

**KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-THIRD
ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491**

April 2010

Andrew P. de Wet
Editor & Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lanc. Pa, 17604

Lara Heister
Symposium Convenor
ExxonMobil Corp.

Keck Geology Consortium Member Institutions:

Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College
Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University
Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

2009-2010 PROJECTS

SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.

Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)

Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.

Faculty: David Dethier (Williams) Students: Elizabeth Dengler, Evan Riddle, James Trotta

WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.

Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)

Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed

OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.

Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U.)

Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien

MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.

Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)

Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos

KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA

Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)

Students: Alena Giesche, Jessa Moser, Terry Workman

SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.

Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)

Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt

UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.

Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)

Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

**Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)
and ExxonMobil**

**Keck Geology Consortium: Projects 2009-2010
Short Contributions – OREGON**

**WEATHERING OF A VOLCANIC LANDSCAPE: THE GEOCHEMISTRY OF
THE DESCHUTES RIVER WATERSHED, CENTRAL OREGON.**

Project Faculty: *HOLLI FREY*, Union College & *KATHRYN SZRAMEK*, Drake
University

**CHEMICAL WEATHERING IN THE DESCHUTES BASIN: HOW WATERSHED
FEATURES EFFECT CATION CONCENTRATIONS IN WATER CHEMISTRY**

LIVIA CAPALDI: Oberlin College
Research Advisor: Steven Wojtal

**SPATIAL VARIABILTY OF TEPHRA SOIL ON DIFFERING GEOMORPHIC
SURFACES WITHIN THE HEADWATERS OF THE DESCHUTTES RIVER,
OREGON**

MATTHEW HARWARD: University of North Carolina at Charlotte
Research Advisor: Dr. Martha C. Eppes

**INCIPIENT WEATHERING IN SILICIC ROCKS INDICATED BY ENRICHMENT
OF REE AND TRACE ELEMENT CONCENTRATIONS: THE HIGH CASCADES,
OREGON**

MATTHEW KISSANE: Union College
Research Advisor: Holli Frey

**PLAGIOCLASE WEATHERING WITH DISTANCE FROM VOIDS IN VOLCANIC
ROCKS OF THE DESCHUTES BASIN, CENTRAL OREGON**

ASHLEY MELENDEZ: California State University, Fullerton
Research Advisor: Brandon Browne

**INFLUENCE OF CLIMATE AND LITHOLOGY ON SPRING CHEMISTRY IN
THE UPPER DESCHUTES RIVER, OREGON**

JULIA SCHWARZ: Carleton College
Research Advisor: Cameron Davidson

**ALKALINITY AND DISSOLVED ORGANIC CARBON IN SURFACE WATERS
OF THE DESCHUTES DRAINAGE BASIN, OREGON**

LAUREN WERCKENTHIEN: DePauw University
Research Advisor: Dr. James G. Mills, Jr.

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

INCIPIENT WEATHERING IN SILICIC ROCKS INDICATED BY ENRICHMENT OF REE AND TRACE ELEMENT CONCENTRATIONS: THE HIGH CASCADES, OREGON

MATTHEW KISSANE

Union College

Research Advisor: Holli Frey

INTRODUCTION

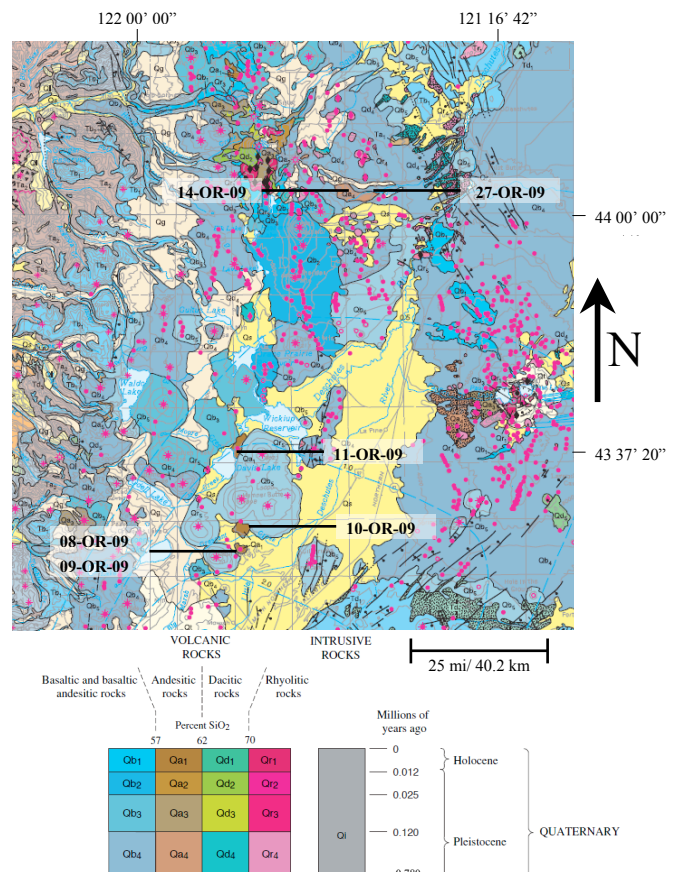
Weathering in volcanic rocks can be observed and quantified through several different textural and geochemical signatures. Previous work has shown major element mobility during the weathering of igneous rocks in more tropical settings including Hawaii, Costa Rica, and Guatemala (Oguchi, 2002; Sak et al., 2003). These studies have primarily focused on basaltic composition clasts already buried in geomorphologic features such as alluvial fill terraces that seem to enhance the rate of weathering rind advance (Sak et al., 2003). Despite the research documenting the relative changes in mobile ions, little is known about trace element behavior during weathering's earliest phases.

The Oregon High Desert is located east of the Cascade Mountain rain shadow receiving only 20.54 cm of rain annually (wrcc.dri.edu). Weathering studies have been previously completed on lava flows in the temperate zones of the Pacific Northwest, but have focused primarily on major element and mineral alteration changes in observable weathering rinds (Colman, 1982). The lava flows in this study have not been subjected to the wet and humid conditions that enhance the weathering processes. This study looks to show how trace elements can be indicative of incipient weathering in young (Holocene and Pleistocene) andesites and dacites that have not yet shown mobile major element trends or textural weathering. Trace elements, porosity, and density could all be useful tools to see how weathering manifests in young silicic clasts.

Figure 1. Geologic map of Three Sister's/Bend Region showing sampling locations and lava compositions and ages. Adapted from (Sherrod and Smith, 2000).

METHODS

Forty andesite-rhyolite lava samples were collected at twenty lava flow locations throughout the Three Sisters/Bend Region, Oregon (Fig. 1). Approximate ages and rock types were determined by locating flows using a geological map of the region (Sherrod and Smith, 2000) and GPS coordinates. A weathered sample was collected at each site by breaking off the outer portion of a clast. After this weathered sample was collected, a fresh clast was then taken from the same clast. Thin sections were prepared for point counting, (1200 counts/slide) and textural analysis. Each sample was crushed and powdered



for geochemical analysis. Powders were shipped to Acme Analytical Laboratories Ltd for major element analysis using an ICP-OES. Trace element concentrations were determined using a PerkinElmer/Sciex Elan 6100 DRC Inductively Coupled Plasma Mass Spectrometer at Union College. The full procedure is detailed at: http://minerva.union.edu/holloch/picotrace/standard_procedure.htm. A Bruker Quantax 200 EDX system on a Zeiss EVO50XVP Scanning Electron Microscope was used to produce elemental maps of pore spaces and the surrounding matrix. Density of each sample was calculated using wet and dry weight. Porosity was estimated under a 10x magnification on an Olympus microscope by determining the percent pores per field of view. To further quantify major element weathering, three weathering indexes based on alkali metals, alkaline earth metals, and Al (CIA, CIW, WI), were used to look at the degree of major mobile element weathering that had taken place (Harnois, 1987; Nesbitt and Young, 1982; Parker, 1970). The six samples that were researched in greater detail were chosen based on their range of porosities, high silicic content, and clear distinction between fresh and weathered samples.

POROSITY ESTIMATES AND DENSITY RESULTS

Porosity estimates range from 0 to 20 %. In addition, a clear increase in porosity occurs between all fresh and weathered samples. Estimated porosity increases as much as 3 to 20% in pair 09-OR-09

and as little as 0 to 1% in the more crystalline pair 27-OR-09. Density measurements range from 2.25 to 2.62 g/cm³. Change in density has an inverse relationship to the change in porosity from fresh to weathered for all pairs, with a largest decrease of .32 g/cm³ for pair 09-OR-09. A decrease in density from fresh core to weathering rind of about 3% was also seen in previous studies that looked at trace element mobility during weathering (Patino et. al 2003).

PHOTOMICROGRAPH AND SEM ANALYSIS RESULTS

The typical mineral assemblage of samples is a volcanic glass dominated matrix (15-44 vol % crystals) with larger plagioclase, orthopyroxen and clinopyroxene phenocrysts. Some small hornblende and olivine crystals were also found in select samples. There is a lack of glass alteration throughout all slides and as it is the least stable phase of the assemblage, is usually a sign of early weathering. This alteration appears as discoloration of the glass to a red or yellow, caused by iron oxidation. Also not evident are alteration products of plagioclase and pyroxene minerals, which cause them to become more opaque, stained, or speckled in a appearance (Colman, 1982). Photomicrographs taken documenting the pore spaces and adjacent minerals of vesicular samples show very little textural evidence of weathering throughout the samples. No indicator of high degrees of weathering such as color change of glassy matrix or grunginess around pore spaces

Table 1. Whole-rock compositions and point counts

Sample	08-OR-09		09-OR-09		10-OR-09		11-OR-09		14-OR-09		27-OR-09	
Lat. (N)	43°28'35.20"		43°29'27.376"		43°31'38.509"		43°37'17.124"		44°1'55.843"		44°2'32.034"	
Long. (W)	121°48'51.76"		121°49'25.799"		121°48'6.047"		121°49'15.625"		121°32'50.567"		121°29'32.155"	
Age	Holocene (0-0.012 Ma)		Holocene (0-0.012 Ma)		Holocene (0-0.012 Ma)		Holocene (0-0.012 Ma)		Pleis. (0.120-0.780 Ma)		Pleis. (0.120-0.780 Ma)	
Fresh/Weath.	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered
SiO ₂	56.8	56.7	57.5	57.4	56.9	56.7	57.5	58.0	65.5	65.6	62.5	62.3
Al ₂ O ₃	18.3	17.8	17.8	17.8	17.8	17.9	17.8	17.7	16.0	15.6	16.4	16.3
Fe ₂ O ₃	6.8	6.7	6.6	6.6	6.7	6.6	6.0	6.2	4.9	5.0	6.2	6.3
MgO	4.2	4.1	4.1	4.1	4.4	4.4	4.2	4.4	1.2	1.2	1.6	1.6
CaO	7.5	7.3	7.3	7.2	7.2	7.2	7.0	7.1	3.2	3.0	4.3	4.3
Na ₂ O	4.0	3.9	3.9	3.9	3.9	3.8	3.8	3.8	4.9	4.9	5.1	5.1
K ₂ O	1.1	1.1	1.2	1.1	1.1	1.1	1.2	1.2	2.9	2.9	1.8	1.8
TiO ₂	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	1.1	1.1
P ₂ O ₅	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.3
MnO	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sum	99.8	98.8	99.5	99.2	99.1	98.9	98.4	99.2	99.5	99.1	99.4	99.2

is evident (Gordon and Dorn, 2005). In addition to the rims of pore spaces, the rims of the clasts themselves show no extensive weathering rinds or change in color as well. Photomicrographs do show honeycomb plagioclase crystals that were determined to be attributed to magma ascent and not weathering of any type.

Elemental maps of pore spaces created with the EDX of the SEM support geochemical results and show no clear movement of mobile major elements around pore spaces. These elemental maps are based on count intensity, so elements with a greater abundance are indicated by a more intense color hue.

GEOCHEMICAL ANALYSIS RESULTS

Major element analysis shows a silica content ranging from 56.6 to 63.4 wt % and shows insignificant/minimal change in mobile major elements (Na, Ca, K, Mg) from fresh to weathered for six chosen pairs (Table 1). All three weathering indexes (CIA, CIW, WI) do not change significantly from fresh to weathered samples.

Trace elements show a more interesting trend with enrichment in both REE and select trace elements (Table 2). Sr concentrations in pair 08-OR-09 increase from 330 to 855 ppm and Ba concentration increases from 200 to 505 ppm. Other pairs show significant, but slightly smaller increases between fresh and weathered samples for Sr and Ba. In ad-

dition to Sr and Ba, all pairs also show Pb, Zr, and Y following similar enriching trends (Fig. 2). REE spider plots show enrichment in REE concentration from fresh to weathered, but this increase is more pronounced in the light rare earth elements (LREE). LREEs of weathered clasts are enriched to about ~40 to 80 times chondrite values, while the heavier rare earth elements plateau at about ~5 to 15 times chondrite values. There is also a strong correlation between a larger change in density and increase in trace element concentration from fresh to weathered rock.

DISCUSSIONS

It is well documented that during extensive weathering of igneous clasts in tropical regions changes in the concentrations of major mobile elements will occur (e.g. Gordon and Dorn, 2005; Patino et al., 2003; Sak et al., 2003). In previous studies it has been determined that Ca, Na, and Mg are all very mobile elements during weathering and will become depleted in weathering rinds in relation to the fresh core (Colman, 1982). These changes are usually much more pronounced in clasts that are basaltic (silica poor) in composition and locations that receive high levels of precipitation and humidity (Sak et al., 2003). However, in dryer regions such as the Oregon High Desert, it is much more difficult to clearly see weathering in andesite and dacites lava flows of a young age (Holocene to Pleistocene).

All major element geochemical data and elemen-

Sample	08-OR-09		09-OR-09		10-OR-09		11-OR-09		14-OR-09		27-OR-09	
Silica (wt %)	56.79	56.67	57.51	57.35	56.86	56.74	57.47	57.99	65.45	65.61	62.45	62.3
Density (g/cm ³)	2.62	2.42	2.57	2.25	2.43	2.29	2.39	2.36	2.47	2.44	2.51	2.49
Porosity (%)	2	10	3	20	10	20	10	15	0	4	0	1
Weath./Fresh	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered	Fresh	Weathered
Weathering Indexes												
CIA**	59.0	59.1	59.0	59.3	59.4	59.7	59.7	59.6	59.4	59.1	59.4	59.5
CIW**	61.2	61.3	61.4	61.6	61.5	61.9	62.2	62.0	66.5	66.4	63.5	63.6
WI***	47.3	46.1	46.6	46.1	45.9	45.3	45.9	45.9	56.7	56.4	51.6	51.2
Select Trace Elements (ppm)												
Sr	330	855	621	745	337	445	352	507	86	143	142	155
Ba	200	505	430	506	223	276	239	314	309	427	170	258
Pb	3	8	3	7	3	4	4	5	8	12	3	4
Zr	73	193	79	174	70	92	57	80	115	205	79	88
Y	8	23	9	20	8	11	8	11	15	24	12	14
*CIA=[Al ₂ O ₃ / (Al ₂ O ₃ + CaO + Na ₂ O + K ₂ O)] x 100 (Nesbitt and Young, 1982)												
**CIW=[Al ₂ O ₃ / (Al ₂ O ₃ + CaO + Na ₂ O)] x 100 (Harnois, 1987)												
*** WI=[(2 x Na ₂ O/0.35) + (MgO/0.9) + (2 x K ₂ O/0.25) + (CaO/0.7)] x 100 (Parker, 1970)												

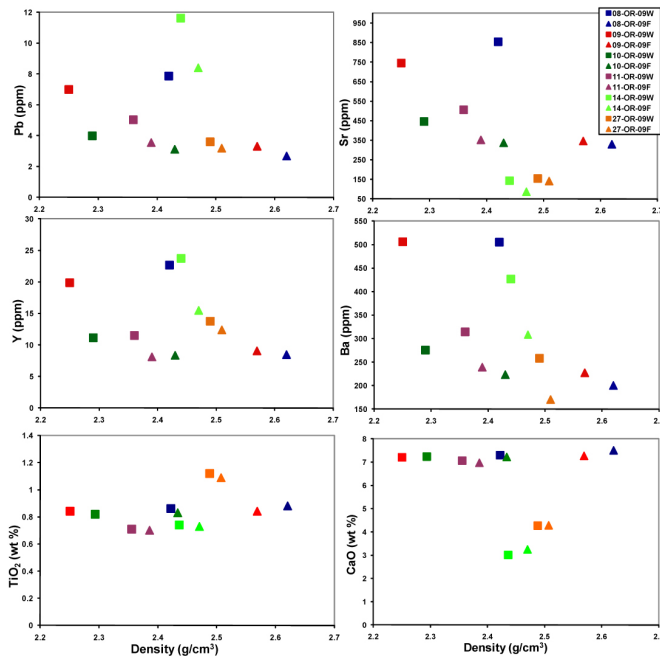


Figure 2. Plot of four select trace elements (Sr, Ba, Pb, and Y) and two major elements (TiO_2 and CaO) against density of each sample. Shows clear enrichment in these trace elements from fresh to weathered. Also shows that with greater decrease in density through weathering, there is a larger enrichment in these elements. This is interpreted to show the movement of these elements from the fresh core into the rind during incipient weathering.

tal mapping clearly show that weathering has not become extensive enough to cause the enrichment or depletion of mobile elements in either fresh or weathered clasts. Photomicrographs do not show any iron oxidation staining of glass grains in the matrix that would be expected with higher degrees of weathering (Colman, 1982). Density measurements and porosity estimates do however indicate that some amount of incipient weathering is affecting these rocks.

In order to quantify the amount of weathering taking place in these silicic rocks, other elements must be used that will show mobility with minimal weathering. For the samples collected in this study, enrichment of both rare earth elements (REE) and select trace elements (Ba, Sr, Pb, Y) is seen in weathered portions of clasts relative to fresh core samples. This indicates that during incipient weathering, weathered portions of clast rims become enriched in trace elements compared to their less weathered cores. Patino et al. (2003) has documented similar

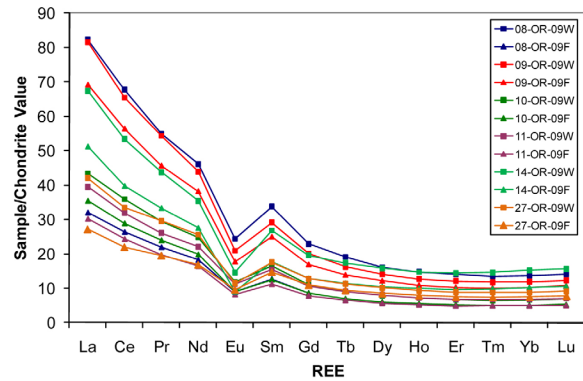


Figure 3. REE spider plot for all pairs with values normalized to chondrite (Sun and McDonough, 1995). Shows enrichment for all REEs in all six pairs that is more pronounced for the LREEs. This may indicate that these LREEs are more mobile during the earliest phases of weathering than are the heavier REEs.

trace element enrichment trends in inner layers of weathered corestones, but the outer, more weathered layers of the corestones show depletion. Thus a typical weathering sequence may first show enrichment of trace elements that is soon followed by depletion. Therefore, as weathering begins it seems that these trace elements are leached into the weathering rinds causing initial enrichment. It has been previously suggested that secondary minerals precipitate and are host to these trace elements during incipient weathering, but the host secondary mineral is destroyed with further weathering, releasing that trace element (Patino et al., 2003). If older clasts were collected from the Deschutes Basin, it would be expected that more extensive weathering would leach these trace elements out causing them to become depleted. Further study using X-ray diffraction could possibly determine what in the weathered clasts, such as mineral or volcanic glass alterations, that the trace elements are enriching. The relationship between the decrease in density and increase in trace element concentration between fresh and weathered samples suggests there is a link between the two that could also be looked at in greater detail.

As many of the world's volcanic centers are not located in the tropical regions of the world, it is

important to be able to determine how weathering proceeds in dry climates. To help answer the larger question of this research of source to sink weathering of igneous rocks in the High Cascades, this trace element proxy could provide information about which flows are weathering into the soil and subsequently into the Deschutes River drainage basin. It is expected that as weathering of these clasts progresses and the rinds of these clasts begin to weather into clays, these trace elements that were enriched will then become depleted as they leach out (Patino et al., 2003). However, many lava flows in this area of the High Cascades are too young at this point to see such sharp depletion after slight enrichment.

REFERENCES

- Bend, Oregon (350694), Western Regional Climate Center. [<http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?orbend>]
- Colman, Steven M., 1982, Chemical Weathering of Basalts and Andesites: Evidence from Weathering Rinds: Geological Survey Professional Paper, paper 1246, pg. 1-51.
- Gordon, Steven J., Dorn, Ronald I., 2005, In situ weathering and erosion: *Geomorphology*, v. 67, pg. 97-113.
- Harnois, Luc, The CIW index: a new chemical index of weathering: *Sedimentary Geology*, v. 55, pg. 319-322.
- Oguchi, Chiaki T., 2004, A porosity-related diffusion model of weathering-rind development: *Catena*, v. 58, pg. 65-75.
- Nesbitt, H.W., Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites: *Nature*, v. 299, pg 715-717.
- Parker, A., 1970. An index of weathering for silicate rocks: *Geology Magazine*, v. 107, pg. 501-504.
- Patino, Lina C., Velbel, Michael A., Price, Jason R., Wade, Jennifer A., 2003, Trace element mobility during spheroidal weathering of basalts and andesites Hawaii and Guatemala: *Chemical Geology*, v. 202, pg. 343-364.
- Sak, Peter B., Fisher, Donald M., Gardner, Thomas W., Murphy, Katherine, Brantley, Susan L., 2004, Rates of weathering rind formation on Costa Rican basalt: *Geochimica et Cosmochimica Acta*, v. 68, pg. 1453-1472.
- Sherrod, David R., and Smith, James G., 2000, Geologic map of upper Eocene to Holocene volcanic and related rocks of the Cascade Range, Oregon: U.S. Geological Survey Geologic Investigations Series Map I-2569, 2 sheets, scale 1:500,000 [<http://pubs.usgs.gov/imap/i-2569/>].