Characterization of Carbonate Sources in the Large Closed Basin Lake System of Lago Sarmiento

Introduction

Paleoclimate reconstruction is a science that cannot create laboratory experiments to test hypotheses. Instead, scientists must utilize the "tracer toolbox" to reconstruct past climate. The study of Holocene climate is one of the key methods that climatologists use to understand modern climate, and the mechanisms that can bring about change to the system.

Paleoclimatology of the Holocene has been a robust field of research in recent years, yet there are few climate records of the southern sub polar region, as useful marine archives are rare and the only landmass at these latitudes is the southern tip of South America. This Patagonian region holds the keys to understanding many influential climate phenomena.

On a large scale, we are interested in reconstructing westerly wind strength throughout the Holocene. The southern westerlies are the most energetic and consistent winds on Earth. They drive upwelling of CO_2-rich water in the Southern Ocean, and profoundly influence the ocean-atmosphere carbon balance. Any shift in the position or strength of the westerlies has the potential to shift the Southern Ocean from a net-carbon sink to source or visa versa (Anderson et al., 2009; Hodgson & Sime, 2010; Lamy et al., 2010).

While there have been studies of westerly wind variation in the southern hemisphere, a range of confounding factors has hindered development of high quality climate reconstructions of the region. Previous studies show great variation, and even opposing results. This reflects complicated westerly wind relationships due to rain shadows created by the Andes in field sites located too far east, discontinuous or short archives, complex or little understood paleoclimate proxies, and inadequate dating methods (Moy et al., 2011). Learning from the difficulties of these studies, we will develop a robust and welldated Holocene chronology of past variability in rainfall, westerly wind intensity, water balance, and temperature from southwestern Patagonia.

Our study will take place in three sedimentary basins: Lago Sarmiento (51°S, 72.5°W), Lago del Toro (51°S, 72.8°W), and the adjacent marine fjords. These three sites have been chosen because their different environments allow for innovative use of different tracers such as C/N ratios to determine productivity, $\delta^{18}O$ in carbonates to determine evaporation/precipitation ratios, as well as other isotopic analyses all to reconstruct variations in westerly wind location and intensity throughout the Holocene.

By combining isotopic data from these three adjacent systems, we can construct a more accurate picture of the southern hemisphere paleoclimate. However, Lago Sarmiento is our main focus as it is a large, closed-basin lake and will provide the most information on westerly wind intensity. Large, closed basin lakes are rare at high latitudes, yet well suited for paleoclimate studies. In a closed system, all water loss is due to evaporation.

The preferential evaporation of ^{16}O relative to ^{18}O allows for construction of accurate evaporation/precipitation ratios by analyzing **δ**^{18}O of lake sediments. Evaporation and precipitation rates are inherently linked to many interesting factors such as temperature and westerly wind strength (Leng & Marshall, 2004).Thus, by analyzing sediment cores extruded from Lago Sarmiento, we will be able to reconstruct westerly wind strength and temperature in Patagonia throughout the Holocene.

Research Objectives:

My role in this project will be to characterize the source of carbonates in this lake system and to develop an initial numerical regional water balance model. The current working assumption is that all carbonate in Lago Sarmiento comes from the calciferous cyanobacteria Rivularia, which forms large bioherm deposits along the shoreline (Solari et al., 2010) (Moy et al., 2008). While the Rivularia surely contribute carbonate to the system, we are unsure whether carbonate may also come from inorganic precipitation as well.

Analysis of carbonate sources and water balance issues will take two forms. For five weeks prior to studies in the field, we will work to create a basin-scale hydrologic-energy balance model of the Sarmiento basin. This will seek to emulate the model created by Harry Rowe and Rob Dunbar for Lake Titicaca in Bolivia, another large closed basin lake system (Rowe & Dunbar, 2004). This will serve to provide a greater understanding of the hydrologic balance of the region, and inform what modern climatological, hydrological, and hypsographic observational data is still needed for a complete model.

During our five-week segment in the field, we will collect drill cores from the bioherm deposits and short gravity cores of lakebed sediment. Upon returning from the field, we will date the sediment using radiocarbon and uranium-series dating methods. After dating we will analyze the cores at the Stanford Stable Isotope Biogeochemistry Laboratory (SIBL) to conduct isotopic analysis. We will analyze **δ**^{18}O and **δ**^{13}C from carbonates in the lakebed sediment to compare with **δ**^{18}O and **δ**^{13}C from the bioherm cores. If the values are the same during similar time periods, carbonate in Lago Sarmiento is likely biogenic in origin. If the bioherm cores show variation it will imply that the sedimentary carbonate may be coming from inorganic sources.

By itself this is an interesting and relevant question, but knowing carbonate sources plays a significant role in the larger scope of research on Lago Sarmiento and paleoclimate modeling of the southern hemisphere as a whole. Biogenic carbonate has different **δ**^{18}O and $\delta^{13}C$ values compared with inorganic carbonate. Inorganic carbonate precipitates in thermodynamic equilibrium with lake-water. However, biogenic carbonate producers often have vital effects, slight offsets of carbonate precipitation from thermodynamic equilibrium. If the carbonate source of lake sediment is unknown, then the vital effect offset from biogenic carbonates could lead to error. Assuming that bulk carbonates collected from sediment are of one source can be misleading, as they are often comprised of both inorganic and biogenic fractions. Without knowing the source of carbonates in the system, we may set an improper baseline for analysis of climate related isotopic signatures (Ito, 2002).

Methods

Modeling:
To construct a model of the Sarmiento hydrologic basin we will use the STELLA systems modeling software. Here we will use data from previous studies of the Lago Sarmiento basin, compiling records of precipitation, temperature, water inflow rates, and isotopic values of various inputs, and other factors to create a model of the hydrologic balance of the system. Studying hydrology of the region in detail will greatly increase understanding of the system prior to the field study component. Also, creation of a numerical model would allow us to input past climate parameters and observe how the region responds.

Coring:
To obtain lakebed sediments we will use a gravity corer to obtain short cores. This will fit perfectly with our planned research as we intend to use a gravity corer as a tripping mechanism for our longer piston corer. Thus each time we take longer core samples, we will obtain gravity cores as well. For the bioherms we will use a rotary diamond coring system to obtain samples. We will take multiple samples to ensure consistency.

Dating:
Accurate dating is of utmost importance to the project. We will use AMS radiocarbon dating and uranium-series dating methods, as well as the existing tephrochronology if the cores show evidence of volcanic activity (Stern, 2007). Radiocarbon dating will take place at the Lawrence Livermore National Laboratory (LLNL) Center for Accelerator Mass Spectroscopy (CAMS), and uranium-series dating will be conducted with Professor Kate Maher's lab in the GES department. We will work to establish a chronostratigraphic correlation between the bioherm and sediment cores. Without proper dating, variance in $\delta^{18}O$ and $\delta^{13}C$ between the bioherms and the sediments could be due to varying environmental factors during different time periods rather than varying carbonate sources.

Stable Isotope Analysis:
Professor Dunbar's lab (SIBL) is one of the best in the world at analyzing isotopic signatures of sediment and carbonates. During the year following the fieldwork, we will follow established methods for quantifying $\boldsymbol{\delta}18O$ and $\boldsymbol{\delta}13C$ of the samples. For 5 weeks prior to the field studies, I will gain experience and familiarity with the system by analyzing previous cores from Southern Patagonia collected on previous expeditions.

Tentative Work Plan:
June 24-July 20:
Construction of a hydrologic basin scale model of the Lago Sarmiento system.
Analysis of lakebed sediment cores from Southern Patagonia to gain familiarity and knowledge of the paleolimnology, and methods of isotopic analysis.

July 20-Early September:
Expedition to Southern Patagonia to collect samples from Lago Sarmiento, Lago del Toro, and the adjacent marine fjords.

2012-2013 Academic Year:
Dating of samples (radiocarbon, uranium series)
Stable isotope analysis ($\delta^{18}O$, $\delta^{13}C$)
Analysis and interpretation of data

Tentative Budget:
Funding from this project will be provided from Professor Dunbar's NSF grant, as well as potential funding from the SESUR program.
Stipend: $7000 for 10 weeks

Sources
Anderson, R., Ali, S., Bradtmiller, L., Nielsen, S., Fleisher, M., Anderson, B., & Burckle, L. (2009). Wind-driven upwelling in the Southern Ocean and the deglacial rise in atmospheric CO2. Science (New York, N.Y.), 323(5920), 1443. American Association for the Advancement of Science.

Hodgson, D. A., & Sime, L. C. (2010). Palaeoclimate: Southern westerlies and CO2. Nature Publishing Group, 3(10), 666–667. Nature Publishing Group. doi:10.1038/ngeo970

Ito, E. (2002). Application Of Stable Isotope Techniquesto Inorganic And Biogenic Carbonates. Tracking environmental change using lake sediments, 351–371. Springer.

Lamy, F., Kilian, R., Arz, H. W., Francois, J.-P., Kaiser, J., Prange, M., & Steinke, T. (2010). Holocene changes in the position and intensity of the southern westerly wind belt. Nature Publishing Group, 3(10), 695–699. Nature Publishing Group. doi:10.1038/ngeo959

Leng, M. J., & Marshall, J. D. (2004). Palaeoclimate interpretation of stable isotope data from lake sediment archives. Quaternary Science Reviews, 23(7-8), 811–831. doi:10.1016/j.quascirev.2003.06.012

Moy, C. M., Dunbar, R. B., Guilderson, T. P., Waldmann, N., Mucciarone, D. A., Recasens, C., Ariztegui, D., et al. (2011). A geochemical and sedimentary record of high southern latitude Holocene climate evolution from Lago Fagnano, Tierra del Fuego. Earth and Planetary Science Letters, 302(1-2), 1–13. Elsevier B.V. doi:10.1016/j.epsl.2010.11.011

Moy, C. M., Dunbar, R. B., Moreno, P. I., Francois, J.-P., Villa-Martínez, R., Mucciarone, D. M., Guilderson, T. P., et al. (2008). Isotopic evidence for hydrologic change related to the westerlies in SW Patagonia, Chile, during the last millennium. Quaternary Science Reviews, 27(13-14), 1335–1349. doi:10.1016/j.quascirev.2008.03.006

Rowe, H. D., & Dunbar, R. B. (2004). Hydrologic-energy balance constraints on the Holocene lake-level history of lake Titicaca, South America. Climate Dynamics, 23(3-4). doi:10.1007/s00382-004-0451-8

Solari, M. A., Hervé, F., Le Roux, J. P., Airo, A., & Sial, A. N. (2010). Paleoclimatic significance of lacustrine microbialites: A stable isotope case study of two lakes at Torres del Paine, southern Chile. Palaeogeography, Palaeoclimatology, Palaeoecology, 297(1), 70–82. doi:10.1016/j.palaeo.2010.07.016

Stern, C. R. (2007). Holocene tephrochronology record of large explosive eruptions in the southernmost Patagonian Andes. Bulletin of Volcanology, 70(4), 435–454. doi:10.1007/s00445-007-0148-z

Talbot, M. (1990). A review of the palaeohydrological interpretation of carbon and oxygen isotopic ratios in primary lacustrine carbonates. Chemical Geology: Isotope Geoscience Section, 80(4), 261–279. Elsevier.