Project Summary

The focus of this multidisciplinary research program is to understand the historical origins and environmental conditions that led to selection and radiation of the major eucaryotic phytoplankton taxa, and the ecological processes that contribute to their continued success in the contemporary ocean. The proposed research utilizes a combination of geological, molecular biological, ecological, and modeling approaches to address an important and complex puzzle in Earth system science. Our primary goal is to develop the first quantitative models of eucaryotic phytoplankton community structure in the contemporary oceans based on paleoecological and evolutionary inference. The central question raised in this proposal is: Why have three phylogenetically diverse groups of eucaryotic, unicellular algae been so ecologically successful and what does their evolutionary history tell us about the history of Earth and the ability of eucaryotic phytoplankton to accommodate to change in the future?

The proposed research seeks to test a set of three related hypotheses, from which we will develop a conceptual model for evolution and ecological success (dominance) of key phytoplankton taxa in the contemporary ocean. The central hypotheses are:

- The three dominant phytoplankton taxa in the contemporary ocean evolved in shallow shelf-seas in the Mesozoic Era in response to changes in the ocean environment, such as anoxia, changes in sea level, or tectonic processes that excluded ecological advantages previously afforded to chlorophytes.
- Once established, these groups radiated rapidly. The rapid tempo of evolution was a consequence of high mutation frequencies relative to reversion and sexual recombination, resulting in high genetic potential and DNA content relative to genetic expression in the three taxa. The rapid tempo of evolution in the three taxa has permitted rapid radiation and adaptation to changing oceanic conditions throughout the Mesozoic. This rapid tempo continues to the present time.
- The ecological dominance of the three major eucaryotic phytoplankton taxa is a consequence of pan-division traits that permit individual species within each group to rapidly accommodate large variations in oceanic conditions. These traits include the evolution of cell walls and vacuoles that respectively provide protection from predation while simultaneously optimizing the exploitation of pulsed nutrient supplies. A corollary of this hypothesis is that the structure of marine food webs in the contemporary ocean is primarily a consequence of the tempo of evolution of the three major taxa of eucaryotic phytoplankton, which itself is a consequence of continuous changes in oceanic regimes.

This ambitious research program involves 27 Senior Research Scientists from 5 US universities, and includes 6 foreign collaborators: 3 from Germany, 1 from the UK and 2 from Canada. Our approach incorporates expertise from three groups of investigators, who were selected not only for their individual expertise, but because of their proven ability to work collaboratively. The three groups contain expertise in geology and geochemistry, molecular biology and biochemistry, and algal physiology and ecological modeling. The fundamental concept is to compare paleoecological data, inferred primarily from geological and geochemical proxies, with molecular biological and biochemical information to test hypotheses 1 and 2. The paleoecological data will serve to help guide physiological experiments and ecological models to test hypotheses 1 and 3. The research program contains three basic elements: (I) A geological/geochemical team focussing on reconstructing the paleoecology at key periods in the Mesozoic; (II) A molecular biology/biochemical team engaged in elucidating how paleoecological processes have selected specific phenotypic traits that led to the origin and subsequent tempo of evolution of the major groups, and (III) An experimental ecophysiology/modeling group that quantitatively evaluates how phenotypic traits relate to the ecological success of specific taxa in the historical and contemporary ocean. These three elements will be integrated across traditional disciplinary lines and will include coordinated field, laboratory and modeling efforts. Modeling efforts will be directed towards hindcasting and forcasting the success of key phytoplankton groups using observational and experimental information.

The research program is coupled to a strong educational effort, designed to provide a broad exposure and opportunity for undergraduate and graduate students, as well as a K-12 and teacher-training program designed to integrate Earth system science in primary and secondary school curricula.