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

April 2014
Mt. Holyoke College, South Hadley, MA

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ISSN# 1528-7491

The Consortium Colleges The National Science Foundation ExxonMobil Corporation

KECK GEOLOGY CONSORTIUM
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2013-2014 PROJECTS

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Students: *ALEXANDRA FREEMAN*, Colorado College, *ANDREW GREGOVICH*, Colorado College, *CAROLINE HACKETT*, Smith College, *MICHAEL HARRISON,* California State Univ.-Chico, *MICHAELA KIM*, Mt. Holyoke College, *ZACHARY OSBORNE*, St. Norbert College, *AUDRUANNA POLLEN*, Occidental College, *MARGO REGIER*, Beloit College, *KAREN ROTH*, Washington & Lee University

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Students: *BRIAN FRETT*, Carleton College, *KATE KAMINSKI*, Union College, *BRIANNA RICK*, Carleton College, *MEGHAN RIEHL*, Union College, *CLAUDIA ROIG*, Univ. of Puerto Rico, Mayagüez Campus, *ADRIAN WACKETT*, Trinity University,

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Students: *LUCY ANDREWS*, Macalester College, *AMY DELBECQ*, Beloit College, *SAMANTHA DOW*, Univ. Connecticut, *CATHERINE DUNN*, Oberlin College, *WESLEY JOHNSON*, Univ. Massachusetts, *RACHEL JOHNSON,* Carleton College, *SCOTT KUGEL*, The College of Wooster, *AIDA OROZCO*, Amherst College, *JULIA SEIDENSTEIN,* Lafayette College

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

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Students: *SUSAN KONKOL*, Univ. Nevada-Reno, *JESSICA MCHALE*, Mt. Holyoke College, *RYAN SAMUELS,* Franklin & Marshall College, *MEGAN SWITZER*, Colgate University, *HESTER VON MEERSCHEIDT*, Boise State University, *CHARLES WISE*, Vassar College

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

Keck Geology Consortium: Projects 2013-2014
Short Contributions— Geobiology of Dolomite Formation Project

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

Learning Science Through Research
Published by Keck Geology Consortium
Short Contributions
27th Annual Keck Symposium Volume
26 April, 2014
ISBN: 1528-7491

A GEOBIOLOGICAL APPROACH TO UNDERSTANDING DOLOMITE FORMATION AT DEEP SPRINGS LAKE, CA

DAVID S. JONES, Amherst College
JASON M. TOR, Hampshire College

INTRODUCTION

Elucidating the mechanisms of modern dolomite formation is a fundamental and longstanding problem in sedimentology and Earth history (Warren, 2000). Dolomite ($CaMg(CO_3)_2$) is a common constituent of ancient sedimentary rocks, and the modern oceans are oversaturated with respect to dolomite precipitation. Despite its abundance in the geologic record and its thermodynamic favorability in many modern environments, dolomite today is only observed to be forming in a narrow range of natural settings. Further complicating the study of dolomite is the inability to precipitate it in the laboratory under temperatures and pressures relevant to earth surface environments (Land, 1998).

Significant progress was made toward understanding aspects of dolomite formation with the discovery that modern dolomite precipitation is often associated with sulfate reducing bacteria (SRB) (Vasconcelos and McKenzie, 1997; Vasconcelos et al., 1995; Warthmann et al., 2000; Wright, 2000). Sulfate reduction is an anaerobic metabolic pathway by which the oxidation of organic matter is coupled to the reduction of sulfate to sulfide. This biogenic hypothesis proposes that sulfate-reducing bacteria may help overcome three major kinetic constraints that otherwise inhibit dolomite formation: 1) they lower sulfate concentrations, which inhibits dolomite formation at high concentration; 2) they increase the availability of magnesium, since sulfate is often associated in seawater with magnesium; and 3) they increase the pH and carbonate alkalinity through respiration (Van Lith et al., 2003a; Wright and Wacey, 2005).

A large and growing body of evidence both in vitro and in situ links sulfate-reducing bacteria with dolomite precipitation. This model is based on observations from three very similar locations, Lagoa Vermelha and Brejo do Espinho in Brazil, and the Coorong region of Southern Australia (Van Lith et al., 2003b). These sites are large, alkaline, hypersaline lagoons that are located at sea level close to marine basins.

Deep Springs Lake is a dolomitic lake in eastern California that formed in a much different context than the sites in Brazil and Australia. It is a small ephemeral playa lake 1,500 m above sea level fed in large part by meteoric water, and thus subject to a vastly different range of geochemical conditions (Jones, 1965). Although the lake has been the study of several geochemical studies since the discovery of its dolomitic sediments (Clayton and Jones, 1968; Jones, 1965; Meister et al., 2011; Peterson et al., 1963), no integrated microbiological and geochemical work has been reported. This project's overall goal is to test models of dolomite precipitation at Deep Springs Lake through study of the geochemistry and microbiology of the sediment, porewater, and spring water.

GEOLOGICAL SETTING

Deep Springs Lake is an ephemeral hypersaline playa lake in eastern California bordered to the south by the Inyo Mountains and to the west by the White Mountains (Fig. 1). The lake is fed by seasonal meltwater from the surrounding mountains, surface flow from nearby springs, and springs in the lake bed itself. The lake covers ~4 km^2 at its maximum

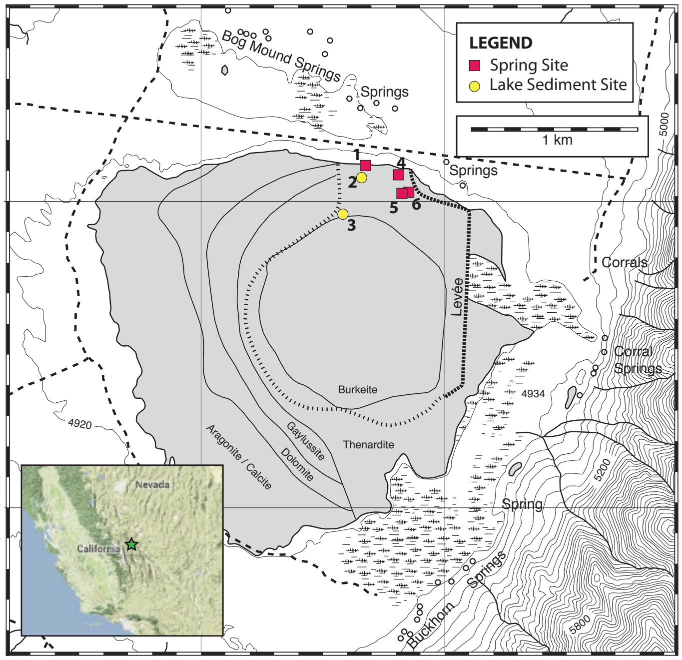

Figure 1. Location map for Deep Springs Lake sampling sites. Star on inset map indicates location of study area. Maximum extent of lake shaded in grey. Evaporite crust mineral zonations after Jones (1965). Map modified from Meister et al. (2011). Site references: 1 – 9S. 2 – MS. 3 – FO. 4 – CS. 5 – ES. 6 – PS.

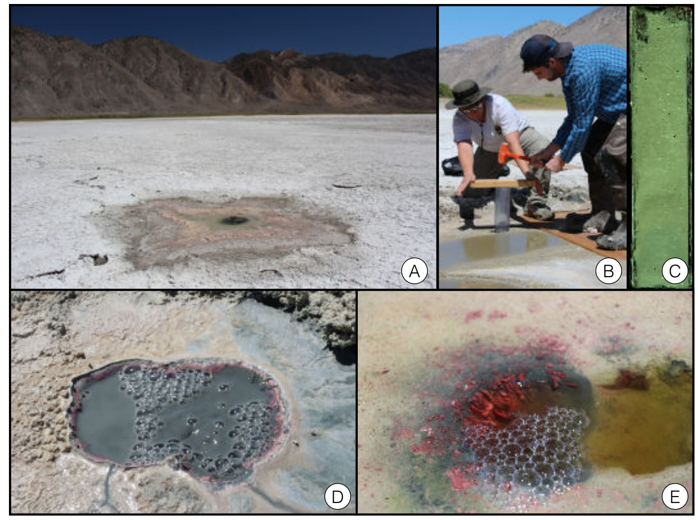

Figure 2. Deep Springs Lake and sediments in June 2013. A) View of the dry lake bed showing extensive evaporite mineral crust with teepee structures. A small spring (~15 cm diameter) is visible in the foreground. B) Keck students Kyra Brisson (left) and Kyle Metcalfe driving a polycarbonate tube into the sediment adjacent to site 9S for core sampling. C) Photograph of sediment core split from site MS, ~25 cm long. Note homogeneous muddy texture without visible lamination. D) and E) Small springs with gas bubbles and colorful biofilms.

extent, which typically occurs between February and April. A crust of evaporite minerals 0-3 cm thick covers much of the lake bed; the dominant mineralogy of the crust changes with increasing distance from the lake center in the sequence burkeite, thenardite, gaylussite, dolomite, and aragonite/calcite (Jones, 1965). The mud beneath the crust is composed of a heterogeneous mixture of siliciclastic, carbonate, and evaporite minerals. Dolomite is the most abundant carbonate mineral, but the composition and relative proportions of the minerals in the mud varies with depth and location across the lake. Ten-twenty cm below the crust the color of the mud changes from tan to dark green or grey, representing the transition from oxic to anoxic conditions. Lacustrine deposits reach a thickness of ~10 m (Jones, 1965).

During field work in June 2013 the lake was dry, with the water table ~20 cm below the lakebed. These hydrologic conditions allowed for the observation and sampling of ~10 small springs on the lakebed near the northern margin of the lake. Abundant field evidence for microbial activity at the springs (including colorful biofilms, methane and sulfide gas bubbles) made them a primary target of the group's research in 2013-14 (Fig. 2).

PROJECT GOALS

The overall goal of the project is to test models of dolomite formation at Deep Springs Lake. The primary end member models are 1) precipitation in anoxic sediment as a direct consequence of the metabolisms of anaerobic microbes (sulfate reducers and/or methanogens), and 2) precipitation in an oxic environment at or above the sediment-water interface without the influence of anaerobic metabolisms.

The specific research goals for this study are to: 1) cultivate and identify the bacteria living in the lake sediment and at lakebed springs that may contribute directly or indirectly to the formation of dolomite; 2) assess the geochemical conditions in various sub-environments of the lake, including the sediment porewater and springs feeding the lake bottom; 3) characterize the sedimentology and mineralogy of the lake deposits; and 4) elucidate differences in microbial communities, based on location within the water column and sediment.

STUDENT PROJECTS

The Keck Geology funded six undergraduate students' research on the geobiology of dolomite formation at Deep Springs Lake.

Kyra Brisson (Hampshire College) developed novel growth media based on spring water chemistry to cultivate microbial biofilms from Deep Springs Lake. In addition to assessing the microbial diversity in the lake sediments and springs, she is studying the composition of the mineral precipitates formed by the biofilms in the laboratory. This work has the potential to directly relate mineralization to specific microbial communities in the lake environment.

Kyle Metcalfe (Pomona College) studied the occurrence of macroscopic nahcolite ($NaHCO_3$) concretions in the lake sediment. Through a combination of microscopy, high-resolution elemental mapping, and geochemical modeling, he is attempting to constrain the conditions under which such concretions can form. By providing new insights into the early diagenetic conditions, Kyle's study helps characterize the boundary conditions for putative dolomite precipitation in the sediment.

Michelle Paradis (Williams College) investigated the biogeochemical cycling of sulfur in the lake sediments, springs, and pore waters by developing stable isotope records of sulfur in carbonate-associated sulfate and sulfate dissolved in porewaters. This work addresses the role of sulfate reducing microbes in subsurface at Deep Springs Lake; such microbes have been shown to mediate dolomite formation in other modern environments and in lab experiments.

Cecilia Pessoa (Amherst College) used stable isotopes of magnesium to investigate the mechanisms of dolomite formation at Deep Springs Lake. She reports the first magnesium isotope data for modern terrestrial dolomites and their potential precursors. These data suggest the isotopic fractionation factor for dolomite formation may be independent of the exact mechanism of authigenesis. She uses paired downcore variations in porewater and dolomite magnesium isotope data to address whether the locus of dolomite formation is the lake water or the sediment pore water.

Hannah Plon (Wesleyan University) carried out geochemical investigations of the porewater and spring water. This work establishes the springs as geochemically distinct water masses that had not been previously reported. She developed quantitative estimates of the mineralogy of the lake sediment using X-ray diffraction and made textural observations of the fine-grained dolomite and clay minerals. Her isotopic studies of the pore water, coupled with Kerry Streiff's measurements (see below), unambiguously highlight the metabolic activity of methanogenic microbes in the subsurface of the lake.

Kerry Streiff (Whitman College) investigated the biogeochemical cycling of carbon and oxygen in the lake sediments. She analyzed stratigraphic variations in the stable isotope composition of bulk carbonate (dolomite and aragonite) and organic matter at sites adjacent to and distal from the springs. Her work extends previously published isotope studies to the newly characterized lake bottom springs, where the effects of anaerobic microbial activity in the subsurface are most readily apparent.

ACKNOWLEDMENTS

We are grateful to the Keck Geology Consortium for funding and administering the project. We thank the several colleagues who generously supported the students in the project through laboratory access and technical support: Anna Martini, Maria Kopicki, and Bill Slocombe at Amherst College and Jon Woodruff, Brian Yellen, Mike Rhodes, and Pete Dawson at University of Massachusetts Amherst. Darby Dyar helped in the planning stages of the project.

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