PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2013
Pomona College, Claremont, CA

Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Jade Star Lackey
Symposium Convener
Pomona College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

ISSN# 1528-7491

April 2013

Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
185 E 6th St., Claremont, CA
91711

Christina Kelly
Proceedings Layout & Design
Scripps College

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

2012-2013 PROJECTS

TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE: SHUMAGIN ISLANDS AND KENAI PENINSULA, ALASKA
Faculty: *JOHN GARVER*, Union College, *CAMERON DAVIDSON*, Carleton College
Students: *MICHAEL DELUCA*, Union College, *NICOLAS ROBERTS*, Carleton College, *ROSE PETTIETTE*, Washington & Lee University, *ALEXANDER SHORT*, University of Minnesota-Morris, *CARLY ROE*, Lawrence University.

LAVAS AND INTERBEDS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON
Faculty: *NICHOLAS BADER & KIRSTEN NICOLAYSEN*, Whitman College.
Students: *REBECCA RODD*, University of California-Davis, *RICARDO LOPEZ-MALDONADO*, University of Idaho, *JOHNNY RAY HINOJOSA*, Williams College, *ANNA MUDD*, The College of Wooster, *LUKE FERGUSON*, Pomona College, *MICHAEL BAEZ*, California State University-Fullerton.

BIOGEOCHEMICAL CARBON CYCLING IN FLUVIAL SYSTEMS FROM BIVALVE SHELL GEOCHEMISTRY - USING THE MODERN TO UNDERSTAND THE PAST
Faculty: *DAVID GILLIKIN*, Union College, *DAVID GOODWIN*, Denison University.
Students: *ROXANNE BANKER*, Denison University, *MAX DAVIDSON*, Union College, *GARY LINKEVICH*, Vassar College, *HANNAH SMITH*, Rensselaer Polytechnic Institute, *NICOLLETTE BUCKLE*, Oberlin College, *SCOTT EVANS,* State University of New York-Geneseo.

METASOMATISM AND THE TECTONICS OF SANTA CATALINA ISLAND: TESTING NEW AND OLD MODELS
Faculty: *ZEB PAGE*, Oberlin College, *EMILY WALSH*, Cornell College.
Students: *MICHAEL BARTHELMES*, Cornell College, *WILLIAM TOWBIN*, Oberlin College, *ABIGAIL SEYMOUR*, Colorado College, *MITCHELL AWALT*, Macalester College, *FREDY, AGUIRRE*, Franklin & Marshall College, *LAUREN MAGLIOZZI*, Smith College.

GEOLOGY, PALEOECOLOGY AND PALEOCLIMATE OF THE PALEOGENE CHICKALOON FORMATION, MATANUSKA VALLEY, ALASKA
Faculty: *CHRIS WILLIAMS*, Franklin & Marshall College, *DAVID SUNDERLIN*, Lafayette College.
Students: *MOLLY REYNOLDS*, Franklin & Marshall College, *JACLYN WHITE*, Lafayette College, *LORELEI CURTIN*, Pomona College, *TYLER SCHUETZ*, Carleton College, *BRENNAN O'CONNELL*, Colorado College, *SHAWN MOORE*, Smith College.

CRETACEOUS TO MIOCENE EVOLUTION OF THE NORTHERN SNAKE RANGE METAMORPHIC CORE COMPLEX: ASSESSING THE SLIP HISTORY OF THE SNAKE RANGE DECOLLEMENT AND SPATIAL VARIATIONS IN THE TIMING OF FOOTWALL DEFORMATION, METAMORPHISM, AND EXHUMATION

Faculty: *MARTIN WONG*, Colgate University, *PHIL GANS*, University of California-Santa Barbara.
Students: *EVAN MONROE*, University of California-Santa Barbara, *CASEY PORTELA*, Colgate University, *JOSEPH WILCH*, The College of Wooster, *JORY LERBACK*, Franklin & Marshall College, *WILLIAM BENDER*, Whitman College, *JORDAN ELMIGER*, Virginia Polytechnic Institute and State University.

THE ROLE OF GROUNDWATER IN THE FLOODING HISTORY OF CLEAR LAKE, WISCONSIN

Faculty: *SUSAN SWANSON*, Beloit College, *JUSTIN DODD*, Northern Illinois University.
Students: *NICHOLAS ICKS*, Northern Illinois University, *GRACE GRAHAM*, Beloit College, *NOA KARR*, Mt. Holyoke College, *CAROLINE LABRIOLA*, Colgate University, *BARRY CHEW*, California State University-San Bernardino, *LEIGH HONOROF*, Mt. Holyoke College.

PALEOENVIRONMENTAL RECORDS AND EARLY DIAGENESIS OF MARL LAKE SEDIMENTS: A CASE STUDY FROM LOUGH CARRA, WESTERN IRELAND

Faculty: *ANNA MARTINI*, Amherst College, *TIM KU*, Wesleyan University.
Students: *SARAH SHACKLETON*, Wesleyan University, *LAURA HAYNES*, Pomona College, *ALYSSA DONOVAN*, Amherst College.

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

Faculty: David Dethier, Williams College, Will Ouimet, U. Connecticut.
Students: CLAUDIA CORONA, Williams College, HANNAH MONDRACH, University of Connecticut, ANNETTE PATTON, Whitman College, BENJAMIN PURINTON, Wesleyan University, TIMOTHY BOATENG, Amherst College, CHRISTOPHER HALCSIK, Beloit College.

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation

Keck Geology Consortium: Projects 2012-2013
Short Contributions— Northeast Oregon Project

LAVAS AND INTERBEDS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON
Faculty: NICHOLAS BADER & KIRSTEN NICOLAYSEN, Whitman College.

A PALEOMAGNETIC RECONAISSANCE STUDY OF THE POWDER RIVER VOLCANIC FIELD
REBECCA L. RODD, University of California, Davis
Research Advisor: Kenneth L. Verosub

GEOCHEMICAL CLIMOFUNCTIONS REVEAL A WARM TEMPERATE, HUMID, CLIMATE IN NORTHEAST OREGON TOWARDS THE END OF THE MIDDLE MIOCENE CLIMATIC OPTIMUM
RICARDO LOPEZ-MALDONADO, University of Idaho
Research Advisors: Karen Harpp, Dennis Geist

GEOCHEMISTRY AND GEOTHERMOMETRY OF MID MIOCENE TO PLIOCENE ALKALIC ROCKS OF THE POWDER RIVER VOLCANIC FIELD
JOHNNY RAY HINOJOSA, Williams College
Research Advisor: Reinhard A. Wobus

CLAY MINERAL ANALYSIS AND PALEOCLIMATE INTERPRETATION OF A MIDDLE MIOCENE PALEOSOL, POWDER RIVER VOLCANIC FIELD, NORTHEAST OREGON
ANNA MUDD, The College of Wooster
Research Advisor: Dr. Meagen Pollock

OLIVINE BASALT: EARLIEST LAVAS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON
LUKE FERGUSON, Pomona College
Research Advisors: Kirsten Nicolaysen and Jade Star Lackey

MINERALOGY AND GEOCHEMISTRY OF BASANITE ERUPTED FROM THE POWDER RIVER VOLCANIC FIELD, NORTHEASTERN OREGON
MICHAEL BAEZ , California State University, Fullerton
Research Advisor: Brandon Browne

Keck Geology Consortium
Pomona College
185 E. 6th St., Claremont, CA 91711
Keckgeology.org

KECK Geology Consortium
Learning Science Through Research
Published by Keck Geology Consortium
Short Contriubtions
26th Annual Keck Symposium Volume
6 April, 2013
ISBN: 1528-7491

GEOCHEMICAL CLIMOFUNCTIONS REVEAL A WARM TEMPERATE, HUMID, CLIMATE IN NORTHEAST OREGON TOWARDS THE END OF THE MIDDLE MIOCENE CLIMATIC OPTIMUM

RICARDO LOPEZ-MALDONADO, University of Idaho
Research Advisors: Karen Harpp, Dennis Geist

INTRODUCTION

A paleosol in Cricket Flat (CFP), outside of Elgin, Oregon, developed within the later cooling stage during a relatively short interval between approximately 14.7 Ma and 14.5 Ma (Bailey, 1990; Ferns et al., 2010). The goal of this study is to determine geochemical climofunctions of the CFP.

The Columbia River Basalt Group (CRBG) is the largest volcanic unit within the Cenozoic. CRBG eruptions finished in northeast Oregon by ~14.7 Ma (Brueseke et al., 2007). The Powder River Volcanic Field (PRVF), a relatively small and isolated province, began erupting at ~14.5 Ma (Bailey, 1990).

This study focuses on a soil developed near the boundary between CRBG and the PRVF in northeast Oregon. The field site location of the CFP is presented in Bader and Nicolaysen, Fig. 2 (v. 26).

METHODS

The CFP is located 5 miles east of Elgin, OR on OR-82, and field study was carried out in the summer of 2012. Paleosol and parent rock samples were collected from 6 horizons exposed in a road cut. The paleosols overlie an ignimbrite known as the Dooley Creek/Dinner Creek tuff and underlie ~14.5 Ma diktytaxitic olivine basalt of the PRVF (Bailey, 1990; Ferns et al., 2013). Radiometric ages indicate the ash-flow tuff erupted about 14.7 to 14.8 Ma, coeval with the CRBG (Bailey, 1990; Ferns et al., 2013).

Samples were taken from each textural unit (Fig. 1) and were processed and crushed at Whitman College. Major and trace element ratios of samples were obtained by fusing lithium tetraborate and analyzed using X-ray fluorescence spectroscopy (XRF) at the GeoAnalytical Laboratory at the Washington State University

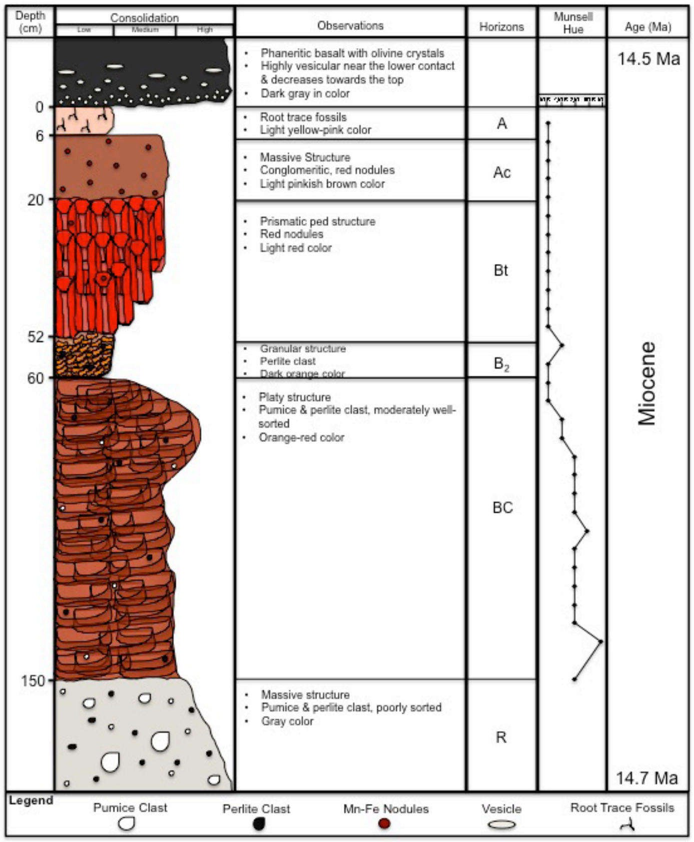

Figure 1. Stratigraphic column of the Cricket Flats paleosol.

RESULTS

Site Description (See also Fig. 1)

Diktytaxitic olivine basalt, Tpb

The olivine basalt is at least 3 m thick, dark gray on weathered surfaces and light bluish-gray on fresh surfaces. The lava is massive with vesicles (~15% and 5 mm in diameter) in the lower part. In the middle of the lava (starting 8 cm above the lower contact) the vesicles decrease in abundance and size (~5% and 5 mm-15 mm in diameter). Vesicularity decreases towards the top. In addition, the vesicles change from slightly circular to near tabular. The lower contact is abrupt and planar.

A horizon

The A horizon is 6 cm thick, non-reactive to 5% HCL, light yellowish-pink on weathered surfaces and light yellowish-orange on fresh surfaces. It has a blocky structure and a clay-sized matrix embedded with root trace fossils (~3%). The root traces are black, ranging in length from 1 to 10 mm, and have dendritic shape. The lower contact is abrupt and planar.

Ac horizon

The Ac horizon is 14 cm thick, non-reactive to 5% HCL, light brownish-pink on weathered surfaces and light pink in fresh material. It has a massive structure and a very fine sand-silt matrix, embedded with coarse nodules (~5%). The nodules exhibit a concentric structure in cross-section with a dark red crust and light blue gray core. The lower contact is sharp and wavy.

Bt horizon

The Bt horizon is 32 cm thick, non-reactive to 5% HCL, light red on weathered surfaces and dark brownish-orange when fresh. It is remarkably prismatic with micro desiccation cracks and nodules equivalent to those in the overlying unit (~3% and 5 mm in diameter). The lower contact is gradational and wavy.

B2 horizon

The B2 horizon is 8 cm thick, non-reactive to 5% HCL, and dark orange. It has a granular structure, and a silty matrix embedded with spherical black perlite (1mm in diameter). The lower contact is gradational and wavy.

BC horizon

The BC horizon is 98 cm thick, non-reactive to 5% HCL, and orange-red. It has a platy structure (5 mm-10 mm thick), and a silt- sized matrix embedded with heterogenous sub-rounded and moderately poorly sorted pumice and perlite clasts (~25 mm in diameter). Pumice increases up section from 1%-5%, but the clasts decrease in diameter to ~5 mm. The lower contact is gradational and wavy.

R horizon

The R horizon is at least 4 m thick, non-reactive to 5% HCL, and gray. It is massive and made up of very poorly sorted sand-sized glass, but larger more abundant clasts (15% pumice clasts, 1 mm-40 mm in diameter; 2% perlite, 1 mm-5 mm in diameter).

Soil Type Identification

Based on the absence of features such as a spodic horizon, evidence of permafrost, organic matter not directly overlying cindery or pumiceous material, and other relevant features, the CFP was probably comparable to an andisol in the modern taxonomic system of the U.S. Department of Agriculture (Soil Survey Staff, 1999). Andisols form on volcanic material and have undergone weathering of primary silicates in the parent material.

Geochemical Climofunctions

Paleotemperature and paleoprecipitation characteristics present during pedogenesis were determined by chemical weathering indices of the Bt horizon (Sheldon, 2009). Before using composition to evaluate climatic conditions, it is essential to establish that the paleosol is genetically related to the underlying rock; I have used Ti and Al, elements that are immobile during normal chemical weathering.

The CFP has low Ti/Al similar to the felsic parent material for most of its profile except for a sharp spike at 20 cm depth, in the Ac horizon (Fig. 2). The low Ti/Al values indicate most of the CFP are from the ignimbrite. My interpretation is that the spike in Ti/Al represents the input of mafic material. The return to rhyolitic Ti/Al above Ac suggests renewed aeolian input of material equivalent to the ignimbrite. An alternate interpretation is that the CFP is genetically related throughout the profile and the high-Ti zone, which is right above a clay-rich zone, is indicative of probably being seasonally permeable; hence, being affected by hydrolysis.

The relationship between mean annual precipitation (MAP) and the chemical index of alteration without K (CIA-K) is the most robust model estimated from paleosols (Sheldon, 2002) and can be solved by the following equation:

$$\text{MAP (mm/yr)} = 221.12\exp^{0.0197(\text{CIA-k})}$$

where CIA-K is defined as $[Al_2O_3/(100)*(Al_2O_3 + CaO + Na_2O)]$ using molecular percentages from whole-rock XRF analysis (Maynard, 1992). The standard error on the above MAP estimation equation is ±181 mm/yr, and $R^2 = 0.72$ for the empirical fit (Sheldon et al., 2002). Estimating mean annual temperature (MAT) during pedogenesis can be evaluated using elemental geochemical data as follows:

$$\text{MAT } (^{o}\text{C}) = 46.9\text{ C} + 4$$

where C is “clayeyness” and defined as the ratio Al/Si (Ruxton, 1968). The standard error for this model is ±0.6 °C and $R^2 = 0.96$ (Sheldon, 2006). All essential geochemical climofunction estimates derived from the above equations are included in Figure 2.

Isocon Diagram

In humid-climate regimes, mobile elements are leached during pedogenesis, whereas immobile elements are unaffected. The gains and losses of material from the original rock necessary to produce the altered rock can be determined with an isocon diagram (Grant, 1986). We graphically identify immobile and mobile components by solving:

$$C_A = (M_O/M_A)\ C_O$$

where C_A is altered concentration; C_O is unaltered concentration; M_A is altered mass; and M_O is unaltered mass. On a plot of C_A vs. C_O the immobile components form a straight line through the origin with slope = M_O/ M_A. My isocon diagram shows how some elements were leached more than others. I believe that we have input of basaltic PRVF ash because Ti/Al are equivalent to PRVF basalt, as indicated by geochemical data in Ferguson (v. 26).

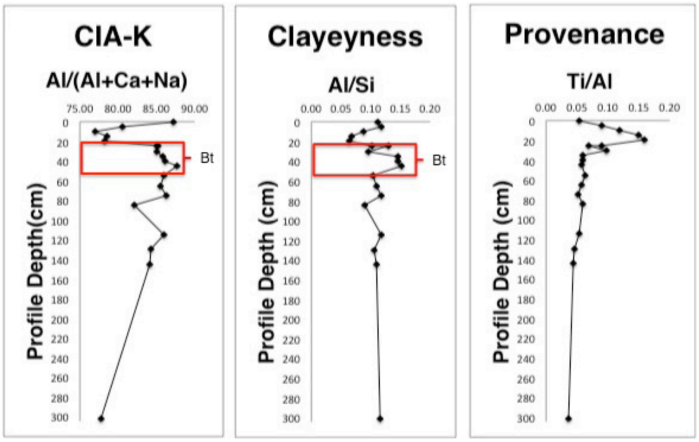

Figure 2. Provenance indicator showing an anomaly at 20 cm depth. CIA-K and clayeyness visually display relative amounts of feldspar alteration and clay accumulation.

DISCUSSION

Development and Regional Climate

The transition between the CRBG and the PRVF was punctuated by a period of quiescence lasting up to about two hundred thousands years, as suggested by the pedogenesis of the CFP.

The CFP is heavily concentrated in clay at 25cm depth, probably illuviated from the A horizon (Fig. 2). Abundant clay indicates heavy precipitation, where hydrolysis breaks down feldspar and mafic minerals (Retallack, 2007). The absence of carbonates and the

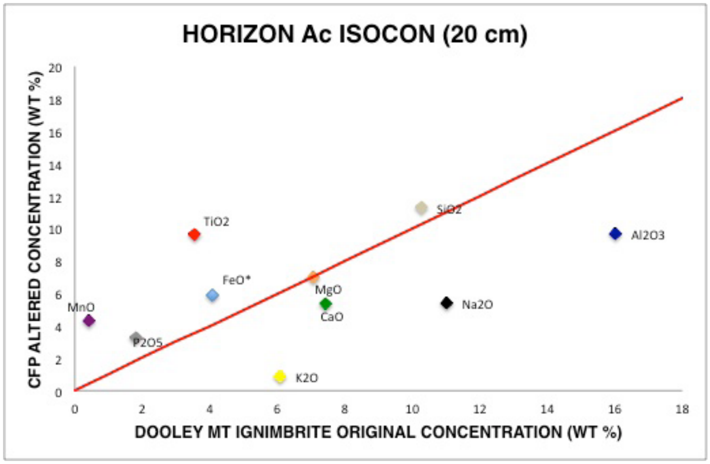

Figure 3. Isocon diagram of the Ac horizon with a 1:1 line.

presence of Mn-Fe nodules indicate relatively high MAP (800 to 1500 mm yr^{-1}) (Stiles et al., 2001). The above correlation is quantitatively supported with an MAP value of 1177.26 mm/yr using CIA-k as a proxy (Maynard, 1992).

The CFP formed under a warm temperate, humid climate with an MAT value of 9.51°C by using clayeyness as a proxy (Kottek et al., 2006; Sheldon, 2006). The yearly precipitation is ~400 mm/yr greater and temperatures ~3-4°C lower than the MMCO (Sheldon, 2006). The relatively high MAP values may be indicative of uplift to the east of the area, which was produced by convective downwelling and detachment of a compositionally dense plutonic root resulting in 200-km-wide topographic uplift (Hales et al., 2005).

Global Climate Implications

Middle Miocene cooling and ice sheet expansion was triggered by climate forcing factors (obliquity and eccentricity) in conjunction with coeval decreasing atmospheric CO_2 as the eruption rate of the CRBG slowed (Holbourn, et al., 2005). This cooler climate was produced under oscillating variations with an overall decreasing trend in global temperature. Similar effects are seen in Sheldon's (2006) Miocene paleosols. As a result, Antarctic ice-sheet expanded and fluctuated between 14.7 and 13.9 Ma (Holbourn et al., 2005). The CFP formed during this cooling trend from the MMCO.

CONCLUSION

I discussed two interpretations: 1) The CFP formed by weathering of parent material from two distinct origins, one rhyolitic and the other basaltic; and 2) the CFP is genetically related throughout the profile and the high-Ti zone was probably seasonally permeable; hence, being affected by hydrolysis. It is preserved between an underlying CRBG-age ignimbrite volcaniclastic unit and an overlying PRVF olivine basalt. The CFP was used to reconstruct regional paleoclimate conditions. Geochemical results from the CFP Bt horizon indicate a lower MAT relative to the MMCO. This is consistent with studies of terrestrial and marine proxies, which indicate global cooling. A higher MAP relative to the MMCO could be attributed cooling climate patterns or to an increase in elevation east of the CFP area.

REFRENCES

Bailey, D.E., 1990, Geochemistry and Petrogenesis of Miocene Volcanic Rocks in the Powder River Volcanic Field, Northeastern Oregon: Pullman, WA., Washington State University, doctoral dissertation, p. 341.

Brueske, M.E, et al., 2007. Distribution and geochronology of Oregon Plateau (U.S.A) flood basalt volcanism: The Steen Basalt revisited. Journal of Volcanology and Geothermal Research. v. 161.3, p. 187-214.

Ferns, M.L., et al., 2010. Geology of the Upper Grande Rhonde River Basin Union County, Oregon. Department of Geology and Mineral Industries Bulletin 107. p. 65.

Flower, B.P., 1994. The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation, and global carbon cycling. Paleogeography, Paleoclimatology, Paleoecology, v. 108, p. 537-55.

Grant, J.A., 1986. The Isocon Diagram-A Simple Solution to the Gresens' Equation for Metasomatic Alteration. Economic Geology, v. 81, p. 1976-1982.

Hales, T.C., et al., 2005. A lithospheric instability origin for Columbia River flood basalts and Wallowa Mountains uplift in northeast Oregon. Nature. v. 438, doi: 10.1038.

Hobbs, K.M., 2010. Global Climate Change in the Miocene Recorded in Columbia River Basalt-Hosted Paleosols: Moscow, ID., The University of Idaho, master thesis.

Holbourn, A., et al., 2005. Impacts of orbital forcing and atmospheric carbon dioxide on the Miocene ice-sheet expansion. Nature. v. 438, doi: 10.1038.

Kraus, M.J., 1999. Paleosols in clastic sedimentary rocks: their geologic applications. Earth-Science Reviews, v. 47, p. 41-70.

Kottek, M., 2006. World Map of the Koppen-Geiger climate classification updated. Meteorologishe Zeitschrift, v. 15, No.3, p. 259-263.

Lindsey, K., et al., 2009. Hydrogeology of the Columbia River Basalt Group in the Columbia River Plateau: Road log and field trip stop descriptions. Geological Society of America.

Maynard, M.B., 1992. Chemistry of modern soils as a guide to interpreting Precambrian paleosols. The Journal of Geology v.100.

Retallack, G.J., 2001a. Carbon dioxide and climate over the past 300 Myr. Philosophical Transactions of the Royal Society.

Retallack, G.J., 2001b. Soils of the Past. 2nd ed. London: Blackwell Science, LTD., p. 404.

Ruxton, B.P., 1968. Measures of the degree of chemical weathering of rocks. Journal of Geology. v. 76, p. 518-527.

Sheldon, N. D et al., 2002. Geochemical Climofunctions from North American Soils and Application to Paleosols across the Eocene-Oligocene Boundry in Oregon. The Journal of Geology v. 110.

Sheldon, N.D., 2006a. Using paleosols of the Picture Gorge Basalt to reconstruct the middle Miocene climatic optimum. PaleoBios 26.2.

Sheldon, N.D., 2006b. Precambrian paleosols and atmospheric CO_2 levels. Precambrian Research 147, 148-155.

Sheldon, N.D., and N.J. Tabor., 2009. Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols. Earth-Science Reviews