

Carbonate Workbench: The Next-Generation Predictive Tool for Carbonate Depositional Systems

Executive Summary

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Aims

The aims of this project are

- to submit a successful proposal to the NSF Cyberinformatics Group to fund a multidisciplinary, multi-institution research project to design and implement a next-generation carbonate forward modelling workbench.
- To calibrate the workbench components by accurately predicting modern and Holocene carbonate facies heterogeneity in well-studied carbonate depositional settings
- to apply this modelling workbench to test important hypotheses regarding causes of carbonate heterogeneity and to enhance our understanding of carbonate deposystems, with applications to reservoir prediction, CO₂ sequestration and climate science.

The proposed timeframe and budget for this project are 1.5 million dollars over 4 years. The final proposal will be submitted by the July 8th deadline.

The Motivation

Developing accurate predictive models of carbonate systems has important implications for understanding, monitoring and managing global climate change, for successfully and efficiently extracting water and hydrocarbons from and sequestering CO₂ in subsurface reservoirs. Carbonate systems are sensitive recorders of recent and ancient climate records, so better theoretical understanding of carbonate system response to changing climate change would enhance the reliable extraction of paleoclimate data from heterogeneous carbonate strata. Ancient carbonate strata also play a significant role in the global economy as important aquifers and hydrocarbon reservoirs. Understanding the heterogeneous distribution of porosity and permeability in carbonate strata is critical in maximizing the efficiency of extraction of water and hydrocarbon resources from carbonate reservoir rocks. It is also critical in developing technology to sequester CO₂ in carbonate strata. Improved understanding of carbonate systems would also enhance prediction of rates and distributions of natural carbon sequestration in carbonate strata which in would in turn enhance modelling and understanding of climate change on a geological time scale.

Testable hypotheses

We hypothesize that carbonate depositional and diagenetic systems are non-linear complex systems. More specifically we hypothesize that:

1. Carbonate systems are composed of multiple interacting biologic, chemical, and hydrodynamic elements that, through internal positive and negative feedbacks as well as external forcing, operate in a complicated yet deterministic manner.
2. Carbonate complex systems generate strata that, although heterogeneous and complex, do contain predictable patterns at certain temporal and spatial scales.

To test these hypotheses, we will construct, calibrate, execute, and validate numerical forward models of carbonate depositional systems and test the model predictions at various spatial-temporal scales, focusing on two aspects:

1. The distribution of carbonate facies of the modern sediment surface in a few representative regions; and
2. The thickness and facies distribution in Holocene sediments in those systems.

Carbonate Workbench Development: First Phase

A new set of numerical modelling tools are required to effectively address these hypotheses, and to act as a repository for our developing knowledge of carbonate systems. Corresponding development of geo-databases is also required to provide quantitative input parameters and data for model validation.

The Carbonate Workbench will be a flexible next-generation carbonate forward modelling and database system composed of a series of interchangeable, integrated modules each tackling an aspect of the formation and preservation of carbonate strata and developed within the framework of the Community Surface Dynamics Modeling System (CSDMS). The workbench will also provide an interface with relevant database systems for model parameter definition, calibration and validation.

The first phase of Carbonate Workbench will develop the following modules:

- Sediment production and availability - kinetic saturation algorithm, production versus water depth curves.
- Biological ecosystems and communities - cellular automata competition models, salinity-temperature-depth-energy controls on fauna and flora, population models.
- Bioengineering – formation of pelloids, bio-erosion, burrowing, biological stabilization of sediment surfaces.
- Dissolution, re-precipitation and cementation – allocation of available carbonate to ooids and peloids, cementation in hardgrounds and reefs.
- Diagenesis – chemical erosion during subaerial exposure
- Objective, inversion, and analysis functions – methods to compare real and synthetic strata, genetic, steepest descent, simulated annealing and other methods for searching for best-fit solutions, and statistical methods for analysing real and synthetic strata for properties of distributions and for presence or absence of order.

The Carbonate Workbench will interface with existing CSDMS modules, including:

- Hydrodynamics and sediment transport – wave and current erosion, entrainment, transport and deposition.
- Tectonic modules – subsidence, compaction and isostatic loading.

Databases to be interfaced with Carbonate Workbench include:

- Levitus database – whole-ocean coverage of temperature and salinity data
- NASA solar incidence wm^{-2} database

- Bathymetry database from CSDMS
- MARLIN – database of marine organisms, tolerances, and spatial occurrences

Field areas for Model Validation and Concept Development

The focus of this aspect of the project is not collection of new data for calibration and validation. Instead, our initial testing will focus on region(s) that already have a wealth of data that can be readily input into models. Although we continue to explore different areas, the Bahamas and the Great Barrier Reef (Australia) appear at first glance to be the most data-rich areas.

People and Institutions

Initial identification of people to contribute to Carbonate Workbench development occurred at the CSDMS Carbonate Focused Research Group meeting, Jan 26-27th 2009 in Boulder, Colorado. Initially identified persons to contribute to proposal development include Rick Sarg, Colorado School of Mines; Chris Jenkins and Albert Kettner, CSDMS, University of Colorado; Gene Rankey and Evan Franseen, University of Kansas; Dave Budd, University of Colorado; Carl Drummond, Purdue University; Bob Demicco, SUNY, Binghamton; Bruce Wilkinson, Syracuse University; Peter Burgess, Royal Holloway University of London, UK; Cedric Griffiths, CSIRO, Australia.

Additional expertise will be required in the areas of carbonate geochemistry, marine biology and ecology, bioengineering, and program code development.