5-27-1988

Geochemical Stratigraphy of the Dooley Rhyolite Breccia and Tertiary Basalts in the Dooley Mountain Quadrangle, Oregon

David Neale Whitson

Portland State University

AN ABSTRACT OF THE THESIS OF David Neale Whitson for the Master of Science in Geology presented May 27, 1988

Title: Geochemical stratigraphy of the Dooley Rhyolite Breccia and Tertiary basalts in the Dooley Mountain quadrangle, Oregon.

APPROVED BY THE MEMBERS OF THE THESIS COMMITTEE:

[redacted]

Marvin H. Beeson, Chair

[redacted]

Ansel G. Johnson

[redacted]

Paul E. Hammond

[redacted]

Daniel J. Scheans

The Dooley Rhyolite Breccia in northeast Oregon was erupted between 12 and 16 million years ago, from central vents and linear feeder dikes within the Dooley Mountain quadrangle. The peraluminous, high-silica rhyolites of the formation were erupted over an irregular highland of eroded pre-Tertiary metamorphic rocks locally overlain by intracanyon, Eocene Clarno-type basalt flow(s). The Dooley

Rhyolite Breccia is exposed in a tectonically disrupted, north-south trending graben across the Elkhorn Range. The formation is variable in thickness with maximum thickness exceeding 660 meters in the south and 600 meters in the north half of the quadrangle. Volumetrically the formation is dominated by block lava flows with lessor associated volcaniclastic and pyroclastic rocks. Although initial and waning phases of eruption of the formation produced ash-flow tuffs which extend well beyond the quadrangle boundaries, volcanism within the quadrangle appears to have been primarily effusive. At least nine geochemically distinct rhyolite subunits belonging to four related chemical groups have been identified in the formation stratigraphy which appear to represent unique eruptive episodes. Chronologic geochemical patterns within the formation are consistent with a petrogenetic model of repeated partial melting and eruption from multiple silicic magma chambers in an attenuated continental crust. Basalts correlative with the Powder River Basalt and the Strawberry Volcanics overlie the Dooley Rhyolite Breccia on the north flank of Dooley Mountain. Calc-alkaline basalts correlative with the Strawberry Volcanics are overlain by thoeliitic basalts of uncertain affinity on the south flank of the mountain. These basalt flows on respective flanks of the mountain were not continuous across the quadrangle. Rhyolitic volcanism in the Dooley Mountain quadrangle is contemporary with the

Strawberry Volcanics and the Picture Gorge Basalt of the Columbia River Basalt Group.

GEOCHEMICAL STRATIGRAPHY OF THE DOOLEY RHYOLITE BRECCIA AND TERTIARY BASALTS IN THE DOOLEY MOUNTAIN QUADRANGLE, OREGON

by

DAVID NEALE WHITSON

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

MASTER OF SCIENCE
in
GEOLOGY

Portland State University

1988

TO THE OFFICE OF GRADUATE STUDIES:

The members of the Committee approve the thesis of David Neale Whitson presented May 27, 1988.

[redacted]

Marvin H. Beeson, Chair

[redacted]

Ansel G. Johnson

[redacted]

Paul E. Hammond

[redacted]

Daniel J. Scheans

APPROVED:

[redacted]

Ansel G. Johnson, Chair, Department of Geology

[redacted]

Bernard Ross, Vice Provost for Graduate Studies

ACKNOWLEDGMENTS

The author would like to acknowledge the valuable assistance and guidance provided by the faculty of the Department of Geology, Portland State University who have contributed to the ideas and methods employed during this study. I would like to thank Dr. Marvin H. Beeson for help provided in understanding the geochemical analysis procedures and for acting as a patient sounding board during thesis preparation, Dr. Ansel Johnson for assistance in computer manipulation of the geochemical data base, and Dr. Paul Hammond for discussions of volcanic processes and for providing much needed bibliographic reference data which were useful during this writing. Appreciation is also expressed for the financial assistance and car parts graciously provided by Mr. Frank Peterson of the Supreme Perlite Company of Portland, Oregon and also funds provided by Oregon's DOGAMI.

The author would also like to acknowledge informal discussions which took place upon several meetings in the study area with Mr. Jim Evans of the U.S.Geological Survey. On these occasions stimulating two-way discussions of specific outcrop characteristics and structural interpretation of the Dooley Rhyolite Breccia type section area provided insight in guiding the thesis field

investigation. Structural information and interpretations presented in this study is generated for the most part from integration of one or more sets of data provided through original field observations, geomorphic interpretation, and geochemical data. The author fully appreciates that structural interpretations in some segments of the thesis study area have been influenced by the informal ideas expressed by Mr. Evans.

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CHAPTER I

INTRODUCTION

The Dooley Rhyolite Breccia is exposed across the salient of pre-Tertiary metamorphic rocks which form the southeastern extension of the Elkhorn Range in the Blue Mountains of northeast Oregon. The most complete stratigraphic sequence of Tertiary volcanic rocks which overlies this salient is exposed within and adjacent to the boundaries of the Dooley Mountain 7 1/2′ quadrangle. Tertiary lavas and pyroclastic rock units form 90 percent of the upland area in the Dooley Mountain quadrangle. Volcanic rocks in the quadrangle include rhyolites of the Dooley Rhyolite Breccia and both Paleogene and Neogene basalts.

The major focus of this study is to describe the geology and geochemical stratigraphy of the Dooley Rhyolite Breccia within the Dooley Mountain 7 1/2′ quadrangle. Also described is the geology, geochemistry, and regional correlations of mafic volcanic rocks found there. Volcanic stratigraphy within the Dooley Mountain quadrangle and in the surrounding region are examined in an effort to establish a bridge for stratigraphic correlation of Mid to Upper Miocene formations from north to south across the backbone of the Elkhorn Ridge which separates the Powder and Burnt River Valley in northeast Oregon.

STUDY AREA DESCRIPTION

The Dooley Mountain quadrangle is located in Baker County, approximately 20 km south of the city of Baker, Oregon. The quadrangle is in the west-central segment of the Baker 1^{o} X 2^{o} quadrangle map sheet (Brooks and others, 1976) between latitudes 44^{o} 30′ N and 44^{o} 37′ 30" N, and longitudes 117^{o} 52′ 30" E and 117^{o} 45′ E.

Geologic mapping in support of this study was restricted to the three areas shown in Figure 1. The two areas designated SA 1 and SA 2 are located within and immediately adjacent to the Dooley Mountain quadrangle. The third area, designated SA 3, is located in the Lower Powder River Valley to the northeast.

Each area was selected for study for the following reasons. SA 1 contains the best outcrop exposures of the Dooley Rhyolite Breccia and Tertiary basalts in the quadrangle. Soil cover in this portion of the quadrangle, although substancial, does not mask the geology as is most often the case elsewhere. The most intensive mapping was done within SA 1 in the Dooley Mountain quadrangle. Sa 2 was selected for study because of the excellent exposures of basalt flows which overlie the Dooley Rhyolite Breccia on the north flank of Dooley Mountain. The third area of

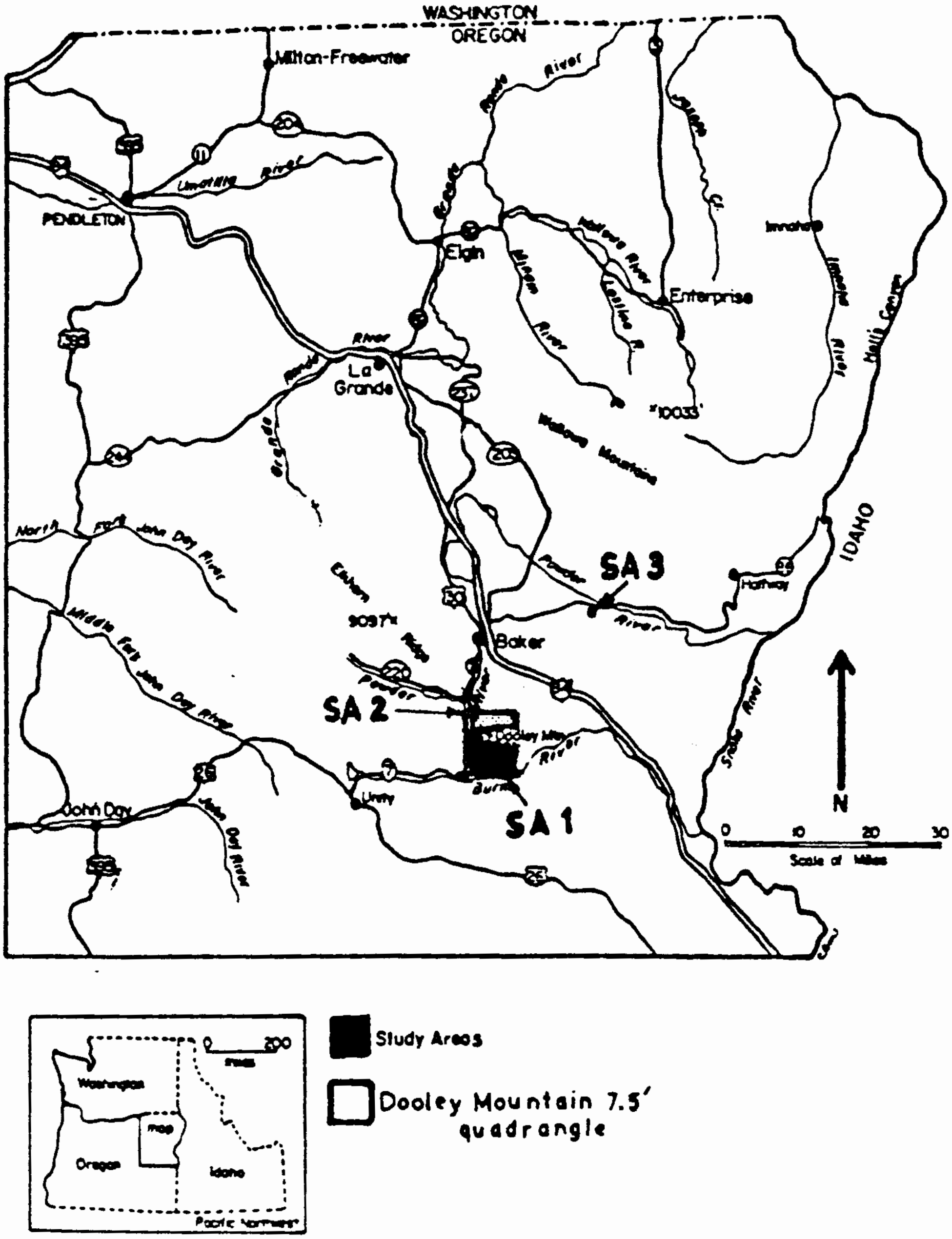


Figure 1. Location map showing the study areas in northeast Oregon.

study, SA 3 is far removed to the northeast of the Dooley Mountain quadrangle in the Lower Powder River Valley. Here rhyolitic rocks were mapped by Gilluly (1937) as portions of the Dooley Rhyolite Breccia. Subsequent workers (Brooks and others, 1976) excluded the rhyolitic rocks north of the Dooley Mountain quadrangle from the formation. No clear evidence was cited for the exclusion of these rock units, but compelling evidence for inclusion of these rocks within the formation remained. It was decided that geochemical sampling of these rock units could provide a difinitive solution to the question of whether the rhyolites in the Powder River Valley were indeed derived from Dooley Mountain.

Map area SA 1 contains approximately 62 km^2 within portions of T11S and T12S, R40E. The northern boundary of SA 1 is formed by the ridge divide between Hill #6278, Dooley Mountain, and Beaver Mountain. The southern boundary is at the margin of the quadrangle sheet in the Burnt River Valley. The western boundary is delineated by Coronet Creek, and the western boundary of the quadrangle. The eastern boundary of SA 1 is defined by a line drawn from the summit of Beaver Mountain to the south along Auburn Creek and Dark Canyon. SA 2 is located on the east side of Stices Gulch in sections 6, 7, and 18 (T11S R40E), on the north flank of Dooley Mountain and encompasses approximately 7 km^2 in portions of the Dooley Mountain and Bowen Valley quadrangles. The third study area investigated, designated

SA 3, contains less than 2 km^2. This area is located 35 km to the northeast of the summit of Dooley Mountain in the Keating 7.5′ quadrangle in sections 1 and 2 of T09S R42E, three kilometers south of Middle Bridge in the Lower Powder Valley.

Both SA 1 and SA 2 are accessed from Baker to the south via state highways 7 and 245 and U.S.F.S. roads in the Wallowa-Whitman National Forest. Study area SA 3 is accessible from Baker, 24 km to the northeast via state highway 86 and then south 1.6 km from the highway, along Ritter Creek road.

GEOMORPHOLOGY, SOILS, AND VEGETATION

Topography within SA 1 and SA 2, as well as throughout the Dooley Mountain 7.5′ quadrangle is characterized by steepsided, elongate ridges separated by deeply incised vee-shaped canyons. In terms of geomorphic maturity the incised volcanic terrane appears to be in the late-youth stage of development. The northern boundary of SA 1 is drawn along the crest of a WNW-trending divide separating tributary systems draining to the north into the Powder River and to the south and southeast into the Burnt River. Drainage patterns on both sides of the divide are dendritic, with both consequent and subsequent reaches within the quadrangle. Elevations within areas SA 1 and SA 2 range from 1200 to 2090 meters.

Much of the quadrangle is mantled by soils formed under forest vegetation and have been classified as Western Brown Forest, Regosol, or Lithosol soils by Franklin and Dyrness (1969). In upland portions of the quadrangle Alpine Turf and Meadow soils were also observed. Western Brown Forest, Regosol, and Lithosol soils cover most of the north half and a substantial portion of the south half of the Dooley Mountain quadrangle. Soil thicknesses are greatest in the northern half of the quadrangle, while the southern half is typically covered with one to several feet of soil. Rock units within SA 1 show little tendency to form continuous outcrop exposures. Most of the information about the bedrock geology in SA 1 was pieced together from scattered, discontinuous outcrops exposed in erosional windows through colluvium and soil on valley walls with slopes at or near their angle of repose. Although Tertiary volcanic rock units are best exposed in SA 1 the soil cover obscures much of the detail of rock unit geology and structure.

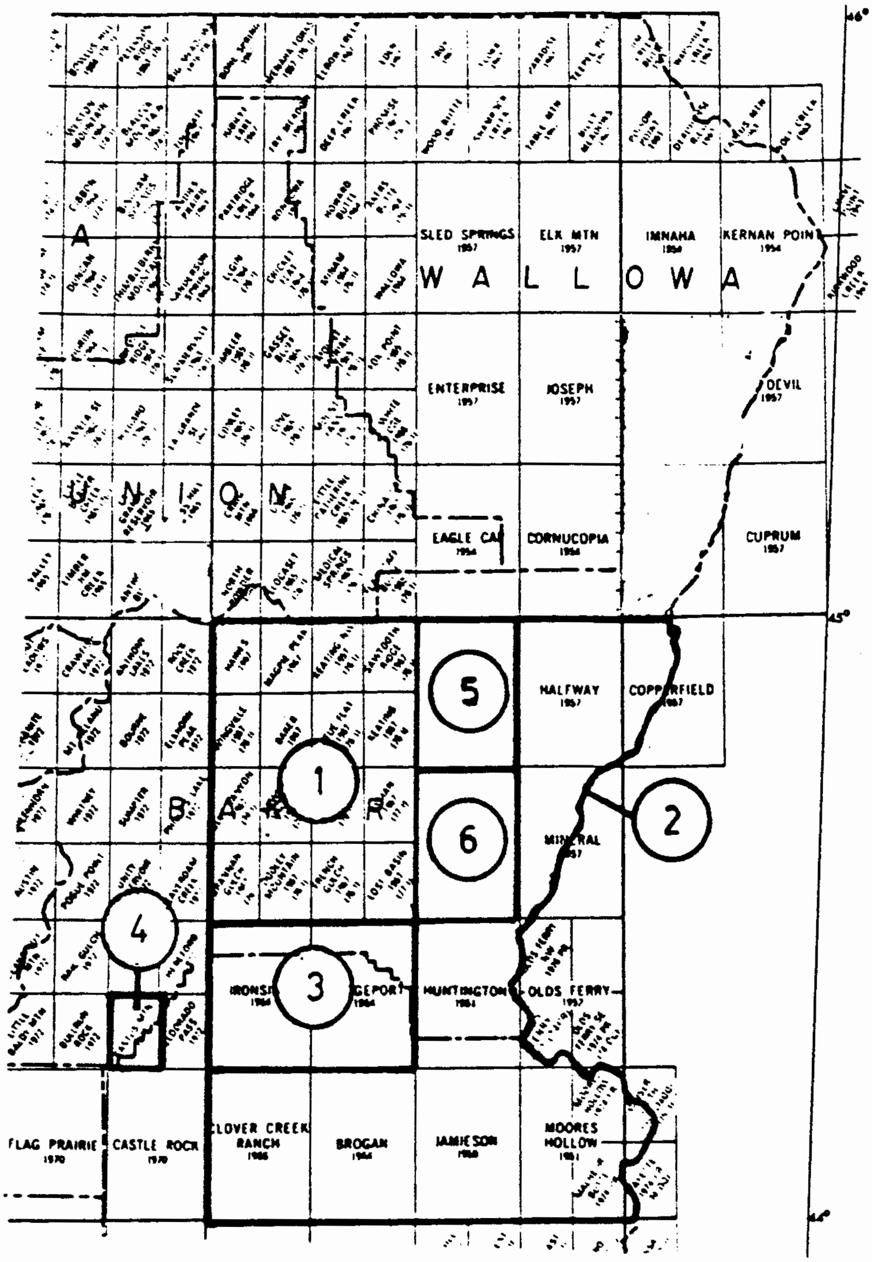
The quadrangle is substantially forested. Climax forest composition includes the dominant Pinus ponderosa (ponderosa pine) forest stands interfingered at lower elevations with associated Pinus contortus (lodgepole pine) or Abes grandis (grand fir). Climax stands of Populus tremuloides (quaking aspen) (Franklin and Dyrness, 1969) are found in riparian zones, valley floors, and spring areas at all elevations in the quadrangle.

Striking vegetation aspect changes were observed at formation boundaries between Tertiary volcanic rocks and pre-Tertiary metamorphic rocks in SA 1. Aspect changes are also noted along the trace of the inferred contact between rock units of the Dooley Rhyolite Breccia and overlying basalt flows examined in SA 2. These were generally manifested as rapid transition from climax Pinus ponderosa forest above rhyolitic rock to Artemisia (sage brush) dominated steppe and/or shrub-steppe plant communities (Franklin and Dyrness, 1969) on soils formed from basalt or metamorphic rock.

Study area SA 3 in the lower Powder River Valley is of low relief and sparsely covered by Artemisia climax communities developed upon thin fine to medium grained Lithosol. The topography consists of low rolling hills and bluffs formed by dendritic, locally incised drainages. Pyroclastic, silicic ash-flow tuffs and interbedded coarse volcanogenic cobble conglomerates are exposed in minor cliff forming outcrops along the slopes of the bluffs in SA 3, and dip gently to the north toward the axis of the Powder River Syncline (Prostka, 1967).

PREVIOUS GEOLOGIC INVESTIGATIONS

The locations of published investigations pertinent to this study are shown in Figure 2. The Dooley Mountain quadrangle geology was originally mapped at 1:125000 scale as part of the Baker 30′ quadrangle (Gilluly, 1937). In the



1. Gilluly (1937)
2. Brooks et al (1976)
3. Wolff (1965)
4. Lowry (1943)
5. Prostka (1962)
6. Prostka (1967)

Figure 2. Location map showing previous geologic investigations related to the study area.

text accompanying the map of Gilluly (1937), pre-Tertiary to Recent rock formations were named and formation type sections were designated. The Dooley Rhyolite Breccia and overlying basalt flows were described in designated type localities at Dooley Mountain from exposures in Mill Creek canyon and Stices Gulch. The Dooley Rhyolite Breccia and other Tertiary volcanic formation descriptions, physical constraints, and areal distribution have since been refined by various investigators (Beaulieu 1972; Brooks and others, 1976; Brown and Thayer, 1966). Revisions to the study areas were presented in the 1:25000 scale geologic map of the Oregon part of the Baker 1° X 2° quadrangle and accompanying text (Brooks and others, 1976).

Geologic investigations of areas proximal to the Dooley Mountain quadrangle which have been examined include 1) geologic investigations within the Burnt River Canyon (Ashley, 1966); 2) mapping of the northern half of the Caviness 30′ quadrangle (Wolff, 1965); 3) mapping in the NE 1/4 of the Ironside 30′ quadrangle in the vicinity of Rastus Mountain south of Unity, Oregon (Lowry, 1943); and 4) geologic investigations in the Sparta 7.5′ quadrangle (Prostka, 1963) and the Durkee quadrangle (Prostka, 1967).

CHAPTER II

METHODS OF STUDY

A combination of geologic mapping, geophysics, geochemistry, and statistics were used in this study to characterize the Tertiary volcanic rocks in the Dooley Mountain quadrangle. Specific methods employed in the study are described.

GEOLOGIC MAPPING

Rock units within study areas SA 1 and SA 2 were mapped on a 1:12000 scale during this study. These maps were subsequently scaled to 1:24000 for presentation in the geologic map of the Dooley Mountain quadrangle shown in Plate 1. Geologic information in areas peripheral to SA 1 and SA 2 in the Dooley Mountain quadrangle is taken from published data (Gilluly, 1937; Brooks and others, 1976).

Metamorphic rocks of the Burnt River Schist are the oldest rocks exposed in the quadrangle. This assemblage of metavolcanic and metasedimentary rocks form the basement complex and is unconformably overlain by intracanyon(?) and flood type basalt flows and ash-flow tuff and block lava flows of the Dooley Rhyolite Breccia. The basalts found within the quadrangle are of three distinct chemical types and stratigraphicly bracket the Miocene rhyolites. Following a brief description of the pre-Tertiary rocks, the geology and geochemistry of the basalts and rhyolites which dominate the geologic terrane in the quadrangle are described in their order of age from oldest to young.

PALEOMAGNETIC INVESTIGATION

The paleomagnetic orientation of the Neogene basalt flows which onlap the Dooley Rhyolite Breccia were measured in the field with a portable flux-gate magnetometer. Orientations were measured in an attempt to correlate the basalt flows from north to south across Dooley Mountain as well as to attempt to correlate them with components of the Columbia River Basalt Group.

GEOCHEMICAL METHODS

The principle method of analysis of all rock types in this study was neutron activation analysis (NAA) following the methods prescribed by Muecke (1980). Irradiation of NAA samples was conducted at the Oregon State University Radiation Center. Splits of 1 gram were made from crushed rock samples, which were irradiated with standards for one hour in a neutron flux of 300 kw. Standards used included USGS standards GSP-1, BIR-1, and OSU standard CRB-3 (chemically identical to USGS standard BCR-1). Induced gamma ray activities were counted at Portland State University utilizing a Ge(Li) detector and Tracor Northern

4000 digital computer system and programs. Peak search data were further reduced utilizing a Zenith microcomputer and PSU Geology department program INAA.FOR version 1.1 (Beeson and Keedy, unpublished program, 1986). Whole rock analysis for major oxide and minor elements was performed on selected samples utilizing X-ray fluorescence (XRF) techniques were performed by P.R. Hooper at Washington State University.

GEOSTATISTICAL METHODS

Geochemical data from felsites, obsidians, and perlites from the Dooley Rhyolite Breccia were reduced by several methods to a meaningful form. Techniques of geostatistical data reduction, correlation, and discriminant analysis (Davis, 1986) were aimed at discriminating cogenetic flow units and identifying chemical patterns represented in the Dooley Rhyolite Breccia. The procedures used in this study were initiated by forming a computer data base of all samples listing their respective analysis data for the eight immobile elements identified in comparative study of cogenetic rock samples discussed in a later chapter. A matrix of correlation coefficients between immobile elements was calculated from the data base. Element pairs with calculated correlation coefficients greater than $\pm$ 0.8 were combined into ratios and reformed into a secondary data base. Covariance coefficients between these ratios were calculated and a covariance matrix was constructed. Ratio components in the data base which showed covariance coefficients of less than $\pm$ 0.2 were selected for further statistical comparison.

Initially only the felsites and obsidians were formed into a data base for statistical correlation. Six elemental ratios with low covariance factors, including La/Fe, Ce/La, Ce/Fe, Ce/Lu, Rb/Yb, and Ba/Rb were formed into a computer data base for cluster analysis using program CLUSTER.FOR (Davis, 1986). Clustered samples of felsites and obsidians were clearly seen to represent four distinct geochemical groups containing nine subgroups. These groups and subgroups were separated within the data base and input into program NDISCRM.FOR (Davis, 1986) in order to test the statistical validity of group separations identified by cluster analysis.

The second correlation group contained perlites as well as selected felsites and obsidians from the nine geochemical subgroups identified. Because Fe was shown to be mobile in perlites, and unreliable as a statistical component, a different set of elemental ratios were used to identify chemically related perlites, felsites, and obsidians within the formation. Ratios between Ce/La, Ce/Lu, Rb/Yb, Ba/Rb, and Sm/Tb were calculated for all of the perlite and selected felsite and obsidian samples in the population. The resulting secondary data base was input into the cluster analysis program to define chemical similarities between perlites and samples from the nine geochemical subgroups previously identified. Perlites were correlated in this manner with selected felsite and/or obsidian samples and accordingly assigned to geochemical subunits of the Dooley Rhyolite Breccia previously defined by cluster and discriminant analysis.

CHAPTER III

GEOLOGIC SETTING

The Dooley Mountain quadrangle lies transverse to the axis of the Elkhorn Range in northeastern Oregon. The basement rock of the quadrangle is comprised of metamorphosed island arc, central melange facies of sedimentary and volcanic rocks which were accreted to the western continental margin and intruded by granitic stocks and batholiths during Cretaceous time (Dickinson and Thayer, 1978). These metamorphic rocks form the roots of the Elkhorn Range and are contemporary with the central melange terrane exposed elsewhere in the Blue Mountains.

The metamorphic rocks of melange terrane in the Elkhorn Range are isoclinally folded with regional strike directions oriented near east-west. The axial planes of these folds dip steeply to the south in the Elkhorn Range, and fold axes plunge to the east or west at less than 30 degrees. This terrane is also cut by east-west and northeast trending shear zones which predate the batholithic rocks which intruded the melange terrane during the Cretaceous (Taubeneck, 1957). Since the orogenic accretion of the central melange terrane sometime in the late Mesozoic (Brooks, 1979), tectonic uplift in the Elkhorn Range must have resulted in vertical uplift on the order of five to seven km in order for batholithic rocks in the range to be unroofed.

The regional tectonic features exclusive of isoclinal folding are seen in the basement rocks of the Dooley Mountain quadrangle. The character of the pre-Tertiary rocks in the Dooley Mountain quadrangle are described below. This is followed by a discussion of the structural features of the Dooley Mountain study area. In the study area components of the Burnt River Schist are exposed in tectonicly disrupted blocks. In addition to the east-west shear zones the melange terrane is disrupted by north-south and northwest-trending faults within the Dooley Mountain quadrangle. These tectonic features crosscut the volcanic rocks ranging from upper Paleogene to Neogene age which unconformably overlie the basement complex in the Dooley Mountain quadrangle.

PRE-TERTIARY ROCKS

The stratigraphic record represented within the Dooley Mountain quadrangle is devoid of late Mesozoic and early Cenozoic rocks (Brooks and others, 1976). Metamorphic rocks of the Burnt River Schist in the Dooley Mountain quadrangle are designated the Mz_{BRS} unit on Plate 1. These rocks form the basement complex of the Dooley Mountain quadrangle. General observations of Burnt River Schist lithology indicate that pelitic phyllite and phyllitic quartzite are the most common rock types present. Lesser, discontinuous coarse grained marble and green, serpentinized metavolcanic (Ashley, 1966) rock units are also present in the Burnt River Schist of SA 1. Map unit Mz_{BRS} is equivalent to the MzPzs unit of Brooks and others (1976).

Foliations measured in the Burnt River Schist at adit portals along Auburn Creek in section 13 and at the Juniper Hill Mine in section 14 (T12S R40E) showed generally consistent strike directions varying from 270 to 290 degrees with dips varying from 20 to 40 degrees to the south. These foliation attitudes are similar to those measured three km northwest of SA 1 on Bald Mountain. In the northeast 1/4 of section 15 (T12S R40E) the structural grain of the Burnt River Schist is crosscut by several parallel vertical or high-angle, south-dipping shear zones ranging from three to thirty meters wide. These strike west, parallel to the trend of the Burnt River Schist formation contact with Tertiary volcanic rocks. Components of the Burnt River Schist are exposed in structural highs in SA 1 in sections 6, 11, 12, 13, 14, 15, and 24 (T12S R40E), and in SA 1 in section 31 (T12S R40E). Stratigraphic relationships between the metamorphic basement and Tertiary volcanic rocks in the Dooley Mountain quadrangle are shown in Figure 3.

The Burnt River Schist, shown on Plate 1, in the northwestern corner of SA 1 is in structural juxtaposition with the Dooley Rhyolite Breccia. Mesozoic rock units are

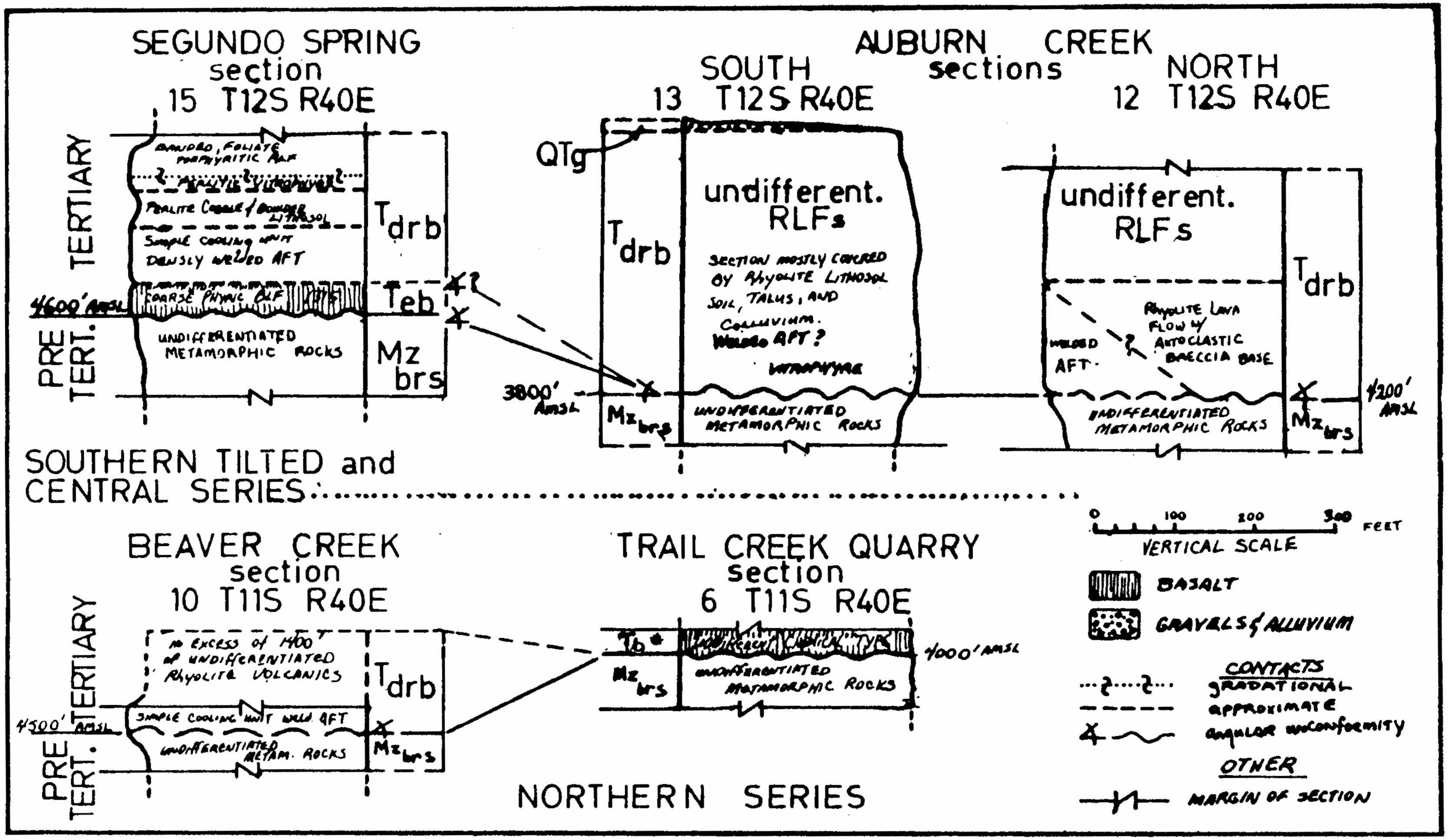


Figure 3. Composite stratigraphic sections showing contact relations between pre-Tertiary metamorphic and Tertiary volcanic rocks in the Dooley Mountain and Bowen Valley quadrangles.

upthrown along north and northeast-trending faults. Along the eastern margin of the Dooley Rhyolite Breccia as mapped by Brooks and others (1976), Mesozoic rocks are upthrown to the west along north-trending faults in Dark Canyon, in the French Gulch quadrangle.

Rock units of the Dooley Rhyolite Breccia unconformably overlie and intrude the Burnt River Schist in the southeastern portion of SA 1 in the Dooley Mountain quadrangle. The unconformity between the Dooley Rhyolite Breccia and the Burnt River Schist seen in widely separated outcrops in sections 11, 13, and 14 (T12S R40E) are notably devoid of intervening sedimentary rock units. The only intervening formation consists of a thin, coarsely phyric basalt lava flow apparent in small outcrops and Regosols present in the eastern 1/2 of the NW 1/4 of section 15 (T12S R40E). This basalt predates the Dooley Rhyolite Breccia and is not present north of the Dooley Mountain-Beaver Mountain divide.

In the northern half of the quadrangle the Burnt River Schist is exposed in the bottom of Beaver Creek section 10, and near the confluence of Trail Creek and Stices Gulch in a rock quarry in section 6 (T11S R40E) of the Bowen Valley quadrangle in study area SA 2. In Beaver Creek in section 10 the Burnt River Schist is overlain by a single welded ash-flow tuff cooling unit and successive components of the Dooley Rhyolite Breccia. In Section 6 (T11S R40E) in a quarry between Stices Gulch and Trail Creek in the Bowen

Valley quadrangle the Burnt River Schist is directly overlain by basalt flows which postdate the Dooley Rhyolite Breccia.

TECTONIC STRUCTURE IN THE DOOLEY MOUNTAIN QUADRANGLE

One of the most difficult problems faced in this study was the detailed characterization of structural deformation within the quadrangle. Poor exposures and the lack of identifiable stratigraphic marker horizons in most areas frustrate clear definition of displacement magnitude and directions. Offset relationships at intersections of major structural features are often masked.

The study area within the Dooley Mountain quadrangle has been informally subdivided into three parts for the purposes of discussion. These subdivisions are shown in Figure 4. They include in SA 1, the southern tilted series (STS) and the central series (CS) areas. Study area SA 2 is contained within the northern series (NS). Structural styles in each subdivision area differ primarily in direction and magnitude of displacement although orientation of faults observed is similar. An interpretive north-south oriented geologic crossection showing these structural relationships is depicted on Plate 1.

The Southern Tilted Series of SA 1

The southern tilted series (STS) is formed from at least four fault blocks oriented in an east-trending, three

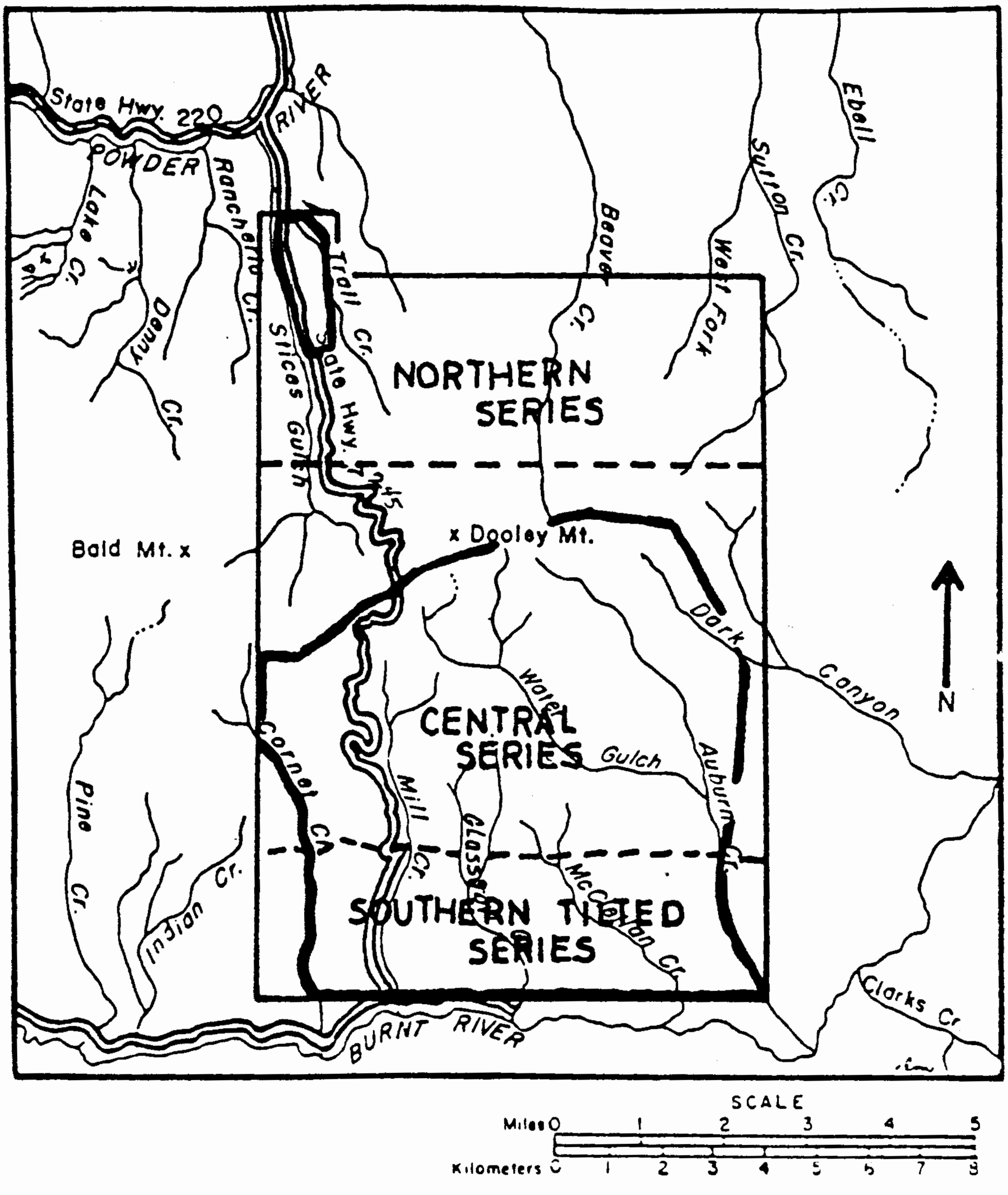


Figure 4. Map showing the tectonic subdivisions of the Dooley Mountain quadrangle.

km wide, linear belt along the southern margin of the Dooley Mountain quadrangle. Rock formations including pre-Tertiary metamorphic to upper Cenozoic volcanic rocks are displaced by the faults in the southern tilted series area. Drainages which transect the STS east of Mill Creek show a strong northwestern deflection coincident with faults separating individual blocks in the series. To the west of Mill Creek, drainages transecting the STS trend north and do not show any marked deflection.

Individual fault blocks of the STS are upthrown on their northern margins along east-west-trending faults parallel to the shear zones described in the pre-Tertiary metamorphic basement rocks in section 15 (T12S R40E). Rock units displaced on individual fault blocks dip from 30 to 40 degrees to the south or southeast toward the Burnt River. Field relationships in the STS indicate that structural displacement along north and northwest-trending faults which control drainage patterns predate the dominant east-west trending faults along the northern margin of the STS. Apparent displacement along east-west-trending faults is primarily vertical and rotational with down throw to the south. Most recent movement along fault planes in the STS is shown by slickensides which plunge between five and fifteen degrees east, along east-west-trending faults in the Dooley Rhyolite Breccia flow units.

Fixing the magnitude of offsets along fault sets noted in mapping of scattered outcrops in the STS is difficult.

structural disruption with relatively small vertical displacements (<30 meters) in Mill Creek and Coronet Creek are noted. Elsewhere offsets are less distinct or are not apparent. Vertical offsets along the east-west-trending faults at the northern boundary of the STS are estimated to be on the order of 200 to 300 meters.

Structure of the Central Series

The central series (CS) area of SA 1 is primarily an incised, tectonically fragmented, volcanic terrane dissected by a partly consequent and subsequent north, northwest, and west-trending dendritic tributary system of the Burnt River. Rhyolite flows, dikes, and pyroclastic units of the Dooley Rhyolite Breccia, and pre-Tertiary rocks are offset by faults of many orientations in the CS area. North, northwest, northeast, and east-west-trending faults bound structural blocks and show varying degrees of displacement in the CS area.

Persistent topographic breaks in slope along ridge lines of the northern and central areas of the CS are considered coincident with intraformational flow unit contacts within the Dooley Rhyolite Breccia. Dip angles were calculated within some of the individual structural blocks using laterally extensive stratigraphic marker beds and/or flow unit margins marked by persistent breaks in slope. Calculated attitudes show that flow units dip at low angles to the south or southeast from 5 to 10 degrees.

Faulting along the eastern margin of the central series in SA 1 has disrupted the Tertiary volcanic rocks along northwest trends parallel to Auburn Creek north of Water Canyon. Here bedding in a single thick laharic breccia dips at 30 degrees east. Foliation planes in flow units between Auburn Creek and Dark Canyon are consistent with this orientation.

The sequence of fault displacement within the CS is interpreted from pre-Tertiary basement displacements. In the western boundary area pre-Tertiary and Tertiary formations are structurally juxtaposed along northeast and north-trending near vertical faults. The metamorphic basement apparently is upthrown at least 770 meters on the west margin of a horst-like fault block. Elsewhere vertical displacements of the metamorphic basement and overlying Tertiary volcanic rocks of the CS occur along north and northeast, as well as west-trending faults in sections 11 and 14 (T12S R40E). North and northeast-trending faults are truncated and offset by younger east-west-trending faults in Auburn Creek and Water Canyon near the eastern boundary of SA 1. Northwest-trending faults near the northern boundary of the southern tilted series are also offset by east-west-trending faults in section 15 (T12S R40E). Similarly vertical displacement of geochemical units of the Dooley Rhyolite Breccia occurs along east-west-trending fault(s) in the northern half of SA 1. Relative offset along these faults indicates the presence of an east-west-trending graben structure through the central portion of SA 1 which postdates north, northwest, and northeast-trending faults in the area.

Vertical displacements and relative magnitude of movements along individual fault sets are difficult to resolve, but it is clear from field evidence that latest movement has occurred along east-west-trending faults resulting in at least 300 meters of vertical displacement along Water Canyon between Rooster Rock Spring and the tributary confluence with Auburn Creek to the east.

Structure of the Northern Series

Generally poor exposures of rock units in SA 2 contained within the northern Series (NS) subdivision of the Dooley Mountain quadrangle provide limited information about the structural nature on the northern flank of Dooley Mountain. Rhyolitic and younger basalt flows in this area are displaced along east-west-trending en echelon normal faults which are downthrown and differentially rotated to the north. Flow units dip from 10 to 20 degrees to the north. These faults post-date a single north-northwest-trending fault which controls the course of Trail Creek in sections 6 and 7 (T11S R40E). Displacement along the north-northwest fault is apparently vertical and down thrown to the west. Displacement on this fault plane is small in magnitude.

SUMMARY

The irregular distribution of Tertiary volcanic formations over the Burnt River Schist, and the lack of intervening sedimentary rock between these rock units in the Dooley Mountain quadrangle indicate that the pre-Tertiary rocks formed a highland of variable, positive relief upon which the volcanic rocks were extruded. This highland acted as a topographic barrier to flows erupted to the south or southwest of the quadrangle, which predate the Dooley Rhyolite Breccia.

The Tertiary volcanic formations appear to be exposed in a north-trending graben structure which is transverse to the structural grain of the metamorphic basement in the quadrangle. The bounding faults postdate the east-west shear zones in the basement complex and crosscut all of the volcanic units of the quadrangle. This graben structure is in turn crosscut and disrupted by east-west-trending faults along which displacement is primarily vertical. A schematic diagram of a north-south cross section across Dooley Mountain is shown on Plate 1. The youngest east-west fault displacements in the quadrangle produced uplift in the central series of an east-west-trending horst block flanked on the north and south by en echelon normal faults. In the northern series displacements of the fault blocks was slightly rotational, and down to the north. On the south side of the mountain displacements along these faults were down and/or rotational to the south.

The sequence of tectonism within the quadrangle and the Elkhorn Range appears to be as follows: 1) late Mesozoic accretion of the central melange terrane to the continental margin accompanied by regional metamorphism and granitic plutonism, and tectonic disruption producing east-west and northeast-trending shear zones and faults (Taubeneck, 1957), 2) orogeny and erosion of the melange assemblage and unroofing of batholiths in the Elkhorn Range, producing a persistent highland through Paleogene time, 3) rhyolitic volcanism and attenuation of the basement complex within the Dooley Mountain quadrangle, normal to the pre-existing structural grain, and north-south graben formation sometime after the initiation of voluminous basaltic eruptions of the Columbia River Group (Goles, 1986) during Middle Miocene time, and 4) Plio-Pleistocene reactivation of deep-seated, east-west basement structures, and uplift along the axis of the Elkhorn Range extending into the Dooley Mountain quadrangle.

CHAPTER IV

PALEOGENE BASALT IN THE DOOLEY MOUNTAIN QUADRANGLE

Basaltic flow rocks which underlie the Dooley Rhyolite Breccia are exposed only in the southwest portion of the quadrangle in sections 17 and 15 (T12S R40E). This basalt is the oldest Tertiary formation in the Dooley Mountain quadrangle and is shown as map unit Teb in Plate 1. The distribution of basalt unit Teb is irregular in the southern portion of SA 1 and is notably absent in exposures of the unconformity between pre-Tertiary and younger formations elsewhere in the Dooley Mountain quadrangle.

The rock unit is composed of a massive, coarsely phyric, glomeroporphyritic olivine basalt flow. This basalt is distinctive from others of the quadrangle in its coarse phyric character. A complete petrographic description of rock sample BAS-1 from this map unit is given in Appendix A. The location of geochemical sample BAS-1 is shown on Plate 2.

The lower contact of the basalt is not exposed in the study area so the total unit thickness cannot be established. Minimum thickness of the Teb unit in Mill Creek is 10 meters. The upper half of the basalt flow exposure is deeply weathered having a poorly developed soil horizon consisting of a conspicuous insitu, red-brown soil intermixed with sphereoidal basalt cobble regolith, grading downward into bedrock. This paleosol horizon is not seen in section 15, but the basalt is substantially obscured by colluvium and the paleosol may be covered. The irregular distribution in the study area suggests that this basalt flow is intracanyon in nature. The basalt of map unit Teb is overlain by a thick, welded, ash-flow tuff cooling unit at the base of the Dooley Rhyolite Breccia in the Mill Creek canyon.

GEOCHEMISTRY AND CORRELATION OF BASALT UNIT TEB

Geochemical data for sample BAS-1 from map unit Teb are presented in Table I. Normative mineral parameters for this basalt were calculated following the methods of Irvine and Baragar(1971) and are presented in Table II. The basalt is quartz normative and is classified as a subalkaline, tholeiite. The tectonic provenance for sample BAS-1 was specified using the terinary Y-Nb-Zr discrimination diagram proposed by Meschede (1986), shown in Figure 5. Sample BAS-1 plots within the volcanic arc basalt field.

Sample BAS-1 was compared geochemically with the basalts of the Clarno Group which include the only basalts of similar provenance in northeastern Oregon. Basalts of the Clarno Group in northeastern Oregon compared on the basis of K_2O vs SiO_2 were shown with sample BAS-1 in Figure 6, to be indistinguishable from basalts from continental

TABLE I

XRF GEOCHEMICAL DATA FROM THE BASALTS OF THE DOOLEY MOUNTAIN QUADRANGLE, OREGON

SAMPLE	SiO2	Al2O3	TiO2	Fe2O3	FeO	MnO	CaO	MgO	K2O	Na2O	P2O5
A-1	52.80	16.55	1.64	2.00	8.00	0.16	9.31	5.90	0.63	2.62	0.39
A-2	53.18	17.03	1.68	2.00	7.25	0.15	9.38	5.52	0.67	2.76	0.39
A-3	52.48	16.82	1.60	2.00	7.85	0.17	9.49	6.06	0.56	2.58	0.38
A-4	53.26	16.70	1.25	2.00	6.60	0.16	8.96	7.70	0.59	2.51	0.28
A-5	52.97	16.57	1.20	2.00	6.66	0.16	9.00	8.13	0.61	2.43	0.28
A-6	53.87	17.43	0.98	2.00	5.83	0.14	10.01	6.83	0.27	2.41	0.22
A-8	53.56	17.20	1.03	2.00	6.16	0.15	9.89	6.96	0.41	2.37	0.26
A-9	51.99	16.64	1.85	2.00	8.78	0.16	9.27	5.97	0.38	2.53	0.44
A-10	52.12	16.28	2.01	2.00	9.23	0.16	9.32	5.42	0.50	2.47	0.50
BAS-1	49.78	17.13	0.92	2.42	8.99	0.22	12.22	4.80	0.22	2.05	0.13

Additional data for sample BAS-1

Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn
40	97	41	254	194	8	282	70	23	2	17	14	79

Oxides in wt. %, all others in ppm.

TABLE II

CALCULATED NORMATIVE MINERAL AND ROCK CLASSIFICATION OF BASALT SAMPLE BAS-1 FROM MAP UNIT Teb AT DOOLEY MOUNTAIN, OREGON

Basalt Sample no.	BAS-1
Normative Mineral	
Quartz	2.71
Orthoclase	1.34
Albite	18.95
Anorthite	37.99
AB % Plag	33.78
Diopside	18.95
Hypersthene	15.81
EN % of Opx	54.47
Magnetite	2.6
Ilmanite	1.32
Zircon	0.01
Apatite	0.28
Color Index	38.96
Differentiation Index	23.01
Normiplag	56.94
Crystallization Index	69.34
Rock Classification	
Alkali subgroup	subalkaline
Subgroup	tholeiitic
Group	Basalt

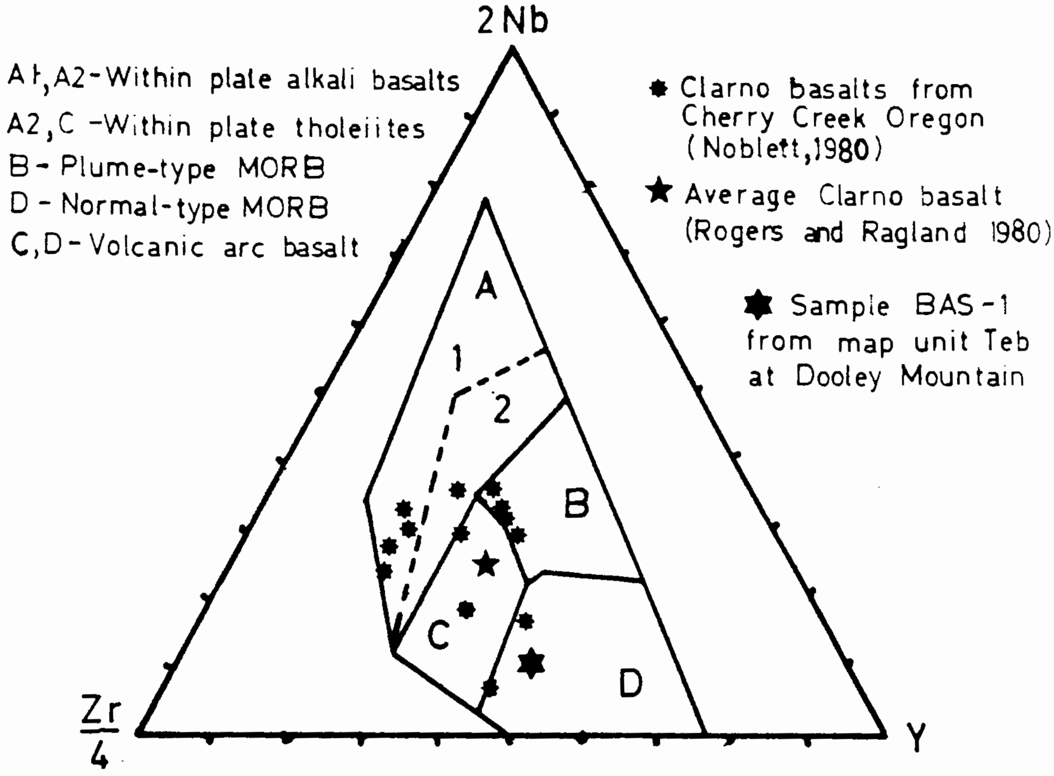


Figure 5. Discriminant diagram showing the tectonic provenance for the Paleogene basalt in the Dooley Mountain quadrangle and selected Clarno basalts. Adapted from Meschede (1986).

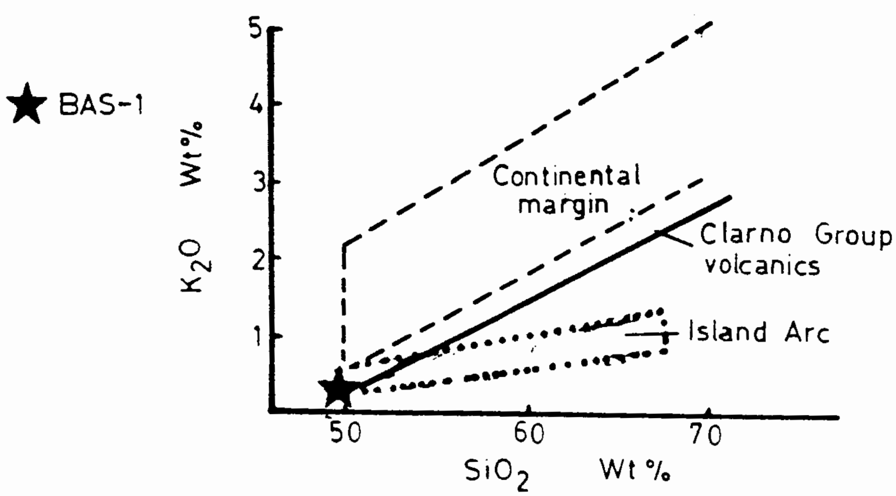


Figure 6. K20-SiO2 relationships in the Clarno Group and sample BAS-1 compared with volcanics in island arc and continental margin settings. Adapted from Rodgers and Ragland (1980).

margin and island arc settings (Jakes and White, 1972). These element ratios were plotted showing continental margin and island arc variation fields, with summarized data from the Clarno Group (Rogers and Novitski-Evans, 1977). Basalt sample BAS-1 from the Dooley Mountain quadrangle plots directly on trend with the Clarno Group volcanics in this diagram. The only geochemical parameter that can be used to distinguish the Clarno Group as a continental margin assemblage is the K/Rb ratio which ranges between 200 and 400 (Novitski-Evans, 1974; Rogers and Novitski-Evans, 1976). The K/Rb ratio in sample BAS-1 is 210. Thus it appears that BAS-1 was erupted as part of a continental margin volcanic assemblage rather than in an island arc tectonic setting.

Sample BAS-1 and basalts of the Clarno Group (Rogers and Novitski-Evans, 1977) are plotted on the Harker variation diagrams of Figure 7. Geochemical similarities exist between the basalts with respect to all relationships plotted. Sample BAS-1 differs slightly from the Clarno basalts in that it contains slightly higher CaO and Al_2O_3. These differences are accentuated by the calculation of the differentiation index (normative Qtz + Ab + An) for BAS-1 of 23.1, compared to an average index value of 34.7 for Clarno basalts from Cherry Creek on the John Day River (Noblett, 1980). Sample BAS-1 has also a high Fe_2O_3 content relative to the Clarno basalts. The above noted compositional differences are not considered significant.

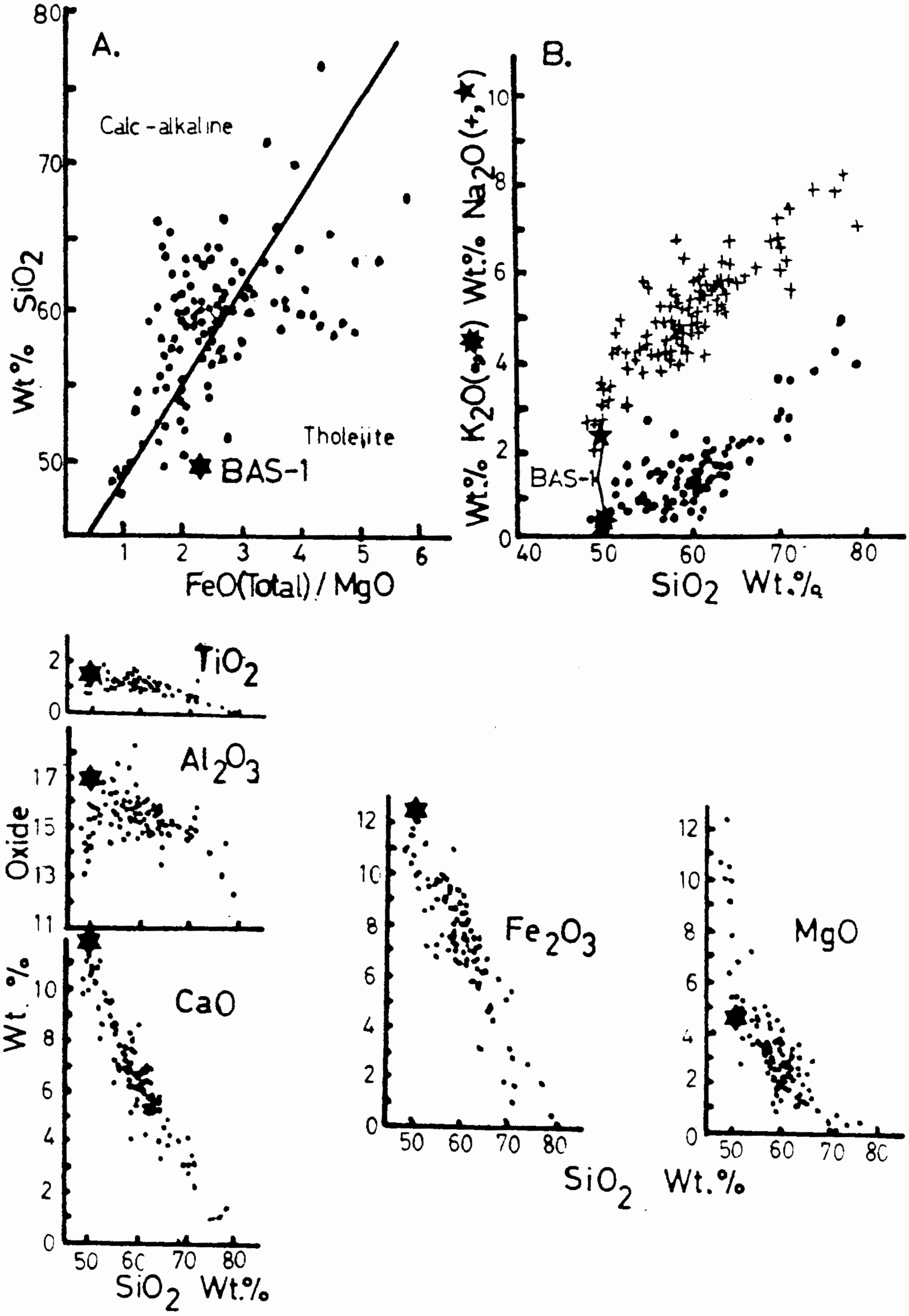


Figure 7. Variation diagrams comparing sample BAS-1 from Dooley Mountain with the Clarno volcanics. Adapted from Rogers and Novitski-Evans (1976).

The basalt flow(s) of map unit Teb in the Dooley Mountain quadrangle are considered correlative with the tholeiitic basalts of the Clarno Group and therefore of Eocene age. The deep paleosol atop the basalt unit is thought to be coincident with the regionally distributed paleosol horizon above the Clarno Group throughout eastern Oregon (Rogers, 1966). Basalt flows which also have been correlated with the Clarno Group underlie rhyolitic rocks in the northeast quarter of the Ironside 30′ quadrangle (Lowry, 1943), southwest of Dooley Mountain.

CHAPTER V

THE DOOLEY RHYOLITE BRECCIA

The Dooley Rhyolite Breccia was described and named from rock units exposed along the canyons of Stices Gulch and Mill Creek in the Dooley Mountain quadrangle (Gilluly, 1937). The formation was described as light-buff to white glassy rocks in huge bouldery breccia masses set in a white matrix with local black or greenish obsidian. Subordinate to these rocks were described spherulitic rhyolite flows and pumice, and glassy flow breccias. Upper flow units of the formation in Mill Creek canyon were described as red andesites which were also considered subordinate to the breccias. The rocks were interpreted as representing coarse fragmental and subordinate lava flows of a volcanic center located somewhere near Mill Creek or Stices Gulch. Detailed geologic mapping and information from measured sections collected during the 1986 field season show this characterization of the Dooley Rhyolite Breccia to be inaccurate.

Rhyolite lava flows in the measured stratigraphic section in Mill Creek make up at least 60 percent of the formation thickness exposed. Elsewhere throughout SA 1 the stratigraphy is clearly dominated by lava flows. Other rock units within the formation include diamictite and laharic breccias, welded and unwelded pyroclastic rocks, and dikes which are all volumetrically subordinate to lava flows. At least four eruptive vents have been located in at least three stratigraphic levels of the formation in the vicinity of Dooley Mountain. Vent types identified include central, composite cone, and linear(?) dike fed vents from which eruption was primarily effusive and lacking significant associated pyroclastic components. Geochemical evidence clearly shows that andesites are not present in the upper stratigraphic units of the formation in Mill Creek, as were described by Gilluly (1937).

The Dooley Rhyolite Breccia represents an accumulation of coarse fragmental material and lava flows within the Dooley Mountain quadrangle. Eruption of these rocks was not from a central source area as originally believed. The widespread distribution of rhyolite dikes which crosscut almost every stratigraphic level in the formation within the quadrangle suggests that eruption of lavas occurred from vents scattered over a wide area in the quadrangle. Numerous localized erosional/depositional intraformational disconformities exist between rhyolite lava flows and pyroclastic units of the formation within the quadrangle indicating that this volcanism was episodic.

Descriptions of the major component rock types observed in the Dooley Rhyolite Breccia during the 1986 field season are presented below. Rhyolite flows, pyroclastic rocks, diamictite breccias, and dikes in the formation are described. Most of the component types were probably produced during each eruptive cycle recorded in the formation and they should thus be considered cogenetic geologic units. Collectively the rhyolitic rocks of the Dooley Rhyolite Breccia form an extensive volcanic upland area encompassing most of the Dooley Mountain quadrangle area. Components of the formation extend beyond the quadrangle in all directions. The following discussion thus begins with a description of the formation distribution and thickness.

THE AGE AND CORRELATION OF THE DOOLEY RHYOLITE BRECCIA

Rock units of the Dooley Rhyolite Breccia form the base of the Middle and Upper Miocene section in the Dooley Mountain quadrangle (Brooks and others, 1976). One K-Ar age date of 14.3 $\pm$ .4 my was obtained from within the formation at 44° 34.5′ N. Lat 117° 48.3 E. Long. (Walker and others, 1974). The dated sample location is in a rock quarry in section 28, (T11S R40E), where an obsidian-bearing perlitic dike crosscuts rhyolite lava flows in the upper stratigraphic levels of the formation. This location coresponds to geochemical sample DMO-2 shown on Plate 2.

The 14.3 my age obtained from this intrusive unit is considered to more closely approximate a youngest activity in the formation rather than oldest. Based upon the age determined from this intrusion the Dooley Rhyolite Breccia is temporally correlative with Dinner Creek welded ash-flow tuff which crops out south of the Dooley Mountain quadrangle. K-Ar dates of the Dinner Creek welded tuff from two locations in Baker County are 14.1 ± .4 and 14.5 ± .4 my., bracketing the age of the Dooley Rhyolite Breccia (Walker and others, 1974). Initial rhyolitic volcanism within the Dooley Mountain quadrangle apparently predates areally extensive basaltic volcanism during Miocene time in this region. Interstratification with basalts on the southern flank of the mountain show that rhyolitic volcanism was at least in part coeval with mafic volcanism to the south or southwest during late Miocene time.

Rhyolitic rock units have been mapped by previous investigators in areas peripheral to, and far removed from, Dooley Mountain quadrangle. These rhyolites include 1) diamictites and obsidian bearing clastic breccias, tentatively correlated with the Dooley Rhyolite Breccia in the lower Tertiary volcanic section mapped in the northern half of the Caviness quadrangle (Wolff, 1965); and 2) rhyolite flows erupted from small, isolated vents in the northeast quarter of the Ironside 30′ quadrangle, on the southwestern flank of Rastus Mountain (Lowry, 1943). Rhyolitic flow units contiguous with the Dooley Rhyolite Breccia also extend to the west of the Dooley Mountain quadrangle into the southeastern corner of the Brannan Gulch quadrangle in T12S R39E.

Ash-flow tuffs in the Ritter Creek section are overlain by tuffaceous sedimentary rocks containing vertebrate fossils of Clarendonian age (Brooks and others, 1976). These ash-flows and related sediments overlie basalts correlative with the Strawberry Volcanics (Brown and Thayer, 1966), as well as pre-Tertiary rocks, in the Powder River Valley.

FORMATION THICKNESS AND DISTRIBUTION

The measured stratigraphic thickness of the Dooley Rhyolite Breccia, in the Mill Creek section and along the southwestern border of the quadrangle exceeds 670 meters. Roughly thirty percent of the Mill Creek section is poorly exposed or covered. In the north-central section of the quadrangle the minimum thickness of the formation in Beaver Creek is approximately 600 meters between the summit of Bald Ridge in section 23, and the bottom of Beaver Creek in section 15 (T11S R40E). These observations of formation thickness are consistent with estimates made by Gilluly (1937). Several measured and composite stratigraphic sections from the southern tilted series in the Dooley Mountain quadrangle are shown in Plate 3.

Gilluly (1937) believed the formation thinned in all directions away from Dooley Mountain. The formation clearly thins to the northeast toward the Lower Powder River Valley where its thickness diminishes to less than 10 meters in SA 3. The east and northwest boundaries of the formation are tectonically disrupted and thinning, other than that produced by erosion of the formation, cannot be clearly demonstrated.

The Dooley Rhyolite Breccia is exposed in its most complete stratigraphic section in Mill Creek canyon. This section was measured transverse to the southern tilted series subdivision of SA 1, where rock units of the formation dip steeply toward the Burnt River. Flow units of the Dooley Rhyolite Breccia are exposed in a south-tilted fault block which is part of the southern tilted series, and extend from the southwestern corner of the quadrangle from Coronet to Pike Creek on the southern flank of Dooley Mountain. Stratigraphic thickness of the rhyolites exposed in this fault block is greater than 330 meters.

The Dooley Rhyolite Breccia unconformably overlies both pre-Tertiary metamorphic basement rocks (Burnt River Schist) and Paleogene basaltic lava flow(s) (T_{eb}). Basal formation contact relationships are shown diagrammatically in Figure 3. The formation is overlain and interstratified with basalt flows of map unit T_b the south flank of Dooley Mountain in the southwestern portion of SA 1. On the north flank of the mountain, basalt flows overlie but do not interfinger with the Dooley Rhyolite Breccia in SA 2. In the Sumpter quadrangle, north and west of these study areas, components of the Dooley Rhyolite Breccia were found interstratified with basalt and andesite flows correlated with the Columbia River basalt by Pardee and Hewett (1914).

RHYOLITE FLOWS AND GLASSY FLOW BRECCIAS

Rhyolitic lava flows dominate the formation stratigraphy throughout the Dooley Mountain quadrangle. Morphologically the flows display many of the features of typical block lava flows described by Macdonald (1972). Individual rhyolite flows exposed in cross section are seen between Mill and Coronet creeks and in road cuts of Highway 245 in section 17 (T12S R40E). Lateral and/or terminal flow margins of flow units show characteristic relationships of block lava flows described by Macdonald (1972) and shown in Figure 8A.

Rhyolite flows are texturally zoned both vertically and laterally. Textural zonation in the rhyolite flows of the Dooley Rhyolite Breccia is analogous to morphological characteristics of Miocene rhyolite lava flows in the Snake River Plain in southwestern Idaho as described by Bonnichsen and Kauffman (1987). A cross section of a typical flow as described by these authors is reproduced in Figure 8b. Similar features are noted in single rhyolite flows in the Basin and Range province of Oregon. One of the most striking examples is exposed in the northern fault scarp of Winter Ridge above the town of Summer Lake in southern Oregon (David Whitson, unpublished data, 1987).

Individual lava flows within the Dooley Rhyolite Breccia vary in thickness from 0 at terminal margins, to greater than 70 meters over lateral distances of less than

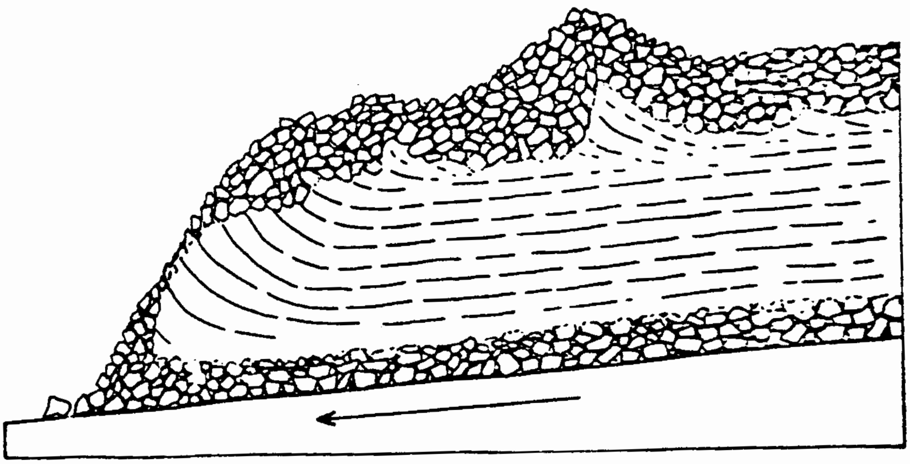


Figure 8a. Diagrammatic cross section of the fron of a block lava flow showing platy jointing. The arrow indicates flow direction (Macdonald, 1972).

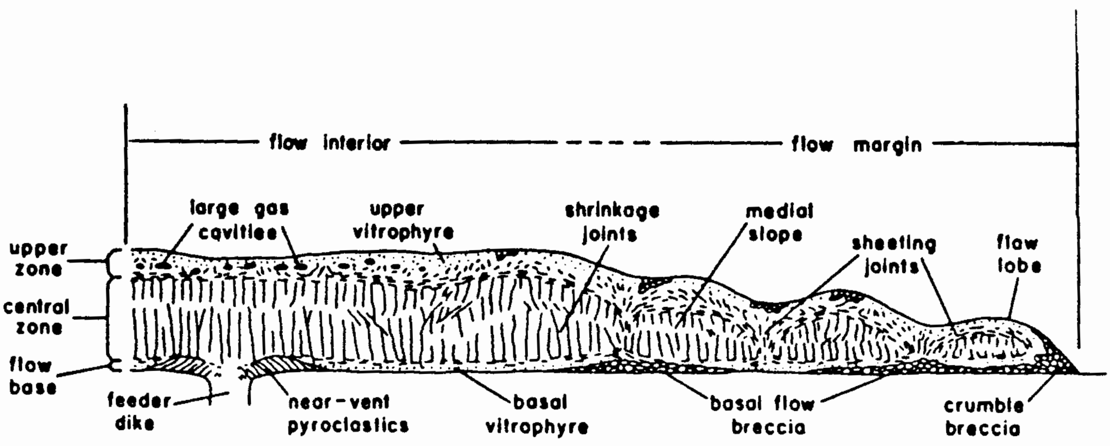


Figure 8b. Schematic diagram showing the textural zonation and features typical to rhyolite lava flows of southwestern Idaho. This idealized longitudinal section combines features found in many flows (Bonnichsen and Kauffman, 1987).

350 meters. Average flow unit thicknesses vary between 70 and 100 meters. Flow units along the west fork of Auburn Creek show lateral continuity in outcrop over four km, and cover at least seven km^2.

Lateral and terminal flow margins are preserved at many stratigraphic levels within the formation. Typical cross sections of these features are shown in Figures 9 and 10. The relative distribution of preserved margins on flow units in Auburn Creek and elsewhere in SA 1 suggest that many of the lava flows in the Dooley Rhyolite breccia were similar morphologically to the Big Obsidian Flow at Newberry Volcano (Higgens and Waters, 1968; Johnson and Donnely-Nolan, 1981).

Rhyolite flows in the formation show complete textural transition from interior to exterior. The interiors of flows are composed of porphyritic felsites with completely cryptocrystalline groundmass textures. These felsites are typically massive and devoid of vesicles. Progressing toward the exterior flow boundaries these felsites show a gradational change to porphyritic, flow banded, and vesicular felsites proximal to the glassy chill margin of the flow. Vesicles in this felsite are normally entrained and flattened parallel to flow margins. They are also completely lined by vapor-phase minerals.

Phenocryst abundances decrease from ten volume percent in felsites in the interior of flows to less than one percent in felsites adjacent to the exterior chill margins.

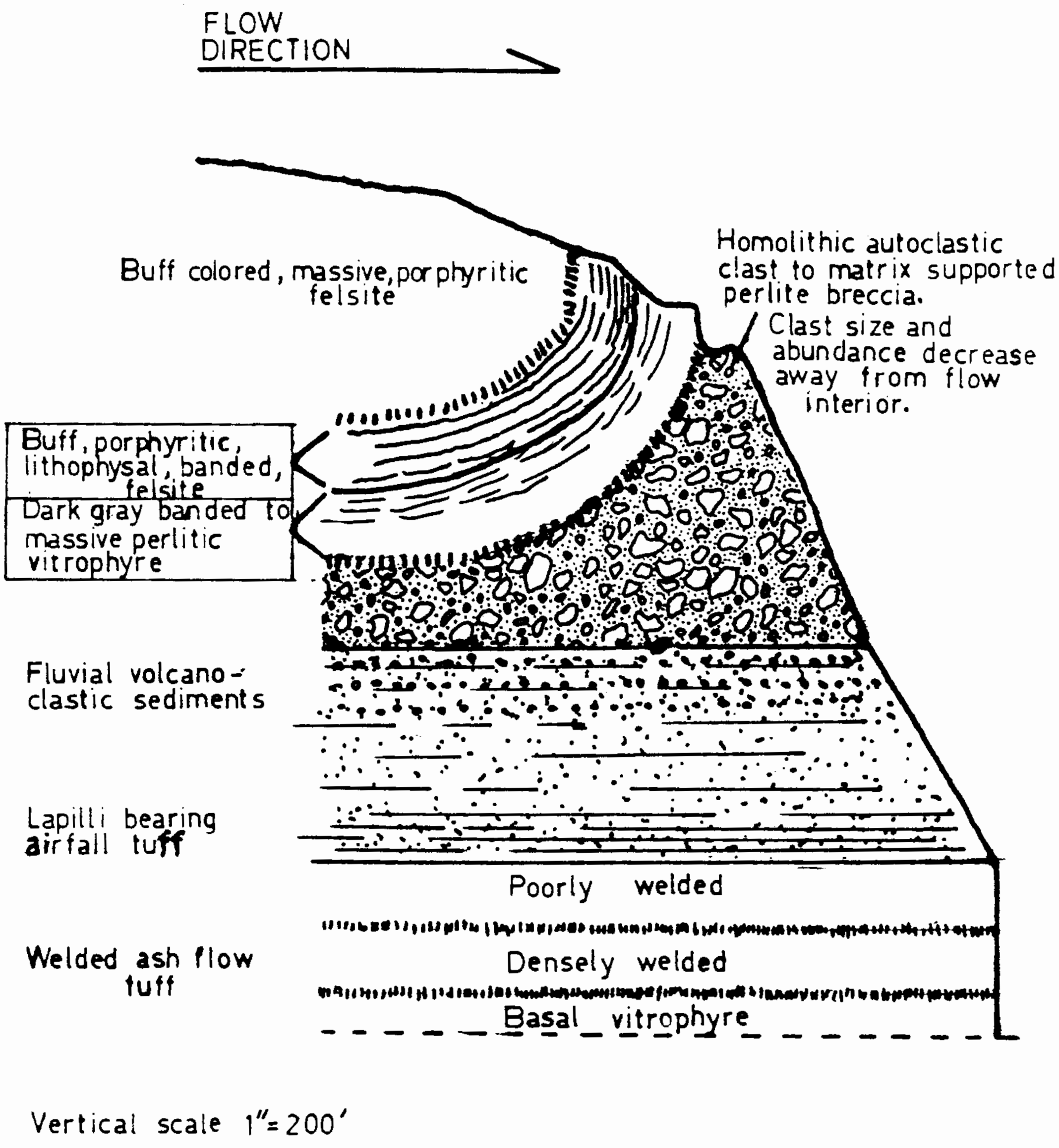


Figure 9. Cross section of a terminal margin of a block lava flow on the east side of Glassgow Creek in section 16, T12S R40E.

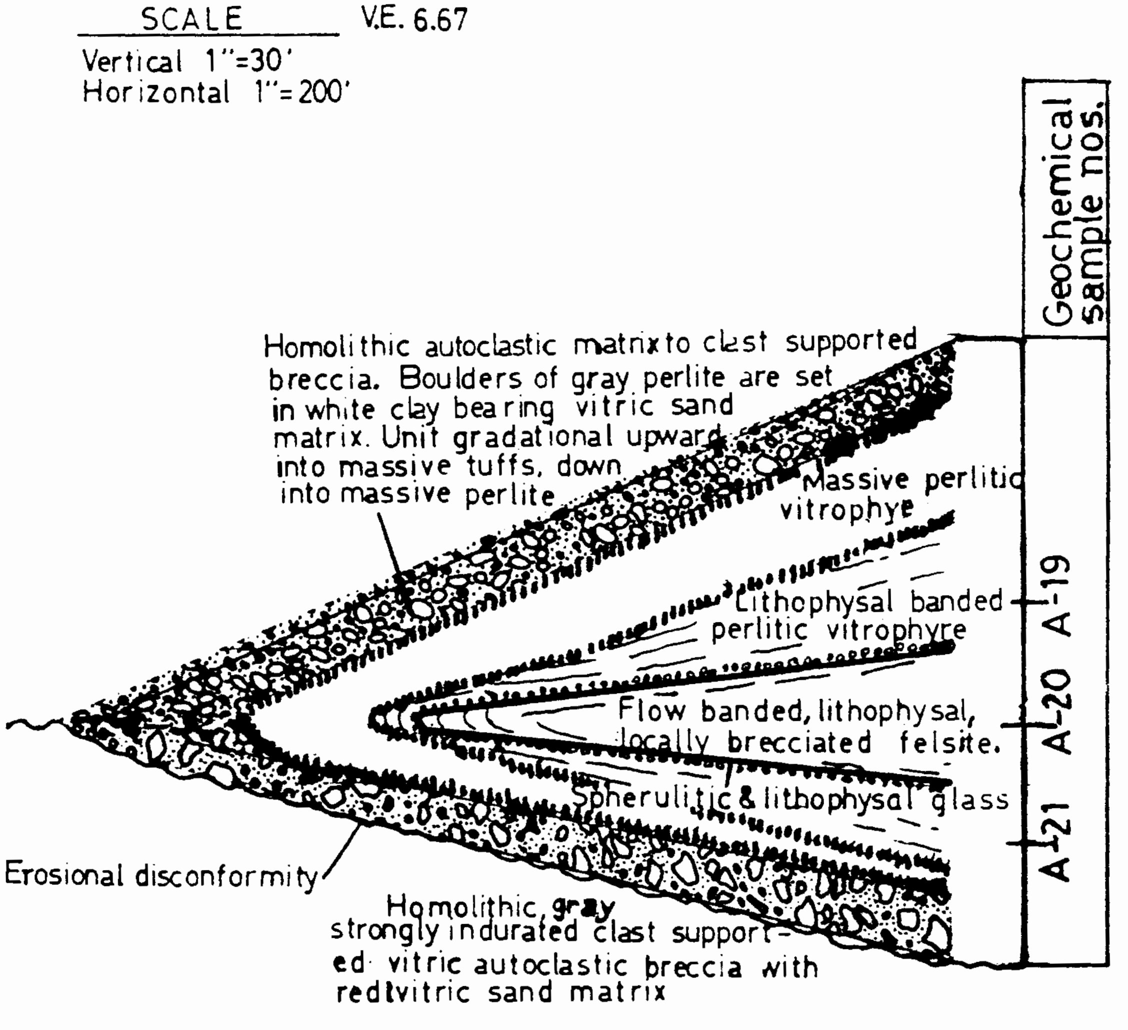


Figure 10. Measured cross section of a lateral rhyolite flow margin in section 18, T12S R40E.

There also is sometimes a progressive color change in the felsites from interior to exterior. Felsites in the interior portions of flow structures are typically buff to cream colored. Changes in rock color progressing from buff or tan to blue gray, pink, and sometimes black near the exterior of the cooling unit. This color change may reflect an increase of glass content in the rock matrix or increased oxidation of iron.

The interior felsitic portion of the flows are sometimes concentrically mantled by a vitrophyric carapace representing the exterior chilled margin of the flow structure. The boundary contact between the interior felsite and exterior glass carapace is sharp and textures are dominated by spherulitic structures in both the glass and felsites within one meter of the contact. The exterior carapace shows a textural transition from massive and/or flow banded and lithophysal near the interior felsite to pumiceous and foliate at the exterior margin of the flow. The exterior pumiceous glass is typically gradational into an autoclastic flow margin crumble breccia which shows a progressive change from clast to matrix supported breccia away from the flow interior. These textural relationships are depicted in Figure 9. Textural zonation observed in the flows at Dooley Mountain is analogous to the zonation described in most rhyolite flows and dome structures which have associated glass chill margins (Bonnichsen and Kauffman, 1987; Whitson, 1982). Textural relationships seen in the vitrophyric chill margins and felsitic cores of individual flows in southwestern Idaho described by Fink and Manley (1987) are analogous to those seen in the Dooley Rhyolite Breccia and probably result from similar mechanisms.

The exterior vitrophyric margins of most of the flows within the formation were partially or wholly eroded between eruptive episodes. As a result only terminal, lateral, and basal portions of the vitrophyric flow margins are commonly preserved in the rock record at Dooley Mountain. The distribution of mappable vitric units in SA 1 is shown by the stippled areas on Plate 1.

Numerous intraformational disconformities are recognized at various stratigraphic levels in the formation which are both erosional and laterally depositional. At disconformities rhyolite lava flow structures are eroded into the interior felsite textural zones on their upper surface. Disconformities traced laterally in both SA 1 and SA 2 change from eroded bedrock surfaces to poorly sorted homolithic, vitrophyric clast to matrix-dominated conglomerates and breccias in the formation. Homolithic breccias and conglomerates of this type as well as autoclastic breccias at flow margins combine to form distinctive units within the formation. It is from road cut exposures of these rock units along state highway 245 in the Dooley Mountain quadrangle that Gilluly (1937) described the Dooley Rhyolite Breccia.

PYROCLASTIC BRECCIAS OF THE DOOLEY RHYOLITE BRECCIA

Collectively breccias of all types make up about 20 percent of the stratigraphic thickness of the Dooley Rhyolite Breccia in the Mill Creek section depicted in Plate 3. The breccia units observed in the southern half of the Dooley Mountain quadrangle were laterally discontinuous through the formation. In addition to autoclastic and volcanoclastic sedimentary breccias and conglomerates, breccias of pyroclastic origin are also present. These include pyroclastic laharic mudflow and lapilli tuff breccias.

Laharic breccias in the formation are most commonly homolithic and composed of subround vitrophyric boulder and cobble clasts set in a whitish glass matrix. The white coloration is due to the presence of montmorillonite, and lesser kaolinite, in low percentages in the glassy breccia matrix. Bedding structures are poorly developed in most of the lahars and often they are identifiable only by the presence of small amounts of accretionary lapilli near the upper limits of the rock unit. Laharic breccia units are discontinuous and irregularly distributed in SA 1. They appear to represent trough fill sediments and channelized shoestring pyroclastic debris deposits adjacent to and interbedded with flows in the formation. The thickness of the lahars is generally irregular and variable from 3 to 30 meters.

The thickest accumulation of pyroclastic rocks in the formation area are found between the 4600 and 6200 foot elevations on the south flank of hill # 6278 in the northwestern corner of SA 1. This pyroclastic accumulation includes light-buff, vitric lapilli tuff breccias and accretionary lapilli tuffs interstratified with lesser thin rhyolite lava flows and mega-clastic laharic breccias with abundant accidental clasts of schistose metamorphic rocks. Megaclastic lahars are channelized and bedding planes in the lapilli tuff breccias exposed in road cuts along highway 245 dip steeply away from the summit area of hill # 6278. Collectively laharic breccias and associated tuffs include a diverse assemblage of pyroclastic rocks deposited in proximal and intermediate facies settings relative to eruptive vent areas within the Dooley Mountain quadrangle.

Numerous isolated outcrops of breccias are found within the Dooley Mountain quadrangle which cannot be classified as lahars because of their lack of internal bedding structures and lack of clear cut relationships with adjacent geologic units. These are classed as diamictite breccias. In outward appearance diamictite breccias resemble lahars except they commonly contain a heterolithic mixture of felsite and vitrophyric breccia clasts. Unique to the southwest corner of SA 1 exposed in the strata of the STS is a single diamictite unit which is heterolithic and contains abundant mafic volcanic cobbles. This unit is exposed in the Mill Creek and lower Mill-Coronet Ridge stratigraphic sections. This unit pinches out to the north and east in SA 1.

RHYOLITE DIKES AND VENTS

Rhyolite dikes intrude all but the uppermost stratigraphic levels of the formation and are found throughout most of the Dooley Mountain quadrangle. The distribution of dikes and vents identified in SA 1 is shown on Plate 1. The strike orientations of dikes are shown in the Rose diagram of Figure 11. Principle strike orientations show a bimodal NNW-NNE and ESE distribution, with minor SE and NE components. Most of the dikes in the quadrangle cut preexisting rock units at near-right angles, and dip in various directions at 70 to 90 degrees.

Rhyolite dikes in the study area vary from one to twenty meters in thickness. Dikes are generally composed entirely of aphyric or porphyritic felsite, although several of the felsite dikes in SA 1 have thin glass selvages at their margins. Other types of dikes noted in the study area are texturally vitrophyric and have been completely altered to perlite.

The dikes in SA 1 show no obvious relationship between rock texture, thickness, or orientation. At least two dikes in the study area are contiguous with rhyolite lava flows and have apparently fed these flows from below. The first dike of this type is identified in roadcut exposures in the

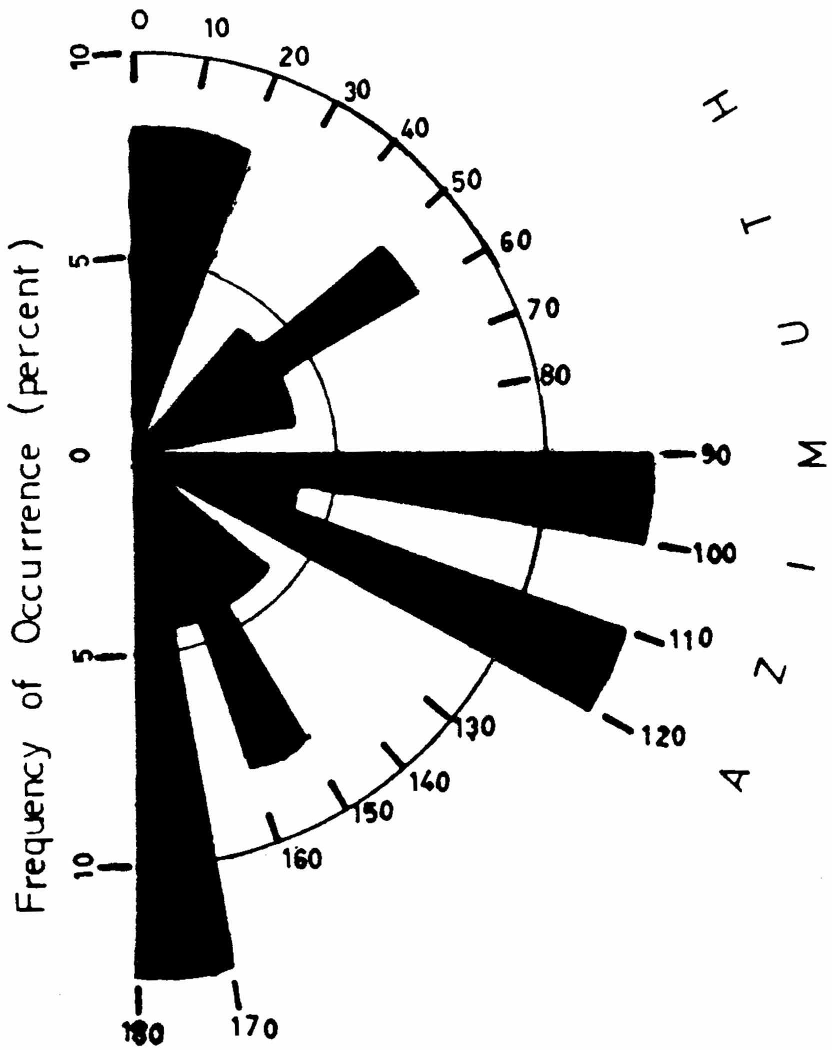


Figure 11. Frequency histogram showing orientation of rhyolite dikes in SA 1 in the south half of the Dooley Mountain quadrangle.

lower-middle strata of the formation at the 5200 foot elevation in section 32 (T12S R40E),shown on Plate 1. This feeder dike is vertical, trends to the northwest, and is entirely vitrophyric in texture. The glass of the dike is color banded and foliated parallel to the dike margins in the confining country rock. At the vent orifice the foliation patterns form a rapidly divergent pattern, like an open, apex down Japanese fan. Foliations become horizontal where the lavas flowed laterally away from the vent. A second eruptive center is tentatively identified at the intersection of vitrophyric dikes which apparently fed flows in the upper stratigraphic units of the formation near the summit of hill # 6164 in section 28 (T11S R40E). Geomorphic outcrop forms suggest the presence of a volcanic neck structure fed by a north-trending dike in Water Gulch to the south of the summit.

Most of the rhyolite dikes in the quadrangle have been eroded below the stratigraphic levels which mark their highest level intruded in the formation. Whether they reached the paleosurface and fed lava flows of the formation is uncertain. Rhyolite dikes are clearly associated with the remaining two eruption centers identified in SA 1 and could have provided upward migration routes for magmas which were produced.

The third eruptive center found in SA 1 is identified with the thick deposits of proximal vent facies pyroclastic tuff, and laharic breccias and subordinate rhyolite lava flows and dikes which form hill #6278. These rocks were apparently erupted from a central vent and formed a steep-sided composite cone in the upper stratigraphic level of the formation. Eruptions from this vent were dominantly pyroclastic in character. The high angle felsite dikes which intrude these fragmental deposits may have fed the thin rhyolite flows on the flanks of this volcano.

The fourth eruptive center in SA 1 is found at intermediate levels within the formation. It is identified on the basis of the presence of convergent, inward dipping foliation attitudes measured in felsite flow units between the 1600 and 1700 meter contour intervals on the slopes of hill # 5350 in section 5 (T12S R40E). Vertical and steeply dipping dikes exposed on the lower flanks of this hill between the 1550 and 1600 meter elevations are exposed in Mill Creek. These dikes trend eastward under the apparent vent area but cannot be conclusively linked to extrusive rocks.

WELDED ASH-FLOW TUFFS IN THE DOOLEY RHYOLITE BRECCIA

Welded ash-flow tuffs in the Dooley Rhyolite Breccia are poorly exposed in the study area. The estimated cumulative stratigraphic thickness of these units is approximately 10 percent of the formation. The most notable welded tuff units are located at the base and in the upper stratigraphic levels of the formation. Other, less well exposed, partially welded ash-flow tuffs and air fall tuffs are discontinuously exposed throughout the quadrangle at various stratigraphic levels within the formation.

The basal stratigraphic unit of the Dooley Rhyolite Breccia is a densely welded ash-flow tuff of irregular distribution and variable thickness. This unit has a measured thickness of thirty meters in section 17 and fourteen meters in section 9 (T11S R40E). The distribution of this unit is apparent from exposures of formation contacts shown in Figure 3. The welded ash-flow tuff at the base of the formation is composed of a single, simple cooling unit (Ross and Smith, 1961; Smith, 1960).

At least two welded ash-flow tuff cooling units form persistent stratigraphic units which cap the ridge lines in sections 1, 4, and 10 in SA 1 (T12S R40E). These ash-flows extend at least 35 km to the northeast of Dooley Mountain. Segments of these pyroclastic units are intermittently exposed in small erosional windows isolated atop down-dropped fault blocks in Pleasant Valley, and across the Virtue Hills into the Lower Powder River Valley. These welded and unwelded tuffs were described as part of the Dooley Rhyolite Breccia from outcrops along the subdued bluffs and in shallow valley slopes in T9 and 10S R40E by Gilluly (1937).

In the shallow valley and tributary gullies of Ritter Creek in section 2 of T9S R40E two vitric ash-flow tuffs, one densely welded and one poorly welded, form resistant minor cliffs and ledges on the valley slopes. These ash-flow tuffs are interstratified with buff to white, massively bedded air fall and water-laid tuffs and cobble conglomerates of pyroclastic origin. The rock units dip uniformly at less than 5 degrees northward toward the axis of the Powder River syncline (Prostka 1963; 1967). A measured stratigraphic section of the ash-flow tuffs units in Ritter Creek is shown in Figure 12. A detailed description of this measured section is provided in the Appendix B.

Obsidian samples were obtained from the upper ash-flow cooling unit of the Ritter Creek section for geochemical analysis. The results of this analysis show the obsidians present in this unit are chemically identical to rhyolites from the upper stratigraphic level of the Dooley Rhyolite Breccia. The geochemical comparisons made are detailed in a following section of this text. Clearly the ash-flow tuffs in the Ritter Creek section were erupted from vents within the Dooley Mountain quadrangle.

HYPOTHETICAL RECONSTRUCTION OF THE DOOLEY RHYOLITE BRECCIA

The Dooley Rhyolite Breccia is composed of a diverse assemblage of rhyolitic flows, volcanoclastic sediments, and pyroclastic welded and unwelded tuffs and lahars erupted from numerous vents within the Dooley Mountain quadrangle. Initial rhyolitic eruptions within the quadrangle were explosive and produced a widespread welded ash-flow tuff which partially blanked an irregular, eroded upland area.

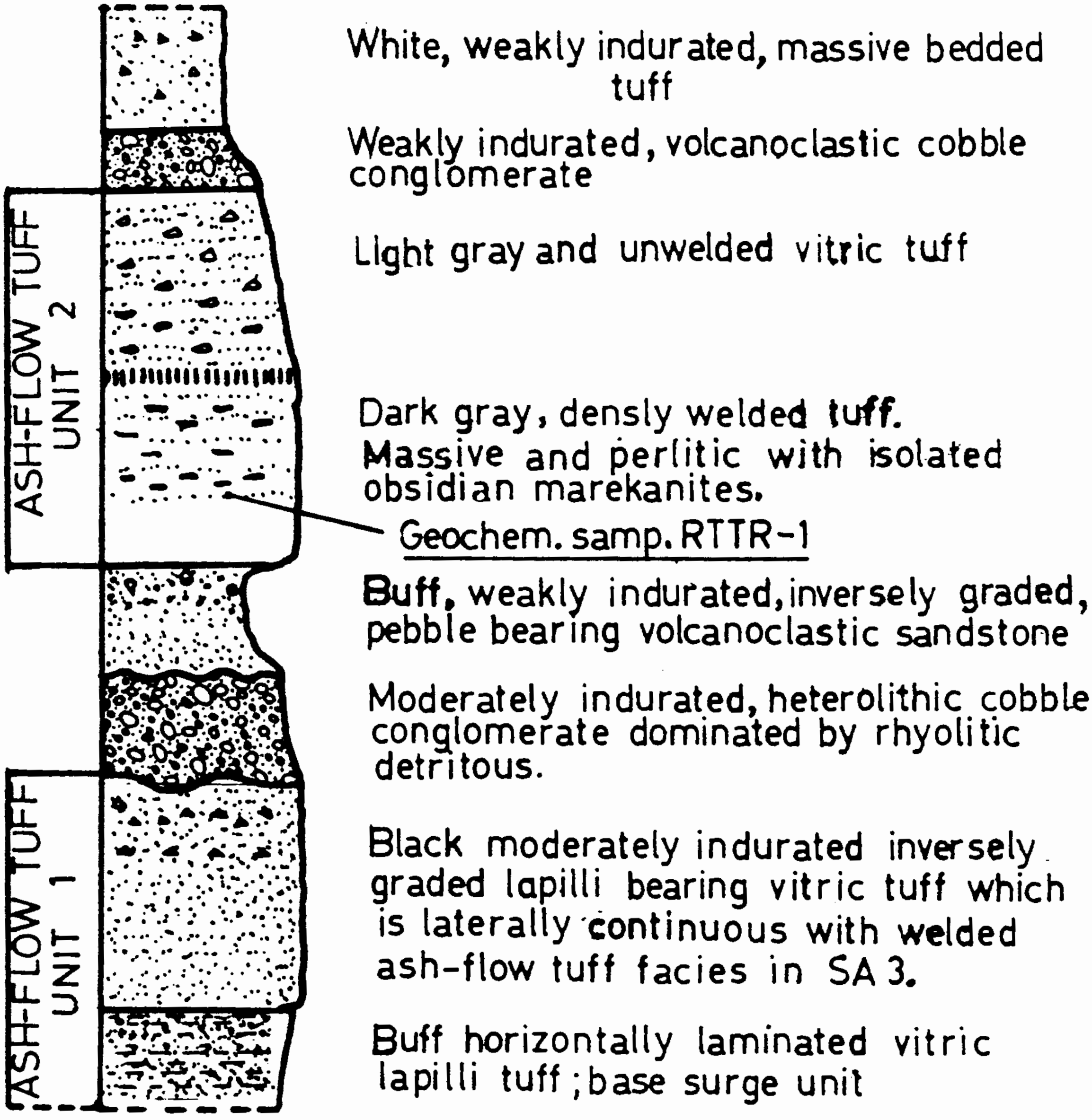


Figure 12. Measured stratigraphic section of the Ritter Creek ash-flow tuff units in SA 3 in section 2, T09S R42E.

Initial pyroclastic eruptions were followed by relatively quiescent extrusions of extensive block lava flows from linear vents fed by dikes, and central vents. Individual eruptive episodes were followed by extended periods of relative inactivity during which the upper surfaces of young lava flows were eroded, and volcanoclastic debris was dumped rapidly into topographic lows peripheral to flow structures. Subsequent eruptions produced laharic mudflows and minor ash-flows and air-fall tuffs which were deposited over, or channelized, by topographic lows in the pre-existing volcanic terrane. These pyroclastic rocks were in turn buried by flows. This cycle was repeated many times during the eruption of the Dooley Rhyolite Breccia. During the waning stages of volcanism, pyroclastic eruptions produced nuee' ardentes which flowed over substantial distances to the north of the quadrangle into the Lower Powder River Valley.

Rhyolitic volcanism within the Dooley Mountain quadrangle is at least in part contemporary with mafic volcanism to the west and/or south of the quadrangle. Evidence for this is seen in the interstratified relationships between basalt flows and rhyolite flows in the stratigraphic sections described between Mill Creek and west of Coronet Creek. Mafic clastic material incorporated in a sedimentary unit in the upper third of the Mill Creek section also provides convincing evidence to support this conclusion.

Rhyolitic eruptions in the Dooley Mountain quadrangle produced a cumulative thickness of volcanic rocks and associated sediments in excess of 660 meters in Mill Creek. The formation thins to the north in the quadrangle. Whether the formation thins in other directions cannot be determined owing to tectonic displacements within and adjacent to the quadrangle. The formation clearly extended well beyond the Dooley Mountain quadrangle and may be genetically related to the voluminous rhyolitic formations mapped to the southwest in the vicinity of Rastus Mountain (Lowry, 1943).

CHAPTER VI

GEOCHEMISTRY OF THE DOOLEY RHYOLITE BRECCIA

The lack of continuous intraformational stratigraphic marker horizons mapped at Dooley Mountain poses the greatest challenge to understanding the structure and extrusive history recorded in the Dooley Rhyolite Breccia. Geochemical methods were applied in an attempt to decipher the complex history of the formation. The results from analysis of ninety-six samples taken from all stratigraphic levels in the formation are shown in Appendix C.

Samples were obtained primarily from SA 1 at Dooley Mountain where the Dooley Rhyolite Breccia is most completely exposed. Geochemical samples locations within the study area are shown on Plate 2. Geostatistical methods were employed in order to logically characterize the compositional patterns, variations, and to determine stratigraphic continuity within rhyolites of the Dooley Rhyolite Breccia.

MAJOR OXIDE GEOCHEMISTRY

Eight geochemical samples from lava flow units at various stratigraphic levels and one sample of a dike within the Dooley Rhyolite Breccia were selected for major oxide analysis. The sample group contains one sample from the upper welded ash-flow tuff from the Ritter Creek section (RTTR-1) in SA 3, and sample DMR-U obtained from a dull red flow unit in the upper stratigraphic section of the formation, which was originally identified as andesite by Gilluly (1937). Analytical results from the sample group are presented in Table III.

Geochemical classification of this suite of samples based upon the calculated total alkali-silica content (Les Bas and others, 1985; Zanettin, 1984) show all of the samples to be rhyolitic in composition. A plot of total alkalis (Na_2O + K_2O) vs. SiO_2 for rock samples of the suite is presented in Figure 13. Further refinement of geochemical classification of the rock suite results from calculation of the alkali/aluminum ratio as prescribed by Shand (1951). The rhyolites all have calculated ratios less than one, thus are classified as peraluminous rhyolites. SiO_2 weight percentages in the rhyolite suite varies from 75.98 to 77.98 which is relatively high, thus the Dooley Rhyolite Breccia formation is further classified as a high silica, peraluminous rhyolite.

The geochemical variation within the suite of samples is small and all samples plot within a restricted area of the graph of Figure 13. It is concluded from this sampling that the formation within the Dooley Mountain quadrangle and the ash-flow tuffs in the Ritter Creek section belong to one geochemical suite.

TABLE III

XRF DATA FOR SELECTED UNITS OF THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	SiO2	Al2O3	TiO2	Fe2O3*	MnO	CaO	MgO	K2O	Na2O	P2O5
					Cogenetic obsidian/perlite pair						
DMO-1	OBS	76.64	13.35	0.07	1.26	0.04	0.66	0.00	4.48	3.39	0.00
DMV-1	PER	76.73	13.45	0.07	1.20	0.04	0.67	0.00	4.79	2.94	0.00
					Unpaired Samples						
RTTR-1	OBS	76.61	13.34	0.07	1.27	0.04	0.67	0.00	4.48	3.39	0.00
DMV-2	PER	76.76	13.34	0.06	1.18	0.04	0.65	0.00	5.01	2.86	0.00
DMO-2	OBS	76.62	12.49	0.17	2.37	0.04	1.11	0.00	3.58	3.40	0.00
DMR-L	FEL	77.34	13.11	0.13	1.05	0.00	0.95	0.00	4.10	3.10	0.00
DMR-U	FEL	76.68	12.47	0.19	2.55	0.02	0.92	0.00	3.61	3.31	0.01
DMR-M	FEL	75.98	13.78	0.31	1.09	0.00	1.32	0.00	3.77	3.52	0.02
DMO-1	FEL	77.98	12.81	0.18	0.82	0.00	0.91	0.00	3.74	3.36	0.00

SAMPLE	TYPE	Ni	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Zn
					Cogenetic obsidian/perlite pair							
DMO-1	OBS	11	6	5	711	132	41	83	38	13	15	34
DMV-1	PER	12	5	15	750	135	43	84	38	13	15	37
					Unpaired Samples							
RTTR-1	OBS	12	4	9	779	130	44	84	38	13	17	37
DMV-2	PER	14	3	26	694	138	41	83	38	14	18	36
DMO-2	OBS	13	1	15	1577	98	115	257	59	18	22	29
DMR-L	FEL	13	8	7	1814	104	105	178	38	14	22	43
DMR-U	FEL	12	8	7	1609	94	114	255	58	19	22	116
DMR-M	FEL	16	8	14	1444	102	138	304	51	18	22	48
DMO-1	FEL	14	6	7	1485	102	103	257	29	17	22	14

Oxides in wt. % ; Fe2O3* = FeO + Fe2O3 ; all other elements in ppm.
Values = 0.0 are below detection limit.

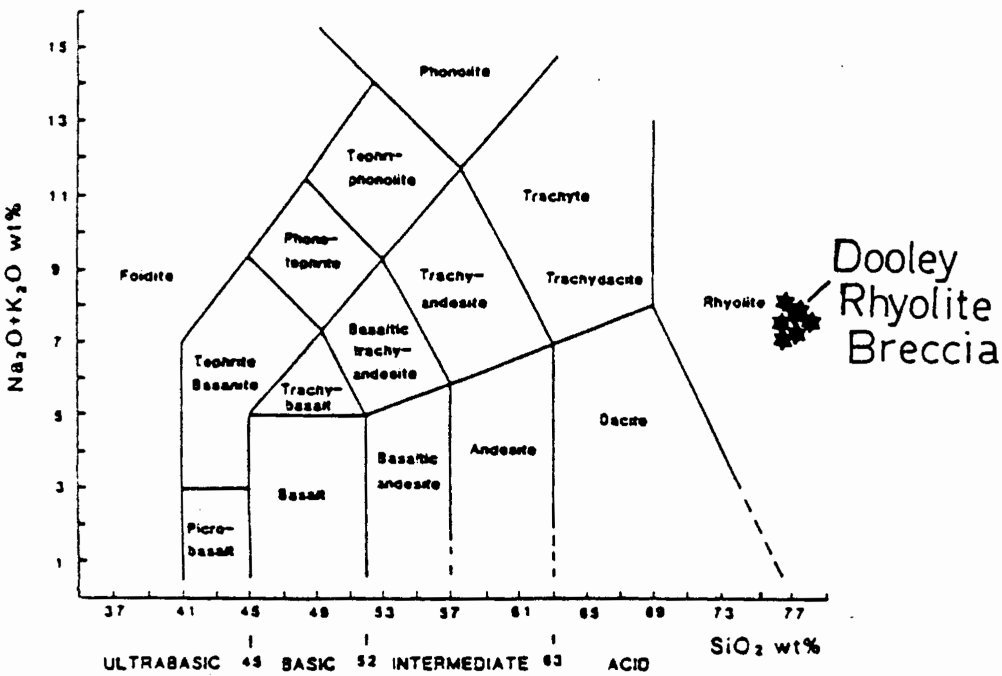


Figure 13. Total alkali-silica classification of the Dooley Rhyolite Breccia. Adapted from Les Bas (1985).

VARIABLE TEXTURES IN RHYOLITES AND GEOCHEMICAL VARIATION

Geochemical comparisons of cogenetic rhyolite textural varieties including perlite, obsidian, and felsites (Lipman, 1965; Lipman and others, 1969; Zielinski and others, 1977) have shown that significant chemical differences occur in such groups. Post emplacement cation exchange during hydration of obsidian to perlite on rhyolite flow margins, and volatile transfer during crystallization of felsite in flow interiors during emplacement lead to marked chemical variations between cogenetic rocks (Lipman 1965). Cogenetic associations between perlite/felsite and perlite/obsidian occur in rhyolite flow cooling units within the Dooley Rhyolite Breccia. Two sample groups from the formation were examined in order to determine the relative magnitude of elemental variation between cogenetic rock textures and identify elements which are relatively immobile during eruption and post emplacement alteration. NAA compositional data from the cogenetic rock samples examined are presented in Table IV.

The first group examined consists of two cogenetic perlite/obsidian pairs consisting of samples DMV-1 and DMO-1 and paired samples C-57 and C-58. These sample pairs were obtained from marekanitic zones in perlitic flow and dike structures in SA 1. Analytical data including major and minor elements in these sample pairs are shown in Table III.

TABLE IV

NAA DATA FROM COGENETIC PERLITE/OBSIDIAN AND PERLITE/FELSITE SAMPLES FROM THE DOOLEY RHYOLITE BRECCIA

TYPE	SAMPLE	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
OBS	DMO-1	4.13	4.00	25.40	4.82	3.40	0.53	3.49	9.80	1.12	0.00	135
PER	DMV-1	3.42	4.10	24.90	4.30	3.10	0.56	3.26	0.00	0.92	0.00	123
OBS	C-58	4.75	4.40	44.30	9.73	5.40	0.91	5.25	6.41	2.18	0.53	87
PER	C-57	3.27	4.70	47.60	9.73	6.00	0.92	4.28	4.20	1.51	0.42	102
FEL	A-20	3.40	3.80	38.50	5.79	3.30	0.57	3.88	4.80	0.89	0.00	109
PER	A-19	2.88	4.40	39.60	5.75	3.00	0.48	3.76	0.00	0.89	0.00	101
PER	A-21	3.24	4.40	39.10	5.73	2.80	0.52	3.61	5.50	1.10	0.00	97

TYPE	SAMPLE	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
OBS	DMO-1	2.12	49.10	1470	0.57	0.16	0.00	0.00	9.83
PER	DMV-1	1.97	45.80	690	0.60	0.14	0.00	0.00	8.92
OBS	C-58	3.80	72.90	1380	1.37	0.21	290.00	0.00	7.23
PER	C-57	4.20	74.50	1410	1.18	0.18	0.00	0.00	8.12
FEL	A-20	1.40	67.80	1710	1.49	0.14	260.00	0.00	9.50
PER	A-19	1.72	68.60	1540	1.30	0.16	0.00	0.00	9.58
PER	A-21	1.60	65.80	1630	1.36	0.15	0.00	0.00	9.03

*Na, K, and Fe in wt. % ; all others in ppm. Values = 0.0 are below detection limit.

Perlites were normalized with respect to their parent obsidian and plotted in figures 14A and 14B. Analytical error bars are shown in this figure in conjunction with normalized minor element data. Relative element immobility is indicated when error bars overlap.

Relative immobility in major elements determined by XRF were observed with respect to Si, Al, Ti, Mn, and Ca in the perlite relative to obsidian. NAA analysis of the cogenetic perlite/obsidian pairs showed that Fe is significantly depleted in perlites, and must be considered mobile. Immobile minor elements determined by both XRF and NAA methods include Ba, Rb, Ce, La, Sm, Eu, Tb, Yb, and Lu. Analytical error bar overlap with respect to Cr is observed, however this error is in excess of 30 percent and is considered unacceptable for use in further comparative analysis.

The second group of cogenetic rock samples compared in this manner, include three samples of cogenetic perlite and felsite from a single rhyolite flow cooing unit exposed in Mill Creek in section 18 (T12S R40E). Two perlite samples, A-19 and A-21, were obtained from the vitric flow margins within 10 feet above and below the crystalline interior felsite core of the flow where sample A-20 was taken. Analytical data determined by NAA in this group are presented in Table IV. Major elements other than Na, K, and Fe were not determined for these samples. The three major elements cited above and minor element data from both

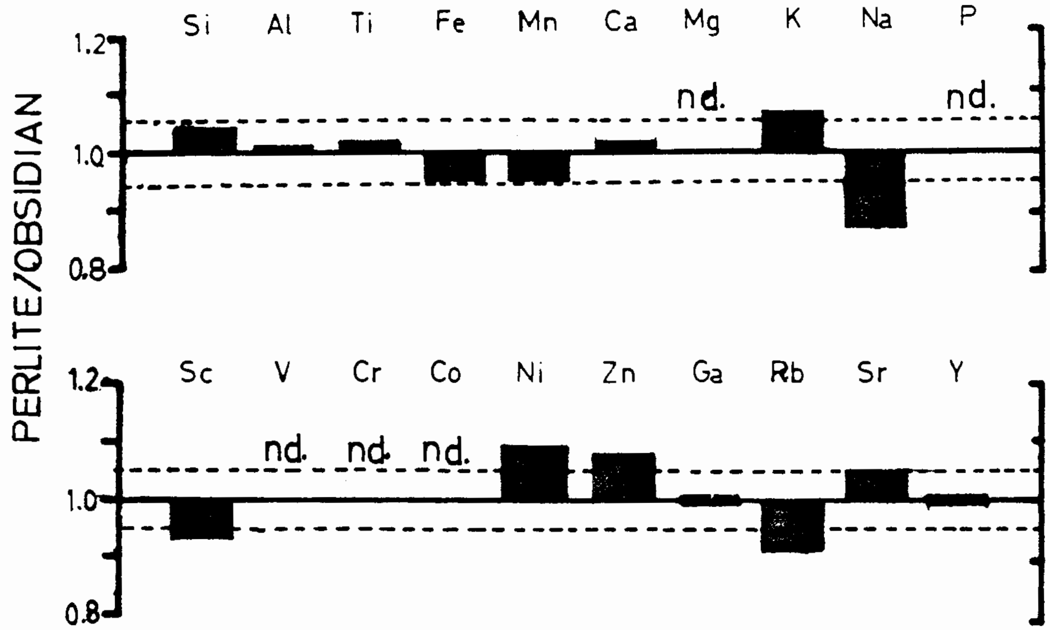


Figure 14a. Histogram plots of XRF data from cogenetic perlite/obsidian samples (DMV-1/DMO-1) indicating relative element mobility produced by perlitization.

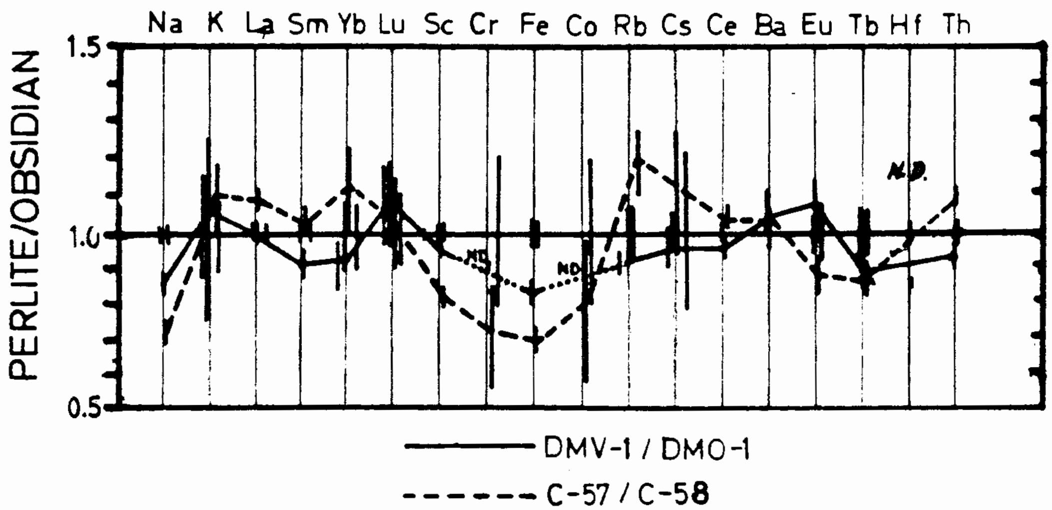


Figure 14b. Normalized spider diagram showing NAA data from paired cogenetic perlite/obsidian samples showing relative mobility of elements produced by perlitization.

perlite samples were normalized to the cogenetic felsite sample for comparison. Normalized data is presented in the spider diagram of Figure 15. Relative elemental immobility between cogenetic felsite and perlite is recognized with respect to Fe, Ba, Rb, Cs, La, Ce, Sm, Tb, Yb, and Lu.

Eight immobile elements are common to both perlite/obsidian and perlite/felsite sample groups. These include Ba, Rb, Ce, La, Sm, Tb, Yb, and Lu. These elements show limited susceptibility to post-eruption cation exchange and volatile transport during extrusion of rhyolitic magmas of the Dooley Rhyolite Breccia. Rock compositions with respect to these elements are believed to closely approximate that of original source magmas. Accordingly these elements are used in geostatistical routines described in a following section.

RESULTS OF STATISTICAL ANALYSIS

Four geochemical groups containing nine subgroups within the sample population were identified by cluster analysis from the data base containing only the felsite and obsidian samples from the Dooley Rhyolite Breccia. The dendogram showing the related chemical groups and their respective subgroups is shown in Plates 4A and 4B. Discriminant analysis tests have shown these groupings and their subdivisions to be chemically distinct. The related chemical groups have been arbitrarily assigned serial codes

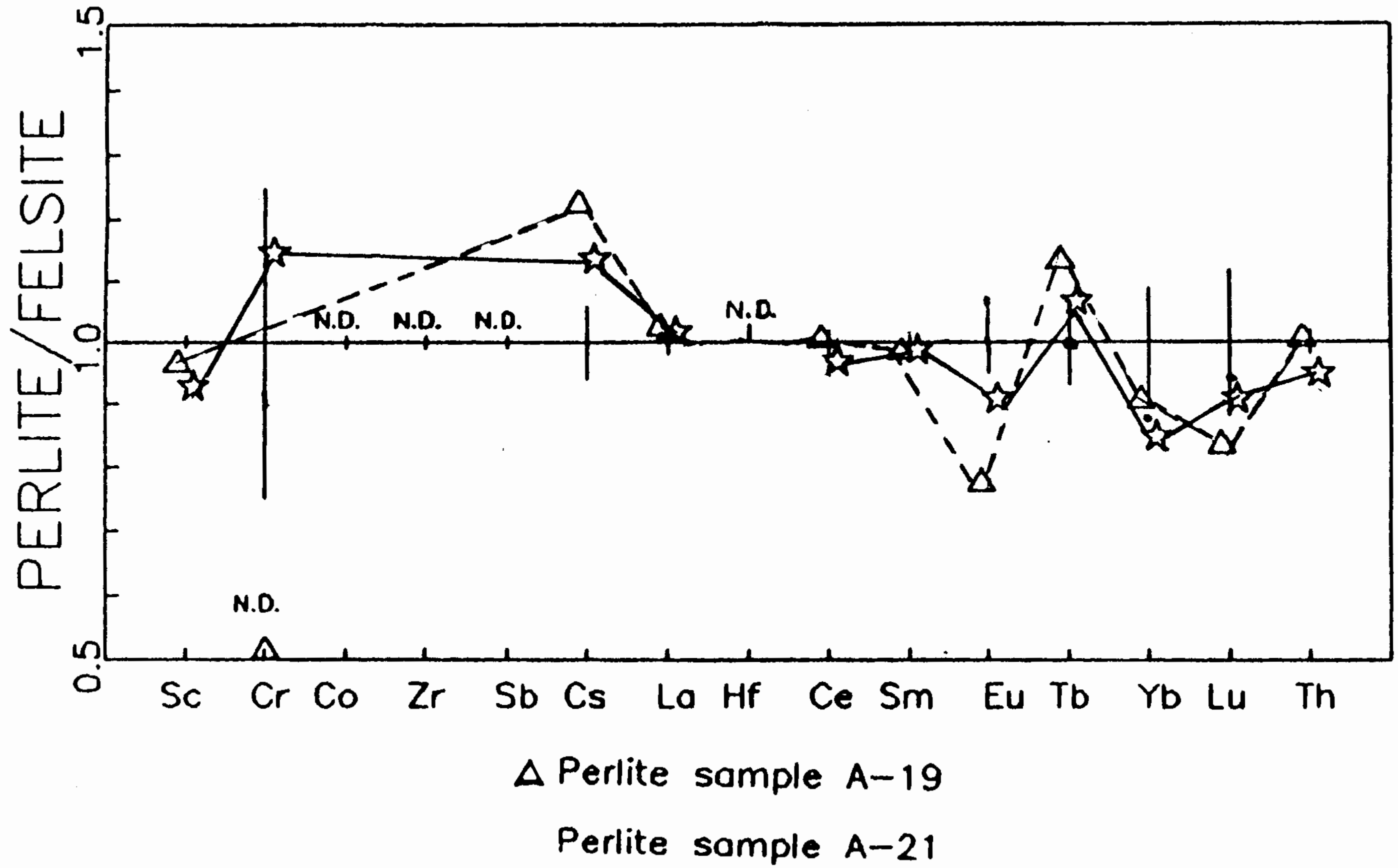


Figure 15. Normalized spider diagram showing minor and trace element data from a cogenetic perlite/felsite sample pair from a rhyolite flow in the Dooley Rhyolite Breccia.

dendograms.

Geochemical rock sample numbers are listed by groups and subgroup in Plate 4. Table V contains calculated averages of major and trace element data determined by NAA from the samples within the individual groups and subgroups identified. Normalized diagrams were constructed to show trends in chemical variation within three of the four chemical groups detected within the formation. Resultant spider diagrams are shown in Figure 16. The largest chemical variations between subgroups are seen in groups 1 and 3, although radical variation between immobile elements of the subgroups is noted with respect to Fe in group 1.

The information discussed above was combined with geologic data in order to describe the geochemical patterns recorded in the complex stratigraphy of the Dooley Rhyolite Breccia in SA 1. Geochemical patterns observed in measured and composite stratigraphic sections are described below.

GEOCHEMICAL STRATIGRAPHY OF THE FORMATION

Vertical geochemical variation in immobile elements and Fe within the Mill and Glassgow creek sections of the formation are shown in Plate 5. Trace elements including Ba, Tb, and Lu show the least variation within these sections. Elemental variations within the vertical sampling of the formation are most pronounced with respect to Fe, Ce, Rb, La, Sm, and Yb in the Mill Creek section, and to a lesser extent in the Glassgow Creek section.

TABLE V

CALCULATED AVERAGE COMPOSITION OF GEOCHEMICAL SUBDIVISIONS OF THE DOOLEY RHYOLITE BRECCIA IDENTIFIED BY CLUSTER ANALYSIS

SUBDIVISION	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
GROUP 1	3.78	4.14	43.67	7.24	3.63	0.54	4.05	5.22	1.23	0.33	101.19
SUBGROUPS											
A-1SG3	3.63	4.3	40.54	6.03	3.52	0.55	3.98	4.38	1.21	0.31	100.58
B-1SG3	4.00	4.01	47.19	8.58	3.78	0.55	3.59	6.11	0.91	0.16	106.75
C-1SG3	3.8	4	45	7.79	3.66	0.51	4.7	5.65	1.63	0.56	95.86
GROUP 2	3.71	3.76	43.58	8.43	4.96	0.83	5.06	4.11	1.22	0.43	91.71
SUBGROUPS											
A-2SG3	4.02	3.89	45.06	8.61	4.43	0.73	5.3	4.79	1.25	0.68	94.46
B-2SG3	3.78	4.14	43.44	8.23	4.4	0.69	4.67	3.98	1.39	0.33	87.88
C-2SG3	3.49	3.53	42.72	8.4	5.5	0.95	5.05	3.74	1.14	0.31	91.48
GROUP 3	3.9	4.19	33.9	6.6	4.07	0.65	4.32	6.07	1.53	0.36	107.76
SUBGROUPS											
A-1SG2	3.66	4.13	29.96	5.55	3.43	0.56	3.91	5.5	1.42	0.36	117.18
B-1SG2	4.17	4.26	38.23	7.75	4.77	0.74	4.77	6.7	1.65	0.36	97.4
GROUP 4	3.86	4.17	46.45	9.41	4.28	0.59	3.99	0	0.44	0.11	100.25

TABLE V (CONTINUED)

CALCULATED AVERAGE COMPOSITION OF GEOCHEMICAL SUBDIVISIONS OF THE DOOLEY RHYOLITE BRECCIA IDENTIFIED BY CLUSTER ANALYSIS

SUBDIVISION	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
GROUP 1	1.89	69.21	1599	1.39	0.16	68.15	0.17	8.58
SUBGROUPS								
A-1SG3	2.03	65.46	1604	1.32	0.15	46.67	0.07	8.62
B-1SG3	1.5	74.88	1665	1.53	0.17	88.75	0.22	8.91
C-1SG3	2.08	69.19	1514	1.34	0.15	81.43	0.26	8.14
GROUP 2	2.88	65.89	1430	1.33	0.17	105.24	1.23	7.68
SUBGROUPS								
A-2SG3	2.68	66.26	1449	1.37	0.17	113.08	0	7.58
B-2SG3	2.85	68.25	1479	1.32	0.17	141.25	4.89	7.67
C-2SG3	3.01	64.75	1399	1.31	0.18	86.67	0.59	7.75
GROUP 3	2.96	54.22	1136	1.05	0.16	52.86	0.1	8.33
SUBGROUPS								
A-1SG2	2.77	51.05	1050	0.91	0.15	49.09	0.08	8.72
B-1SG2	3.18	57.71	1231	1.21	0.17	57	0.13	7.9
GROUP 4	2.24	77.4	1513	1.57	0.19	70	0.23	8.65

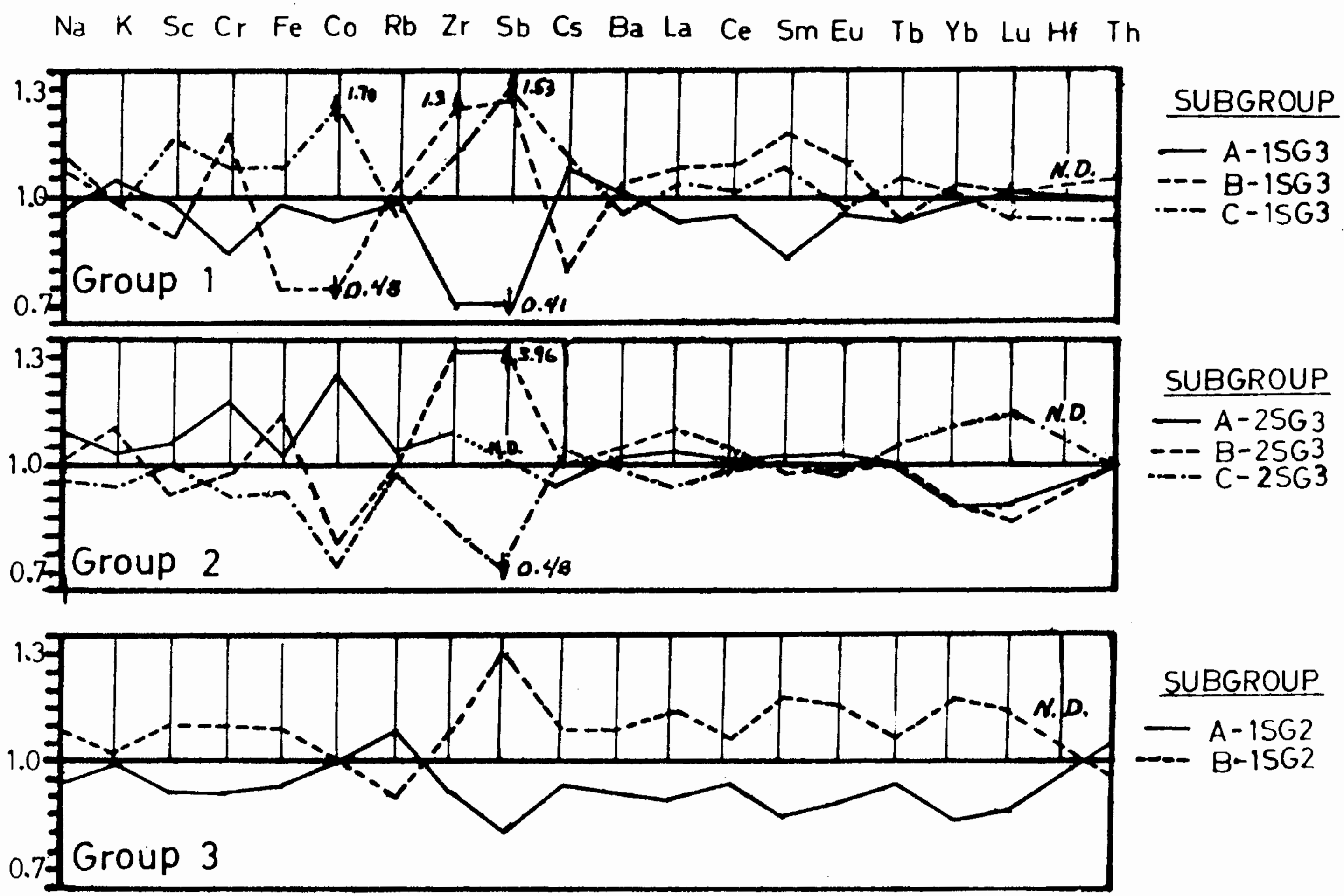


Figure 16. Normalized spider diagrams showing the chemical variation within the major chemical groups of the Dooley Rhyolite Breccia. Average compositions of geochemical subgroups are normalized to chemical group averages.

In the lower two-thirds of the the Mill Creek section two repeated sequences of subunits of chemical group 1 were identified. Chemical groups and respective subgroups for individual flow units in these sections are identified by serial code. Comparison of sample compositions listed in Table 4 show that individual flow units in the repeated sequences, with the exception of flow units A-18 and A-20, represent separate flows and not structural repetition within the stratigraphic section. Samples A-18 and A-20 are from correlatable rock units, respectively located to the north and south of a west-trending fault in section 17 (T12S R40E). Flow units of geochemical group 1 in the Mill Creek section are overlain by interstratified flow units belonging to subunit B1-SG2 of group 3 in the upper stratigraphic levels of the Mill Creek section. In addition, no subunits of the group 2 chemical type are present in the Mill Creek stratigraphy.

The geochemical stratigraphy of the Glassgow Creek section differs from the Mill Creek section. Chemical subunits including B2-SG3 and A1-SG3, of chemical groups 2 and 1 respectively, in the Glassgow Creek section are not found in the Mill Creek stratigraphy, two miles to the west. At least one flow of subunit B2-SG3 of chemical group 2, is interstratified within a thick series of flows of the group 1 chemical type which form the lowest stratigraphic units of the formation in Glassgow Creek canyon. Chemical subgroups B1-SG3 and C1-SG3 of group 1 are absent from the

Glassgow Creek section. In addition, flow units from chemical group 3 which cap the Glassgow Creek section belong to a different chemical subgroup than the flows of the upper Mill Creek section. Flow types from the chemical subgroup C2-SG3 of group 2, and from chemical group 4 identified by cluster analysis are not present in either the Mill Creek or Coronet Creek sections. Vertical sequential patterns from three composite stratigraphic sections within SA 1 at Dooley Mountain were compared with the Mill and Coronet Creek sections in Plate 6. Locations of the composite section areas are shown on Plate 2.

Subunit components of chemical group 1 form the base of each the five stratigraphic sections, although lateral discontinuities with respect to each subunit except B1-SG3 in the chemical group are noted. Chemical groups 2 and 3 are laterally discontinuous between the sections and show unequal distribution in the stratigraphy of SA 1 at Dooley Mountain. Geochemical group 2 is interstratified and predated by group 1 flows in Glassgow Creek, and also interstratified but postdated by group 3 chemical types on Beaver Mountain. Group 4 geochemical types within the formation are anomalus and do not appear to be volumetrically significant in the study areas.

Geochemical subunit sequences in group 1 and 2 chemical types were determined from the stratigraphic sections from SA 1. The chronologic stacking order of subunits in chemical group 1 from lowest to highest consists of A1-SG3, B1SG3, and C1-SG3 in the measured Mill Creek and the Beaver Mountain composite sections in SA 1. This sequence is repeated in the stratigraphy of the Mill Creek section as described above. The sequence from chemical group 2 subdivisions seen in the measured Glassgow Creek and the Rooster Rock Spring and Dooley Mountain composite sections begins with subgroup B2-SG3 and is followed in vertical sequence by subgroup C2-SG3, A2-SG3, and finally C2-SG3. Chronologic patterns within chemical groups 3 and 4 cannot be determined at this time.

DISCUSSION

The Dooley Rhyolite Breccia exposed within the southern half of the Dooley Mountain quadrangle is composed of at least nine chemically distinct subdivisions of four major chemical groups. These geochemical subgroups are considered to represent products of distinct eruptions within the formation. Lateral stratigraphic discontinuities and irregular aeral distribution of chemical groups 2 and 3 in the southern half of the Dooley Mountain quadrangle contrast with the lower geochemical group 1 of the formation which is present throughout the area. Although A1-SG3, B1-SG3, and C1-SG3 subunits of geochemical type 1 flows are laterally discontinuous in the stratigraphic sections these lavas collectively form a relatively continuous platform onto which the rhyolites of chemical groups 2 and 3 were erupted. Lateral discontinuities in geochemical subunits of the formation support conclusions drawn from field observations that eruptions were from multiple vents throughout the quadrangle area.

Major oxide analysis of samples from the four major chemical groups in the formation show that these groups are geochemically related, peraluminous, high-silica rhyolites. The chronologic elemental variations between the major geochemical groups of the formation were normalized relative to group 3 for comparison. Normalized patterns are shown in the spider diagram of Figure 17. Although the rhyolites of the formation belong to a definable suite, the chronologic trace element patterns within and between major chemical groups of the formation are inconsistent with modeled patterns of element variation produced by simple differentiation or partial melting (Hansen, 1981).

Samples from the four geochemical groups are plotted in Nb/Y and Rb/Y+Nb discriminant diagrams (Pearce and others, 1984) in Figure 18. The Dooley Rhyolite Breccia rhyolites plot unambiguously in the field of granite types generated in a within-plate-granite tectonic setting. The averages of trace element data from each geochemical group within the Dooley Rhyolite Breccia were normallized to an mid-ocean granite composition and plotted in a normalized spider diagram for comparative purposes (Pearce and others, 1984). The resultant diagram is shown in Figure 19. Patterns of variation in the Dooley Rhyolite Breccia suite samples are comparable to within-plate-granites.

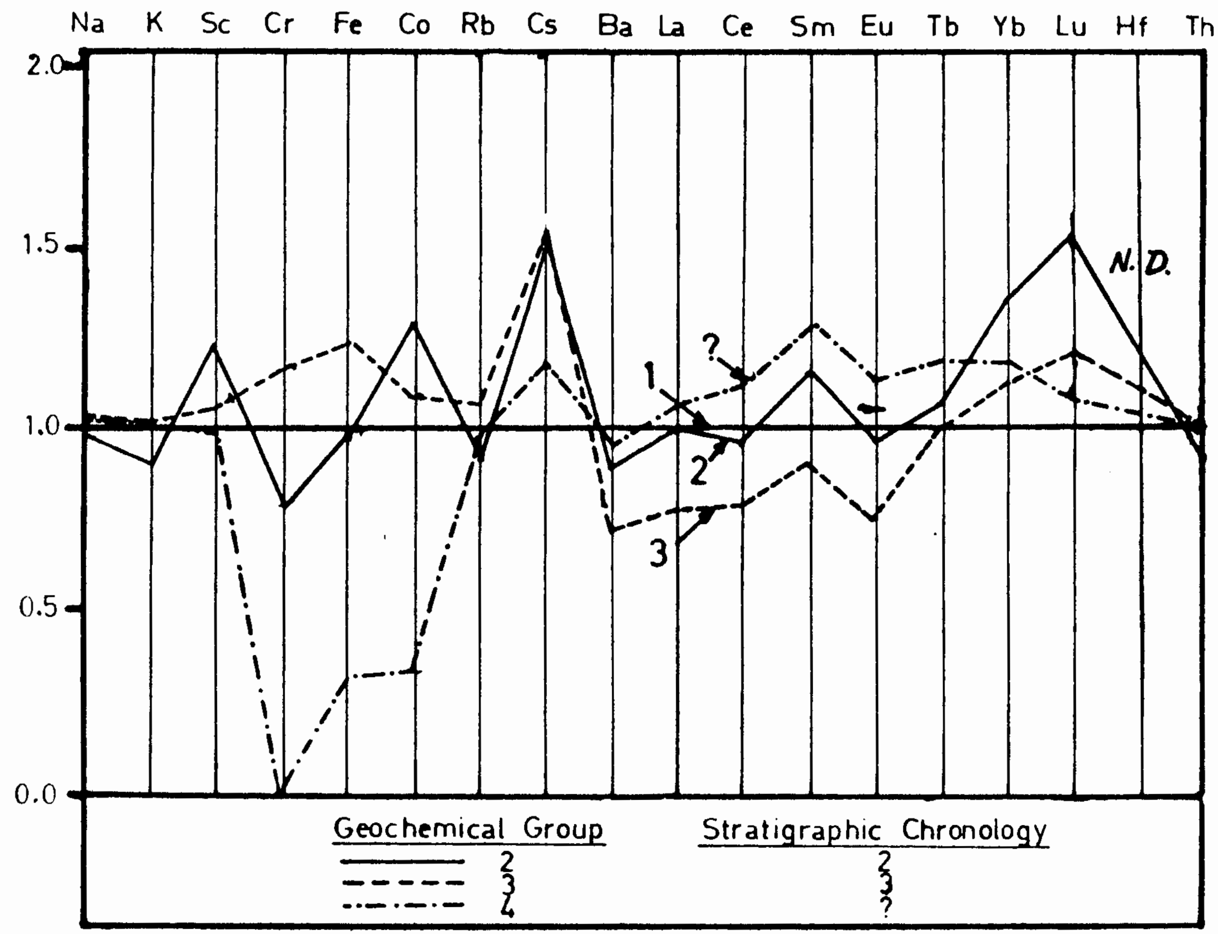


Figure 17. Normalized spider diagram showing the geochemical variation between the major groups in the Dooley Rhyolite Breccia. Average compositions of each group are normalized to group 1 to show the chronology of variation in the formation.

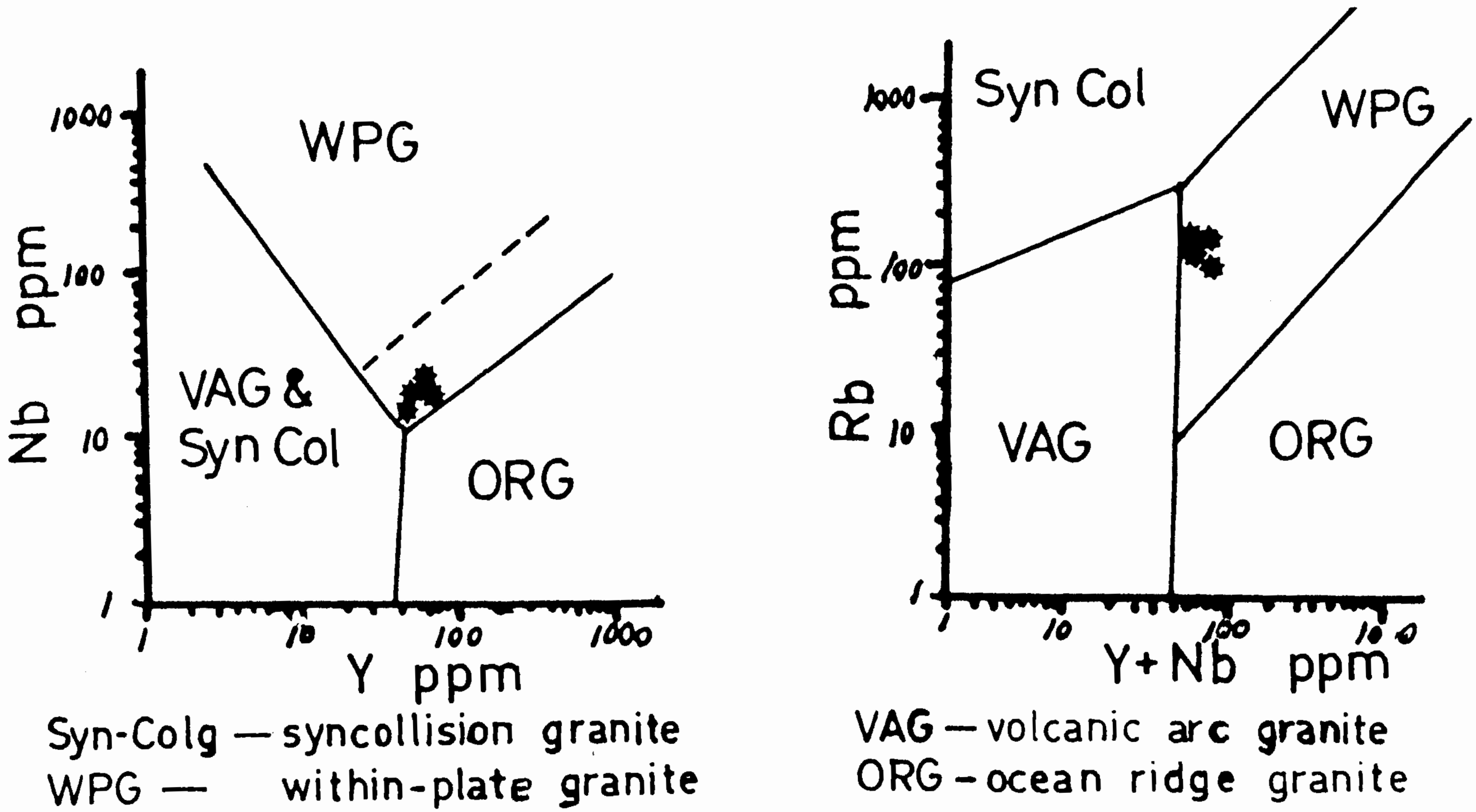


Figure 18. Discriminant diagrams showing the tectonic provanence of the geochemical groups of the Dooley Rhyolite Breccia (Pearce and others, 1984).

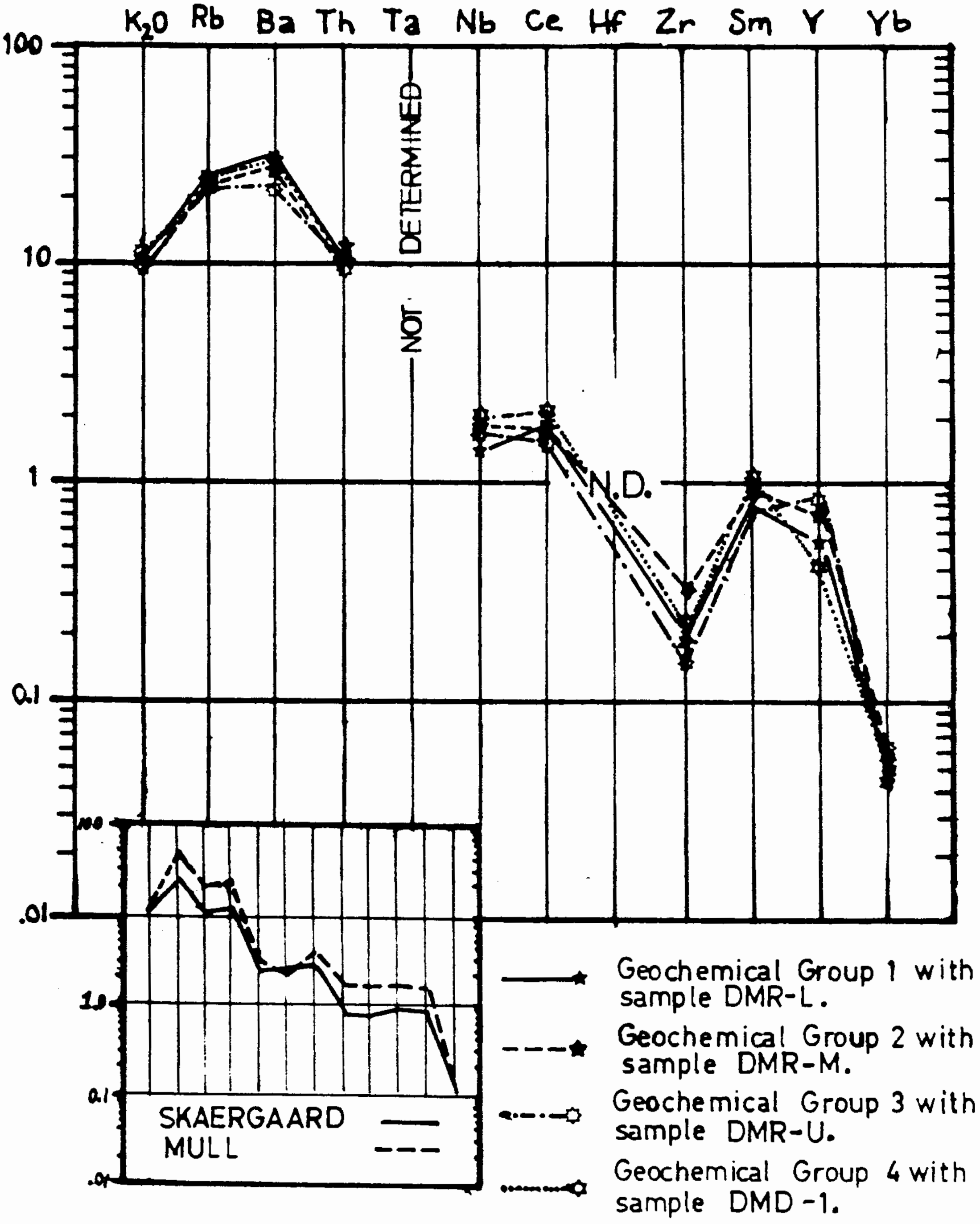


Figure 19. Geochemical group averages from the Dooley Rhyolite Breccia normalized to the average mid-ocean granite (pearce and others, 1984). Inset shows typical within-plate granite.

Within-plate-granites are distinctive in their combination of i: values of Hf to Yb are close to the normalizing value; and ii: high values of K, Rb, and Th (Pearce and others, 1984). The Dooley Rhyolite Breccia suite differs from these characteristics with respect to having a high positive enrichment in Ba, and strong negative depletion in Yb relative to the normalizing value. The remaining element pattern is similar in all respects to the crustal dominated granite types exemplified by granites from the Skaergaard intrusions and from the island of Mull, Scotland which were emplaced in an attenuated crustal tectonic environment (Pearce and others, 1984). Variable percentages in crustal contamination and volatile phase transport play a significant role in distorting the trace element patterns in this tectonic environment (Pearce and others, 1984) and probably account for the divergence of the Dooley Rhyolite Breccia suite from ideal trace element patterns. The erratic variation patterns within individual geochemical groups of the Dooley Rhyolite Breccia formation is considered most consistent with a petrogenetic model of eruption from multiple, temporally separate magma chambers below the Dooley Mountain quadrangle produced by repeated episodes of partial melting of granitic crustal materials.

Welded ash-flow tuffs of Ritter Creek (sample # RTTR-1) in the Powder River Valley, northeast of Dooley Mountain is correlative with samples from subunit A1-SG2 of group 3 from the upper stratigraphic levels of the Dooley Rhyolite

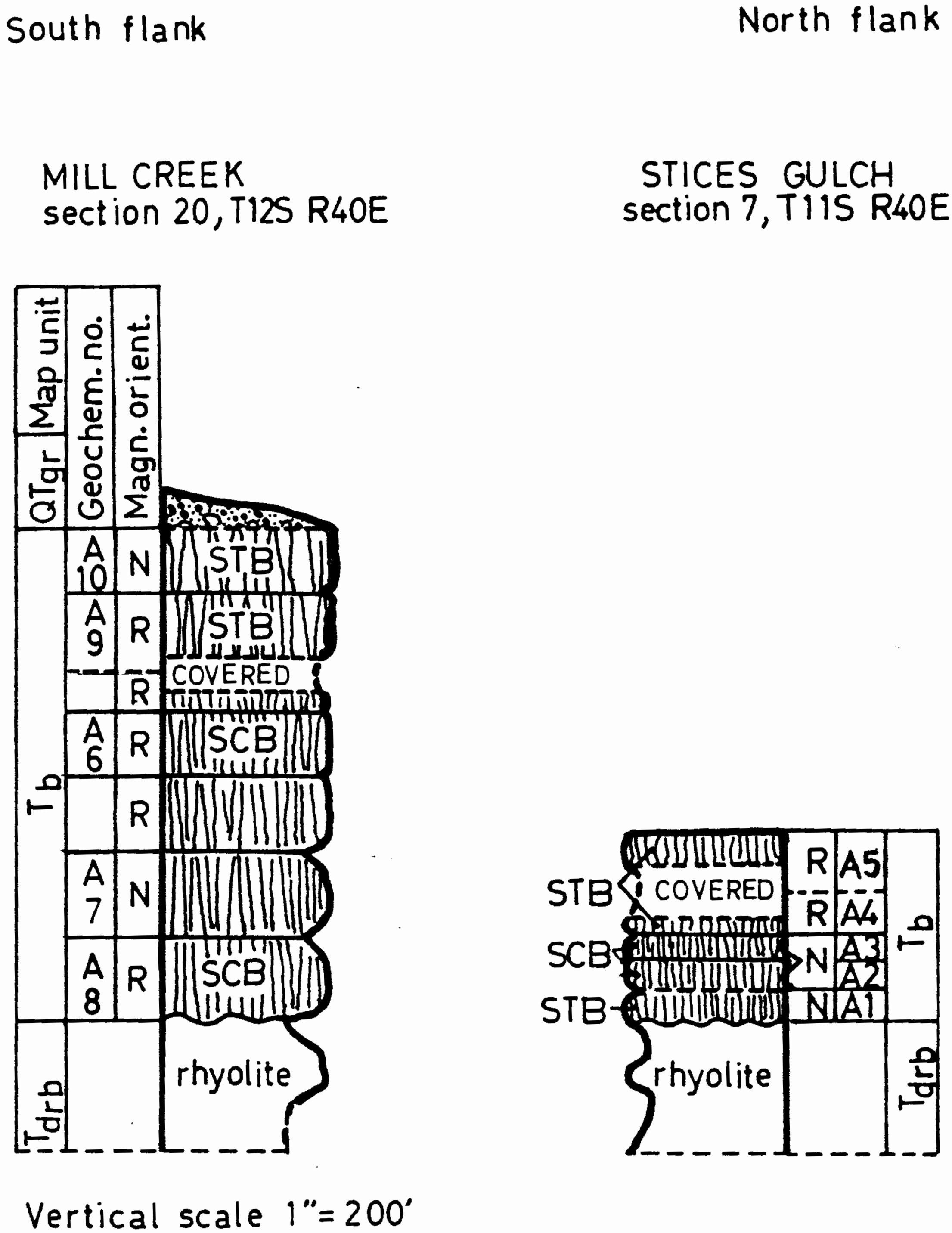
Breccia. Flows and pyroclastic rocks from this subunit are exposed in the Glassgow Creek and Beaver Mountain sections in SA 1, and cap the ridge line south and east of Rooster Rock Spring in section 1, 9, and 10 in T12S R40E. Late stage pyroclastic rocks of the upper Dooley Rhyolite Breccia were apparently deposited well beyond the limits of the Dooley Mountain quadrangle.

CHAPTER VII

NEOGENE BASALTS OF THE DOOLEY MOUNTAIN QUADRANGLE

The basalt flows which overlie and are interstratified with the Dooley Rhyolite Breccia are included in the Tb map unit shown in Plate 1. On the north flank of Dooley Mountain these basalt flows are exposed in stratigraphic section in SA 2 in sections 7 and 18 in Stices Gulch (T11S R40E). On the southern flank of the mountain basalt flows are exposed in stratigraphic section in the canyons of Coronet Creek and Mill Creek, in sections 19 and 20 (T12S R40E). On the northern flank of Dooley Mountain these flows dip at a moderate angle to the north, having been displaced along steeply dipping normal faults. Fault blocks have been downthrown and rotated to the north. The Tb map unit in SA 2 includes two hundred feet of basalt flows and talus covered sections which were measured and described along the east side of Stices Gulch in section 7. The measured sections from these areas are shown in Figure 20.

At least six lava flow units were identified in this section. These flow-on-flow basalts include dark gray columnar jointed flows with vesicular, autobrecciated flow margins and medium to dark gray basalt flows with massive entablature jointed interiors and thin autobrecciated



STB: subalkaline tholeiitic basalt
SCB: subalkaline calc-alcalic basalt

Figure 20. Measured stratigraphic sections of Neogene basalt flows on the north and south flanks of Dooley Mountain.

margins. Individual flow thicknesses range from 10 to 60 feet. Several of the flows in the section are separated by red-brown baked paleosols. The basalts in Stices Gulch overlie the Dooley Rhyolite Breccia across an erosional, low-angle(?) unconformity. Flows of unit Tb also directly overlie, with angular unconformity, pre-Tertiary rocks of map unit Mz_{BRS} along Trail Creek in section 6 (T11S R40E).

On the south flank of Dooley Mountain a cumulative stratigraphic thickness of 230 meters of basalt flows is exposed along highway 245 in Mill Creek in section 20 (T12S R40E). These basalts dip between 30 and 40 degrees to the south and are displaced, along with the flow units of the Dooley Rhyolite Breccia, along west-trending faults. A minimum of seven flow units are definable within this section, but flow unit boundaries are difficult to distinguish in the section and there may be as many as 20 individual flow units present. The basalt flows measured in Mill Creek canyon extend to the west to Cow Creek in the southeastern quarter of the Brannan Gulch quadrangle (Brooks and others, 1976). East of Mill Creek the basalt flows thin rapidly and pinch out toward Glassgow Creek. No basalts of the Tb map unit crop out within or east of Glassgow Creek in the quadrangle.

The contact between the Dooley Rhyolite Breccia and the basalts of unit Tb is structural in nature in Mill Creek, and covered by talus in Coronet Creek. Basalt flows of the lower section of unit Tb on the south flank of Dooley

Mountain are interstratified with the upper portion of the Dooley Rhyolite Breccia. Lens shaped basalt flows appear to represent shallow intracanyon occurrences, or thin flood basalts underlie rhyolite flow units of the upper strata of the Dooley Rhyolite Breccia in section 19 (T12S R40E) on the ridges separating Mill, Coronet, and Pine creeks.

PALEOMAGNETICS AND GEOCHEMISTRY OF THE TB FLOWS

Paleomagnetic orientation in the basalts in the measured sections from both the Stices Gulch section on the north, and the Mill Creek section on the south flank of Dooley Mountain were measured in the field utilizing a portable flux-gate magnetometer. Three polarity reversals are recognized in the basalt flows on the south flank, and only one reversal in the basalts on the north. The patterns of paleomagnetic orientation recorded in the two stratigraphic sections are dissimilar. The recorded orientations for individual flows are shown on Figure 20. Six Basalt flow units in the Mill Creek measured stratigraphic section in SA 1 and five flow units from the Stices Gulch section in SA 2 were sampled for geochemical analysis. Whole rock major oxide and trace element geochemical analysis from these flow units are presented in Table I. Normative mineral calculations (Irvine and Baragar, 1971) show that flows are quartz normative, olivine basalts and rocks are classified as either subalkaline, calc-alkaline or tholeiitic basalts. These data are shown in Table VI. Basalt series on both the north and south flank of Dooley Mountain include calc-alkalic and tholeiitic chemical types. Flow unit chemical types present in the stratigraphic sections are indicated in Figure 20. Vertical sequential patterns in geochemistry of flow units in the Stices Gulch and Mill Creek sections are dissimilar, as are the paleomagnetic orientations described above.

PETROLOGY OF THE BASALTS OF MAP UNIT TB.

Calc-alkaline basalts as a group generally are phyric, medium to dark gray and weather to a red-brown soil. Textures vary from densely crystalline in flow interiors to vesicular or scoriaceous and brecciated at flow margins. Basalts of the calc-alkaline type typically contain low percentages (<3%) of macro to microphenocryst assemblages of euhedral plagioclase (An_{53-58}) and lesser euhedral to subhedral olivine and augite. Phenocrysts are commonly segregated in small glomeroporphyritic clusters. Olivine phenocrysts show nearly complete deuteric alteration to brucite, iddingsite, and magnetite. Groundmass textures vary from dicktytaxitic and felty to tracyiotoid with subhedral plagioclase crystals (An_{28-35}) dominant. Interstitial to groundmass feldspar, the rock contains anhedral pyroxene, and magnetite. Calc-alkaline basalts in the measured section of Stices Gulch on the north flank of Dooley Mountain are similar in many respects in their

TABLE VI

CALCULATED NORMATIVE MINERAL AND ROCK CLASSIFICATION OF THE NEOGENE BASALTS IN THE DOOLEY MOUNTAIN QUADRANGLE, OREGON

Basalt Sample no.	A-1	A-2	A-3	A-4	A-5
Normative Mineral					
Quartz	4.94	5.35	4.54	4.37	3.76
Orthoclase	3.76	3.99	3.34	3.49	3.6
Albite	23.77	25	23.38	22.54	21.79
Anorthite	31.87	32.39	32.98	32.56	32.47
AB % Plag	43.22	44.06	41.99	41.4	40.66
Diopside	9.78	9.59	9.64	8.05	8.24
Hypersthene	20.63	18.38	20.96	24.57	25.79
EN % of Opx	65	66.84	66.02	74.84	75.45
Magnetite	2.11	2.11	2.11	2.09	2.09
Ilmanite	2.31	2.36	2.25	1.74	1.67
Zircon					
Apatite	0.82	0.82	0.8	0.59	0.58
Color Index	35.66	33.27	35.76	37.04	38.38
Differentiation Index	32.47	34.34	31.26	30.39	29.15
Normiplag	55.64	57.39	56.36	55.1	54.26
Crystallization Index	57.77	56.43	58.99	59.79	60.81
Rock Classification					
Alkali subgroup	subalkaline	subalkaline	subalkaline	subalkaline	subalkaline
Subgroup	tholeiitic	calc-alkalic	calc-alkalic	tholeiitic	tholeiitic
Group	Basalt	Basalt	Basalt	Basalt	Basalt

TABLE VI (CONTINUED)

CALCULATED NORMATIVE MINERAL AND ROCK CLASSIFICATION OF THE NEOGENE BASALTS IN THE DOOLEY MOUNTAIN QUADRANGLE, OREGON

Basalt Sample no.	A-6	A-8	A-9	A-10
Normative Mineral				
Quartz	6.45	5.82	4.84	5.66
Orthoclase	1.6	2.43	2.27	3.01
Albite	21.68	21.33	23.02	22.57
Anorthite	36.02	35.18	33.36	32.43
AB % Plag	38.07	38.25	41.32	41.54
Diopside	9.84	9.85	8.26	9.05
Hypersthene	20.48	21.31	22.58	21.25
EN % of Opx	74.89	73.94	63.02	59.6
Magnetite	2.09	2.1	2.12	2.13
Ilmanite	1.37	1.44	2.61	2.85
Zircon				
Apatite	0.46	0.54	0.93	1.06
Color Index	34.25	35.24	36.5	36.33
Differentiation Index	29.73	29.58	30.13	31.24
Normiplag	57.7	56.51	56.38	55
Crystallization Index	61.97	61.74	59.19	58
Rock Classification				
Alkali subgroup	subalkaline	subalkaline	subalkaline	subalkaline
Subgroup	calc-alkalic	calc-alkalic	tholeiitic	tholeiitic
Group	Basalt	Basalt	Basalt	Basalt

petrographic character to those described above except phenocryst percentages are somewhat higher.

Tholeiitic basalts of unit Tb can be distinguished from the calc-alkaline flows on the basis of their higher percentage of phenocrysts. In the tholeiitic basalts phenocrysts range from 7 to 20 percent. Phenocrysts typically range in size from 1 to .5 mm and include plagioclase (An_{55-70}) and faylite in equal proportions. Olivine commonly is present as crystals with the largest dimension. Within several rocks examined, olivine has associated keliplectic pyroxene rims forming euhedral crystal faces about anhedral olivine cores. Phenocrysts show trachytic to crudely glomeroporphyritic textures in these basalts and groundmass textures are variable between felty, dicktytaxitic, or tracyiotoid. Dominant groundmass minerals include plagioclase (An_{35-50}) and interstitial pyroxene, magnetite, and rare apatite.

CORRELATIONS OF THE NEOGENE BASALTS AT DOOLEY MOUNTAIN

The basalt series exposed on the north flank of Dooley Mountain has been correlated with Upper Miocene basalts of the Columbia River Basalt Group and/or the Strawberry Volcanics (Brooks and others, 1976; Brown and Thayer, 1966). The lack of continuity between the flows of the north and south flank of the mountain led previous investigators to question whether the flow on flow basalts on the south flank of the mountain are parts of flows which once extended across the mountain or whether they came from unidentified sources.

Differentiation index values (modal Qtz+Ab+An vs SiO_2) were calculated for the basalts from each section and are plotted in Figure 21. The large variations between flows of both chemical types in the sections of Stices Gulch and Mill Creek show that no flow type is common to both sections. Thus basalts were not deposited as a continuous series across the axis of Dooley Mountain.

Harker variation diagrams for the calc-alkaline basalts in the Stices Gulch and Mill Creek sections at Dooley Mountain are presented in Figure 22. The closest geochemical correlation between the calc-alkaline basalts at Dooley Mountain and similar lavas of the region, is with the basalts of the unnamed and transitional chemical types of the Bear Creek and Slide Creek basalts of the Strawberry Volcanics (Goles, 1986). Calc-alkaline basalts were deposited on both the north and south flanks of Dooley Mountain. On the south flank this deposition occurred simultaneously with flows of the Dooley Rhyolite Breccia. On the north flank these basalts are interstratified only with tholeiitic basalts which post date the Dooley Rhyolite Breccia.

A terinary discrimination diagram of MgO, FeO^*(FeO + Fe_2O_3), and Al_2O_3 (Pearce and others, 1977) showing the tectonic environment of calc-alkaline basalts at Dooley Mountain and the Strawberry Volcanics is shown in Figure 23.

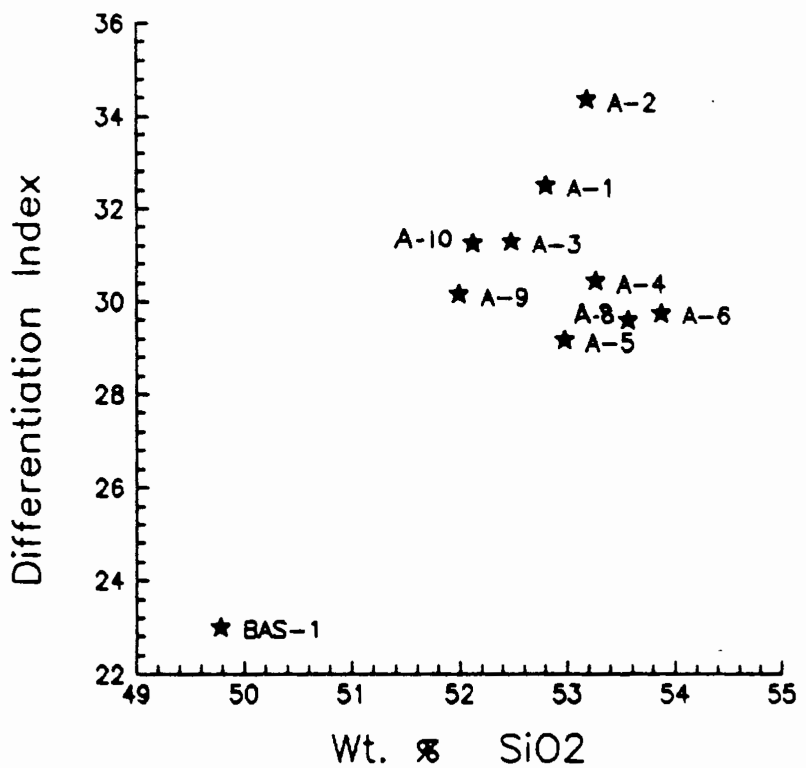


Figure 21. Differentiation index (modal Qtz + Ab + Or) vs SiO2 diagram showing the basalt flows of the Dooley Mountain quadrangle (Irvine and Barger, 1971).

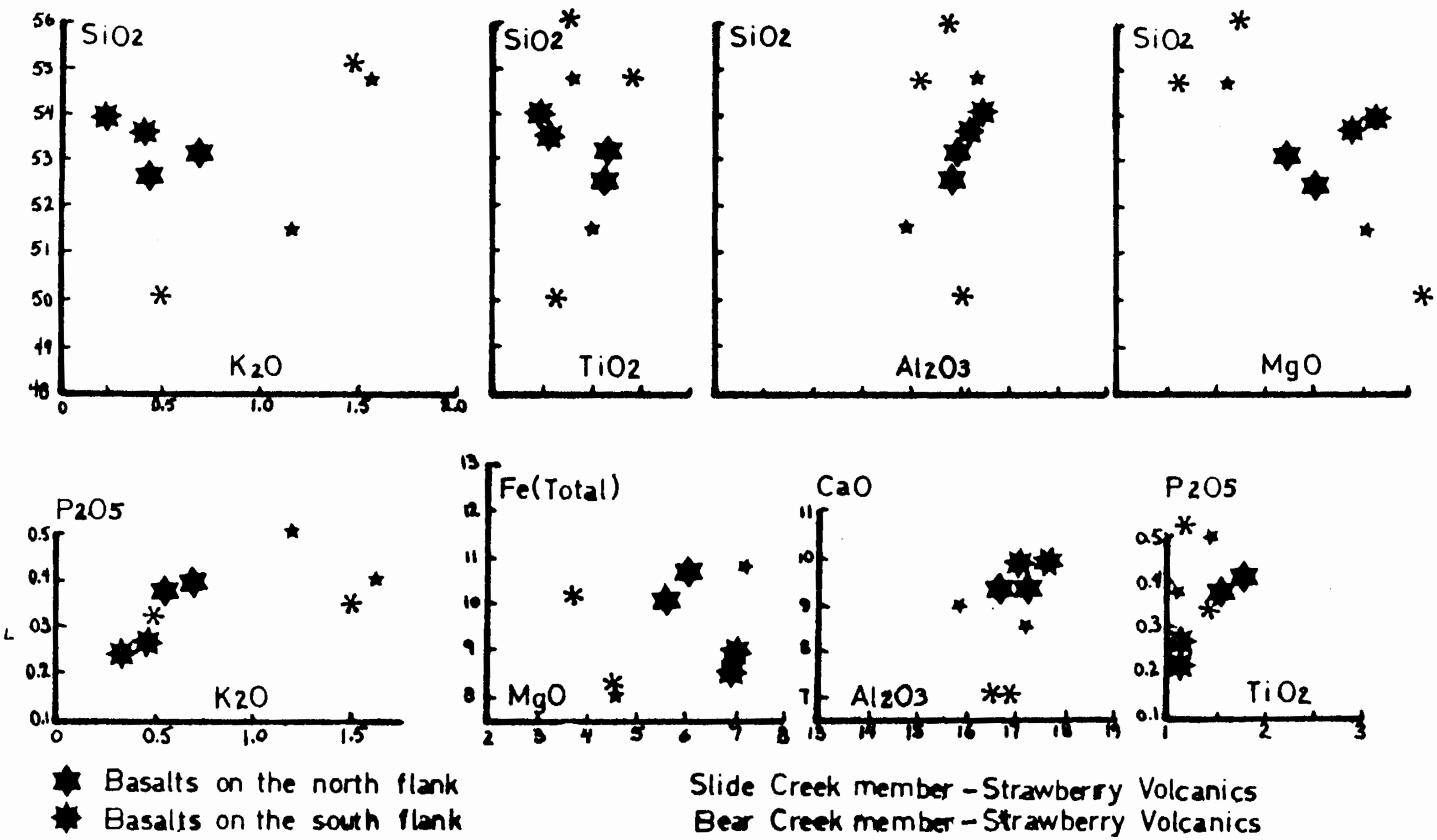


Figure 22. Harker variation diagrams showing major oxide variation in the calc-alkaline basalts from the Dooley Mountain quadrangle compared with the Strawberry Volcanics (Goles, 1986).

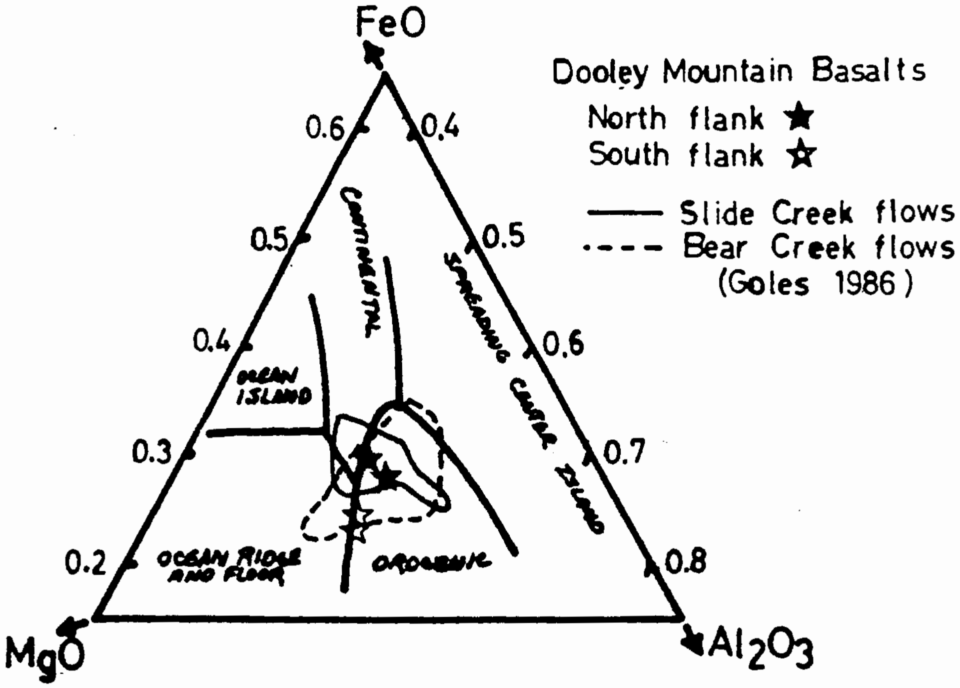


Figure 23. Discriminant diagram showing the tectonic provanence of the calc-alkaline basalts at Dooley Mountain and the Strawberry Volcanics. Adapted from Pearce and others (1977).

Calc-alkaline basalts of both groups are orogenic and continental basalt types. The Slide Creek Member of the Strawberry Volcanics is coeval with flows of the Picture Gorge Basalt of the Columbia River Basalt group. The most voluminous eruptive periods in the Strawberry Volcanics, including extrusion of these two volcanic suites occurred between 15 to 12 M.Y.B.P. (Robyn, 1978).

Major oxide data from the five tholeiitic basalt flows onlapping the flanks of Dooley Mountain are plotted in the Harker diagrams of Figure 24. The two chemical groups are defined in the tholeiitic basalts on the basis of differing FeO^*/MgO and P_2O_5/K_2O ratios. Two Samples WMB-13 and 15 from the upper stratigraphic units of the Mill Creek section on the south flank of Dooley Mountain form the first group. The second group is formed by basalt samples WMB-2, 5, and 7 from the flow units of the section in Stices Gulch, on the north flank of the mountain. The first group of tholeiitic basalts has high FeO/MgO and P_2O_5/K_2O ratios relative to the second group.

Geochemical data fields from the tholeiitic basalts at Dooley Mountain, the Powder River Basalt (Hooper and others, 1984), and Owyhee Basalt group (Brown and Petros, 1985) are superimposed, for comparative purposes, on the Harker diagrams of Figure 24. The low iron basalt group on the north flank of Dooley Mountain shows consistent similarities, and is correlated with the Powder River Basalt. The Powder River Basalts have been referred to as

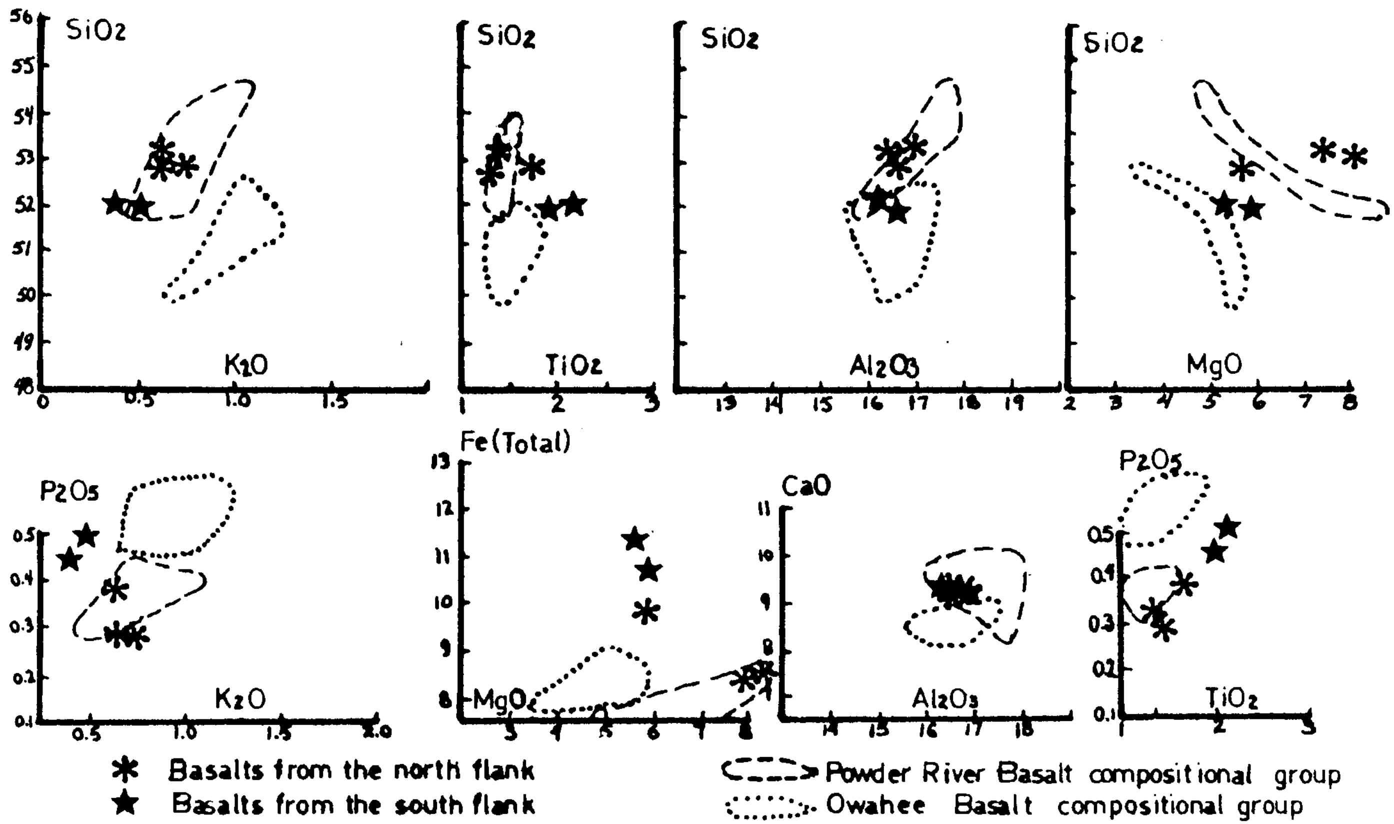


Figure 24. Harker variation diagrams showing major oxide variation in the tholeiitic basalts of the Dooley Mountain quadrangle compared with similar basalt chemical types in northeast Oregon.

part of the Saddle Mountains formation of the Columbia River Basalt Group (CRBG) by Swanson and others (1981) however their distinct chemical characteristics led Hooper and others (1984) to conclude that they are chemically distinct from the CRBG. The paleomagnetic patterns in the basalts of Stices Gulch compare favorably with documented orientations and reversals noted within the Priest Rapids and Roza Members of the Wanapum Basalt (Hooper and others, 1984). Accordingly the tholeiitic basalts on the north flank of Dooley Mountain are correlated with the Powder River Basalt.

The high iron tholeiitic basalt flows on the south flank of Dooley Mountain show ambiguous comparative relationships with both the Oyahee and Powder River basalt groups. Although similarities are seen in Figure 24, direct chemical correlations between these basalt groups cannot be made. The stratigraphic position of these basalts on the southern margin of the quadrangle suggests that these basalts are correlative with basalts in the upper Tertiary section located to the south of the Burnt River, in the Caviness quadrangle (Wolff, 1965).

CHAPTER VIII

CONCLUSIONS

Middle to late Miocene volcanic activity in the Dooley Mountain quadrangle is recorded by the thick and complex assemblage of blocky lava flows and associated pyroclastic and volcanogenic sedimentary rocks which form the Dooley Rhyolite Breccia. The suite of rocks in the formation are peraluminous, high silica rhyolites. At least nine distinct geochemical subgroups were identified in the suite and each is considered to be representative of a separate eruptive cycle in the formations history. Four related geochemical groups were formed from the nine trace element subgroups and compared. Comparisons within these groups showed that simple models for partial melting or differentiation of a single magma could not explain the trace element variations within these groups. The Dooley Rhyolite Breccia appears to have been erupted from multiple magma sources produced by repeated partial melting of continental crust. Trace element patterns in the chemical groups are indicative of eruption in a within-plate, tectonically attenuated crustal setting.

Rhyolitic rocks of the formation were erupted from at least four vents in the quadrangle. Eruptions were from both linear feeder dikes and central vents. The vents identified in the field are separated both areally and stratigraphically within the formation and probably represent only a small number of the eruptive sources present within the quadrangle.

Initial and waning episodes of volcanic activity in the formation were dominated by pyroclastic eruptions which produced welded ash-flow tuffs. The initial welded ash-flow tuff was erupted onto an irregular, eroded topographic surface and was channelized in drainages. The extent of this tuff cannot be determined. During the late stages of eruption of the formation, ash-flow tuffs were erupted over large areas to the north of Dooley Mountain into the Powder River Valley.

Following the initial pyroclastic eruptions at Dooley Mountain, volcanic activity changed to relatively quiescent eruptions of extensive block lava flows and subordinate associated pyroclastic debris. Between eruptions erosion removed poorly consolidated rock materials from the upper surfaces of flow structures and dumped them rapidly into topographic lows at flow margins. Subsequent eruptions buried the eroded surface, and the cycle was repeated. The cumulative effect was the construction of an extensive volcanic platform of irregular thickness in the Dooley Mountain quadrangle, upon which later less voluminous rhyolite flows and pyroclastic rocks were deposited.

Eocene Clarno basalts erupted to the south and/or west of Dooley Mountain and encroached into the southwest corner of the quadrangle. These were weathered and partially eroded prior to the initial rhyolitic eruptions. These flows are absent north of Dooley Mountain and apparently did not cross the quadrangle. The rhyolites of the formation were erupted onto an eroded topographic surface cut in the pre-Tertiary metamorphic basement rocks of the Elkhorn Range which formed a topographic barrier to lava flow transport from south to north across the Dooley Mountain quadrangle in Paleogene times.

Rhyolitic volcanism was contemporary with calc-alkaline basalt eruptions to the southwest of Dooley Mountain. Calc-alkaline basalt flows chemically correlative to the Strawberry Volcanics are interstratified with the Dooley Rhyolite Breccia at the southwest margin of the quadrangle. The Strawberry Volcanics were erupted between 15 and 12 million years ago into a north-trending graben on the southern margin of the Blue Mountain Anticline formed at the intersection of major structural components of the Basin and Range and the Blue Mountain provinces (Robyn, 1978). Striking similarities in the structure and tectonic setting of the Strawberry Volcanics and the Dooley Rhyolite Breccia exist.

Eruption of the Strawberry Volcanics was contemporary with the Picture Gorge Basalt of the Columbia River Basalt Group. The Dooley Rhyolite Breccia by analogy is in part contemporaneous with the lower Columbia River Basalt Group in northeastern Oregon (Robyn, 1978). Calc-alkaline lavas on the north flank of Dooley mountain are correlative with the Strawberry Volcanics, but are not contiguous with flow units on the south flank of the mountain.

Calc-alkaline basalt flows are interstratified with tholeiitic flows of the Powder River Basalt (Swanson and others, 1981; Hooper and others, 1984) on the north flank of Dooley Mountain. The tholeiitic basalts are also correlative with the Wanapum Basalt of the Columbia River Basalt Group. Tholeiitic basalt flows are also found on the south flank of the mountain. These basalts overlie and do not interfinger with the older calc-alkaline basalts. Chemically the tholeiitic basalts on the south flank of the mountain show ambiguous similarities with the Owyhee and Powder River Basalt chemical types, and may even belong to the basalts of the Unnamed Igneous Complex (Wolff, 1965). Tholeiitic flows on respective flanks of the mountain, like the calc-alkaline types, were not continuous.

The Dooley Rhyolite Breccia was erupted from vents within the Dooley Mountain quadrangle between 16 and 12 million years ago. One K-Ar date from a high level rhyolitic intrusion gives a young age of 14.3 $\pm$ .4 mybp for the formation. This age is similar to ages obtained from the Dinner Creek ash-flow tuff from two locations to the south of Dooley Mountain, in Baker County. Whether pyroclastic units of the Dooley Rhyolite Breccia extend to the south of the quadrangle and coalesce with the Dinner Creek Tuff is unknown. The formation in the Dooley Mountain quadrangle clearly extended beyond the map area to the south and is correlative to rhyolites mapped to the southwest in the vicinity of Rastus Mountain (Lowry, 1943). It is conceivable that the Dooley Rhyolite Breccia is a part of the Miocene silicic volcanic terrane which extends over substantial areas of northeastern Oregon, south of the Blue Mountain Anticline (Luedke and Smith, 1982).

It is clear that the Dooley Rhyolite Breccia was erupted in an extensional tectonic environment. The voluminous rhyolitic eruptions produced a highland area which posed a barrier to basalt flow and sediment transport across the Dooley Mountain quadrangle which persists today. Whether crustal extension produced the north-trending graben, now occupied by the formation, during the eruption of the rhyolites, or following cessation of volcanism within the quadrangle is an open question. Much needed structural information in the quadrangle area is masked under prohibitive thickness of soils. It is likely that the information needed to resolve structural details in this region could be gained by mapping areas peripheral to the Dooley Mountain quadrangle.

REFERENCES CITED

Ashley, R.P., 1966. Metamorphic petrology and structure of the Burnt River canyon area, northeastern Oregon : Stanford Univ. doctoral dissert., 300p.

Beaulieu, J.D., 1972. Geologic formations of eastern Oregon, east of longitude 121^{o} 30′ : Oregon Dept. Geol. and Mineral Indus. Bull. 73, 78p.

Beeson, M.H., and Keedy, C.R., 1986. Program : INAA version 1.1 : Portland State Univ. Geol. Dept. software library.

Bonnichsen, B., and Kauffman, D.F., 1987. Physical features of rhyolite lava flows of the Snake River plain volcanic province, southwestern Idaho : Geol. Soc. America, special paper 212, pp. 119-145.

Brooks, H.C., McIntyre, J.R., and Walker, G.W., 1976. Geology of the Orgegon part of the Baker 1^{o} by 2^{o} quadrangle : Oregon Dept. Geol. and Mineral Indus., geological map series GMS-7, 25 p. and 1 map sheet.

Brooks, H.C., 1979. Plate tectonics and the geologic history of the Blue Mountains : Oregon Geology, vol. 41, no. 5, pp. 71-80.

Brown, C.E., and Thayer, T.P., 1966. Geologic map of the Canyon City quadrangle, northeast Oregon : U. S. Geol. Survey, Misc. Invest. Map I-447.

Brown, D.E., and Petros, J. R., 1985. Geocchemistry, geochronology, and magnetostratigraphy of a measured section of the Owahee Basalt, Malheur county, Oregon : Oregon Geology, vol. 47, no. 2, pp. 15-20.

Davis, J.C., 1986. Statistics and data analysis in geology : second edition, John Weiley and Sons, Inc., New York, New York, 646p.

Dickinson, W.R., and Thayer, T.P., 1978. Paleogeographic and paleotectonic implications of the Mesozoic stratigraphy and structure of the John Day Inlier of central Oregon in Mesozoic paleogeography of the western United States : Soc. Econ. Paleontologists and Mineralogists, p. 147-160.

Ekambaram, V., Kawabe, I., Tanaka, T., Davis, A.M., and Grossman, L., 1984. Chemical comparison of refractory inclusions in the Murchison C-2 chondrite : Geochimica et Cosmochimica Acta, vol. 48, pp. 2089-2105.

Fink, J.H., and Manley, C.R., 1987. Origin of pumiceous and glassy textures in rhyolite flows and domes : Geol. Soc. America, Special Bull. 212, pp. 77-89.

Franklin, J.F., and Dyrness, C.T., 1969. Vegetation of Oregon and Washington : U. S. Forest Serv. Research Paper PNW-80, 216p.

Gilluly, J., 1937. Geology and mineral resources of the Baker quadrangle, Oregon : U.S. Geol. Survey Bull. 879, 119p.

Goles, G.G., 1986. Miocene basalts of the Blue Mountain province in Oregon. I : Compositional types and their geological setting : Journal of Petrology, vol. 27, part 2, pp. 495-520.

Hansen, G. N., 1981. The application of trace elements to the petrogenesis of igneous rocks of granitic composition : Earth and Planetary Sci. Letters, no. 53, pp. 26-43.

Higgins, M.W., and Waters, A.C., 1968. Newberry caldera field trip, in the Andesite Conference guidebook : Oregon Dept. of Geology and Mineral Industres Bull., pp. 59-77.

Hooper, P.W., Kleck, W.D., Knowles, C.R., Reidel, S.P., and Thiessen, R.L., 1984. Imnaha Basalt, Columbia River Basalt group : Journal of Petrology, vol. 25, part 2, pp. 473-500.

Irvine, T.N., and Baragar, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks : Canadian Journ. Earth Sci., vol. 8, pp. 523-548.

Jakes, P., and White, A.J.R., 1972. Major and trace elements in volcanic rocks of orogenic areas : Geol. Soc. of America Bull., vol. 83, 29p.

Johnson, D.A., and Donnely-Nolan, J., 1981. Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California : U.S. Geol. Survey Circular, 189p.

Le Bas, M.J., LeMaitre, R.W., Streckeisen, A., and Zanettin, B., 1985. A chemical classification of volcanic rocks based on the total alkali-silica diagram : Journal of Petrology, vol. 27, part 3, pp. 745-750.

Lipman, P.W., 1965. Chemical comparison of glassy and crystalline volcanic rocks : U.S. Geol. Survey Bull. 1201-D, 24p.

Lipman, P.W., Christiansen, R.L., and Van Anstine, R.E., 1969. Retention of alkalis by calc-alkaline rhyolites during crystallization and hydration : American Mineralogist, vol. 54, pp. 286-291.

Lowry, W.D., 1943. The geology of the northeast quarter of the Ironside Mountain quadrangle, Baker and Malheur counties, Oregon : Univ. of Rochester doctoral dissert., 106 p.

Luedke, R.G., and Smith, R.L., 1982. Map showing the distribution, composition, and age of late Cenozoic volcanic centers in Oregon and Washington : U.S. Geol. Survey Miscellaneous Invest. Series, Map I-1091-D.

Macdonald, G.A., 1972. Volcanos : Prentice-Hall, Inc., Elglewood Cliffs, New Jersey, 507p.

Meschede, M., 1986. A method of discriminating types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram : Chemical Geology, vol. 56, pp. 207-218.

Muecke, G.K., 1980. Short course in neutron activation analysis in the geosciences : Mineral. Assn. of Canada, Short Course Handbook, vol.5, 279p.

Noblett, J.B., 1980. Volcanic petrology of the Eocene Clarno formation on the John Day river near Cherry Creek, Oregon : Stanford Univ. doctoral dissert., 162p.

Novitsky-Evans, J.M., 1974. Petrochemical study of the Clarno Group : Eocene-Oligocene continental volcanism of north-central Oregon : Rice Univ., Houston, Tx., M.A. thesis, 97p.

Pardee, H.T., and Hewett, D.F., 1914. Geology and mineral resources of the Sumpter quadrangle, Oregon in Mineral Resources of Oregon : Oregon Bur. of Mines and Geology, vol.1, no. 6, pp. 3-128.

Pearce, T.H., Gorman, B.E., and Birkett, T.C., 1977. The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks : Earth and Planet. Sci. Letters, vol. 36, pp. 121-132.

Pearce, T.H., Harris, N.B.W., and Tindle, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks : Journal of Petrology, vol. 25, part 4, pp. 956-983.

Prostka, H.J., 1963. The geology of the Sparta quadrangle, Oregon : Johns-Hopkins Univ. doctoral dissert., 245p.

Prostka, H.J., 1967. Preliminary geologic map of the Durkee quadrangle, Oregon : Oregon Dept. Geol. and Mineral Indus. GMS-3.

Robyn, T.L., 1978. Miocene volcanism in eastern Oregon : An example of calc-alkaline volcanism unrelated to subduction : Journ. of Volcanology and Geothermal Research, vol. 5, pp. 149-161.

Rogers, J.W., 1966. Coincidence of structural and topographic highs during post-Clarno time in north-central Oregon : Amer. Assn. of Petroleum Geologists Bull. no. 50, 390p.

Rogers, J.W., and Novitsky-Evans, J.M., 1977. The clarno formation of central Oregon, USA - Volcanism on a thin continental margin : Earth and Planetary Sci. Letters, vol. 34, no.1, pp. 55-66.

Rogers, J.W., and Ragland, P.C., 1980. Trace elements in the Clarno formation of central Oregon and the nature of the continental margin on which eruption occurred : Summary : in Trace elements in continental margin magmatism. Part 1 : Geol. Soc. of America Bull. vol. 91, pp 196-198.

Ross, C.S., and Smith, R.L., 1961. Ash-flow tuffs : Their Origin, geologic relations, and identification : U.S. Geol. Survey, Professional Paper no. 366, 81p.

Shand, S.J., 1951. Eruptive rocks : John Weiley and Sons, Inc., New York, New York, fourth edition, 488p.

Smith, R.L., 1960. Ash Flows : Geol. Soc. of America Bull. vol 71, pp. 795-842.

Swanson, D.A., Anderson, J.L., Camp, V.E., Hooper, P.R., Taubeneck, W.H., and Wright, T.L., 1981. Reconnaissance geologic map of the Columbia River Basalt, northern Oregon and western Idaho : U.S. Geological Survey Open-File Report 81-797

Taubeneck, W.H., 1957. Geology of the Elkhorn mountains, northeastern Oregon : Bald Mountain batholith : Geol. Soc. America Bull., vol. 68, pp. 181-238.

Walker, G.W., Dalrymple, G.B., and Lanphere, M.A., 1974. Index to Potassium-Argon ages of cenozoic volcanic rocks of Oregon : U.S. Geol. Survey, Misc. Field Studies MFS-569.

Whitson, D.N., 1982. Geology of the perlite deposit at No Agua Peaks, New Mexico in Industrial Rocks and Minerals of the Southwest : New Mexico Bur. of Mines and Miner. Resources circular 182, pp. 89-95.

Wolff, E.N., 1965. The geology of the northern half of the Caviness quadrangle, Oregon : Univ. of Oregon doctoral dissert., 200p.

Zanettin, B., 1984. Proposed new chemical classification of volcanic rocks : Episodes, vol. 7, no. 4, pp 19-20.

Zielinski, R.A., Lipman, P.W., and Millard, H.T., 1977. Minor-element abundancec in obsidian, perlite, and felsite of calc-alkaline rhyolites : American Mineralogist, vol. 62, pp. 426-437.

APPENDIX A

DETAILED PETROGRAPHIC DESCRIPTION OF BASALT SAMPLE BAS-1 FROM MAP UNIT T_{EB} AT DOOLEY MOUNTAIN

The basalt of the Teb map unit is composed of melanocratic, coarsely phyric, sparsely vesicular, massive basalt. A petrologic description of rock sample BAS-1 from this map unit in the central area of section 17, T12S R40E is provided below.

Thin Section BAS-1.

<u>Texture</u>: Phyric, sparsely vesicular, hypidiomorphic-granular, and glomeroporphyritic with groundmass texture displaying both ophitic and hyalophitic character. Phenocrysts comprise 5-7 modal percent and groundmass 93-95 modal percent of rock.

<u>Phenocrysts</u>: 1 cm-2 mm : Labradorite (An_{54-63}) 2-3% 1 mm-.25 mm : Olivine 1%, Ca-Oligoclase (An_{36-48}). Large plagioclase phenocrysts occur as isolated crystals while smaller plagioclase phenocrysts are generally arranged in radially distributed glomeroporphyritic clusters. All plagioclase phenocrysts contain rare microcrystalline apatite inclusions and some trapped glass(?) inclusions and show poorly developed normal to oscillatory zonation at

crystal boundaries. Olivine phenocrysts are glomeroporphyritic and entirely altered to brucite and locally iddingsite where phenocrysts boundary contacts with mesostasis glass occur.

<u>Groundmass</u>: >.2 mm : Plagioclase 40%, Augite 50%, Glass 8-10%, Magnetite 0-2%.Plagioclase microlites are generally less than .1 mm in length and occur in randomly distributed twinned euhedral prisms surrounded in ophitic relationship by augite and by late stage mesostasis glass. Subhedral augite minerals are also occasionally found isolated in glass where they are completely altered to Fe oxide. Magnetite is disseminated throughout groundmass areas devoid of mesostasis glass. Vesicles within the rock are of two sizes, comprising less than one percent of the rock volume. The largest range from 1 to 4 mm and are spherical in shape. The smaller group is generally less than .2 mm and are dispersed randomly throughout the matrix occurring as angular to subround void spaces interstitial to groundmass crystals.

All vesicles in the rock are completely filled by secondary minerals. These secondary minerals include first a cryptocrystalline lining of quartz at the vesicle walls with the bulk of the remaining vesicle filled by calcite.

APPENDIX B

DETAILED STRATIGRAPHIC DESCRIPTION OF THE RITTER CREEK SECTION

The lower ash-flow tuff unit in the Ritter Creek section conformably overlies massively bedded, buff colored tuffs. The lower five feet of the unit consists of a laminar bedded base-surge deposit immediately overlain by 12 to 15 feet of dark gray, poorly welded vitric tuff. This vitric tuff is laterally transgressive into a single, moderately welded ash-flow tuff cooling unit elsewhere in Ritter Creek canyon. The lower ash-flow tuff cooling unit is truncated by an erosional disconformity. Post-eruption erosion of the unit produced shallow fluvial channels on the flow unit surface which were subsequently filled with poorly sorted volcanogenic cobble conglomerates derived from a rhyolitic terrane. The clastic cobbles in this unit are dominantly felsites with lesser obsidian as is the finer sized matrix material. Sediments of this unit were deposited on a topographic surface of low relief and infilled all existing fluvial channels. The upper surface of the conglomerate unit is somewhat irregular but is planar in overall appearance, and is conformably(?) overlain by a reversely graded lapilli-bearing air-fall(?) tuff. The conglomerate lacks internal fluvial sedimentary bedding structures and are thus considered to be rapidly deposited as a single unit, perhaps as the distal facies of a pyroclastic debris or mud flow deposit.

A simple, 7 meter thick, moderately welded ash-flow tuff cooling unit caps the Ritter Creek measured section. The basal vitrophyre of the cooling unit contains dark green-gray perlitic glass making up at least 50 percent of the stratigraphic unit thickness. The basal vitrophyre directly overlies the unwelded, reversely graded lapilli-bearing tuffs in the section. The basal vitrophyre unit is texturally upward gradational into gray, poorly welded vitric, lapilli-bearing tuffs which are overlain by buff colored tuffs that are considered to be lower pliocene in age (Brooks and others, 1976).

APPENDIX C

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
				Unclassified Sample Group								
C-33	FEL	4.36	4.50	45.80	8.63	3.70	0.00	4.23	7.25	0.87	0.31	99
A-60	TWT	2.69	3.30	39.10	8.94	5.50	0.90	5.37	7.50	2.09	0.57	68
				Geochemical Group 1 - Subgroup A-1SG3								
A-50	PER	3.39	4.70	37.40	5.87	4.00	0.59	3.86	4.90	1.10	0.38	95
A-23	PER	2.95	4.70	41.10	6.44	4.00	0.55	3.35	6.10	1.27	0.42	115
A-21	PER	3.24	4.40	39.10	5.73	2.80	0.52	3.61	5.50	1.10	0.00	97
C-51	FEL	4.56	2.80	31.40	5.56	3.30	0.51	6.31	5.60	2.86	1.70	81
A-20	FEL	3.40	3.80	38.50	5.79	3.30	0.57	3.88	4.80	0.89	0.00	109
A-53	FEL	4.20	3.30	40.30	6.65	4.40	0.59	4.06	0.00	0.79	0.00	115
A-34	PER	4.31	5.50	47.70	7.29	4.60	0.65	5.35	6.90	1.42	0.00	120
C-9	PER	3.77	3.50	39.50	5.95	3.20	0.52	3.85	4.18	1.28	0.41	88
DMR-L	FEL	3.94	4.90	43.80	6.62	3.70	0.63	3.53	6.00	0.88	0.35	102
A-24	PER	3.81	4.60	48.90	4.75	3.00	0.44	2.80	4.30	1.00	0.46	83
A-19	PER	2.88	4.40	39.60	5.75	3.00	0.48	3.76	0.00	0.89	0.00	101
A-18	PER	3.10	5.00	39.20	5.96	2.90	0.53	3.45	4.30	1.09	0.00	101
				Geochemical Group 1 - Subgroup B-1SG3								
A-14	FEL	4.03	3.90	42.50	6.43	3.30	0.52	3.45	6.50	0.85	0.28	121
A-15	FEL	3.93	4.20	41.10	6.34	3.40	0.50	3.71	11.80	0.75	0.00	100
A-17	FEL	4.10	3.80	55.60	11.18	4.80	0.67	4.00	7.40	1.05	0.00	116
A-51	FEL	3.88	4.20	41.30	7.23	3.00	0.55	3.22	6.70	0.59	0.00	105
A-52	FEL	4.04	4.00	59.60	12.59	3.80	0.58	3.00	4.20	1.16	0.00	101
C-36	FEL	4.28	3.70	46.40	9.63	3.60	0.50	4.67	0.00	0.85	0.59	90
A-28	FEL	4.24	4.40	48.00	8.86	4.50	0.55	3.11	7.80	0.82	0.00	119

Na, K, Fe in wt. % ; all others in ppm.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
A-32	PER	3.48	3.90	43.00	6.38	3.80	0.52	3.57	4.50	1.23	0.43	102
Geochemical Group 1 - Subgroup C-1SG3												
A-13	FEL	4.10	4.50	49.60	8.78	3.80	0.53	4.12	5.20	1.29	0.00	115
A-16	FEL	3.61	3.70	41.90	6.49	3.40	0.48	3.57	7.20	1.01	0.00	115
A-33	FEL	3.47	3.70	39.00	6.10	4.10	0.54	4.23	4.60	1.27	0.71	87
C-35	FEL	4.21	3.80	53.40	10.60	3.60	0.49	9.06	4.28	3.07	1.78	76
C-14	PER	3.26	5.20	43.00	6.62	3.90	0.52	3.39	0.00	1.59	0.30	92
A-59	FEL	3.60	3.10	43.10	7.08	4.00	0.56	3.32	12.30	1.22	0.49	96
C-41	FEL	4.35	4.00	45.00	8.85	2.80	0.42	5.23	6.00	1.99	0.65	90
Geochemical Group 2 - Subgroup A-2SG3												
C-12	PER	3.19	5.60	42.70	6.72	4.10	0.63	3.28	0.00	0.20	0.48	98
A-31	FEL	4.48	3.60	49.70	10.09	6.80	1.08	6.08	8.40	1.13	0.60	102
DMR-M	FEL	4.58	3.70	37.30	7.18	4.80	0.67	6.17	6.50	0.89	1.17	104
A-54	FEL	4.02	4.40	45.30	7.80	3.60	0.65	3.86	8.50	0.74	0.33	105
C-48	PER	4.18	0.00	38.90	7.16	3.60	0.66	6.85	4.18	1.91	0.77	83
C-23	PER	4.42	3.80	48.80	9.30	5.10	0.83	6.84	0.00	2.88	1.65	92
C-34	FEL	4.53	3.70	71.00	17.24	7.70	1.11	6.32	9.40	1.11	0.41	91
C-28	PER	4.45	4.70	43.70	8.41	4.60	0.78	5.83	6.30	2.02	1.08	90
C-16	FEL	4.58	3.80	45.80	8.92	4.20	0.77	9.41	7.81	1.37	1.63	96
C-18	FEL	3.31	4.70	41.00	6.21	2.90	0.60	4.13	0.00	0.92	0.41	94
C-7	PER	3.72	4.60	40.60	6.53	3.10	0.52	4.01	3.53	1.39	0.00	91
C-17	FEL	3.79	3.70	41.10	10.38	3.60	0.54	3.05	3.60	0.66	0.31	101
A-26	PER	3.02	4.30	39.90	5.99	3.50	0.69	3.09	4.10	1.05	0.00	81

Na, K, and Fe in wt.% ; all others in ppm.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
					Geochemical Group 2 - Subgroup B-2SG3							
C-13	FEL	4.01	4.50	43.20	6.91	4.00	0.51	3.27	8.18	0.62	0.00	88
A-29	PER	3.69	3.40	40.70	7.62	4.30	0.71	6.44	5.20	2.08	0.75	83
A-30	FEL	3.61	4.00	41.00	9.17	2.70	0.64	3.73	9.20	0.67	0.00	92
C-70	PER	4.40	3.10	46.90	10.42	5.10	0.79	4.44	5.39	0.75	0.00	90
A-55	PER	3.37	4.50	40.40	7.60	4.80	0.78	4.22	3.90	1.93	0.58	93
C-50	PER	3.75	4.80	44.80	6.73	4.10	0.65	3.81	0.00	1.38	0.53	78
A-25	PER	3.81	3.80	40.10	7.64	5.50	0.65	6.39	0.00	2.29	0.77	80
C-30	PER	3.60	5.00	50.40	9.72	4.70	0.81	5.08	0.00	1.36	0.00	99
					Geochemical Group 2 - Subgroup C-2SG3							
C-20	FEL	2.89	0.00	55.90	11.15	4.30	0.78	4.78	6.78	0.81	0.00	99
C-63	FEL	2.57	3.80	34.30	6.72	5.40	0.85	5.13	0.00	0.52	0.00	91
C-53	FEL	4.51	3.30	68.00	15.90	21.60	3.70	9.03	11.62	0.97	0.40	79
C-61	FEL	1.29	4.90	42.80	6.70	3.70	0.64	4.42	5.58	0.53	0.00	102
A-36	FEL	4.31	3.80	38.00	8.02	5.50	0.85	4.39	12.20	0.43	0.00	85
A-38	PER	4.56	5.60	48.50	9.21	6.10	0.92	6.53	5.50	1.64	0.50	80
C-46	PER	4.24	5.30	50.00	9.77	4.10	0.69	5.19	5.76	1.76	0.67	94
C-8	PER	3.41	3.80	41.90	6.55	3.50	0.65	3.10	0.00	1.12	0.39	90
C-39	PER	4.13	0.00	41.80	8.19	4.90	0.92	6.43	0.00	2.97	1.34	89
C-64	PER	3.61	3.80	41.80	8.78	5.60	0.91	7.19	5.80	2.36	0.55	82
A-39	PER	3.18	3.70	42.50	7.71	5.00	0.75	3.94	0.00	1.55	0.39	101
C-32	FEL	3.74	4.40	49.40	10.87	6.00	1.05	3.55	7.00	0.63	0.00	102
C-49	PER	3.19	4.50	39.30	6.05	3.30	0.64	3.05	0.00	0.90	0.00	94
C-6	FEL	2.09	4.50	36.40	6.26	4.00	0.67	4.21	0.00	0.46	0.00	95

Na, K, and Fe in wt. % ; all others in ppm.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
C-44	PER	3.87	3.90	42.10	7.63	4.00	0.84	6.06	5.00	1.38	0.63	82
C-38	PER	3.72	4.00	47.20	11.56	6.00	1.13	11.85	0.00	1.87	1.30	77
C-62	FEL	5.57	3.30	56.10	12.80	7.50	1.18	1.53	4.50	0.57	0.00	72
C-47	PER	3.79	0.00	43.10	6.68	3.50	0.69	3.35	0.00	1.36	0.31	92
C-19	PER	2.86	3.70	23.60	4.18	2.30	0.57	2.63	0.00	0.75	0.00	91
C-10	PER	3.73	4.20	27.40	5.51	3.60	0.64	3.20	4.10	0.97	0.00	136
C-3	FEL	2.00	3.60	27.10	6.06	5.50	0.87	6.53	4.65	0.46	0.00	88
				Geochemical Group 3 - Subgroup A-1SG2								
A-57	FEL	3.99	3.60	47.00	9.32	4.70	0.63	4.68	4.70	2.16	0.84	128
DMV-1	PER	3.42	4.10	24.90	4.30	3.10	0.56	3.26	0.00	0.92	0.00	123
A-56	FEL	4.03	4.00	40.30	7.69	4.60	0.77	4.83	6.40	2.17	0.82	99
C-25	FEL	4.44	3.90	27.40	4.80	2.80	0.58	5.97	5.50	2.53	0.98	90
C-22	PER	3.68	5.50	28.10	4.77	2.80	0.49	3.60	3.81	0.84	0.26	100
C-11	PER	2.58	4.60	30.00	5.58	2.80	0.53	3.59	0.00	0.83	0.00	136
DMO-2	OBS	3.34	3.40	33.70	7.00	4.60	0.70	3.79	11.70	2.05	0.43	110
DMO-1	OBS	4.13	4.00	25.40	4.82	3.40	0.53	3.49	9.80	1.12	0.00	135
RTTR-1	OBS	4.14	4.30	26.50	4.48	3.10	0.47	3.51	10.10	1.14	0.00	127
C-68	PER	3.70	4.30	25.50	4.66	2.70	0.50	2.93	4.30	0.90	0.32	106
DMV-2	PER	2.76	3.70	20.80	3.58	3.10	0.37	3.41	4.20	0.93	0.26	135
				Geochemical Group 3 - Subgroup B-1SG2								
DMR-U	FEL	3.79	3.50	38.10	8.17	5.30	0.78	3.85	5.80	2.01	0.00	108
A-12	FEL	4.03	4.50	45.30	9.58	5.50	0.77	3.74	7.10	2.00	0.00	101
C-24	FEL	4.51	3.40	43.10	7.73	3.70	0.74	8.29	5.30	2.30	1.43	76
C-66	OBS	4.46	4.60	27.50	5.11	4.00	0.58	3.93	7.90	1.05	0.29	101
C-58	OBS	4.75	4.40	44.30	9.73	5.40	0.91	5.25	6.41	2.18	0.53	87

Na, K, Fe in wt. % ; all others in ppm.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Na	K	La	Sm	Yb	Lu	Sc	Cr	Fe	Co	Rb
C-57	PER	3.27	4.70	47.60	9.73	6.00	0.92	4.28	4.20	1.51	0.42	102
C-60	PER	3.44	6.20	25.30	5.28	3.80	0.54	2.87	6.00	0.70	0.00	109
A-11	FEL	4.12	3.10	38.80	8.25	4.60	0.76	3.61	7.40	2.01	0.00	100
C-43	FEL	4.66	3.70	43.40	8.47	5.10	0.82	7.75	8.74	1.61	0.92	74
C-67	OBS	4.65	4.50	28.90	5.49	4.30	0.62	4.10	8.18	1.10	0.00	116
				Geochemical Group 4								
C-21	FEL	3.85	3.40	48.10	9.97	4.30	0.56	3.05	0.00	0.47	0.00	104
C-27	FEL	4.17	4.40	59.50	13.57	6.00	0.88	6.30	0.00	0.34	0.44	89
DMD-1	FEL	4.23	4.30	37.80	7.80	2.90	0.29	3.20	0.00	0.66	0.00	109
C-2	FEL	3.18	4.60	40.40	6.28	3.90	0.64	3.42	0.00	0.29	0.00	99

Na, K, Fe in wt. % ; all others in ppm.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
Unclassified Sample Group									
C-33	FEL	2.70	63.30	1520	1.32	0.17	200.00	0.00	7.79
A-60	TWT	0.45	60.30	1360	2.14	0.17	0.00	0.90	5.20
Geochemical Group 1 - Subgroup A-1SG3									
A-50	PER	1.49	62.60	1570	1.31	0.15	0.00	0.00	7.81
A-23	PER	1.65	67.20	1650	1.30	0.14	0.00	0.00	8.27
A-21	PER	1.60	65.80	1630	1.36	0.15	0.00	0.00	9.03
C-51	FEL	0.90	59.20	1220	1.20	0.12	0.00	0.00	7.27
A-20	FEL	1.40	67.80	1710	1.49	0.14	260.00	0.00	9.50
A-53	FEL	1.44	63.40	1710	1.47	0.16	0.00	0.00	8.96
A-34	PER	4.00	79.20	1920	1.58	0.19	300.00	0.00	10.30
C-9	PER	3.90	57.90	1420	1.08	0.15	0.00	0.00	7.36
DMR-L	FEL	1.33	73.10	1900	1.39	0.16	0.00	0.00	8.65
A-24	PER	3.40	55.90	1340	1.06	0.12	0.00	0.49	8.19
A-19	PER	1.72	68.60	1540	1.30	0.16	0.00	0.00	9.58
A-18	PER	1.54	64.80	1640	1.27	0.14	0.00	0.35	8.51
Geochemical Group 1 - Subgroup B-1SG3									
A-14	FEL	1.18	71.20	1790	1.36	0.15	0.00	0.54	8.80
A-15	FEL	1.35	69.20	1830	1.43	0.15	210.00	0.77	9.01
A-17	FEL	1.51	90.40	1660	1.52	0.20	0.00	0.00	9.33
A-51	FEL	1.19	72.60	1610	1.26	0.16	0.00	0.48	9.10
A-52	FEL	1.20	76.40	1720	1.56	0.20	0.00	0.00	9.16
C-36	FEL	2.10	67.00	1280	1.53	0.16	250.00	0.00	7.50
A-28	FEL	1.77	79.60	1570	1.39	0.19	250.00	0.00	9.49

Units in ppm. Data = 0.0 is below detection limit.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
A-32	PER	1.69	72.60	1860	2.21	0.15	0.00	0.00	8.92
Geochemical Group 1 - Subgroup C-1SG3									
A-13	FEL	1.53	77.90	1570	1.54	0.17	290.00	0.00	9.60
A-16	FEL	1.18	74.80	1810	1.45	0.16	0.00	0.57	9.00
A-33	FEL	1.51	63.40	1590	1.32	0.13	0.00	0.00	8.18
C-35	FEL	2.70	65.70	1240	1.23	0.17	0.00	0.00	6.64
C-14	PER	3.30	65.20	1450	1.14	0.13	0.00	0.00	7.97
A-59	FEL	1.62	71.90	1750	1.37	0.15	0.00	0.69	8.59
C-41	FEL	2.70	65.40	1190	1.32	0.15	280.00	0.58	7.03
Geochemical Group 2 - Subgroup A-2SG3									
C-12	PER	3.20	64.90	1510	1.21	0.13	200.00	0.00	8.02
A-31	FEL	1.15	84.20	1690	1.66	0.20	0.00	0.00	8.36
DMR-M	FEL	1.45	57.20	1550	1.56	0.15	360.00	0.00	8.26
A-54	FEL	1.38	71.20	1520	1.30	0.16	0.00	0.00	8.91
C-48	PER	3.40	54.40	1260	1.28	0.14	270.00	0.00	6.35
C-23	PER	3.40	70.10	1370	1.42	0.17	260.00	0.00	7.05
C-34	FEL	2.00	88.70	1470	1.74	0.27	0.00	0.00	7.68
C-28	PER	3.30	67.20	1220	1.49	0.16	0.00	0.00	6.81
C-16	FEL	3.90	74.20	1360	1.50	0.19	0.00	0.00	7.60
C-18	FEL	3.40	59.00	1610	1.04	0.15	190.00	0.00	7.96
C-7	PER	3.30	57.60	1490	0.97	0.14	0.00	0.00	7.50
C-17	FEL	2.10	54.10	1490	1.55	0.17	190.00	0.00	6.67
A-26	PER	2.90	58.60	1300	1.11	0.13	0.00	0.00	7.39

Units in ppm. Values = 0.0 are below detection limit.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
Geochemical Group 2 - Subgroup B-2SG3									
C-13	FEL	2.80	63.40	1770	1.29	0.16	0.00	1.60	7.91
A-29	PER	1.78	67.90	1340	1.42	0.14	320.00	0.00	7.61
A-30	FEL	2.10	75.00	1420	1.42	0.20	270.00	0.00	7.61
C-70	PER	2.40	75.40	1630	1.61	0.21	290.00	37.00	7.97
A-55	PER	1.92	73.80	1550	1.25	0.15	0.00	0.56	8.39
C-50	PER	3.70	58.70	1510	1.07	0.14	0.00	0.00	7.02
A-25	PER	3.50	58.00	1150	1.29	0.15	250.00	0.00	6.45
C-30	PER	4.60	73.80	1460	1.20	0.19	0.00	0.00	8.40
Geochemical Group 2 - Subgroup C-2SG3									
C-20	FEL	3.00	98.30	1910	1.53	0.20	0.00	0.00	9.20
C-63	FEL	1.40	56.40	1400	1.08	0.16	230.00	2.80	8.50
C-53	FEL	2.40	106.70	1730	1.56	0.49	0.00	0.00	7.16
C-61	FEL	2.40	63.60	1560	1.21	0.16	0.00	0.00	8.45
A-36	FEL	2.00	64.40	1510	1.27	0.15	260.00	0.00	7.50
A-38	PER	2.00	62.50	1320	1.33	0.17	0.00	0.00	7.33
C-46	PER	2.50	43.70	1420	1.24	0.18	0.00	0.51	8.34
C-8	PER	3.20	60.70	1400	1.02	0.14	0.00	0.00	7.55
C-39	PER	4.00	65.10	1320	1.44	0.15	0.00	0.00	7.00
C-64	PER	3.50	64.90	1230	1.45	0.16	0.00	0.00	6.31
A-39	PER	3.70	69.40	1360	1.20	0.18	250.00	0.00	8.17
C-32	FEL	3.10	76.20	1700	1.75	0.20	0.00	0.00	7.95
C-49	PER	3.00	57.60	1480	1.05	0.13	0.00	0.00	7.38
C-6	FEL	4.00	57.80	1600	1.33	0.16	300.00	6.10	8.57

Units in ppm. Values = 0.0 are below detection limit.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
C-44	PER	3.20	63.40	1330	1.49	0.13	310.00	0.00	7.27
C-38	PER	3.70	71.80	1460	1.89	0.19	0.00	0.00	6.40
C-62	FEL	1.90	84.70	1620	2.53	0.23	260.00	0.45	7.17
C-47	PER	3.00	62.90	1430	1.19	0.14	0.00	0.00	8.06
C-19	PER	3.40	35.80	550	0.38	0.11	0.00	0.00	7.55
C-10	PER	4.60	41.50	570	0.47	0.15	0.00	0.53	9.01
C-3	FEL	3.20	52.40	1480	1.20	0.16	210.00	2.10	7.79
				Geochemical Group 3 - Subgroup A-1SG2					
A-57	FEL	1.60	69.80	1600	1.51	0.18	0.00	0.00	9.03
DMV-1	PER	1.97	45.80	690	0.60	0.14	0.00	0.00	8.92
A-56	FEL	1.46	72.00	1540	1.47	0.18	0.00	0.00	8.92
C-25	FEL	3.10	31.50	1070	1.37	0.12	280.00	0.00	7.52
C-22	PER	4.60	38.30	730	0.49	0.14	0.00	0.00	8.17
C-11	PER	6.00	41.60	710	0.50	0.13	0.00	0.00	8.28
DMO-2	OBS	1.72	75.90	1620	1.79	0.18	260.00	0.48	7.70
DMO-1	OBS	2.12	49.10	1470	0.57	0.16	0.00	0.00	9.83
RTTR-1	OBS	2.10	50.40	810	0.64	0.16	0.00	0.42	9.77
C-68	PER	3.60	41.30	610	0.52	0.13	0.00	0.00	8.18
DMV-2	PER	2.17	45.90	700	0.56	0.15	0.00	0.00	9.56
				Geochemical Group 3 - Subgroup B-1SG2					
DMR-U	FEL	1.15	64.10	1720	1.79	0.19	280.00	0.61	8.04
A-12	FEL	1.07	60.00	1700	1.87	0.19	0.00	0.00	8.48
C-24	FEL	2.90	59.40	1220	1.36	0.15	0.00	0.00	7.11
C-66	OBS	5.10	41.80	670	0.50	0.13	0.00	0.66	8.39
C-58	OBS	3.80	72.90	1380	1.37	0.21	290.00	0.00	7.23

Units in ppm. Values = 0.0 are below detection limit.

NAA GEOCHEMICAL ANALYSIS DATA FROM THE DOOLEY RHYOLITE BRECCIA

SAMPLE	TYPE	Cs	Ce	Ba	Eu	Tb	Zr	Sb	Th
C-57	PER	4.20	74.50	1410	1.18	0.18	0.00	0.00	8.12
C-60	PER	4.30	39.00	550	0.48	0.13	0.00	0.00	8.05
A-11	FEL	1.14	57.10	1630	1.80	0.17	0.00	0.00	7.86
C-43	FEL	3.40	63.40	1290	1.26	0.14	0.00	0.00	6.66
C-67	OBS	4.70	44.90	740	0.50	0.17	0.00	0.00	9.10
Geochemical Group 4									
C-21	FEL	3.20	87.70	1480	1.47	0.22	0.00	0.00	9.37
C-27	FEL	2.50	87.20	1550	1.96	0.24	0.00	0.00	8.31
DMD-1	FEL	1.15	68.30	1540	1.62	0.16	280.00	0.00	8.39
C-2	FEL	2.10	66.40	1480	1.23	0.15	0.00	0.90	8.58

Units in ppm. Values = 0.0 are below detection limit.