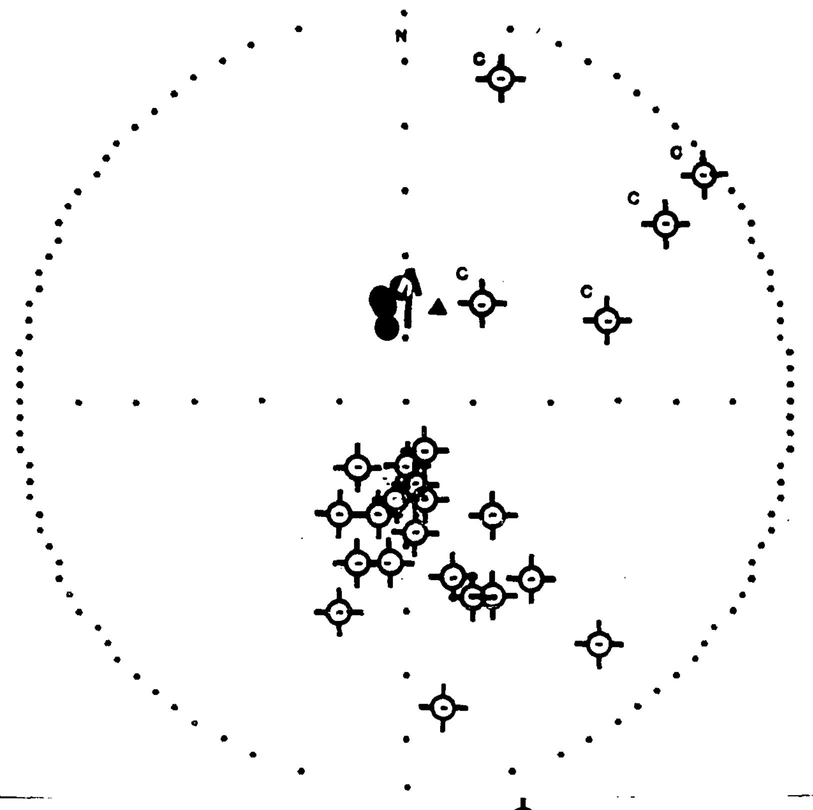
STRUCTURE: Strike S10E, dip 13° west. Overlaps Idaho batholith intrusives three miles to east.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN DEC. (DEG.) | MEAN INC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 71.2 | 53.9 | 38 | 15.9 | 1.7 | 28.0 | 54.6N | 84.5W | M |
| 175 Oe. A.C. | 64.4 | 36.5 | 32 | 29.4 | 11.9 | 7.7 | 64.4N | 43.6W | M (Display) |

RESULTS: 36.5° rotation suggested since 16 m.y.b.p. Polarity from top of section is 12 samples reverse, 25 samples normal.

SAMPLE LOCALITY 29885: Crane Creek, Washington County, Idaho. Section 7, T11N R3W, 44°18.2'N, 116°44.3'W.




Schmidt stereonet display, direction of magnetization after 200 Oe. A.C. demag., , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: No age date but volcanics are Columbia River Basalt of Miocene age. Overlapped by Payette formation.

ROCK DESCRIPTION: Black fine-grained basalt. Central portion is vesicular.

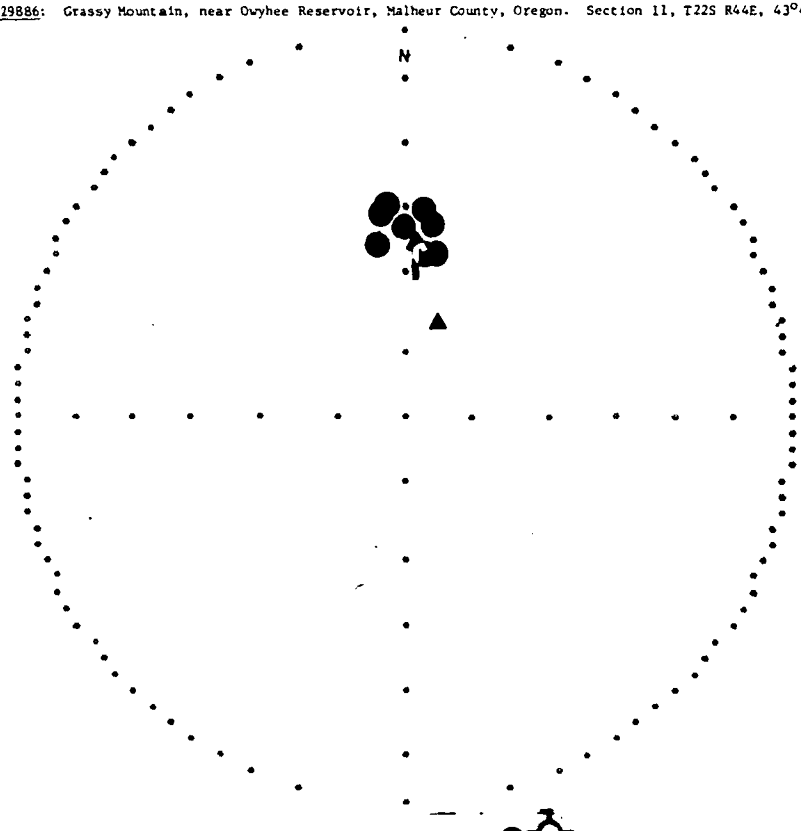
STRUCTURE: Approximately flat.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -21.4 | 203.3 | 32 | 14.9 | 1.8 | 27.9 | 51.2S | 155.0W | M |
| 100 Oe. A.C. | -52.6 | 187.2 | 32 | 19.8 | 2.5 | 20.4 | 77.5S | 145.7W | M (mostly R) |
| 200 Oe. A.C. | -63.0 | 180.4 | 32 | 30.0 | 15.2 | 6.7 | 89.7S | 123.7E | M (display) |

RESULTS: Results suggest no rotation since Miocene. Uppermost four samples normal, rest are reversed.

SAMPLE LOCALITY 29886: Grassy Mountain, near Owyhee Reservoir, Malheur County, Oregon. Section 11, T22S R44E, 43°40.5'N, 117°17.6'W.




Schmidt stereonet display, direction of magnetization after 175 Oe. A.C. demag. , , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Dates for Grassy Mountain Basalt are 7.3, 7.6 and 9.3 m.y. K-Ar from Geochron.

ROCK DESCRIPTION: Grassy Mountain Basalt. Overlies Owyhee Basalt.

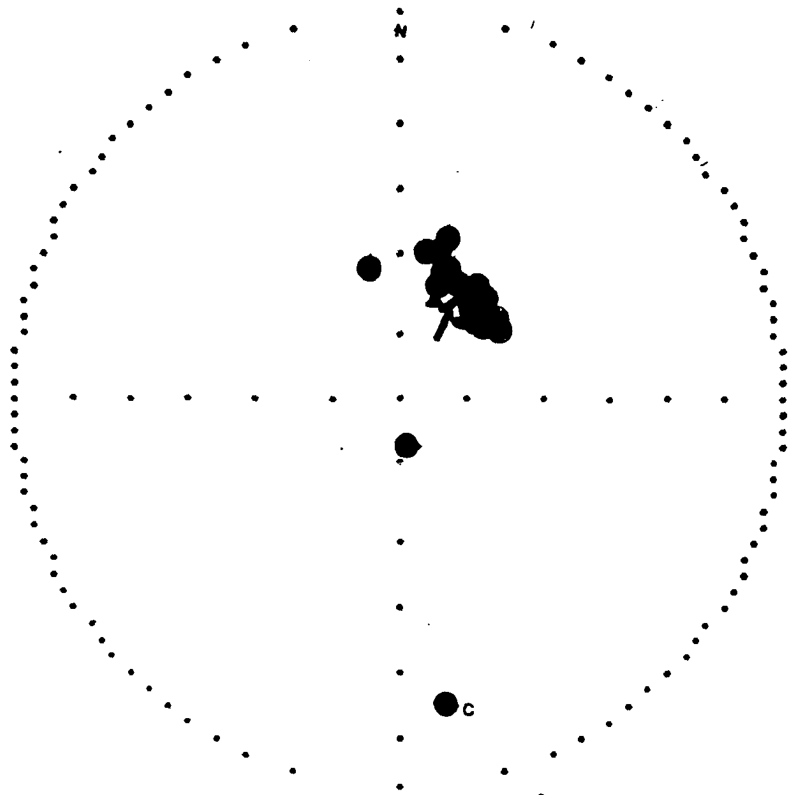
STRUCTURE: Gentle.

PALEOMAGNETIC RESULTS:

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 96 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 47.5 | 4.1 | 8 | 7.7 | 23.4 | 11.7 | 74.6N | 49.1E | N |
| 175 Oe. A.C. | 51.1 | 3.1 | 8 | 8.0 | 158.5 | 4.4 | 77.9N | 50.1W | N (Display) |

RESULTS: Results suggest 3° clockwise rotation since 7 m.y.b.p. However, number of samples (8) may be insufficient to average out diurnal variation.

SAMPLE LOCALITY 29887: Owyhee Reservoir, Malheur County, Oregon. Sections 20 and 21, T22S R44E, 43°38.7'N, 117°20.6'W.




Schmidt stereonet display, direction of magnetization after 175 Oe. A.C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Various samples are 12.5, 14.4, 15.1, 15.2 m.y.b.p. K-Ar. Watkins and Baksi (1974) have 5-mile distant locality with 13.5 m.y. K-Ar age. Average of 4 ages, 14.3 m.y.

ROCK DESCRIPTION: Owyhee Basalt. Total of 1340 feet measured, total of 18 apparent flow units. Alternating finely crystalline and scoriaceous basalt or andesite. Lower 260 foot thick unit is massive flow foliated rhyo-dacite. Twenty feet of weathered cobble surface on rhyo-dacite indicates erosion prior to Owyhee basalt deposition.

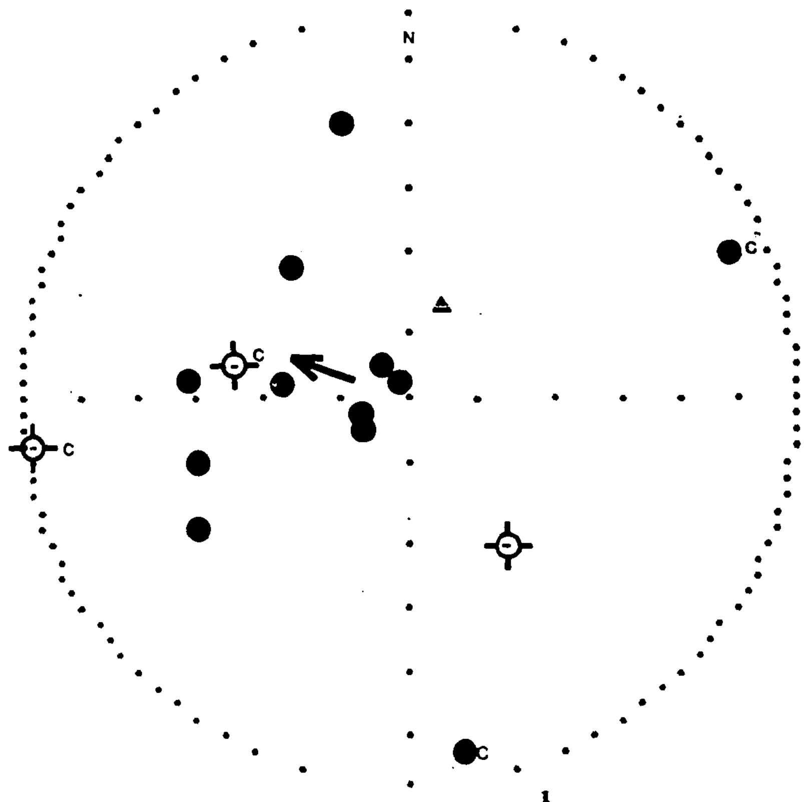
STRUCTURE: Gentle. Lower rhyo-dacite unit overlies tuffaceous sediment.

PALEOMAGNETIC RESULTS: (Measured by C. E. Helsley)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 70.1 | 27.5 | 28 | 26 | 13.5 | 7.7 | 69.3N | 67.0W | N |
| 175 Oe. A.C. | 65.1 | 30.3 | 27 | 26.6 | 71.0 | 3.3 | 68.6N | 47.2W | N (Display) |

RESULTS: 30° clockwise rotation since 14 m.y.b.p. Agrees remarkably well with locality by Watkins and Baksi (1974) five miles away. All samples normally magnetized.

SAMPLE LOCALITY #29888: Squaw Butte, Owyhee County, Idaho. Sections 12&13, T2S R5W, 43°15.6'N, 116°52.5'W.




Schmidt stereonet display, direction of magnetization after 300 Oe. A.C. demag. , north-seeking polarity downward and upward, respectively; , present north-seeking geomagnetic field direction in east-central Oregon; , tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Thought to be correlative to Columbia River or Steens Mountain Basalt. Tcr on Idaho State Geologic Map, Ross and Forrester (1959). Sixteen miles to south, age is 16.6± 4 m.y. for lower basalt unit (Panze /1972/).

ROCK DESCRIPTION: 500 feet of section measured. Upper units dense, black massive, well-bedded flows. Lowest 50 feet unit is dense porphyritic basalt with large plagioclase laths.

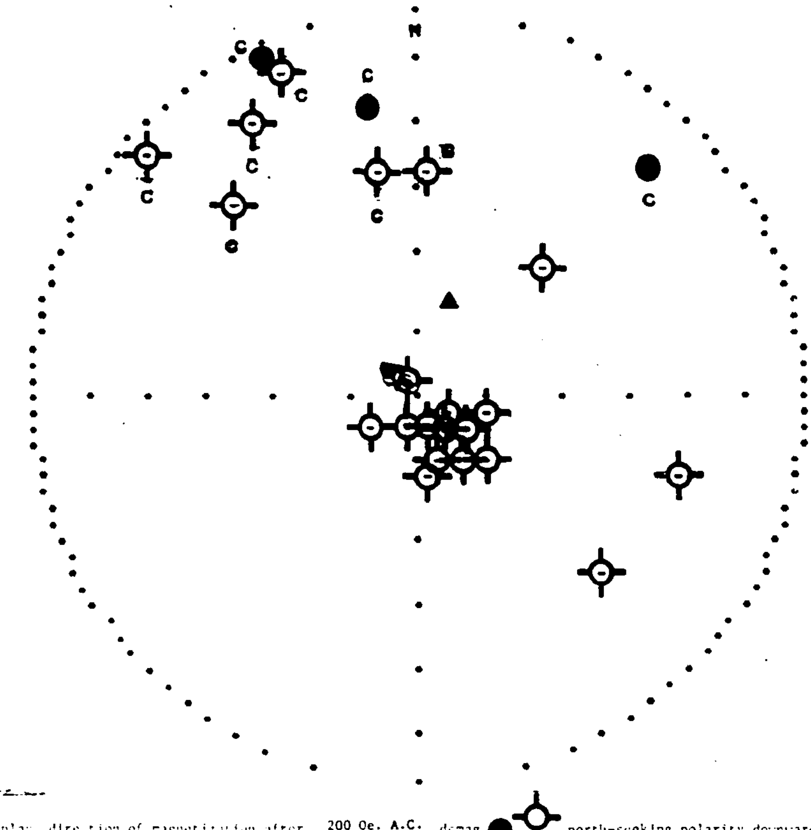
STRUCTURE: Strike S5W, dip 6°W. Four miles northwest of Cretaceous intrusive which these volcanics overlap.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | 50.3 | 329.9 | 15 | 5.6 | 1.5 | 53.3 | 63.3N | 136.0E | M |
| 100 Oe. A.C. | 46.6 | 292.5 | 15 | 6.1 | 1.6 | 49.2 | 34.6N | 160.6E | M |
| 200 Oe. A.C. | 57.2 | 273.2 | 15 | 9.7 | 2.6 | 29.6 | 26.9N | 179.2W | M |
| 300 Oe. A.C. | 64.2 | 287 | 11 | 9.8 | 8.1 | 17.1 | 39.9N | 176.9W | M (Display) |

RESULTS: May suggest 43° counterclockwise rotation. Mostly normal magnetization, three reversed samples in lower part of section. This is opposite to direction of most areas and may represent small microplate or complex folding.

SAMPLE LOCALITY 29890: Reynolds Creek, Owyhee County, Idaho. Section 21, T2S R3W, 43°14.1'N, 116°41.2'W.




Schmidt stereo net display, direction of magnetization after 200 Oe. A.C. demag. ●, ⌖, north-seeking polarity downward and upward, respectively; ▲, present north-seeking geomagnetic field direction in east-central Oregon; ➡, tip of arrow denotes position of mean north-seeking sample points or reflected south-seeking points; C denotes culled or rejected points deleted from final statistics.

AGE: Equivalent to Columbia River or Steens Mountain Basalts, Tcr on Idaho State Geologic map, Ross, C.P., and Forrester, J. D., (1959). Twenty miles to south, age 16.6± 4 m.y. for lower basalt unit (Panze /1972/).

ROCK DESCRIPTION: Vesicular basalt. 800 feet of section, 27 samples. Individual units 20 to 130 feet thick.

STRUCTURE: Strike S30°E, dip 30° to west. Deposited unconformably on Cretaceous granitic rock.

PALEOMAGNETIC RESULTS: (Measured by W. L. Basham)

| TREATMENT | MEAN INC. (DEG.) | MEAN DEC. (DEG.) | N | R | PRECISION FACTOR (K) | ALPHA 95 (DEG.) | VIRTUAL POLE LAT. | VIRTUAL POLE LONG. | NORMAL REVERSE MIXED |
|---|---|---|---|---|---|---|---|---|---|
| N.R.M. | -56.5 | 4.4 | 27 | 13.7 | 2.0 | 28.3 | 9.5N | 59.8E | M |
| 100 Oe. A.C. | -65.6 | 6.8 | 27 | 12.0 | 1.7 | 32.0 | 1.2S | 58.7E | M |
| 200 Oe. A.C. | -81.4 | 130.3 | 16 | 15.6 | 39.7 | 5.9 | 52.1S | 42.3E | R (Display) |

RESULTS: 50° counterclockwise motion suggested since Miocene. This may be a local block rotated oppositely to most of the other volcanic sample areas. Another possibility is hydrothermal alteration associated with ore bearing fluids. More scatter is present than for other volcanic areas measured. Polarity from top to bottom is 2 samples N, 3 samples R, 1 sample N, 20 samples R. Dip is so steep that rotation may be highly inaccurate.