Introduction

Carbon capture and sequestration is one of the major bio/geoengineering options being investigated to help mitigate rising CO₂ concentrations and global warming (DOE, 2003, 2005). Given projected reserves of coal and natural gas, projected future energy demands, and current rates of development of alternative energy sources, some form of carbon sequestration is a highly likely component of any future climate change mitigation strategy. However, bio/geoengineered sequestration cannot be planned and implemented effectively without a parallel understanding of dynamics in the natural carbon cycle as the Earth’s average temperature increases. Evidence from the geologic record shows that some warm intervals of Earth history include major increases in rates of natural carbon sequestration (e.g., Cretaceous Ocean Anoxic Events - Barclay et al., 2010). However, there are also warm episodes that appear to have triggered massive release of CO₂ to the atmosphere, resulting in a period of rapid and extreme global warming (e.g., the Paleocene-Eocene Thermal Maximum – DeConto et al., 2012). Because of this, the processes and feedbacks that drive the natural carbon cycle have become an area of intense research interest in recent years.

A significant portion of my research program has been focused on understanding the natural carbon cycle through study of carbon burial processes and events in Earth history. A major focus of this work has been on the Late Cretaceous, a time that surface temperature proxy data indicate was among the warmest of the past 250 myr (Friedrich et al., 2012). Some of the main tools used to study ancient carbon cycle dynamics are geochemical measurements including determinations of weight percent carbon concentrations, carbon type (inorganic or organic), organic matter source (marine, terrestrial, or bacterial), and stable isotopic composition ($\delta^{13}$C). All of these techniques are employed in my lab, but the last method is particularly powerful as significant positive and negative changes in $\delta^{13}$C recorded by preserved organic matter and carbonate minerals are caused by major events of carbon burial or carbon release, respectively. This booster grant funded new directions in the investigation of carbon cycle dynamics in the Western Interior basin of North America using stable carbon isotopes (and other supporting geochemical methods – see below). The results of this research have been used to leverage funding from NSF in three successive proposals, none of which have been funded. At present I am negotiating with Shell Oil who may be interested in supporting the ongoing research. I am also planning to submit a revision of the proposal to the American Chemical Society, Petroleum Research Fund.

Results

This project constitutes a major part of the dissertation work of Young Ji Joo, who has produced the composite $\delta^{13}$C$_{org}$ curve shown in Figure 1. This data represents the carbon isotopic composition of preserved bulk organic matter contained in the shales and limestones of the Western Interior basin of North America. The record in Figure 1 is a composite of data from three different cores that sampled different parts of a stratigraphic sequence representing about 16 million years of Earth history. This intervals spans the middle Cenomanian through early Campanian stages of the Cretaceous, a time interval that is of great interest to climate scientists, as well as to energy companies exploring for unconventional natural gas deposits in the Rocky Mountain and High Plains states. On one hand, the Cretaceous time interval witnessed one of the most pronounced greenhouse climates of the past 250 million years. On the other, it was a period during which a very significant fraction of known North American hydrocarbon reserves were produced and buried.
Figure 1. Composite $\delta^{13}C_{\text{org}}$ curve constructed from records developed in three research cores: the Aristocrat Angus, the USGS #1 Portland, and the USGS CL-1 (see map inset). Indicated in the figure are major "marker events," such as Ocean Anoxic Event 2 and the Mid-Cenomanian Event (MCE), as well as other events numbered according to stage (C1,C2 for Cenomanian, etc.).
The study of stable isotopes of preserved organic carbon in rocks of the Cretaceous offers two significant advantages for studies of ocean-climate interactions and burial of organic matter (i.e., natural carbon sequestration) to form hydrocarbon source rocks. On one hand, shifts in the preserved $\delta^{13}C_{org}$ record are caused by changes in the major fluxes of the global carbon cycle. These include volcanic $CO_2$ emissions or $CH_4$ outgassing, which shift the signal to isotopically lighter values (more negative numbers), or events of massive organic carbon burial, which shift the signal to isotopically heavier values (more positive numbers). On the other hand, because the shifts in $\delta^{13}C$ are rapid and global in extent (due to the geologically short residence time of carbon and the communication of all reservoirs via the atmosphere), these shifts in $\delta^{13}C_{org}$ constitute a tool for the correlation of many rock sequences that lack other means of correlation. This allows the revised time scale for the Cretaceous, being developed by Sageman and colleagues based on integration of new radioisotope dates with astronchronologic techniques (e.g., Meyers et al., 2012), to be applied in any other generally time equivalent basins where $\delta^{13}C_{org}$ records can be developed.

In Figure 1, some major organic carbon sequestration events, such as Ocean Anoxic Event 2, are clearly recorded. This interval is represented globally by rocks that are enriched in organic matter, which was originally interpreted to mean that the world’s oceans became suddenly anoxic. These organic carbon-rich strata are the source rocks for many of the world’s great hydrocarbon reserves (especially unconventional natural gas deposits, which are currently a high value target to the energy industry). Recently, researchers have concluded that anoxicity was a consequence rather than a cause of the event, and in fact the driver was volcanically induced global warming that led to a significant increase in nutrient fluxes followed by massive increase in global marine primary production (e.g., Adams et al., 2010 and references therein). If most of the positive excursions in the $\delta^{13}C_{org}$ record represent similar mechanisms, integration of the new time scale will allow the data in Figure 1 to be analyzed to determine many key temporal features, such as the timing of repeated events, the rapidity of event onset, etc. Conversely, some of the negative excursions (T2 and T4 in Fig. 1) could represent carbon release events and this possibility has never been explored. The next phase of the research will explore these hypotheses.

Conclusions

The ISEN Booster grant has supported an aspiring female biogeochemist, Ms. Young Ji Joo, who completed analysis of over 500 samples for basic carbon concentrations (total organic carbon and total inorganic carbon) via coulometry, as well as stable isotopic analysis of organic carbon using the EA-irms system of the department’s stable isotope laboratory. Following analysis, the samples were carefully calibrated to their stratigraphic frameworks based on extensive literature work and a long period of trouble shooting to remedy inconsistencies. Finally, based on the common stratigraphic framework, Ms. Joo was able to create a composite from the three records, which allowed the best sections in each to be used for the composite. The resulting $\delta^{13}C_{org}$ record for the Western Interior U.S. is a major advance and I am currently editing the manuscript that Ms. Joo has written to publish this work. I believe that the production of this composite stable isotope record has played an important role in the recent development of a collaborative relationship with Shell Oil and it is my hope that it will also assist in the acquisition of support from ACS-PRF. The relationship with Shell is important because, like other major energy firms, Shell is working to produce unconventional natural gas reserves, which can provide an important transitional fuel on the path to a low or no-carbon future. Northwestern needs industry partners in its effort to become a thought leader on issues like hydraulic fracturing and natural gas production. The new $\delta^{13}C$ composite will help Shell explore for and produce new gas resources within the U.S.
References


