USGS
science for a changing world

# Catalog of Mount St. Helens 2004 – 2005 Tephra Samples with Major- and Trace-Element Geochemistry

By Michael C. Rowe, Carl R. Thornber, Daniel J. Gooding,and John S. Pallister

This report presents a catalog of sample information and bulk-ash, glass, and phenocryst geochemical data for tephra erupted at Mount St. Helens, Washington between October 2004 and August 2005. A summary of sampling techniques, descriptions of the categories of sample information (column headers) for the database fields, and analytical methods, are presented as a PDF file. The 2004-5 Mount St. Helens tephra sample catalog and geochemical database is reported in six tables and is downloadable in a separate Microsoft Excel file. Glass standard analyses are reported in Appendix 1.

Open-File Report 2008–1131

**U.S. Department of the Interior**
**U.S. Geological Survey**

**U.S. Department of the Interior**
DIRK KEMPTHORNE, Secretary

**U.S. Geological Survey**
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2008

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:.

Rowe, M.C., Thornber, C.R., Gooding, D.J. and Pallister,J.S., 2008, Catalog of Mount St. Helens 2004–2005 Tephra Samples with Major- and Trace-Element Chemistry: U.S. Geological Survey Open File Report 2008-1131

# Catalog of Mount St. Helens 2004 – 2005 Tephra Samples with Major- and Trace-Element Geochemistry

By Michael C. Rowe,[1] Carl R. Thornber,[2], Daniel J. Gooding[2] and John S. Pallister[2]

## Introduction

This open-file report presents a catalog of information about 135 ash samples along with geochemical analyses of bulk ash, glass and individual mineral grains from tephra deposited as a result of volcanic activity at Mount St. Helens, Washington, from October 1, 2004 until August 15, 2005. This data, in conjunction with that in a companion report on 2004-2007 Mount St. Helens dome samples by Thornber and others (2008a) are presented in support of the contents of the U.S. Geological Survey Professional Paper 1750 (Sherrod and others, ed., 2008). Readers are referred to appropriate chapters in USGS Professional Paper 1750 for detailed narratives of eruptive activity during this time period and for interpretations of sample characteristics and geochemical data presented here. All ash samples reported herein are currently archived at the David A. Johnston Cascades Volcano Observatory in Vancouver, Washington.

The Mount St. Helens 2004–2005 Tephra Sample Catalogue along with bulk, glass and mineral geochemistry are tabulated in 6 worksheets of the accompanying Microsoft Excel file, OF2008-1131.xls. Samples in all tables are organized by collection date. Table 1 is a detailed catalog of sample information for tephra deposited downwind of Mount St. Helens between October 1, 2004 and August 18, 2005. Table 2 provides major- and trace-element analyses of 8 bulk tephra samples collected throughout that interval. Major-element compositions of 82 groundmass glass fragments, 420 feldspar grains, and 213 mafic (clinopyroxene, amphibole, hypersthene, and olivine) mineral grains from 12 ash samples collected between October 1, 2004 and March 8, 2005 are presented in tables 3 through 5. In addition, trace-element abundances of 198 feldspars from 11 ash samples (same samples as major-element analyses) are provided in table 6. Additional mineral and bulk ash analyses from 2004 and 2005 ash samples are published in chapters 30 (oxide thermometry; Pallister and others, 2008), 32 (amphibole major elements;

[1]Department of Geosciences, 104 Wilkinson Hall, Oregon State University, Corvallis, OR 97331; now at Department of Geoscience, 121 Trowbridge Hall, University of Iowa, Iowa City, IA 52242
[2]U.S. Geological Survey, 1300 SE Cardinal Court,Vancouver, WA 98683

Thornber and others, 2008b) and 37 ($^{210}$Pb; $^{210}$Pb/$^{226}$Pa; Reagan and others, 2008) of U.S. Geological Survey Professional Paper 1750 (Sherrod and others, 2008).

A brief overview of sample collection methods is given below as an aid to deciphering the tephra sample catalog. This is followed by an explanation of the categories of sample information (column headers) in table 1. A summary of the analytical methods used to obtain the geochemical data in this report introduces the presentation of major- and trace-element geochemistry of Mount St. Helens 2004–2005 tephra samples in tables 2-6. Rhyolite glass standard analyses are reported (Appendix 1) to demonstrate the accuracy and precision of similar glass analyses presented herein.

## Sample Collection

Samples were collected at designated ash stations, on recent snowfall, by dome "spiders" (monitoring and collection devices stationed within the crater and on the growing dome; LaHusen and others, 2008), and on other clean surfaces. Following the initial phreatic eruption on October 1, 2004, 27 ash collection stations were established around the periphery of the volcano at distances ranging from 2.4 to 10 km from the vent (fig. 1 in Rowe and others, 2008). Stations were cleaned and ash collected at intervals varying from less than 3 to greater than 15 days, depending on accessibility of the station and the likelihood of deposited ash based on predicted wind directions. Following November 29, 2004, most ash was collected on snow, or otherwise clean surfaces, after discrete ash producing events.

## Explanation of the Mount St. Helens 2004-2005 Tephra Sample Catalog

The tephra sample catalog is presented as table 1 in the accompanying Microsoft Excel file (*OF08-###.xls)* . Included in the sample catalog are: the sample identification number, the event collected (where applicable), the type of event that generated ash, the date and time of collection, whether there had been prior collections at that location, ash station number, location notes/description, latitude and longitude of collection station, distance and azimuth from the vent to the collection site, collector, sample notes, sample weight (in grams), and when possible mass per unit area (grams/square meter). The categories of sample information (column headers) are further explained as follows.

### Table 1. Mount St. Helens 2004-2005 Tephra Sample Catalog

**Sample ID**: The sample number includes a prefix "MSH04 or MSH05" indicating the year it was collected followed, by the sample station (when possible) or the initials of the collector, with the sampling date and number/letter if multiple samples were taken. For ash samples of phreatic events on October 1, 4 and 5, the prefix is followed by E1, E2, or E3.

**Event Collected:** The date, and time (PST/PDT) when possible, of specific vent explosion and dome collapse events. For dome collapse events, dates are often based on the appearance of fresh ash on snow covered surfaces traceable back to specific regions of the dome. Date and times for vent explosions are based on visual observations. N/A indicates the ash sample is not correlated to a specific event.

**Event Type**: The type of event is defined as either “Vent Explosion,” “Dome Collapse,” or “intermittent steam and ash.”

**Date-Time Collected**: Month-Day-Year (for example, 10_02_2005) and when available time (PST/PDT) of sample collection.

**Prior Collection**: For established ash collection stations prior collection dates and times provide constraints on the time interval for ash deposition. N/A indicates no prior collection at that location.

**Ash Station#:** Ash stations include JL1 (the first station established near June Lake) and A02-A27. Samples collected at locations without ash stations do not have a number. N/A indicates that the collection was not made at an established ash station.

**Location Notes/Description:** Notes provided by collector at time of ash collection, indicating conditions of sampling, location and any sampling details.

**Latitude and Longitude**: The geographic coordinates of each sample are referable to the World Geodetic System datum, 1984 (WGS84). Latitude is positive (north) and longitude is negative (west) and both are reported in decimal degrees. Measurements were determined from handheld GPS at the time of collection or at the time of site establishment.

**Distance and Azimuth from Vent**: Sampling location from the vent reported in kilometers and degrees from north (360°). Vent location estimated at 46.197°N and -122.188°W.

**Collector**: Last name of collector(s).

**Sample Notes**: Any sample notes provided at time of collection (for example: area of collection) or the condition that the sample was provided to the lab in (for example: the sample was collected wet or there was likely contamination). N/A indicates that no notes were provided.

**Sample Weight (g) (table 1)**: The dry weight of the ash sample is reported in grams.

**Sample Mass/Square Meter ($g/m^2$) (table 1)**: For samples collected over a known area the sample per unit area (grams/meter squared) is reported. For established stations the bucket collection area is $4.56*10^{-3}$ $m^2$.

# Analytical Methods

## Bulk Tephra Major- and Trace-Element Analysis

Whole-rock abundances of major elements for ash samples were measured at the U.S. Geological Survey's Denver Analytical Laboratories by Tammy Hannah and Joe Taggart using wavelength dispersive spectrometry X-ray fluorescence (WDS-XRF). Techniques for this current era of XRF analyses are described by Taggart and others (2002). Standard reproducibility and precision of major-element analysis from this laboratory are given by Thornber and others (2002).

Trace-element abundances in bulk ash samples were determined by inductively coupled plasma mass spectrometry (ICP-MS) analysis, performed at the U.S. Geological Survey Denver Analytical Laboratories by Monique Adams and Paul Lamothe. Methods for ICP-MS analysis are detailed in Briggs and Meier (2002).

Major- and trace-element analyses of USGS Geochemical Reference Standard AGV-2 produced by these laboratories concurrently with tephra data reported herein, closely matches the recommended values (see tables 4 and 5 of Thornber and others 2008a)

## Glass Major-Element Analysis

Glass major-element abundances reported here were determined by electron microprobe analysis (EMPA) using a Cameca SX100 at Oregon State University. The analytical procedure is a modification of the method suggested by Morgan and London (1996) where Na and K were counted for 60 seconds with a 2-nA beam current, after which, other major-elements (including S and Cl) were counted using a 30-nA beam current. A 15-keV accelerating voltage and 10-μm beam diameter were used throughout. Repeat analysis of rhyolite glass standard (USNM 72854 VG-568) are summarized in Appendix 1 at the end of this report. $Na_2O$ concentrations averaged ~7% low, based on the average deviation from the recommended concentration, likely the result of $Na^+$ migration during analysis.

## Phenocryst Major-Element Analysis

Phenocryst major-element abundances were measured by EMPA at Oregon State University. Analyses were performed near grain edges (within 10-15μm) whenever possible. Feldspars were analyzed using a 5-μm beam (30-nA) while pyroxenes, amphiboles and olivine were analyzed using a 1-μm beam (50-nA), with a 15-keV accelerating voltage. Successful analyses of a labradorite standard (USNM 115900) and the Kakanui Augite standard (USNM 122142) were obtained prior to each analytical session.

## Feldspar Trace-Element Analysis

Feldspar trace-element abundances were measured by laser ablation (LA)- ICP-MS at Oregon State University in the W.M. Keck Collaboratory for Plasma Spectrometry. Measured trace-elements include Li, Ti, V, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Pb, Th, and U with $^{29}Si$ and $^{43}Ca$ isotopes for internal standardization. Measurements were made with a 70μm stationary spot ( 4 Hz pulse rate) using a NewWave DUV 193 nm ArF Excimer laser and VG PQ ExCell Quadrupole ICP-MS. Analytical methods are discussed in detail by Kent and others (2007). During ablation, data were acquired for 40 seconds, with background count rates measured for 30 seconds prior to ablation. Trace-element abundances were calculated relative to the NIST 612 glass standard, with USGS glass BCR-2G analyzed as a secondary standard. Overall, average deviations from accepted BCR-2G abundances for trace-elements are below 15% (Y, Zr, and Sm are below 25% and Th has a maximum deviation of 35%; 1 standard deviation). All trace-element abundances within an analytical session are reproducible to better than 15% (2 standard deviations), determined from repeat analysis of BCR-2G, with the exception of Li for one session with reproducibility (2 standard deviations) of 20%.

# Chemistry of Mount St. Helens 2004-2005 Tephra Samples

## Table 2. Bulk Tephra Chemistry

Bulk-rock chemical analyses of Mount St. Helens 2004-2005 tephra samples are presented in worksheet 2 of the accompanying Microsoft Excel file (OF08-###.xls), where they are grouped by analysis type, as decribed here and in the following order:

1. **WDXRF Major-element abundances** weight percent oxides with all iron (FeOt) calculated as FeO, LOI refers to weight loss on ignition
2. **WDXRF Major-element abundances** normalized to 100 weight percent oxides with all iron (FeOt) calculated as FeO
3. **EDXRF Trace-element abundances** in parts per million
4. **ICP-MS Trace-element abundances** in parts per million

## Tables 3-5. Glass and Phenocryst Major-element Chemistry

Electron Microprobe analyses of 2004-2005 Mount St. Helens tephra samples presented in worksheets 3, 4 and 5 of the accompanying Microsoft Excel file (OF08-###.xls) correspond to:

Table 3. Volcanic Glass Compositions

Table 4. Feldspar Phenocryst Compositions, and

Table 5. Mafic Silicate Phenocryst Compositions

In each of these tables, analyses of individual grains or groundmass glass are provided an analysis number after the sample identification. All oxides (and Cl) are reported in weight percent and total Fe reported as Ferrous Oxide ($FeO_t$) Anorthite content (An#) is calculated as the atomic proportion of Ca relative to Ca + K + Na are provided for feldspar analyses, respectively. For mafic mineral phases, abbreviations used are amph (amphibole), cpx (clinopyroxene), hyp (hypersthene) and ol (olivine).

## Table 6. Feldspar Trace-Element Chemistry

LA-ICP-MS analyses of feldspar phenocrysts in 2004-2005 Mount St. Helens tephra samples (table 6) are presented in worksheet 6 of the accompanying Microsoft Excel file (OF2008-1131.xls). Data are reported in micrograms/gram. Analysis number of feldspar trace-elements correlates with the feldspar major-element analysis numbering table 4.

# Acknowledgments

The authors would like to thank the staff and volunteers of the U.S. Geological Survey's Cascade Volcano Observatory (CVO), especially M. Couchman, D. Dzurisin, A. Eckberg, T. Herriot, J. Hungerford, S. Konfal, S. McConnell, D. Ramsey, W. Scott, D. Sherrod, J. Vallance, and A. Sondergaard, who assisted with ash collection, drying, weighing, and cataloging. Fellow "MSH Ash Team" member, D. Ramsey (CVO), provided invaluable assistance with establishment and mapping of ash stations. A. Kent and F. Tepley at Oregon State University, Corvalis provided access to and assistance with the laser ablation induction-coupled mass spectrometer and the electron microprobe Review comments of D. Ramsey (CVO), M. Doukas (CVO) and C. Gardner (CVO) served to improve this report.

# References


Briggs, P.H., and Meier, A.L., 2002, The determination of forty-two elements in geological materials by inductively coupled plasma – mass spectrometry, chapter "I", *in* Taggart, J.E. Jr., ed., Analytical methods for chemical analysis of geologic and other materials: U.S. Geological Survey Open File Report 02-223.

Jarosewich, E., Nelen, A., Norberg, J.A., 1980, Reference samples for electron microprobe analysis: Geostandards Newsletter, v.4, p. 43-47.

Kent, A.J.R., Blundy, J., Cashman, K., Cooper, K.M., Donnelly, C., Pallister, J.S., Reagan, M., Rowe, M.C., Thornber, C.R., 2007, Vapor transport prior to the October 2004 eruption of Mount St. Helens, Washington: Insight from Li and $^{210}$Pb systematics: Geology, v. 5, p. 231-234.

LaHusen, R.G., Swinford, K.J., Logan, M., and Lisowski, M., 2008, Instrumentation in Remote and Dangerous Settings: an Example from GPS "Spider" Deployments during 2004-2005 Eruption of Mount St. Helens,chap. 16, *in* Sherrod, D.R., Scott, W.E., and Stauffer, P.H., eds., A volcano rekindled: the renewed eruption of Mount St. Helens, 2004-2006: U.S. Geological Survey Professional Paper 1750.

Morgan, G. IV., and London, D., 1996, Optimizing the electron microprobe analysis of hydrous alkali aluminosilicate glasses: American Mineralogist, v.81, p.1176-1185.

Pallister, J.S., Thornber, C.R., Cashman, K.V., Clynne, M.A., Lowers, H.A., Mandeville, C.W., Brownfield, I.K., and Meeker, G.P., 2008, Petrology of the 2004-2006 Mount St. Helens lava dome- implications for magmatic plumbing and eruption triggering, chap. 30, *in* Sherrod, D.R., Scott, W.E., and Stauffer, P.H., eds., A volcano rekindled: the renewed eruption of Mount St. Helens, 2004-2006: U.S. Geological Survey Professional Paper 1750.

Reagan, M.K., Cooper, K.M., Pallister, J.S., Thornber, C.R., and Wortel, Matthew, 2008, Timing of degassing and plagioclase growth in lavas erupted from Mount St. Helens, 2004–2005, from $^{210}$Po–$^{210}$Pb–$^{226}$Ra disequilibria, chap. 37 *in* Sherrod, D.R., Scott, W.E., and Stauffer, P.H., eds., A volcano rekindled: the renewed eruption of Mount St. Helens, 2004–2006: U.S. Geological Survey Professional Paper 1750.

Rowe, M.C., Thornber, C.R., and Kent, A.J.R., 2008, Identification and evolution of the juvenile component in 2004–2005 Mount St. Helens ash, chap. 29 *in* Sherrod, D.R., Scott, W.E., and Stauffer, P.H., eds., A volcano rekindled: the renewed eruption of Mount St. Helens, 2004–2006: U.S. Geological Survey Professional Paper 1750.

Sherrod, D.R., Scott, W.E., and Stauffer, P.H., eds., A volcano rekindled: the renewed eruption of Mount St. Helens, 2004-2006: U.S. Geological Survey Professional Paper 1750.

Taggart, J., E. and Siems, D.F., 2002, Major-element analysis by wavelength dispersive x ray fluorescence spectrometry, chapter "T", *in* Taggart, J.E. Jr., ed., Analytical methods for chemical analysis of geologic and other materials: U.S. Geological Survey Open File Report 02-223.

Thornber, C.R., Pallister, J.S., Rowe, M.C., McConnell, S., Herriott, T.M., Eckberg, A., Stokes, W.C., Johnson Cornelius, D., Conrey, R.M., Hannah, T., Taggart, J.E., Adams, M., Lamothe P.J, Budahn J.R. and Knaack, C.M., 2008a, Catalog of Mount St. Helens 2004–2007 Dome Samples with Major and Trace-element Chemistry: U.S.Geological Survey Open File Report 2008-1130, 9 p. with digital database.

Thornber, C.R., Pallister, J.S., Lowers, H.A., Rowe, M.C., Mandeville, C.W., and Meeker, G.P., 2008b, Chemistry, mineralogy, and petrology of amphibole in Mount St. Helens 2004-2006 dacite, chap. 32, *in* Sherrod, D.R., Scott, W.E., and Stauffer, P.H., eds., A volcano rekindled: the renewed eruption of Mount St. Helens, 2004-2006: U.S. Geological Survey Professional Paper 1750

Thornber, Carl R., Sherrod, David R., Siems, David F., Heliker, C. Christina, Meeker, Gregory P., Oscarson, Robert L., and Kauahikaua, James P., 2002, Whole-rock and glass major-element geochemistry of Kilauea Volcano, Hawaii, near-vent eruptive products: September 1994 through September 2001:U.S.Geological Survey Open File Report 02-17, 9p. with digital database.

# Appendix

## Repeat analyses of glass standard (USNM 72854 VG-568)

**Appendix 1: Repeat analysis of glass standard (USNM 72854 VG-568) over multiple analytical sessions (in weight percent oxides; $FeO_t$. indicates that all ferric and ferrous iron oxide is presented as ferrous**

| Analyzed | 3-Mar-05 N=4 | 6-Mar-05 N=3 | 9-Mar-05 N=3 | 11-Mar-05 N=3 | 13-Mar-05 N=2 | 10-Apr-05 N=2 | Overall Avg. N=17 | 1σ SD | Reported Values* | Diff |
|---|---|---|---|---|---|---|---|---|---|---|
| **Weight % Oxide** | | | | | | | | | | |
| **$SiO_2$** | 75.67 | 75.94 | 77.21 | 77.10 | 77.13 | 76.84 | 76.55 | *0.7* | 76.71 | 0.16 |
| **$Al_2O_3$** | 12.22 | 12.37 | 12.37 | 12.63 | 12.69 | 12.59 | 12.44 | *0.19* | 12.06 | 0.38 |
| **$TiO_2$** | 0.09 | 0.08 | 0.08 | 0.08 | 0.08 | 0.07 | 0.08 | *0.01* | 0.12 | -0.04 |
| **$FeO_t$** | 1.13 | 1.08 | 1.13 | 1.12 | 1.21 | 1.01 | 1.11 | *0.07* | 1.23 | -0.12 |
| **MnO** | 0.01 | 0.02 | 0.05 | 0.02 | 0.03 | 0.02 | 0.02 | *0.02* | 0.03 | -0.01 |
| **CaO** | 0.37 | 0.40 | 0.40 | 0.40 | 0.41 | 0.39 | 0.39 | *0.02* | 0.5 | -0.11 |
| **MgO** | 0.03 | 0.01 | 0.04 | 0.05 | 0.04 | 0.03 | 0.03 | *0.02* | <0.1 | -- |
| **$K_2O$** | 4.93 | 4.84 | 5.00 | 4.98 | 4.87 | 4.76 | 4.91 | *0.13* | 4.89 | 0.02 |
| **$Na_2O$** | 3.45 | 3.74 | 3.35 | 3.54 | 3.57 | 3.48 | 3.51 | *0.24* | 3.75 | -0.24 |
| **$P_2O_5$** | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | *0.01* | <0.01 | -- |
| **$SO_2$** | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0 | *0* | NA | NA |
| **Cl** | 0.11 | 0.12 | 0.12 | 0.12 | 0.13 | 0.11 | 0.12 | *0.01* | NA | NA |
| **Total** | 98.01 | 98.60 | 99.75 | 100.05 | 100.14 | 99.28 | 99.18 | *0.92* | 99.57 | -0.39 |

*Jarosewich and others (1980)