REMAINING QUESTIONS AND NEXT STEPS

Biomarker data in this thesis unequivocally shows that seep carbonate-associated microbial communities are sensitive to changes in seepage flux. Longevity of biomarkers appears to increase from 16S rRNA genes to IPLs to core lipids, with IPLs demonstrating turnover times more similar to 16S rRNA genes than core lipids. The work presented in this thesis raises multiple lines of inquiry to further understand the complex relationship between microorganisms, their biomarker taphonomy, carbonate mineralogy, and time- and splace-variant methane seepage:

• Do microbial biomarker profiles differ if a carbonate is sampled with spatially-resolved resolution, rather than in bulk? If so, are differences in microbial biomarker profiles associated with mineralogy, age, other factors, or a combination of multiple factors?

• How sensitive are seep microorganisms to fine-scale differences in magnitude of seepage flux, rather than binary "active" and "low-activity" designations? Is this the same for sediment- and carbonate-hosted seep microorganisms?

• What is the radial distance-decay rate between microbial assemblage similarity and methane seepage? Does it differ for sediment- and carbonate-hosted microorganisms?

• How do carbonate-specific microorganisms spread from seep to seep? Is endemism higher in seep carbonates than in seep sediments?

• Some bacterial IPLs appear to be preferentially associated with dolomite mineralogy − what species are these associated with, and can they inform the precipitation of dolomite in subsurface sediments?

• Do new carbonates precipitate at low-activity sites even after "high" levels of seepage disappear? What role does secondary alteration of mineralogy play in seep carbonates, and on what timescale?

• Is the hypothesis of log-linear changes in microbial biomarkers as a function of time since quiescence supported by experiments with finer time resolution?

PERSPECTIVES

My choice to study science was the result of a chain of inspirational mentors. In 7th grade, at Glacier Creek Middle School, Andrew Harris infused science with merriment and inventiveness. Three years later, in 10th grade Honors Chemistry, Julie Jensen appealed to my sense of organization and structure. In 12th grade, Kathryn Eilert's Biotechnology class drew intimate connections between science and daily life. Entering college, I knew I wanted to major in Chemistry, and was inspired over four years by various professors, including Bill Buhro and Dewey Holton. I was also introduced to laboratory research through the advising of Dan Giammar at Washington University and Laura Robinson at Woods Hole Oceanographic Institution. Their leadership helped me develop a keen interest in applying my Chemistry background to Earth science, which, with their support, I decided to pursue in graduate school. At Caltech a multitude of advisors, mentors, and colleagues further shaped my understanding of the natural world – Victoria Orphan, Jess Adkins, and Fumio Inagaki, to name a few.

I mention these to highlight the human component of one's intellectual development. Science can be, and often is, portrayed as an emotionless discipline, immune to sentiment and driven by dispassionate analysis in white lab coats and pristine laboratories. While scientists of course strive for objective analysis in their experiments, the actual day-to-day life of a scientist is very much driven by human interactions. Indeed, the inevitable challenges of scientific pursuit – failed experiments, unsupported hypotheses, conflicting results – are offset by the commiseration and positive encouragement of colleagues. It would probably not be possible, and certainly would not be pleasurable, to pursue science absent scientist friends. And so as I conclude my time in graduate school, I want to emphasize the importance of fostering not just a laboratory with top-notch equipment, but of seeking, growing, and maintaining an academic environment with friendly and supportive students, staff, and faculty throughout. Caltech and Victoria Orphan have provided this environment, for which I am grateful.

Inseparable from the view of science as a human-driven endeavor is the role of creativity in scientific progress. Despite the often promulgated view of scientists as stodgy Type-A persons who don't have the chops for the arts, I have found the best and brightest scientists to be among the most creative persons I have known. Working at the boundaries of human knowledge, exploring ideas and experiments which no human has ever before encountered, by definition requires an ability to think creatively. I have found, and indeed I did not appreciate this before graduate school, that creativity and a taste for the unknown are indispensable character traits for the successful scientist.

Perhaps the largest difference I can identify between my current understanding of science and that with which I arrived in graduate school is an appreciation for the inter-disciplinary nature of the endeavor. It is now clear to me that the borders between one discipline and another are diffuse – perhaps they do not exist at all. Certainly as a high school student, and even for much or all of my undergraduate education, it was natural to feel that science was divided into discrete units – Chemistry, Physics, and Biology, for example. Graduate school has taught me that not only are the disciplines not unique, but in fact understanding one is essential to understanding the others. In a sense this is an old viewpoint – more that of the well-rounded Renaissance scholar than the 20th century specialist. Coming around to this appreciation for the holistic nature of science has felt like the single largest "turning point" of my graduate career and maturation of my intellectual self. Furthermore, it feels entirely consistent with my now-credentialed title of *ecologist*. Ecology, by definition, deals with the relationships between organisms and their surroundings. The principles of ecology promote an appreciation for not merely the description of individuals, but the overarching principles that relate individuals to one another. Ecology is, by nature, a study of the in-betweens, the derivatives, the connectedness between units. I would argue, then, that if a PhD fundamentally involves an appreciation for the connectedness of all disciplines, then a PhD is, at its base level, an understanding of all science in an ecological manner. I believe that, whether they see it or not, all scientists are in some manner really ecologists, and that the title *Ecologist* is the highest honor to be afforded to a student of the natural world.