

KECK GEOLOGY CONSORTIUM

**PROCEEDINGS OF THE TWENTY-SECOND
ANNUAL KECK RESEARCH SYMPOSIUM
IN GEOLOGY**

April 2009
Franklin & Marshall College, Lancaster PA.

Dr. Andrew P. de Wet, Editor
Keck Geology Consortium Director
Franklin & Marshall College

Dr. Stan Mertzman
Symposium Convenor
Franklin & Marshall College

Kelly Erb
Keck Consortium Administrative Assistant

Diane Kadyk
Academic Department Coordinator
Department of Earth & Environment
Franklin & Marshall College

*Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster PA 17604-3003
717 291-4132 keckgeology.org*

ISSN # 1528-7491

The Consortium Colleges

National Science Foundation

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

April 2009

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

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

Stan Mertzman
Symposium Convenor
Franklin & Marshall C.

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

2008-2009 PROJECTS

**THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS
(GRENVILLE PROVINCE, NEW YORK)**

Faculty: *WILLIAM H. PECK*, *BRUCE W. SELLECK* and *MARTIN S. WONG*: Colgate University

Students: *JOE CATALANO*: Union College; *ISIS FUKAI*: Oberlin College; *STEVEN HOCHMAN*: Pomona College; *JOSHUA T. MAURER*: Mt Union College; *ROBERT NOWAK*: The College of Wooster; *SEAN REGAN*: St. Lawrence University; *ASHLEY RUSSELL*: University of North Dakota; *ANDREW G. STOCKER*: Claremont McKenna College; *CELINA N. WILL*: Mount Holyoke College

PALEOECOLOGY & PALEOENVIRONMENT OF EARLY TERTIARY ALASKAN FORESTS, MATANUSKA VALLEY, AL.

Faculty: *DAVID SUNDERLIN*: Lafayette College, *CHRISTOPHER J. WILLIAMS*: Franklin & Marshall College

Students: *GARRISON LOOPE*: Oberlin College; *DOUGLAS MERKERT*: Union College; *JOHN LINDEN NEFF*: Amherst College; *NANCY PARKER*: Lafayette College; *KYLE TROSTLE*: Franklin & Marshall College; *BEVERLY WALKER*: Colgate University

**SEAFLOOR VOLCANIC AND HYDROTHERMAL PROCESSES PRESERVED IN THE ABITIBI GREENSTONE BELT OF
ONTARIO AND QUEBEC, CANADA**

Faculty: *LISA A. GILBERT*, Williams College and Williams-Mystic and *NEIL R. BANERJEE*, U. of Western Ontario

Students: *LAUREN D. ANDERSON*: Lehigh University; *STEFANIE GUGOLZ*: Beloit College; *HENRY E. KERNAN*: Williams College; *ADRIENNE LOVE*: Trinity University; *LISA SMITH*: Amherst College; *KAREN TEKVERK*: Haverford College

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

Faculty: *DAVID P. DETHIER*: Williams College and *MATTHIAS LEOPOLD*: Technical University of Munich

Students: *EVEY GANNAWAY*: The U. of the South; *KENNETH NELSON*: Macalester College; *MIGUEL RODRIGUEZ*: Colgate University

GEOARCHAEOLOGY OF THE PODERE FUNGHI, MUGELLO VALLEY ARCHAEOLOGICAL PROJECT, ITALY

Faculty: *ROB STERNBERG*: Franklin & Marshall College and *SARA BON-HARPER*: Monticello Department of Archaeology

Students: *EVERY R. COTA*: Minnesota State University Moorhead; *JANE DIDALEUSKY*: Smith College; *ROWAN HILL*: Colorado College; *ANNA PENDLEY*: Washington and Lee University; *MAIJA SIPOLA*: Carleton College; *STACEY SOSENKO*: Franklin and Marshall College

GEOLOGY OF THE HÖH SERH RANGE, MONGOLIAN ALTAI

Faculty: *NICHOLAS E. BADER* and *ROBERT J. CARSON*: Whitman College; *A. BAYASGALAN*: Mongolian University of Science and Technology; *KURT L. FRANKEL*: Georgia Institute of Technology; *KARL W. WEGMANN*: North Carolina State University

Students: *ELIZABETH BROWN*: Occidental College; *GIA MATZINGER*, *ANDREA SEYMOUR*, *RYAN J. LEARY*, *KELLY DUNDON* and *CHELSEA C. DURFEY*: Whitman College; *BRITTANY GAUDETTE*: Mount Holyoke College; *KATHRYN LADIG*: Gustavus Adolphus College; *GREG MORTKA*: Lehigh U.; *JODI SPRAJCAR*: The College of Wooster; *KRISTIN E. SWEENEY*: Carleton College.

**BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC & NATURAL ENVIRONMENTAL
CHANGE**

Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University

Students: *ALANA BARTOLAI*: Macalester College; *EMMA KRAVET* and *CONOR VEENEMAN*: Wesleyan University; *RACHEL NEURATH*: Smith College; *JESSICA SCHEICK*: Bryn Mawr College; *DAVID JAKIM*: SUNY.

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

**Keck Geology Consortium: Projects 2008-2009
Short Contributions – COLORADO**

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

Project Director: *DAVID P. DETHIER*: Williams College

Project Faculty: *MATTHIAS LEOPOLD*: Technical University of Munich

**FRACTURE CONTROL OF GLACIAL EROSION WITHIN GREEN LAKES VALLEY,
FRONT RANGE, COLORADO**

EVEY GANNAWAY: The University of the South

Research Advisor: Martin Knoll

**CHARACTERIZATION AND COMPARISON OF WEATHERING PROFILES WITHIN
BETASSO CATCHMENT, FRONT RANGE, COLORADO**

KENNETH NELSON: Macalester College

Research Advisor: Raymond Rogers

APATITE IN THE SOILS OF BETASSO PRESERVE, COLORADO

MIGUEL RODRIGUEZ: Colgate University

Research Advisor: Dr. Richard April

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

APATITE IN THE SOILS OF BETASSO PRESERVE, COLORADO

MIGUEL RODRIGUEZ: Colgate University
Research Advisor: Dr. Richard April

INTRODUCTION

Phosphorus, an essential limiting macronutrient for plants, is found most abundantly in soils in its inorganic form as the mineral apatite (Welch, 2002). Some previous studies have concluded, however, that decomposition of the organic component in soil may provide 30% to 80% of the total available phosphorus to an ecosystem through recycling (Tarafdar and Claassen, 1988). Commonly occurring as an accessory mineral, apatite plays a crucial role in plant growth because its weathering provides a continuous source of non-organic phosphorus. Phosphorus is incorporated in the transportation of cellular energy in adenosine triphosphate (ATP) and serves as part of the structural framework in RNA and DNA. The purpose of this study is to determine the source of phosphorus and to quantify the amount of apatite in fresh bedrock and soils of the Betasso subcatchment of the Boulder Creek watershed in Colorado.

The study site is the Betasso catchment of middle Boulder Creek, located west of Boulder, Colorado, in the Front Range. It is the most weathered of the three catchments studied in the Boulder Creek Critical Zone Observatory (Anderson, Boulder Creek Proposal). The critical zone is the area above fresh bedrock that has weathered in response to exposure to the forces of the hydrosphere, atmosphere, and biosphere that bedrock does not experience at depth (Anderson, 2007; Anderson, 2008). The ultimate source of nutrients, it is imperative to understand the weathering processes and mechanisms of this zone. The soils in this veneer represent the zone where minerals break down and release nutrients such as phosphorus.

The presence of apatite in granitic rocks as a source

of phosphorus has been confirmed in bedrock similar to that found in Boulder Creek, including the Bemboka and Bullenbalong granodiorites of New South Wales (Banfield and Eggleton, 1989; Taunton, 2000; Banfield, 1990), the Trois Seigneurs granodiorites (Oliva, 2004), and in the granodiorites of the Front Range (Condie, 1995). Preliminary investigations of the mineralogy and chemistry of Boulder Canyon granodiorites sought to characterize the weathering rates of major minerals such as plagioclase and potassium feldspars. Condie (1995) provided preliminary evidence of phosphorus concentrations in bedrock, saprolite and soils. Dethier and Lazarus (2006) calculated the average denudation rates of grus, saprolites, and bedrocks near the glacial limit. Based on the bulk chemistry of the rocks investigated by these studies, we assume the primary mineral source of phosphorus is apatite. However, apatite has not been studied in local bedrock and soils. This study focuses on quantifying the presence of apatite in soils and to identify mechanisms of apatite weathering in the Betasso catchment.

The Betasso catchment has not been glaciated, but it is likely that climate change affected the area at the same time as the Pleistocene glaciations that have been documented from nearby areas (Madole et al., 1999). There is evidence of an older glacial history, but local deposits preserve best the Bull Lake glaciation, which lasted from about 200,000 to 130,000 years ago, and the Pinedale glaciation, from about 30,000 to 15,000 years ago. Deeply weathered and covered mainly by undated saprolite, unconsolidated materials, and alluvial deposits, seismic tests, electrical resistivity lines and, ground penetrating radar have all found the soils, grus and saprolite to extend to as much as eight meters below the surface in the Betasso area.

The sampling site for soils is a gully exposure, four meters deep, assumed to have been excavated by a flood from a break in a water pipeline, located uphill. Positioned in an area classified as alluvial and colluvial deposits of Pinedale age, a buried soil profile, more than a meter below the surface, has been radio-carbon dated. Results suggest the preserved weathered profile was buried deeply enough to stop exchanging carbon with the atmosphere about 8,500 years ago. Based on the development of the profile, it represents exposure times to surface weathering on the order of tens of thousands to perhaps a hundred thousand years.

METHODS AND MATERIALS

Grain mounts were prepared by sonicating soil samples for sixty seconds to shake off clays and then wet sieved for a 63-125 micron fraction. The fine-sand fraction has been found to be the most proportionally representative fraction of mineral assemblages for most soils (Manage, 1992). A trace mineral in the bedrock (Condie, 1995), it is necessary to concentrate the apatite. Heavy minerals were separated from an initial mass of ten grams following the gravity separation technique described in Manages' Heavy Minerals in Colour (1992). The density of the methylene iodide liquid was 3.1 g/cm³, just below the 3.14 to 3.26 g/cm³ density of apatite. The liquid was drained, recalibrated, and reused. The heavy minerals were sonicated for four minutes in acetone and dried before weighing.

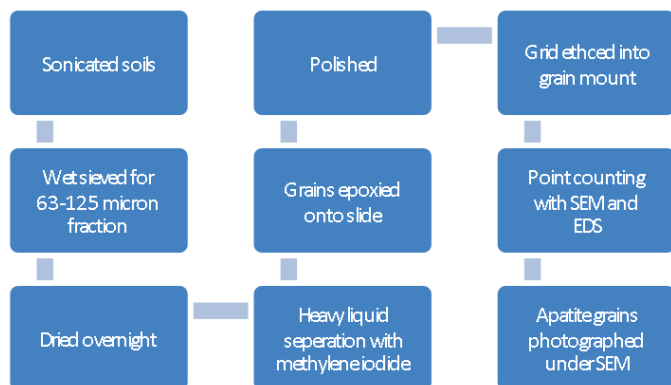


Figure 1: Simplified flow chart of research procedures

Epo-tek epoxy #201 was used to mount the grains for analysis. Epoxy was first spread on a glass slide so that the grains could be evenly distributed onto the slide by shaking them through a 125-micron sieve. After drying for an hour in a 90°C convection oven, more epoxy was poured over the mount and dried overnight in the oven. The slides were polished on the 600 and 320 micron grit wheels until grains were exposed. A grid was etched into the grain mounts using a metal scribe template with four-millimeter tick marks on both axes. The purpose of the grid was to establish a method in which a section of the slide could be aligned under the SEM so that the EDS could be used to map grains with calcium and phosphorus.

Each slide was carbon coated and then analyzed in a JEOL JSM636OLV Scanning Electron Microscope (SEM) with a PTG Electron Dispersive X-ray Spectrometer (EDS). Each mineral with both elements was assumed to be apatite because other calcium phosphate minerals, such as monetite and brushite, are very rare. At least 300 total grains were counted to ensure a statistically representative population (Manage, 1992). Individual grains were identified, photographed, and described for both the young and older, buried soils. A simplified version of the methods is illustrated in Figure 1.

RESULTS

The primary phosphorus-bearing mineral identified by the SEM/EDS was apatite. Zircon, sphene, and magnetite composed the majority of the remaining fraction. The data allowed the calculation of the amount of the heavy minerals in the total mineral assemblage. The apatite in the soils were graphed against depth to illustrate the vertical special relationships (Fig. 2). Assuming that the heavy minerals are of equal weights, we are able to determine the weight of apatite in soils of the gully by knowing the amount of heavy minerals in the fine fraction and the percent of apatite within this fraction. Bulk chemical data compared to point counting data is illustrated in Figure 3.

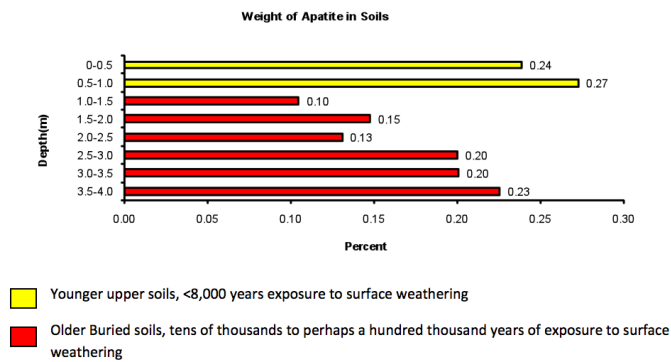


Figure 2: The amount of apatite, by weight percent, has been graphed against depth to reveal spatial trends. The lower buried profile represents a weathering trend that could be expected from soils that have been weathered for tens of thousands of years. The less abundant apatite in the more depleted A and B horizons are illustrated in the 1-2.5 meter depth intervals. However, the upper profile, has experienced only minimal surface weather, so it has a greater abundance of apatite overall.

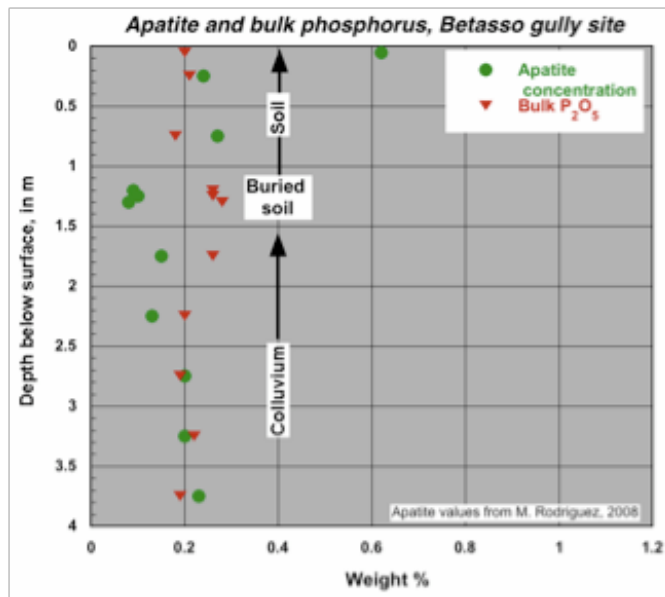


Figure 3: The bulk P₂O₅ content submitted for XRF analysis and point counting data are graphed against depth. The upper horizons of the buried soil profile have differing values. A possible explanation requires the partitioning of phosphorus into the clay and Fe(OH)_x compounds in the soil.

The weathering of individual grains of apatite is similar both the surface and buried profiles at similar depths and horizons. Etching into grains of the A- and B-horizons of the buried soils is comparable to that in the surface O-horizon in the young soils, however, there is sufficient evidence to suggest

that the primary mechanism of weathering is chemical, as if apatite is dissolved away. Even in horizons where we expect intense erosion, the edges of apatite grains are relatively smooth. There is no evidence of any alteration of apatite at rims or along fractures, but several areas of iron, potassium, and titanium rich clays were identified along fractures and as partial rims to the grains, but these may be clays that were not fully removed (Fig. 4). At greater depths within each profile, more euhedral and less fractured grains are more abundant. Observations of other minerals has led us to conclude that the buried soil have experienced more intense weathering than the younger upper soils.

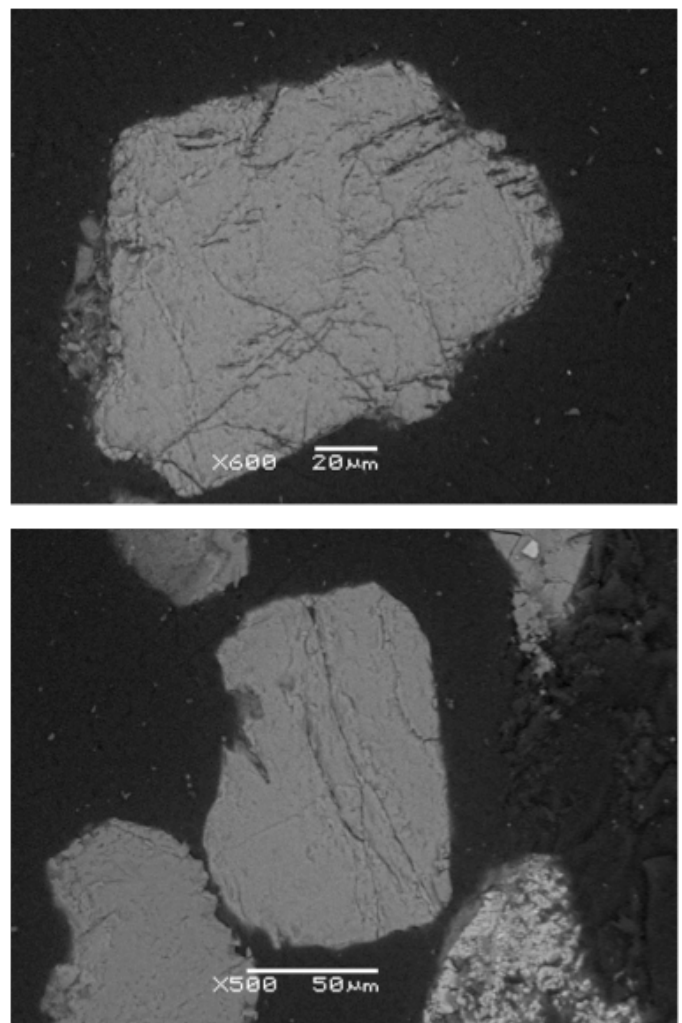


Figure 4: (Top) Under the SEM, etching into the apatite grains was found in the O horizon of the younger soils, while there are similar attributes on apatite grains in the buried soil profile. (Bottom) An apatite grain in the buried B horizon has been slightly etched. Clays have filled in the etched areas in all the grains identified.

DISCUSSION

Presence of apatite in the buried profile suggests exposure to weathering from tens of thousands to perhaps beyond one hundred thousand years. In the buried profile, the apatite may have experienced more intense weathering near the surface. Since Betasso is not known to be acidic through natural or anthropogenic mechanisms, presently, the sources of weathering for the apatite could be a consequence of the production of acids from naturally occurring organic processes in the O-horizon during its exposure to the surface. We believe that the conditions under which these buried soils were at the surface existed under dense forest material likely to produce organic acids. Based on observation of the minerals in the grain mounts, we believe that the apatite has been chemically dissolved. It is possible that partitioning of the bulk phosphorus has resulted in increased amounts of phosphorus in clays and $\text{Fe}(\text{OH})_x$ compounds (Penn, 2005).

The Holocene soil has a similar abundance of apatite compared to maximum of the preserved profile. Mass waste transports materials down slope with the deposits retaining mineral assemblages representing parent bedrock or less weathered materials from upslope. Because the lower soil was buried about 8,500 years ago, this young soil has experienced only minimal weathering, so we do not see depletion of apatite.

Even with expected trends, potential error in this study was the assumption that all the heavy minerals had the same density. Other heavy minerals may have a density greater than apatite. This would result in decreased lower the weight of the apatite in the soils by a fraction of a percent.

CONCLUSION

This study suggests that apatite is the primary mineral source of phosphorus in Betasso. It is present in the bedrock and is therefore weathered and available in the Betasso soils and colluvial materials, ranging in weight from 0.1 to 0.27% of

the soils. The buried soil profile represents exposure times of tens of thousands of years, perhaps more than one hundred thousand years. The overlying, younger soil is likely regolith derived from less weathered materials upslope and has had less time to weather. The primary weathering mechanism seems to be chemically dissolving the apatite. Also, phosphorus that has been removed from apatite but is still present in the soil was possibly partitioned into clays and $\text{Fe}(\text{OH})_x$ compounds.

Additional study is needed to characterize the weathering of phosphorus-bearing minerals more thoroughly. This data can be normalized against zircon to compare apatite's weathering relative to a highly resistant mineral. Others working in the Colorado Critical Zones Observatory can integrate ideas discussed in this research to create a more comprehensive understanding of the chemical properties of this critical zone.

ACKNOWLEDGEMENTS

Support for this study came from several people and programs. First, I would like to extend my gratitude for my advisors, Dr. Richard April and Dr. David Dethier for their support, review, and guidance of my study. Also, I am grateful for the support, critique, and advice from the Colgate Geology Department, both faculty and students, and for the Keck Geology Consortium.

REFERENCES

- Anderson, Suzanne Prestrud. Boulder Creek Critical Zone Observatory Proposal. <<http://www.czen.org/system/files/BoulderCreekCZOproposal.pdf>>
- Anderson, S. P., 2008, Critical Zone Observatories; Building a Network to Advance Interdisciplinary Study of Earth Surface Processes. Ed. R. C. Bales and C. J. Duffy. Vol. 72. United Kingdom: Mineralogical Society : London, United Kingdom.

- Anderson, Suzanne Prestrud., 2007, Physical and Chemical Controls on the Critical Zone. Ed. Friedhelm von Blanckenburg and Arthur F. White. Vol. 3. International: Mineralogical Society of America and Mineralogical Society of Great Britain and Ireland and Mineralogical Association of Canada and Geochemical Society and Clay Minerals Society, International.
- Banfield J.F. Eggleton R. A., 1990, Analytical Transmission Electron Microscope Studies of Plagioclase, Muscovite, and K-Feldspar Weathering." *Clays and Clay Minerals* 38.1.
- Banfield J.F. Eggleton, R. A., 1989, Apatite Replacement and Rare Earth Mobilization, Fractionation, and Fixation during Weathering." *Clays & Clay Minerals* 37.2.
- Condie, Kent C., 1995, Behavior of Rare Earth Elements in a Paleoweathering Profile on Granodiorite in the Front Range, Colorado, USA. Ed. Jessie Dengate and Robert L. Cullers. Vol. 59. International: Elsevier : New York, NY, International.
- Dethier, David P. Eli D. Lazarus., 2006, Geomorphic Inferences from Regolith Thickness, Chemical Denudation and CRN Erosion Rates Near the Glacial Limit, Boulder Creek Catchment and Vicinity, Colorado. Ed. Vol. 75. Netherlands: Elsevier : Amsterdam, Netherlands.
- Madole, R.F., VanStine, D.P., Michael J.A., 1999, Pleistocene Glaciation in the Upper Platte River Drainage Basin, Colorado. U.S. Geological Survey. Geologic Investigations Series I-2644.
- Manage, Maria A., 1992, Heavy Minerals in Colour. Ed. Heinz F. W. Maurer. United Kingdom: Chapman & Hall : London, United Kingdom.
- Oliva, Priscia, et al., 2004, The Role of Trace Minerals in Chemical Weathering in a High-Elevation Granitic Watershed (Estibère, France): Chemical and Mineralogical Evidence." *Geochimica et Cosmochimica Acta*, 68.10, 2223-43.
- Penn, C.J., 2005, Mineralogy in relation to phosphorus sorption and dissolved phosphorus losses in runoff: *Soil Science Society of America Journal*, v. 69, p. 1532-1540.
- Tarafdar J.C. Classen N., 1988, Organic Phosphorus Compounds as a Phosphorus Source for Higher Plants through the Activity of Phosphates Produced by Pant Roots and Microorganisms." *Biol Fertil Soils* 5.
- Taunton, Anne E., 2000, Microbial Controls on Phosphate and Lanthanide Distributions during Granite Weathering and Soil Formation. Ed. Susan A. Welch and Jillian F. Banfield. Vol. 169. Netherlands: Elsevier : Amsterdam, Netherlands.
- Welch, S. A., 2002, Effect of Microorganisms and Microbial Metabolites on Apatite Dissolution. Ed. A. E. Taunton and J. F. Banfield. Vol. 19. United Kingdom: Taylor & Francis : London, United Kingdom.