

Report as of FY2007 for 2006MT89B: "Carbon cycling and the temporal variability in the concentration and stable carbon isotope composition of dissolved inorganic and organic carbon in streams"

Publications

Project 2006MT89B has resulted in no reported publications as of FY2007.

Report Follows

Title: Identifying and characterizing sources of dissolved organic carbon in the Big Hole and Clark Fork Rivers, a continued investigation

PI: Stephen Parker Ph.D., Associate Professor, Department of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT

Co-PI: Douglas Cameron, Ph.D., Professor, Department of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT

Project Type: Biogeochemical research into the cycling of carbon between DOC and DIC pools using carbon stable isotopes.

Focus Category: Geoche, Hydgeo, WQL.

Research category: Hydrological processes

Keywords: Dissolved organic carbon, dissolved inorganic carbon, carbon isotopes, diel, biogeochemistry

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End date: Feb. 28, 2008

PI: Stephen Parker Ph.D., Associate Professor, Department of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT, sparker@mtech.edu, 406-496-4185 (office), 406-496-4135 (FAX), website: <http://www.mtech.edu/chem/faculty/Parker/parker.htm>

Co-PI: Douglas Cameron, Ph.D., Professor, Department of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT, dcameron@mtech.edu, 406-496-4247.

Congressional district: at large

Abstract:

Recent work has identified daily concentration cycles in dissolved organic (DOC) and inorganic carbon (DIC) in the Clark Fork (CFR) and Big Hole (BHR) Rivers in Montana¹. The DOC in the two rivers showed inverse temporal patterns suggesting that very different mechanisms control the processes in these two rivers. Preliminary study using an isolation chamber on the BHR suggested that the large nighttime increase in DOC observed may have been due to groundwater influx through benthic sediments associated with the daily evapotranspiration cycle. The stable C-isotope composition of the DIC was also investigated. The $\delta^{13}\text{C}$ -DIC in both the CFR and BHR showed the patterns expected for DIC that is influenced primarily by photosynthesis and respiration.

¹ Smith, M. G., Parker, S. R., Cameron, D. C., Abstract, Montana AWRA meeting, Oct. 2006.

This proposal outlines work to further test the reproducibility of the observed diel cycles in DIC and DOC. Also, the work described will help define the sources and causes of these daily DOC changes using additional laboratory and field experiments. Furthermore, the project will attempt to identify the types and molecular-weight distributions of organic compounds that make-up the DOC using Liquid Chromatography-Mass Spectrometry (LC-MS) analysis.

Title: Identifying and characterizing sources of dissolved organic carbon in the Big Hole and Clark Fork Rivers, a continued investigation.

Problem statement:

Recent investigations of this research group, which have been funded by the Water Resources Research Program (USGS, 104(b)), have identified diel concentration cycles in dissolved organic and inorganic carbon (DOC & DIC) in the Clark Fork (CFR, Fig. 1) and Big Hole (BHR, Fig. 2) Rivers in Montana. In the CFR the diel changes in DIC are well correlated with the daytime removal of CO₂ by photosynthesis and the nighttime increase from respiration (Parker et al., 2005). The DOC concentrations were low and showed an increase during the day and a decrease at night (Fig. 1).

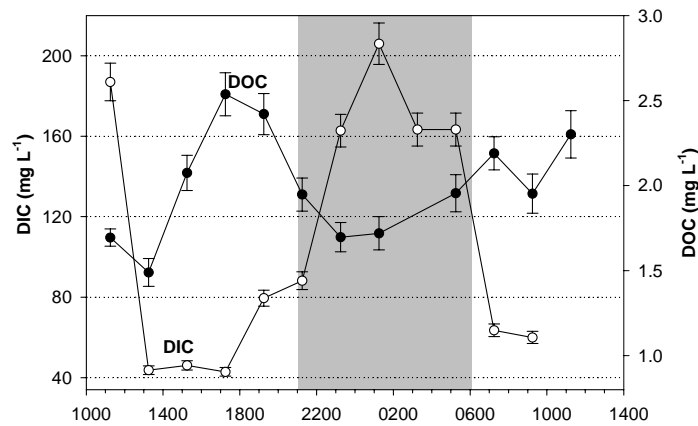


Figure 1: DIC & DOC in the Clark Fork River, July, 2006. Time is shown on the horizontal axis and the shaded area represents night time.

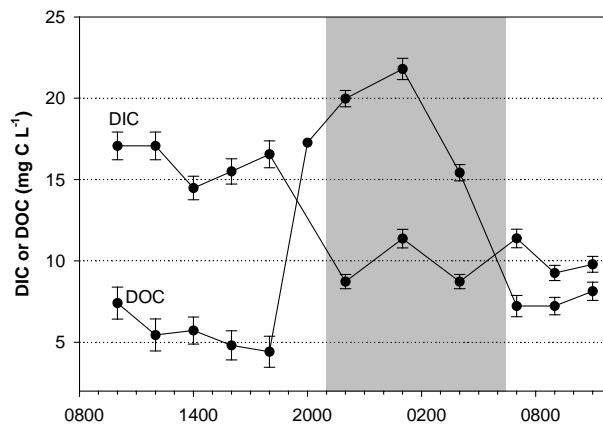


Figure 2: DIC & DOC in the Big Hole River, Aug. 2006.

During the day plants and algae are known to exude (“leak”) carbon compounds being produced during photosynthesis (Falkowski & Raven, 1997; Ziegler and Fogel, 2003). These reduced organics and others produced by microbial degradation of detritus are known to be the

single most important forms of reduced carbon in streams available to heterotrophic microorganisms as an energy source (Volk et al., 1997).

DOC in the BHR showed the inverse temporal pattern (to that of the CFR) with a significant concentration increase at night while the DIC did not follow the “typical” relationship normally associated with highly productive rivers and streams (as seen in Fig. 1). These two dramatically different outcomes emphasize the need for a more thorough understanding of how carbon compounds are produced and consumed within aquatic systems. Additionally, the types and concentration of the DOC can have a significant influence on the chemical composition of surface waters (McKnight et al., 1997).

This proposal adds two new components to the on-going study. 1) Shallow groundwater and hyporheic water in the vicinity of the rivers will be sampled using piezometers to attempt to identify the groundwater contribution of carbon to the river. 2) Liquid chromatography-mass spectrometry will be used to identify the types and mass distributions of DOC found in the CFR and BHR.

In summary, this proposal outlines work to better define the sources and causes of these daily DOC and DIC changes as well as attaining a better understanding mechanistically of the differences between the CFR and BHR carbon dynamics. Additionally, the project will attempt to identify the types of organic compounds that make-up the DOC, the molecular weight distributions of the material that make up the DOC, and how type and distribution vary with time. Knowing the types of organics will help to better determine the sources within the river system.

The distinctly different dynamics detailed above between the BHR and CFR underscore the need for a better understanding of how different river systems function. The outcomes of this project will be important to researchers and water managers investigating energetics and dynamics of hydrological systems.

Results and benefits statement:

This proposal will expand the previous investigations by looking for a connection between organic and inorganic carbon in the local shallow groundwater with respect to those compounds found in the rivers. Rivers are dynamic, “living” systems that are an integral component of the global hydrological network and there is a need for a better fundamental understanding of the science of how rivers and other hydrological systems function.

The details from the first parts of this investigation outlined above (problem statement) have shown that two rivers in close proximity to each other have very different behaviors in terms of the diel concentration cycles of carbon compounds that are critical to the ecological function of the lotic system as a whole. By gaining a better understanding of the factors contributing to these differences in diel carbon cycles, an improved insight will be provided into the subtlety of the biogeochemical cycling of carbon compounds in streams.

Nature, scope and objectives of project:

Background: Diel (aka: diurnal) processes in surface waters are regular, dynamic, changes in physical and biogeochemical parameters that occur over 24-h periods. Investigations over the past 16 years have shown that diel changes in the concentration of chemical species in flowing systems are robust, reproducible processes that play an integral role in the health and water quality of river systems (e.g., Fuller and Davis 1989; Bourq and Bertin 1996; Brick and Moore

1996; Sullivan et al. 1998; Nimick et al. 2003, 2005; Jones et al. 2004; Gammons et al. 2005; Parker et al., 2005, in press). The diel variations are driven by the normal photoperiod, which influences: photosynthesis and respiration of aquatic organisms; daily instream temperature cycles; daily changes in dissolved gas gradients between air and water; and affects either directly or indirectly a variety of other photo-catalytic processes (e.g., photo-reduction of metals; Mn, Sunda et al. 1983; Sunda and Huntsman 1994; Fe, McKnight et al., 1988; McKnight and Bencala 1988; Sullivan et al., 1998; Gammons et al., 2005). Healthy river systems can exhibit large diel pH, O₂ and CO₂ cycles that are largely driven by photosynthetic aquatic plants and algae. Typically, this results in the net production of O₂ during the daytime while at night the reverse process happens (net production of CO₂) when respiration is operating in the absence of photosynthesis (Odum 1956; Pogue and Anderson, 1994; Nagorski et al., 2003).

Recent work by this research group has investigated the diel changes in the concentration of DOC and DIC in two rivers as discussed in the problem statement. This work is currently in progress and includes the analysis of the carbon stable isotope composition of inorganic ($\delta^{13}\text{C}$ -DIC) and organic carbon ($\delta^{13}\text{C}$ -DOC) compounds. Additionally, the concentration of dissolved and particulate phase metals is being determined. DOC is known to complex dissolved metals and the relationship between these organic compounds and transport needs to be better understood.

First objective: The first component of this project continuation would be to: 1) conduct additional diel samplings on both the CFR and BHR to determine if the observed changes in DOC and DIC are reproducible, 2) use an isolation (flux) chamber (Fig. 3) to determine if the DOC and DIC changes are produced by instream processes or from groundwater influx, and 3) use stream-side piezometers as sampling sites to measure groundwater levels, chemical composition, isotope composition and types of DOC and DIC.

One important part of investigating and measuring diel changes in the concentration of a variety of analytes has been to show that these processes are robust and reproducible on a year to year scale. This question is important with respect to DOC since there is little published literature that discusses short term (diel) temporal changes in organic carbon.



Figure 3: One of the isolation (flux) chambers used in the BHR. Tubing is connected to a streamside peristaltic pump. Conductivity, dissolved oxygen and pH probes are inserted into the chamber and it is filled with small rocks and periphyton.

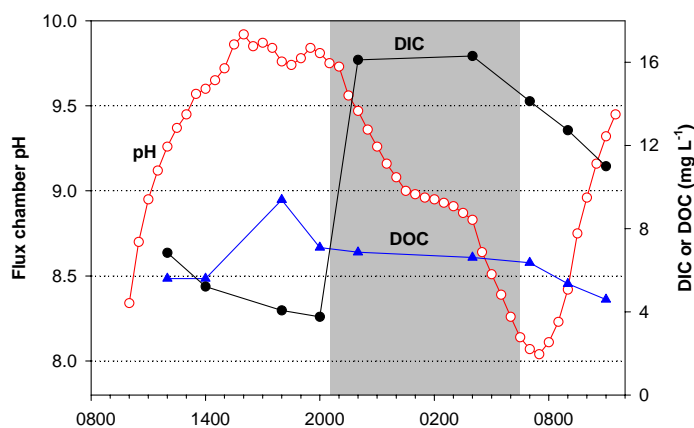


Figure 4: pH, DIC and DOC in the isolation chamber in the Big Hole River, Aug. 2006.

Secondly, the origin of the DOC is important to understand. Groundwater influx through benthic sediments may be an important source of carbon to streams. So, a component of this study will be to use isolation chambers to better separate the effects of instream process versus those produced by groundwater contributions. The isolation chambers (Fig. 3) that we have been using are constructed out of clear acrylic plastic and are filled with small river cobbles with attached periphyton. The chambers (and connecting tubing) are submerged in the river so that they are temperature equilibrated and receive approximately the same light as the river bottom. During the sampling experiments the chambers are continuously mixed with a small peristaltic pump that circulates the enclosed water. This method was used at the BHR site in Aug. 2006. A normal diel cycle of pH and DIC was observed in the chamber (Fig. 4). At the same time little change in DOC was observed when compared to river (Fig. 2). This suggests that the large increase overnight observed in the BHR may be due to groundwater influx not instream processes. An isolation chamber was not used in the CFR sampling for organic carbon and would be included in the continued investigation.

In this proposed continuation of the current study we want to better assess the question of groundwater versus instream processes in terms of organic carbon contributions by using streamside piezometers² at both the CFR and BHR sites. Water level in the piezometers versus the stream would be monitored over the diel sampling period. This would provide a measure of the direction of flow between surface and groundwater. Additionally, the piezometers would provide a sampling point to shallow groundwater in the vicinity of the river. Both groundwater and river water would be sampled for the same parameters which would allow a better comparison of the relative contributions of DOC and DIC from both sources. Another field technique that will be used to help determined the DOC concentrations, and whether there are changes in the types of organics present is UV-VIS spectrometry. A portable, fiber optic spectrometer would be used to take hourly scans across the UV-VIS spectrum and note any changes in total absorption and also the wave lengths of absorption. Many naturally occurring soluble organic species such as fulvic acids have characteristic absorption spectra which could be monitored over the sampling period. Purchase of this spectrometer is included in the project budget.

² A piezometer is a small diameter water well used to measure the hydraulic head of groundwater in aquifers.

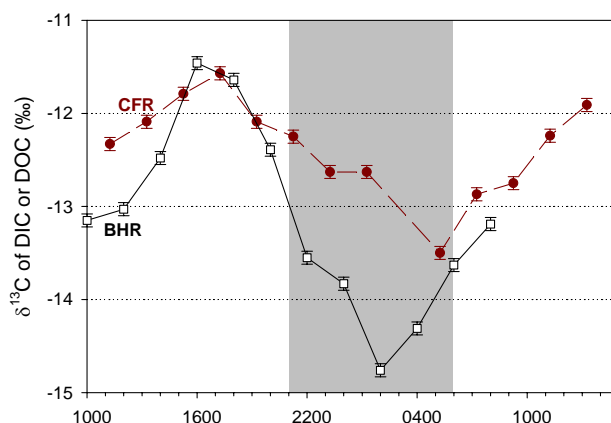


Figure 5: $\delta^{13}\text{C}$ -DIC from the CFR and BHR, summer 2006. [Note: the samples for analysis of $\delta^{13}\text{C}$ -DOC have been sent to the lab but the results were not available at the time of submission of this proposal (11/20/06).]

Second objective: Laboratory work using Liquid Chromatography coupled with a Mass Spectrometer (LC-MS) would be performed to identify, where possible, individual compounds as well as the molecular weight distribution and classes of organics present throughout the diel cycle. For uncontaminated natural waters, the bulk of the DOC is typically natural organic matter. Low molecular weight and hydrophilic organic compounds such as free amino acids, simple carboxylic acids, carbohydrates and some hydrocarbons are common components of natural organic matter (NOM) in natural waters (Macalady, 1998) and can be identified as individual compounds. Operationally defined classes of NOM; fulvic, humic, and hydrophilic acids typically make up the bulk of aquatic NOM. Individual compounds within these classes are difficult to identify; however, molecular weight profiles can be used to study changes in composition and concentration. The Bruker LC/MS instrument at Montana Tech has the capability for MS/MS analyses. Consequently, it will be possible to look for changes in some functional group composition of the NOM in the molecular weight profiles. Questions that would be addressed include: 1) can individual organic compounds be identified? 2) Does the composition of DOC change throughout the diel period? 3) Is there a change over the diel period in terms of the classes of organics based on the mass? And, 4) what is the relationship of the ^{13}C composition of the organics to the types and masses found? The first stages of this project include investigating the C-stable isotope composition of the DIC and DOC in samples already collected (Fig. 5). These results are particularly interesting since Fig. 2 showed that the total concentration of DIC in the BHR did not change significantly over the diel period but the $\delta^{13}\text{C}$ -DIC shows the normal isotope composition change expected as a result of the influence of photosynthesis and respiration.

Timeline:

	2007			2008	
	May-June	July-Aug	Sep-Dec.	Jan-Apr.	Oct
LC-MS analysis (2006 samples)					
Peizometer installation					
Field measurements, sample collection					
LC-MS analysis (2007 samples)					
Analysis of results					
Presentation of results					

Methods, procedures and facilities:

The PI (in conjunction with collaborators) has conducted 17 diel sampling experiments on eleven different streams (on three continents) in the past five years including the BHR and the CFR. Methods for collecting water samples to examine concentrations of dissolved inorganic carbon as well as dissolved and total metals concentrations have been detailed in Gammons et al. (2005) and Parker et al. (2005).

Samples for DIC, DOC, $\delta^{13}\text{C}$ -DIC and $\delta^{13}\text{C}$ -DOC analysis will be collected in the field in acid washed, oven dried, glass bottles. Preparation and analysis for $\delta^{13}\text{C}$ -DOC will follow the methods detailed by Gandhi et al. (2004). All stable isotope analyses will be performed by Dr. Simon Poulson at the University of Nevada-Reno. The PI on this proposal has worked collaboratively on several projects previously with Dr. Poulson.

All DIC and DOC analysis will be performed at Montana Tech by the student supported through this project. The Department of Chemistry and Geochemistry has an Ionics (Model 1505) Total Carbon Analyzer that will be used for all samples collected for this project.

Diel field experiments will include hourly samples collected over a 24-h period for the determination of the concentration of DOC and DIC as well as $\delta^{13}\text{C}$ -DIC, δD -H₂O, $\delta^{18}\text{O}$ -H₂O, and $\delta^{13}\text{C}$ -DOC. All field sites will also have *in situ* datasondes for measurement of pH, temperature, specific conductivity, photosynthetically active radiation and other pertinent parameters. The datasondes will be deployed for at least 24-hours before and after the diel sampling experiment to monitor the reproducibility of the observed chemical cycles. The CFR and BHR sampling sites are adjacent to USGS gaging stations which provide accurate streamflow data at 15 minute intervals. Additionally, seasonal sampling over the funding period covered by this proposal would be conducted to establish a range of values for the measured parameters over a year-long time period.

Piezometer transects would be used to determine the groundwater levels in the sampling area with respect to river level. The piezometers are also needed to characterize the chemistry of shallow groundwater, as well as hybrid waters in the hyporheic zone. Nested piezometers may be used to evaluate vertical head gradients in the vicinity of creek beds, and therefore the gaining or losing characteristics of the stream. At the end of the project, the piezometers can be left in place for long-term monitoring, or removed.

All piezometer waters and surface waters will be analyzed in the field for temperature (T), pH, Eh, dissolved oxygen (DO), specific conductivity (SC) and alkalinity. Analyses of groundwater samples will employ a peristaltic pump connected to a low-volume flow cell, to prevent contamination from air. The sample will be pumped until key parameters measured in the flow cell stabilize (e.g., pH, DO, Eh, T). [These data will be used to map spatial and temporal

gradients.] Once the water chemistry in the flow cell stabilizes as described above, samples will be collected for $\delta\text{D-H}_2\text{O}$, $\delta^{18}\text{O-H}_2\text{O}$, $\delta^{13}\text{C-DIC}$, $\delta^{13}\text{C-DOC}$, $\delta^{18}\text{O-DO}$ and ICP analysis for metals. The use of stable isotopes is an important tool for investigating the dynamic connection of the ground water-surface water system.

All LC-MS analysis will be performed at Montana Tech using the Bruker Datonics, Esquire 4000 Liquid Chromatograph-Mass Spectrometer. The co-PI (Cameron) is an experienced analytical chemist with background in using the LC-MS for identification of organic compounds. Extraction of the dissolved organic matter and separation into various compound classes will be accomplished using standard column separation procedures for DOC (Macalady, 1998). LC/MS analyses will be done using both atmospheric pressure chemical ionization (APCI) and electrospray ionization (ESI). Where possible individual compounds will be identified using reference compounds and the corresponding retention times and mass spectra. When reference compounds are not available, comparisons to literature spectra or interpretation of the MS and MS/MS spectra will be used for tentative identifications.

- **Laboratory:** The PI shares a well equipped laboratory at Montana Tech with Dr. Christopher Gammons (Dept. of Geological Engineering, Montana Tech). The space is approximately 1000 sq. ft. and has facilities for preparative work and wet chemical analysis. The co-PI also has similar laboratory space at Montana Tech. The Montana Tech Chemistry & Geochemistry Dept. also has an analytical facility that has the following instrumentation: ICP-AES, AAS, GF-AAS, IR and FTIR spectrometer, UV-VIS spectrometer, Raman spectrometer, 300 MHz NMR, LC-MS, TOC analyzer, Ion Chromatograph.
- **Computer:** The PI has an office computer for writing and data analysis as well as a laptop computer for field work.
- **Office:** The PI has adequate office space with access to printers, photocopiers and scanners.
- **Other:** Field equipment includes (shared with C. Gammons): Peristaltic pump and in-line filtration system, Hach portable spectrometer, portable fluorimeter, Troll 9000 DataSonde, Hydrolab 3 DataSonde, Hydrolab mini-sonde, WTW portable multi-probe system, Marsh-McBirney current flow meter.

Related Research (References):

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- Fuller, C.C., Davis, J.A., 1989. Influence of coupling of sorption and photosynthetic processes on trace element cycles in natural waters, *Nature*, **340**, 52-54.
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- Parker, S. R., Poulson, S. R., Gammons, C. H., DeGrandpre, M. D., 2005. Biogeochemical Controls on Diel Cycling of Stable Isotopes of Dissolved O_2 and Dissolved Inorganic

Carbon in the Big Hole River, Montana, *Env. Sci. Technol.*, 39(18), 7134-7140, DOI: 10.1021/es0505595.

Parker, S. R., Gammons, C. H., Jones, C.A., Nimick, D.A., in press. Role of hydrous iron oxide formation in attenuation and diel cycling of dissolved trace metals in a stream affected by acid rock drainage. accepted, *Air, Water, Soil Pollution*.

Pogue, T.R. , Anderson, C.W., 1994. Processes Controlling Dissolved Oxygen and pH in the Upper Willamette River Basin. U.S. Geol. Surv. Water-Resources Investigations Report 95-4205.

Sullivan A. B., Drever J. I., McKnight D. M., 1998. Diel variation in element concentrations, Peru Creek, Summit County, Colorado. *J. Geochem. Explor.* **64**, 141-145.

Sunda W.G. Huntsman & S.A. Harvey G.R. (1983) Photoreduction of manganese oxides in seawater and its geochemical and biological implications. *Nature*, 301, 234-236.

Sunda W. G. & Huntsman S. A. (1994) Photoreduction of manganese oxides. *Marine Chem.* 46, 133-152.

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Training potential:

This project would provide continued support for an undergraduate student from Montana Tech for assistance with both field and laboratory work. The student that has been working on the previously funded parts of this project is currently a sophomore who is interested in continuing into this next phase. He recently presented his results at the AWRA meeting in Polson, MT (Smith, M.G., Parker, S.R., Cameron, D.: Preliminary investigations of temporal variability in the concentration and composition of DIC and DOC in streams, MT-AWRA, Oct. 13, 2006). This student would continue to receive background and training in field techniques. Additionally, he would be trained to run the LC-MS for analysis of the types of DOC in river samples. He would continue to be involved in the analysis of the results and data as well as presenting these results at the undergraduate research symposium held at Montana Tech each year and at another appropriate state or regional conference. The student would also be involved in manuscript preparation for eventual publication.

PI-Parker has recently (2005) completed a Ph.D. in Environmental Chemistry with The University of Montana-Missoula working in the area of riverine biogeochemistry. The doctoral work included studies to better understand the diel processes involved in both carbon cycling and the mobilization and transport of metals in streams. Funds provided for the project described in this proposal will allow the PI to continue establishing an independent research program dealing with scientific issues surrounding Montana's rivers

Biographical Sketch: (PI) Stephen R. Parker:

(i) Professional preparation:

Hope College, B.A., Chemistry, June 1970.

Indiana University, M.S., Biochemistry, August 1972.

University of Montana, Ph.D., Environmental Chemistry, July 2005.

(ii) Appointments:

1) 2006-present, Associate Professor, Dept. of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT.

2) 2001 to 2005, Assistant Professor, Dept. of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT.

3) 1988 to 2001, Laboratory Director and Adjunct Instructor, Dept. of Chemistry and Geochemistry, Montana Tech of The University of Montana, Butte, MT.

(iii) Recent publications

1) Parker, S. R., Gammons, C. H., Jones, C.A., (in press). Role of hydrous iron oxide formation in attenuation and diel cycling of dissolved trace metals in a stream affected by acid rock drainage, *Water, Air, Soil Poll.*

2) Nimick, D.A., McCleskey, R. B., Gammons, C.H., Cleasby, T.H., & Parker, S.R., (in press) Diel Mercury-Concentration Cycles in Streams Affected by Mining and Geothermal Discharge. *Sci. of the Total Env.*

3) Wood S. A., Gammons C. H., Parker S. R., The behavior of REE in naturally and anthropogenically acidified waters. *Journal of Alloys and Compounds* 418, 161-165 (2006), DOI:10.1016/j.jallcom.2005.07.082.

4) Parker, S. R., Poulson, S. R., Gammons, C. H., Biogeochemical Controls on Diel Cycling of Stable Isotopes of Dissolved O₂ and Dissolved Inorganic Carbon in the Big Hole River, Montana, *Environmental Science and Technology*, 39(18), 7134-7140, (2005), DOI: 10.1021/es0505595

5) Gammons, C.H., Nimick, D.A., Parker, S.R., Cleasby, T.E., McClesky, R.B., Diel behavior of iron and copper in a mountain stream with acidic to neutral pH: Fisher Creek, MT, USA. *Geochim. Cosmochim. Acta*, 69(10), 2505-2516, (2005), DOI:10.1016/j.gca.2004.11.020.

6) Parker, S.R., Gammons, C. H., Pedrozo, F.L., Wood S. A., (in review) Diel changes in metal concentrations in a geogenically acidic river: Rio Agrio, Argentina. [submitted to *J. Volcanology & Geothermal Res.*]

7) Parker, S. R., Gammons, C. H., Poulson, S. R., DeGrandpre, M. D., (in review). Diel changes in stable carbon isotope ratios and trace element concentrations in the Clark Fork River, MT. [submitted to *App. Geochem.*]

(iv) Recent meetings and presentations:

1) American Water Resources Association (Montana Section), Polson, MT, October 2006, Diel iron behavior in the hyper-acidic waters of the Rio Tinto and Rio Odiel, Andalusia, Spain., Parker, S.R., Gammons, C.H., Nimick, D.A., Snyder, D.

2) Goldschmidt Conference, Moscow, ID., May 2005. Diel cycles in stable isotopic composition of dissolved O₂ and DIC in a river due to biogeochemical processes, Stephen R. Parker, Simon R. Poulson, Christopher H. Gammons, Michael D. DeGrandpre.

3) American Geophysical Union, San Francisco, Dec. 2004, Diel changes in stable carbon isotope ratios and trace element concentrations in the Clark Fork River, MT.

(v) Recent research funding sources:

1) Mine Waste Technology Program (EPA), \$70,000, The role of biogeochemical processes affecting the flux of metals to and from sediments in mining impacted streams, awarded Sep. 2006.

2) USGS 104(b) (Montana Water Center), \$14,646, Carbon cycling and the temporal variability in the concentration and stable carbon isotope composition of dissolved inorganic and organic carbon in streams, awarded Jan. 2006.

Biographical Sketch: (co-PI) Douglas Cameron**Academic Rank:** Professor**Degrees:** Ph.D. Analytical Chemistry, Purdue University, 1979
M.S. Analytical Chemistry, Purdue University, 1978
B.S. Chemistry, Montana State University, 1975**Related Experience:**

- 8/2005 to present. **Department Head** in the Chemistry and Geochemistry Department and Pre-Professional Health Studies at Montana Tech of the University of Montana.
- 8/1999 to present. **Professor** in the Chemistry and Geochemistry Department at Montana Tech of the University of Montana.
- 8/1993 – 8/1999. **Associate Professor** in the Chemistry and Geochemistry Department at Montana Tech of the University of Montana.
- 8/1990 – 8/1993. **Assistant Professor** in the Chemistry and Geochemistry Department at Montana College of Mineral Science and Technology.

Recent Publications:

- 1) Cameron, D.; Willett, M.; Hammer, L., "Distribution of Organic Carbon in the Berkeley Pit Lake, Butte, Montana," *Mine Water and the Environment*, 2006, 25(2), 93-99.
- 2) Cameron, D.; Willett, M.; Hieb, A., "Berkeley Pit Lake - Organic Carbon Remediation Potential," *Mine Waste Technology Program Activity IV, Project 16, Interagency Agreement between the Department of Energy and the U. S. Environmental Protection Agency, DE-AC22-88ID12735, Butte, MT, accepted.*
- 3) Cameron, D.; Willett, M., "Organic Carbon in Berkeley Pit Sediments," *Mine Waste Technology Program Activity IV, Project 11, Interagency Agreement between the Department of Energy and the U. S. Environmental Protection Agency, DE-AC22-88ID12735, Butte, MT, April 2005.*
- 4) Cameron, D., "Characterization, Remediation, and Resource Recovery: the Berkeley Pit and the Mine Waste Technology Program," *Interagency Agreement between the Department of Energy and the U. S. Environmental Protection Agency, DE-AC22-88ID12735, Butte, MT, October 2003.*

Recent Meetings and Presentations:

- 1) Cameron, D.; (Johnson) Brown, N., "Characterization of Dissolved Organic Carbon in Berkeley Pit Lake Water Using Stirred-Cell Ultrafiltration and Spectroscopic Analysis," *Pit Lakes 2004, Reno, NV, November 16-18, 2004.*
- 2) Cameron, D.; "Teaching Problem Solving in Chemistry - An Example to Stimulate Discussion," *Confchem On-Line Conference "Problem Solving in Chemistry", <http://www.ched-ccce.org/confchem/>, June 2002.*
- 3) Cameron, D.; Willett, M., "An Investigation into the Effects of Organic Amendments on Berkeley Pit Lake Water Quality Under Various Environmental Conditions," *2000 Conference on Hazardous Waste Research, Denver, Colorado, May 23-25, 2000.*
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