2015

Geochemistry and Petrography of Igneous Components of the Dalles Formation in the Dufur West Quadrangle, Oregon

Heather H. Herinckx
Portland State University

Follow this and additional works at: <https://pdxscholar.library.pdx.edu/honorstheses>

Let us know how access to this document benefits you.

Recommended Citation

Herinckx, Heather H., "Geochemistry and Petrography of Igneous Components of the Dalles Formation in the Dufur West Quadrangle, Oregon" (2015). *University Honors Theses*. Paper 209.
<https://doi.org/10.15760/honors.201>

This Thesis is brought to you for free and open access. It has been accepted for inclusion in University Honors Theses by an authorized administrator of PDXScholar. Please contact us if we can make this document more accessible: pdxscholar@pdx.edu.

Geochemistry and petrography of igneous components of the Dalles Formation in the Dufur West quadrangle, Oregon

by

Heather H. Herinckx

An undergraduate honors thesis submitted in partial fulfillment of the

requirements for the degree of

Bachelor of Science

in

University Honors

and

Geology

Thesis Adviser

Martin J. Streck

Portland State University

2015

ABSTRACT

The Dalles Formation is a sequence of volcanic, volcanoclastic and sedimentary deposits of the late Miocene to Pliocene. The unit stretches along the eastern flanks of Mount Hood from Maupin, northward to the Columbia River, near The Dalles, Oregon (Figure 1). The Dalles Formation consists of lavas that are generally dacitic in composition and are composed of block-and-ash flows, debris-flows, and reworked fluvial sediments. Past workers have mapped the unit as the Dalles Formation “Undivided”. The scope of this project has been to investigate the geochemical and petrographic characteristics and whether they may suggest distinct units. A section of the Dalles Formation in the Dufur West quadrangle has been mapped and geochemical data and thin sections were analyzed. The clustering and spread of the geochemical data along with mineralogical indicators such as texture and phenocryst abundance suggest the unit can be divided into different lava types.

INTRODUCTION

This project focuses on a section of the geologic unit known as the Dalles Formation that is located near Dufur in north-central Oregon (Figure 2, 3). From the eastern flanks of Mt. Hood, the Dalles Formation extends 40 km (25mi) basinward to the Columbia River. It is composed of volcanoclastic and fluvial sedimentary rocks with interbedded lava flows that overlie the Columbia River Basalt Group (CRBG), typically mapped as the Dalles Formation Undivided. A particular section of the Dalles Formation that is found in the Postage Stamp Butte and Dufur West quadrangles has been investigated (Figure 4). Mapping established the distribution of some welded and pumiceous tuff beds and a series of channel filling debris flows along with block-and-ash flows. Samples were collected at each outcrop for later geochemical and mineralogical investigation. Very little is known about the central vent locations for these deposits. The purpose of this report is to study the lithology and geochemistry of the Dalles Formation and determine if the deposits can be differentiated. Being able to divide the Dalles Formation would provide a more coherent and concise nomenclature. More detailed descriptions of the local geology are needed to better understand the regions groundwater supply.

Figure 1. Map of the local geology surrounding the study area. The Dalles Formation (blue) is widespread on the east flanks of Mount Hood. The unit is found to the south near Maupin and northward to The Dalles (McClaghry et al., 2015).

Figure 2 Google earth satellite image of study area, bounded by Mount Hood to the west, Deschutes River to the east and the Columbia River to the north.

Figure 3. Map of the Middle Columbia Basin. The study area is located on the eastern flanks of Mount Hood near Dufur, Oregon (black star) (McClaghry et al., 2015).

Figure 4. This map displays mapping projects of past, present and future. Dufur West and Postage Stamp Butte are the quadrangles mapped for this project in 2014 (McClaghry et al., 2015).

Geographical and geological setting

Dufur is located in north-central Oregon. It is situated between the High Cascades and the Columbia Plateau and bounded from the north by the Columbia River. The region is part of the dry eastern Oregon climate zone controlled by the rain-shadow of the Cascade Range. The regional ecology includes widespread prairie grasses, barren land and white oak. Agricultural uses have historically involved farming of dry croplands making up approximately 117,260 acres (Clark, 2003). However, from 1991 – 2003 irrigated agriculture of orchards has risen from 200 acres to 2100 acres. The Fifteenmile Creek Watershed makes up the network of streams that cut through the geology, forming the landscape of rolling ridges and valleys.

Large accumulations of volcanoclastic and sedimentary rocks of the Dalles Formation fill in the region's valleys. The Dalles Formation is thought to represent the onset of magmatism related to the High Cascades eruptive episode ca. 8-6 Ma, consisting of thickly bedded andesitic and dacitic block-and-ash flows, and laharic deposits (McCloughry et al., 2012). The Dalles Formation overlies the CRBG, which are a succession of tholeiitic basalt and basaltic andesite lava flows that erupted between ca. 17 and 14 Ma (Swanson et al., 1979b). Late Pliocene basaltic lava flows of the High Cascades overlie the Dalles Formation (McCloughry et al., 2012).

Previous and current work

Past geological studies of the region produced conflicting nomenclature on the Dalles Formation. Farooqui et al. (1981) proposed renaming the Dalles Formation to "Chenoweth Formation" and assigning the Dalles Formation to group status. The "Dalles Group" was then formally assigned five discrete formations, which are the Alkali Canyon, McKay, Tygh Valley, Deschutes, and Chenoweth Formations. The five formations assigned to the "Dalles Group" are composed of volcanoclastic sediments that range in age from middle or late Miocene to early Pliocene. All of these formations overlie the middle Miocene CRBG on the east flanks of the Cascade Range. Some recent work pertaining to this region has used this nomenclature (Farooqui et al., 1981; Lite and Grondin, 1988; Burns et al., 2012). For the purpose of this study, the name Dalles Formation Undivided will be used, as by earlier workers (Condon, 1874; Cope, 1880; Piper, 1932; Newcomb, 1966, 1969; Korosec, 1987; Gray and other, 1996; McCloughry et al., 2012).

Based on isotopic K/Ar dating on andesitic and dacitic domes, the Dalles Formation has an estimated age of 8 to 6 Ma (Gray et al., 1996). Analysis of vertebrate and leaf fossils in the area also corroborates this age range (Newcomb, 1996).

In June 2015 the Oregon Department of Geology and Mineral Industry (DOGAMI) in concert with Oregon Water Resource Department (OWRD) completed a mapping project for Postage Stamp Butte and Dufur West quadrangles near Dufur, Oregon (Figure 3). Knowledge regarding the region's groundwater supply is dependent upon a solid understanding of the local geology. The mapping project began in April 2014 and was recently completed in June 2015. As part of my internship with DOGAMI I have been assisting Jason D. McClaughry, RG with mapping these quadrangles.

METHODOLOGY

Geologic data were collected applying techniques and standards specified by Oregon Department of Geology and Mineral Industries. Full detailed descriptions of methods have been provided by the agency located in the Appendix A. Geochemical data were analyzed to determine rock type and to compare compositions among rock units and thin sections were made to analyze the petrography of the units.

Geochemistry

Twenty-eight whole-rock samples of the Dalles Formation were selected while conducting the 2014/15 field work. The freshest possible samples were taken, avoiding extremely weathered and altered rocks. Chemical analyses of major and trace elements were carried out at the Washington State University GeoAnalytical laboratory, Pullman, Washington and at the Department of Geosciences, Franklin and Marshall College, Lancaster, Pennsylvania. Samples were analyzed using X-ray fluorescence (XRF). Major element concentrations are normalized to a 100-percent volatile-free basis and iron was expressed as FeO (FeO*). Table 1 in Appendix B presents the major and trace element analyses of the 28 whole-rock samples.

Geochemical data were used to plot variation diagrams using certain elements that proved helpful in distinguishing eruptive units.

Petrography

Thin section analyses were performed on seventeen of the collected samples. Observations and descriptions of thin sections and hand samples based on textures and mineral assemblage of selected samples were compiled (Appendix C). Modal abundances were estimated for a number of thin sections (Table 2 Appendix C). Detailed colored scans showing mineral abundances were produced with the aid of a Nikon slide scanner and Photoshop (Figures 8, 9 Appendix C). Difference in modal abundances and types of phenocrysts were also used to differentiate eruptive units.

GEOCHEMICAL DATA

Variation diagrams of major and trace elements relative to silica were evaluated (Figure 5, 6). The spread of the data indicates there are six distinct clusters. Each cluster of data was assigned as one lava type group resulting in types 1 through 6. A total-alkali-silica (TAS) diagram was created to classify lava types (Figure 7). Data collected from past workers (McCloughry et al., 2012; Westby, 2014) on lava flows associated with Mount Hood and other nearby areas were also plotted for comparison.

Figure 5

. Variation diagrams separating lava type groups 1-6. (A) A total aluminum vs silica. (B) Potassium vs. silica.

Figure 6. Variation diagrams of trace elements in lava types 1-6. (A) Diagram of zirconium vs. silica and (B) zirconium vs. niobium.

Figure 7. Total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) vs. silica (SiO_2) (TSA) classification of 28 geochemical samples from the Dalles Formation. Lava types 1-6 were each assigned a colored symbol. Data consist of 4 andesites, 1 trachyandesite, 21 dacites, and 2 rhyolotes. Geochemistry from Mount Hood lavas collected by McClaughry et al, (2012) (black x) and Westby (2014) (black open circles) are shown on plot with the Dalles Formation samples. Total alkalis-silica classification after LeBas et al., 1986.

PETROGRAPHY

The results of the geochemical analyses of whole-rock samples were supported by the results of thin section analyses. A number of thin sections were scanned and edited in Photoshop to provide modal abundance of each mineral type, normalized to 100 percent (Table 2 Appendix C). Each phenocryst was colored according to mineral type (Figures 8, 9).

Figure 8. Scanned thin sections from two lava types (1 and 3) to show variation of modal abundance. (A) Lava 1 is a sample from clast in debris flow deposit (Tmdd). (B) Lava 3 is a sample from pumice tuff at base of debris flow deposit (Qpdd). Color code for minerals; plagioclase (blue), amphibole (purple), clinopyroxene (pink), orthopyroxene (orange) and (yellow) alteration minerals.

Figure 9. Scanned thin sections from two lava types (4 and 5) to show variation of modal abundance. (A) Lava 4 is a Sample from clast in debris flow deposit (Qpdd). (B) Lava 5 is a dacite of Fifteenmile creek (Tmdf). Color code for minerals; plagioclase (blue), amphibole (purple), clinopyroxene (pink), orthopyroxene (orange) and (yellow) alteration minerals.

RESULTS

Clustering and separation among data points on plots with major elements vs. silica indicate the existence of different units. The aluminum vs. silica (Figure 5,A) shows the separation of lava 2 from the other lavas and potassium vs. silica (Figure 5,B) shows the distinction of lava 3 from the other lava samples. Trace elements were also evaluated. The zirconium vs. silica diagram (Figure 6,A) exhibits a clear distinction between all lava types. The

zirconium vs. niobium diagram (Figure 6,B) suggests a separation of lava 1 from the rest and lava 4 from lava 5.

In conjunction with geochemistry thin section analyses indicate a separation of units. Lava 3 is chemically differentiated from the rest and petrographic analysis shows that lava 3 (Figure 8) contains a glassy groundmass (< 90 percent) (Appendix C). The amount of pyroxenes and plagioclase is much less than lava 1 sample (Figure 8). Analysis of thin sections of lava 5 (Figure 9) supports results of the geochemical analysis. Lava 5 contains large phenocrysts of plagioclase and although lava 4 does contain plagioclase, the size distribution is different and smaller and fewer mafic minerals are present.

The deposits associated with lava 1 are the debris flows, tuffs, and sandstones (Tmdl) and lava 5 is the dacite of Fifteenmile Creek (Tmdf). These are the sediments of the Early High Cascades Dalles Formation. Lava groups 2, 3 and 4 are the glassy dacite-clast debris flow deposits and tuffs related to the Late High Cascades. The deposits of the Late High Cascades are inferred on the basis of stratigraphic position along with differentiation of geochemical and mineralogical observations. The younger unit is found embedded into present-day valley walls. The deposits can be mapped from distal to proximal within the valley. The deposits on the western boundary of the quadrangle (proximal) are big blocks of glassy dacite and welded tuffs. Mapping eastward through the valley (distal) deposits become less welded with the presence of more pumice and air fall material

DISCRIPTION OF UNITS

Quaternary and/or Pliocene deposits of the Late High Cascades

Qpg Gravel deposits (lower Pleistocene or upper Pliocene) – Tan, massive, matrix-supported, ash-pumice-crystal tuff overlying cobble boulder gravel. Feldspar phyric pumice tuff is poorly lithified, poorly sorted. Grains are subrounded to angular and very fine- to coarse. Unit is composed of ~ 40 percent pumice also present are subangular to subrounded lithic fragments up to 1 cm in size.

Qppt Non-welded pumice-tuff (lower Pleistocene or upper Pliocene) – Pumice fragments are locally observed within top soils and animal burrows. Pumice fragments are angular- shaped. Pumice rich soils are overlying debris flow bounders.

Qptw Welded tuff (lower Pleistocene or upper Pliocene) – Gray, welded tuff are exposed as float in sparse localities. Tuff contains euhedral, prismatic- shaped crystals of plagioclase up to 3 mm in length and needle- shaped pyroxene crystals up to 2 mm in length. Lythophysaes, a feature of devitrification are present locally.

Qpdd Glassy dacite-clast debris flow deposits and tuff (lower Pleistocene or upper Pliocene) – Glassy dacite dominated, block-and-ash flow. Monolithologic, glassy dacite boulders are black, with variations from porphyritic to abundantly porphyritic. Tightly packed cobbles and boulders are matrix supported. Boulders are locally observed rolling down hills to surrounding low land areas.

Lower Pliocene and upper Miocene volcanic and sedimentary rocks of the Early High Cascades

Tmdl Dalles Formation undivided (lower Pliocene and upper Miocene) – Tan to gray, ledge forming sandstone with coarse to pebble size grains, interbedded with a cobble gravel and boulder conglomerate. Boulders are subrounded, hornblende, feldspar phyric tuffs supported in a pebbly, feldspar rich coarse sand. Sandstone has massive, planar and trough crossbedding features. Sandstone overlain by matrix supported conglomerate. Fluvial, channel filling of reworked volcanoclastic sediments are locally exposed as hyper-concentrated flood flows and debris flows.

Tmdg Plateau-capping gravel (lower Pliocene and upper Miocene) – Fluvial gravels of well-rounded boulders and cobbles capping ridges locally. Gravels are mixed with loess soils that are overlying the area.

Tmdf Dacite of Fifteenmile Creek (lower Pliocene and upper Miocene) – Cliff forming outcrop of massive to platy jointed lava flow locally capping ridge. Blue gray to light purple, vesicular, feldspar phyric dacite. Locally present in hand samples are lath and blocky to subrounded feldspar phenocrysts up to 5 mm contained within a glassy groundmass.

Tmdt Tuff (lower Pliocene and upper Miocene) – Outcrop exposures of tabular bedded tuff. Light gray to white, non-welded, hornblende and potassium-feldspar phyric ash-crystal tuff. Phenocrysts of hornblende and potassium-feldspar are euhedral and up to 1 cm in size.

Tmdd Dacite-clast debris flow deposits (lower Pliocene and upper Miocene) – Debris flow consists of large hornblende phyric, dacitic boulders.

DISCUSSION

Based on geochemical analysis and petrographic variations, the Dalles Formation has been lithologically divided into separate units. The units consist of the already established lower Pliocene and upper Miocene Dalles Formation of the Early High Cascades. Now a second unit has been identified and will be referred to as the younger Quaternary and/or Pliocene (?) deposits of the Late High Cascades. Units are further subdivided based on lithological components and depositional emplacement. Acquiring age dates for the newly inferred unit of the Late High Cascades is the next step in the identification.

Comparison of lavas mapped in the Dufur West quadrangle to the lavas of Mount Hood (McClaughry et al., 2013; Westby, 2014) show that there is not a relation in terms of composition (Figure 5). The Westby (2014) data present a suit of rhyolite lava types found on the eastern flanks of Mount Hood near Tygh Valley along with andesite type. McClaughry et al. (2012) data represents lavas mostly composed of andesite. The Mount Hood data sets do not indicate a dacite component. This does raise questions into the magmatic sources responsible for the deposition of the Dalles Formation. Is the magmatism of the Dalles Formation totally unrelated to that of Mount Hood? Does it represent earlier magmatic processes of the High Cascade Range? It is also suggested that Mount Hood volcanism has progressively changed from andesitic composition to dacitic (Koleszar et al., 2012). Do the deposits of Dalles Formation represent the evolution of the Cascade Range? These are the next phase of question to be investigated with the continuation of dividing the Dalles Formation.

CONCLUSION

The purpose of this study was to provide a concise and clear means of dividing the Dalles Formation. Based on detailed geologic mapping, supported by geochemical and mineralogical evaluation of whole-rock samples, the Dalles Formation is divided.

REFERENCENCES

- Burns, E. R., Morgan, D. S., Lee, K. K., Haynes, J. V., and Conlon, T. D., 2012, Evaluation of long-term water-level declines in basalt aquifers near Mosier, Oregon: U.S. Geological Survey Scientific Investigations Report 2012-5002, 134 p., GIS files. <http://pubs.usgs.gov/sir/2012/5002/>
- Clark, J. S., 2003, Fifteemile Watershed Assessment: Wasco County Soil and Water Conservation District: The Dalles Oregon
- Condon, T., 1874, Preliminary report of the State Geologist to the Legislative Assembly, 8th regular session: Salem, Oregon, 22 p.
- Cope, E. D., 1880, Corrections of the geological maps of Oregon: American Naturalist, v. 14, p. 457–458.
- Darr, C.M., 2006, Magma chamber processes over the past 475,000 years at Mount Hood, Oregon: Insights from crystal zoning and crystal size distribution studies [M.S. Thesis]: Corvallis, Oregon State University.
- Farooqui, S. M., Beaulieu, J. D., Bunker, R. C., Stensland, D. E., and Thomas, R. E., 1981, Dalles Group: Neogene formations overlying the Columbia River Basalt Group in north-central Oregon: Oregon Geology, v. 43, no. 10, p. 131–140.
- Gray, L. B., Sherrod, D. R., and Conrey, R. M., 1996, Potassium-argon ages from the northern Oregon Cascade Range: Isochron/West, no. 63, p. 21–28.
- Koleszar, A.M., Kent, A.J.R., Wallace, P.J., Scott, W.E., 2012, Controls on long-term low explosivity at andesitic arc volcanoes: Insights from Mount Hood, Oregon: Journal of Volcanology and Geothermal Research, v. 219–220, p. 1-92.

- Korosec, M. A., 1987, Geologic map of the Hood River quadrangle, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-6, 41 p., scale 1:100,000.
- Lite, K. E., and Grondin, G. H., 1988, Hydrogeology of the basalt aquifers near Mosier, Oregon: A ground water resource assessment: Oregon Water Resources Department Ground Water Report 33, 119 p., 5 pls.
- McClaughry, J. D., Herinckx, H. H., Hackett, J. A., and Mickelson, K., A., 2015, Geologic Map of the Dufur West and Northern Part of the Postage Stamp Butte 7.5' Quadrangles, Wasco County, Oregon: Oregon Department of Geology and Mineral Industries Open-file Report 0-XX-XX.
- McClaughry, J. D., Wiley, T. J., Conrey, R. M., Jones, C. B. and Lite, K. E., 2012, Digital geological map of the Hood River Valley, Hood River and Wasco Counties, Oregon: Oregon Department of Geology and Mineral Industries Open File Report O-12-03
- Newcomb, R. C., 1969, Effect of tectonic structure on the occurrence of groundwater in the basalt of the Columbia River Group of The Dalles area, Oregon and Washington: U.S. Geological Survey Professional Paper 383- C, 33 p., geological map pl., scale 1:62,500.
- Newcomb, R. C., 1966, Lithology and eastward extension of The Dalles Formation, Oregon and Washington, in Geological Survey Research 1966, chapter D: U.S. Geological Survey Professional Paper 550-D, p. D59–D63.
- Piper, A. M., 1932, Geology and ground-water resources of The Dalles region, Oregon: U.S. Geological Survey Water-Supply Paper 659-B, p. 107–189.

Swanson, D. A., Wright, T. L., Hooper, P. R., Bentley, R. D., 1979b, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Westby, E. G., 2014, The Geology and Petrology of Enigmatic Rhyolites at Graveyard and Gordon Buttes, Mount Hood Quadrangle, Oregon [M.S. Thesis]: Portland, Portland State University.

APPENDIX A. METHODOLOGY

Geologic data were collected digitally using a GPS-enabled Apple™ iPad 2 loaded with iGIS™, a geographic information system software package compatible with Esri ArcGIS™. Digital mapping used tiled, hillshaded raster images, derived from high- resolution (8 pts/m^2) lidar digital elevation models (DEMs) as basemaps. Additional basemap information was derived from standard 1:24,000-scale USGS digital raster images (DRGs) and digital orthophoto imagery (2013) obtained from Google Earth™. Fieldwork conducted during 2014 and 2015 consisted of data collection along major highways and roads, combined with targeted traverses across private rangelands where access was available.

Geologic interpretations were aided by GIS analyses based in part on 1-m lidar DEMs, USGS 10-m DEMs, and 2011 and 2014 National Agriculture Imagery Program (NAIP) digital orthophotos. The mapped distribution of surficial deposits is derived in part from soils maps and descriptions published by the Natural Resource Conservation Service (NRCS) of the U.S. Department of Agriculture (Haagen, 1989). Lidar DEMs were used to depict the distribution of both bedrock and surficial geologic units at a maximum scale of 1:8,000. The geologic time scale used is the 2015 (v2015/01), version of the International Stratigraphic Commission's International Stratigraphic Chart <http://www.stratigraphy.org/index.php/ics-chart-timescale> revised from Cohen and others (2013).

Mapping was supported by new and compiled X-ray fluorescence (XRF) geochemical analyses of whole rock samples and thin-section petrography. Whole rock geochemical samples were prepared and analyzed by X-ray fluorescence (XRF) at the Washington State University GeoAnalytical laboratory, Pullman, Washington and at the Department of Geosciences, Franklin and Marshall College, Lancaster, Pennsylvania. Analytical procedures for the Washington State

University GeoAnalytical laboratory are described in Johnson and others (1999) and can be obtained online at <http://www.sees.wsu.edu/Geolab/note/xrf.html>. Analytical procedures for the Franklin and Marshall X-ray laboratory are described by Boyd and Mertzman (1987) and Mertzman (2000), and are available online at <http://www.fandm.edu/earth-environment/laboratory-facilities/xrf-and-xrd-lab>. Whole-rock chemical data are useful in classifying volcanic rocks, as many lavas are too fine grained and glassy to be adequately characterized by mineralogical criteria alone. Major element determinations are normalized to a 100-percent total on a volatile-free basis and recalculated with total iron expressed as FeO*. Descriptive rock unit names for volcanic rocks are based in part on the online British Geological Survey classification schemes (Gillespie and Styles, 1999; Robertson, 1999; Hallsworth and Knox, 1999) and normalized major element analyses plotted on the total alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) versus silica (SiO_2) diagram (TAS) of Le Bas and others (1986), Le Bas and Streckeisen (1991), and Le Maitre and others (1989).

APPENDIX B. GEOCHEMICAL DATA

Table 1. Whole-rock geochemical analyses of rocks from the Dalles Formation in north central Oregon

Sample number	17 DFWJ 14	25 DFWJ 14	29 DFWJ 14	37 DFWJ 14	66 DFWJ 14	76 DFWJ 14	102 DFWJ 14	107 DFWJ 14	187 DFWJ 14
Quadrangle	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Wolf Run Dalles	Dufur East Dalles
Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation
Map Unit	Tmdd	Tmdt	Tmdt	Tmdt	Tmdl	Qppt	Tmdd	Tmdf	Tmdl
UTM N (NAD27)	5032627	5028609	5027147	5028694	5037966	5029808	5034676	5032835	5036121
UTM E (NAD27)	643293	641433	638204	637428	643155	645707	644336	634300	649694
SiO ₂	63.52	65.19	63.20	63.10	73.48	68.19	64.25	63.84	63.90
Al ₂ O ₃	17.26	17.08	17.69	18.44	15.35	15.60	17.25	16.33	17.72
TiO ₂	0.69	0.70	0.73	0.75	0.22	0.64	0.65	0.97	0.82
FeO*	5.00	4.55	5.01	5.22	2.41	4.42	4.62	5.64	5.56
MnO	0.09	0.08	0.09	0.10	0.06	0.08	0.09	0.09	0.09
CaO	5.45	5.14	5.50	5.35	2.31	2.27	5.24	4.15	5.18
MgO	2.29	1.62	2.28	1.72	0.57	0.58	2.17	1.79	1.67
K ₂ O	1.83	1.37	1.27	1.33	2.77	4.12	1.77	2.76	1.48
Na ₂ O	3.70	4.13	4.08	3.84	2.74	3.93	3.84	4.22	3.42
P ₂ O ₅	0.18	0.14	0.15	0.15	0.09	0.15	0.14	0.19	0.15
Ni	20	23	21	21	3	4	17	20	23
Cr	30	41	32	31	4	4	24	19	37
Sc	11	11	11	13	3	9	11	14	12
V	83	83	94	87	7	16	82	89	101
Ba	359	332	337	318	453	609	370	504	434
Rb	34	24	16	22	49	84	39	69	44
Sr	423	547	522	512	267	187	405	344	444
Zr	154	155	135	142	148	486	156	334	160
Y	17	11	11	14	13	45	17	27	19
Nb	8.7	8.5	7.5	8.1	8.5	27.2	9.1	17.4	9.6
Ga	19	20	20	21	16	21	20	22	20
Cu	12	28	20	37	10	10	13	37	36
Zn	63	62	65	65	45	79	60	64	67
Pb	5	4	4	6	8	9	7	8	9
La	16	15	15	17	21	39	20	33	19
Ce	32	33	31	40	34	84	34	62	37
Th	3	5	5	3	6	11	5	9	5
Nd	16	15	16	16	13	38	17	32	17
U	1	2	1	1	1	4	2	2	1

Table 1. Whole-rock geochemical analyses of rocks from the Dalles Formation in north central Oregon

Sample number	212 DFWJ 14	232 DFWJ 14	265 DFWJ 14	269 DFWJ 14	288 DFWJ 14	291 DFWJ 14	333 DFWJ 14	345 DFWJ 14	372 DFWJ 14
Quadrangle	Dufur West	Dufur West	Dufur West	Dufur West	Dufur West	Dufur West	Dufur West	Dufur West	Dufur West
Formation	Dalles	Dalles	Dalles	Dalles	Dalles	Dalles	Dalles	Dalles	Dalles
Map Unit	Tmdd	Tmdd	Qpdd	Qpdd	Tmdf	Tmdf	Qpdd	Qpdd	Qpdd
UTM N (NAD27)	5032880	5032975	5028864	5029003	5035163	5034868	5028580	5028465	5029551
UTM E (NAD27)	642769	640030	643126	643230	637567	637380	642449	642342	644908
<i>Oxides, weight percent</i>									
SiO ₂	66.14	62.90	65.14	67.44	64.49	64.29	63.75	67.41	64.06
Al ₂ O ₃	16.06	17.61	15.24	15.21	15.91	15.72	16.26	16.36	16.29
TiO ₂	0.62	0.71	0.92	0.48	0.95	0.97	0.86	0.56	0.86
FeO*	4.45	5.21	6.18	6.53	5.47	5.70	5.48	4.24	5.47
MnO	0.08	0.10	0.12	0.11	0.09	0.09	0.10	0.08	0.09
CaO	4.55	5.61	3.44	2.75	4.04	4.06	4.76	4.05	4.55
MgO	2.08	2.50	1.18	0.76	1.71	1.98	2.06	0.91	1.99
K ₂ O	2.22	1.41	3.14	3.22	2.92	2.85	2.50	3.10	2.04
Na ₂ O	3.67	3.80	4.33	3.42	4.18	4.13	4.02	3.18	4.44
P ₂ O ₅	0.13	0.14	0.31	0.08	0.23	0.20	0.22	0.10	0.22
<i>Trace Elements, parts per million</i>									
Ni	16	20	1	4	17	17	19	6	19
Cr	26	30	1	6	19	19	16	8	17
Sc	11	13	11	9	13	12	12	7	13
V	77	85	37	31	88	92	76	37	77
Ba	361	364	664	540	527	510	522	641	508
Rb	49	32	68	62	74	71	52	76	51
Sr	373	422	273	268	345	332	393	297	392
Zr	149	151	411	270	340	341	245	260	248
Y	14	15	46	31	33	34	30	33	34
Nb	8.6	8.3	27.5	18.1	17.6	16.5	17.2	19.1	17.7
Ga	18	19	23	20	19	18	20	21	20
Cu	19	30	11	13	31	45	18	17	26
Zn	59	62	100	78	67	66	76	76	77
Pb	7	5	9	9	8	9	8	10	8
La	18	19	37	26	35	42	29	38	35
Ce	32	34	78	62	65	57	55	63	51
Th	7	5	8	9	10	9	7	9	6
Nd	15	15	39	25	31	38	27	28	30
U	2	0	3	3	2	3	0	2	1

Table 1. Whole-rock geochemical analyses of rocks from the Dalles Formation in north central Oregon

Sample number	373 DFWJ 14	378 DFWJ 14	422 DFWJ 14	6 DFWJ 15	13a DFWJ 15	30 DFWJ 15	45 DFWJ 15	55 DFWJ 15	71 DFWJ 15	98 DFWJ 15
Quadrangle	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Dufur West Dalles	Friend Dalles	Postage Stamp Butte Dalles	Friend Dalles	Dufur West Dalles	Dufur West Dalles
Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation	Formation
Map Unit	Qpdd	Tmdd	Qpdd	Qpdd	Tmdd	Qptw	Qpdd	Qpdd	Qpdd	Qpdd
UTM N (NAD27)	5029628	5029902	5029650	5030983	5035152	5023999	5024799	5022501	5027394	5028241
UTM E (NAD27)	644934	637783	644738	645829	645726	636875	638445	630457	640501	641012
SiO ₂	67.26	62.36	63.77	63.68	65.64	73.13	59.31	63.24	60.68	63.52
Al ₂ O ₃	15.79	19.14	16.32	16.67	16.75	15.21	16.79	16.97	16.90	16.71
TiO ₂	0.82	0.77	0.85	0.80	0.58	0.15	1.21	0.83	0.61	0.81
FeO*	5.45	5.32	5.40	5.30	4.22	1.99	7.19	5.50	5.22	5.52
MnO	0.08	0.10	0.09	0.10	0.08	0.06	0.15	0.11	0.10	0.11
CaO	3.17	5.75	4.70	4.88	4.84	1.25	6.02	5.01	2.95	4.94
MgO	1.10	1.39	2.01	2.10	1.96	0.16	2.94	2.17	1.14	2.15
K ₂ O	2.84	1.17	2.87	2.45	1.90	3.51	2.15	2.29	2.03	2.38
Na ₂ O	3.34	3.86	3.77	3.78	3.88	4.48	3.92	4.15	2.22	3.95
P ₂ O ₅	0.14	0.13	0.21	0.25	0.15	0.05	0.32	0.21	0.18	0.25
Ni	6	19	17	20	18	8	27	20	13	21
Cr	10	30	15	32	40	11	51	32	13	37
Sc	11	12	12	9	8	1	14	10	8	9
V	74	85	72	73	69	6	109	73	41	78
Ba	585	316	535	510	420	790	574	525	645	604
Rb	73	19	51	43.2	41.4	100.2	39.6	43.8	62.5	46.7
Sr	249	569	390	416	380	170	410	422	367	419
Zr	255	133	244	243	172	250	277	246	334	243
Y	34	14	29	29	18	33	42	29	108	31
Nb	19.3	7.5	16.9	18.1	8.8	29.9	21.0	18.7	18.8	18.0
Ga	21	20	20	23.4	21.1	25.2	23.3	23.3	25.9	23.5
Cu	13	42	18	30	23	21	36	29	29	27
Zn	83	63	77	74	53	58	95	77	84	77
Pb	9	5	7	<1	<1	14	3	<1	2	1
La	33	17	27	32	26	48	40	31	85	30
Ce	64	33	54	56	51	93	48	56	65	57
Th	9	4	6	7.8	3.7	19.2	5.6	4.0	16.3	7.5
Nd	28	14	26	nd	nd	nd	nd	nd	nd	nd
U	2	2	2	0.7	<0.5	1.7	<0.5	0.5	1.4	0.5

APPENDIX C. PETROLOGY AND MINERALOGY

Table 2. Modal abundances normalized to 100 percent.

Sample #	Mafic %	Plagioclase %	Groundmass %
17	10	30	60
25	< 5	40	55
29	10	45	45
102	5	45	50
107	5	35	60
232	7-10	40	50
265	5	15	80
291	5-7	30	65
333	3	25	> 70
345	< 1	3	96
373	< 2	5	93
422	2	25	> 70

Images of thin-sections

Lava 1 slides

Tmdd Dacite-clast debris flow deposit (lower Pleistocene and upper Miocene)

Sample # 17 DFWJ 14 (crystal tuff)

Sample location (UTM meters NAD 83)

Geologic unit: Tmdd – Dacite-clast debris flow deposit

Hand sample description

Medium gray dacite, containing ~20 percent (vol), euhedral, blocky to prismatic shaped plagioclase up to 6 mm in length and <2 percent (vol), euhedral, pyroxene microphenocryst and phenocryst up to 7 mm in length distributed within a fine, diktytaxitic crystalline groundmass.

Thin section description

Dacite clast contain ~30 percent, colorless, euhedral to anhedral, inequigranular – textured blocky to prismatic- shaped plagioclase microphenocryst and phenocryst up to 6 mm in length and ~1-2 percent euhedral to anhedral, prismatic to lath- shaped, inequigranular – textured colorless to yellow-brown orthopyroxene microphenocryst and phenocryst ranging in size from 0.2 to 6 mm in length and sparse clinopyroxene microphenocryst contained within a fine grained, vesicular/diktytaxitic hypocrySTALLINE groundmass. Plagioclase phenocryst occur as single prismatic crystals that commonly have oscillatory and concentric zoning and polysynthetic and Carlsbad twinning. < 1 percent opaque oxides and sparse amphibole showing pleochroic colors.

Sample # 232 DFWJ 14 (Crystal tuff)

Sample location (UTM meters NAD 83)

Geologic unit: Tmdd – Dacite-clast debris flow deposit

Hand sample description

Light gray pink dacite, containing ~20 percent (vol) blocky to prismatic, euhedral plagioclase phenocryst and < 2 percent (vol) euhedral pyroxene microphenocrysts and phenocrysts up to 5 mm in length distributed within a fine crystalline groundmass.

Thin section description

Dacite clast characterized by ~25-30 percent, colorless, blocky to prismatic- shaped, inequigranular – textured plagioclase microphenocrysts and phenocryst ranging in length from 0.1 to 2 mm and < 1 percent lath-shaped microphenocrysts and phenocrysts of orthopyroxene with straight extinction and a less amount of clinopyroxene microphenocrysts contained within a hypocrySTALLINE groundmass. Plagioclase phenocrysts occur as single prismatic crystals and commonly have oscillatory zoning and polysynthetic twins. Pyroxene phenocrysts are brown under ppl with slight pleochroism, under xpl 1st order orange color and straight extinction, dark red rims. Sparse clusters of glomerocrysts containing plagioclase, pyroxene, glass, and oxides up to ~ 5 mm across occur. <1 percent opaque oxides.

Lava 3 slides

Lava 4 slides

Lava 5 slides