'Building Core Knowledge – Reconstructing Earth History'

Transforming Undergraduate Instruction by Bringing Ocean Drilling Science on Earth History and Global Climate Change into the Classroom

This NSF-funded, Phase 1 CCLI project effectively integrates scientific ocean drilling data and research (DSDP-ODP-IODP-ANDRILL) with education. We have developed, and are currently testing, a suite of data-rich inquiry-based classroom learning materials based on sediment core archives. These materials are suitable for use in introductory geoscience courses that serve general education students, early geoscience majors, and pre-service teachers. 'Science made accessible' is the essence of this goal. Our team consists of research and education specialists from institutions ranging from R1 research to public liberal arts to community college. We address relevant and timely 'Big Ideas' with foundational geoscience concepts and climate change case studies, as well transferable skills valued in professional settings. The exercises are divided into separate but inter-related modules including: introduction to cores, seafloor sediments, microfossils and biostratigraphy, paleomagnetism and magnetostratigraphy, climate rhythms, oxygen-isotope changes in the Cenozoic, past Arctic and Antarctic climates, drill site selection, interpreting Arctic and Antarctic sediment cores, onset of Northern Hemisphere glaciation, onset of Antarctic glaciation, and the Paleocene-Eocene Thermal Maximum.

Each module has several parts, and each is designed to be used in the classroom, laboratory, or assigned as homework. All exercises utilize authentic data. Students work with scientific uncertainty, practice quantitative and problem-solving skills, and expand their basic geologic and geographic knowledge. Students have the opportunity to work individually and in groups, evaluate real-world problems, and formulate hypotheses. Initial exercises in each module are useful to introduce a topic, gauge prior knowledge, and flag possible areas of student misconception. Comprehensive instructor guides provide essential background information, detailed answer keys, and alternative implementation strategies, as well as providing links to other supplementary materials and examples for assessment. Preliminary assessment data indicates positive gains in student attitudes towards science, and in their content knowledge and scientific skills. In

addition, student outcomes appear to depend somewhat on students' motivation for taking the course and their institution, but are generally independent of students' class rank or GPA. Our classroom-tested learning materials are being disseminated through a variety of outlets including instructor workshops and eventually to the web.

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Building Core Knowledge – Reconstructing Earth History exercises:

To download all instructor guides and student worksheets go to:
http://csmres.jmu.edu/geollab/stjohn/buildingcoreknowledge/

1. Intro to Cores. This exercise serves as an introduction to sedimentary sequences, cores, and the coring procedure.

Part 1.1: Earth History Archives. In Part 1.1 students are asked to consider a conceptual block diagram and compare photos of an outcrop and a core to assess the value of sedimentary sequences as archives of Earth's past environmental and climatic changes.

Part 1.2: How Are Ocean Cores Obtained? In Part 1.2 students are asked to consider the challenges and technological solutions to obtaining cores from the sub-sea floor and the means of keeping core samples organized for scientific research.

2. Seafloor Sediments. This exercise set explores marine sediments using core photos and authentic datasets in an inquiry-based approach.

Part 2.1: Sediment Predictions. Students' prior knowledge on seafloor sediments is explored in Part 2.1.

Part 2.2: Core Observations and Descriptions. In Part 2.2 students observe and describe the physical characteristics of sediments cores**.**

Part 2.3: Sediment composition. In Part 2.3 students determine sediment composition using smear slide data and a decision tree.

Part 2.4: Geographic Distribution and Interpretation. In Part 2.4 students develop a map showing the distribution of the primary marine sediment types of the Pacific and North Atlantic Oceans and develop hypotheses to explain the distribution of the sediment types shown on their map.

3. Microfossils and Biostratigraphy. This exercise explores the use of microfossil data to determine age and calculate sedimentation rates of marine sedimentary sequences.

Part 3.1: Microfossils in Deep-Sea Sediments. In Part 3.1, as an initial exploration of microfossil, students make observations and develop questions concerning calcareous nannofossil data in photomicrographs and a distribution table.

Part 3.2: Microfossils First and Last Occurrences. In Part 3.2 students will gain experience using microfossil distributions in deep-sea cores to apply a biostratigraphic zonation and interpret relative age.

Part 3.3: Using Microfossils to Calculate Rates In Part 3.3 students use microfossil data to calculate rates of sediment accumulation.

Part 3.4: How Reliable are Microfossils Datums? In Part 3.4 students correlate biostratigraphic data from one region of the world ocean to another.

4. Paleomagnetism and Magnetostratigraphy

Part 4.1: Nature of Earth's Magnetic Field. In Part 4.1 students will explore the paleomagnetic record of deep-sea cores and interpret magnetostratigraphy from two sites, one in the Northern and one in the Southern Hemisphere.

Part 4.2: Paleomagnetism in Sediments and Ocean Crust. In Part 4.2 students compare and contrast magnetic records in mid-ocean basalts and in seafloor sediments, and infer how such data can be used to determine geologic ages.

Part 4.3: Using Paleomagnetism to Test Seafloor Spreading. In Part 4.3 students work with some of the original data used to test the hypothesis of seafloor spreading.

Part 4.4: The geomagnetic Polarity Timescale. In Part 4.4 students learn how paleomagnetism has been used to create the Mesozoic-Cenozoic Geomagnetic Polarity Timescale used today. They then use the GPTS to identifying magnetic chrons and polarity events in a magnetic record from a sediment core in the northwest Pacific.

5. Cenozoic Overview. This inquiry-based exercise module starts with a 'primer' on oxygen isotopes where students construct new and/or deepen their present understanding of oxygen isotope records and their use as paleoceanographic and paleoclimatic proxies. Students make observations, pose hypotheses, consider how to test them and form predictions through this 4 part module that prepares them to undertake a detailed analysis of a robust global Cenozoic $\delta^{18}O$ record.

Part 5.1: Deep Sea $\delta^{18}O$ Record: Introduction. In Part 5.1, students are introduced to the $\delta^{18}O$ record and to the organisms from which oxygen isotopes are commonly measured.

Part 5.2: Deep Sea $\delta^{18}O$ Record: Understanding the Data. Part 5.2, enables students to make connections between the isotopic record where the measurements come from and the hydrologic cycle and thus must consider the implications of the ^{16}O and ^{18}O isotopes in the natural world.

Part 5.3. Deep Sea $\delta^{18}O$ Record: Significance. In Part 5.3, students examine a schematic scenario over 4 time intervals, read a short *Nature* review and finally pose hypotheses for how to interpret variations in the $\delta^{18}O$ record.

Part 5.4: Deep Sea $\delta^{18}O$ Record: Patterns, Trends and Implications for Cenozoic Climate. Part 5.4 is a detailed analysis of a composite deep sea $\delta^{18}O$ record for the Cenozoic. Students identify patterns and trends, characterize changes as abrupt, gradual or cyclic and then interpret what they think these patterns, trends and change indicate thereby, recognizing some of the most significant climatic events of the past 65 my.

6. Climate Rhythms. This exercise set explores cyclic climate change from the geologic record, and the explanation of that change using astronomical theory.

Part 6.1: Patterns and Periodicities. In Part 6.1 students examine a variety of records displaying cyclic climate change, calculate the periodicities of these records, and reflect on sources and implications of scientific uncertainty.

Part 6.2: Orbital Metronome. In Part 6.2 students first consider seasonality to draw out prior knowledge and misconceptions, and then are introduced to the long-term orbital variations of eccentricity, obliquity, and precession. They connect these orbital drivers to the periodicities in the climate proxy records in Part 1.

Part 6.3: A Break in the Pattern. In Part 6.3 students dissect the CO2 record of the last 400 kyr to characterize greenhouse gas levels during past glacial-interglacial periods and today. Students should identify a distinct break in the cyclicity and develop hypotheses to explain this change in climate.

7. Past Antarctic Climates. This exercise set introduces students to the status and role of Antarctica in Cenozoic climate change, and sets the stage for evaluating the two sediment cores retrieved from the floor of McMurdo Sound by the Antarctic Geologic Drilling Project (ANDRILL) in 2006 and 2007, which are introduced in the Antarctic Sediment Cores Case Study Module. The Past Antarctic Climates exercises build basic geographic and geologic knowledge of Antarctica, and use geologic reasoning.

Part 7.1: History of Antarctic Climate. In Part 7.1 students review their understanding of the oxygen isotope curve, and of global climate interpretations based on the curve, as well as the validity of interpretations based on the global distribution of sediment cores.

Part 7.2: Geologic and geographic Context. In Part 7.2 students become familiar with the geography and geologic units of the Ross Sea region of Antarctica, and review or build their knowledge of southern-hemisphere seasons, sea-ice, ice-shelves, and the challenges associated with obtaining a sediment core from the floor of McMurdo Sound. Students also build and use their understanding of simple geologic maps, cross sections and the geologic time scale, so they can explain the reasons for selecting drillsites in McMurdo Sound.

Part 7.3: Selecting a Drillsite. In Part 3 students review the existing data from sediment cores in the Ross Sea region of Antarctica, and use the knowledge gained in Parts 1 & 2 to identify a target stratigraphic interval and select two drillsites. Evaluation of the ANDRILL core is undertaken in the 'Interpreting Antarctic Sediment Cores' module.

8. Case Study: Interpreting Antarctic Sediment Cores. This set of exercises focuses student attention on the use of sedimentary facies in core interpretation, with attention to the facies associations that are diagnostic of ice-proximal and ice-distal settings in high latitudes.

Part 8.1: What Sediment Types are Deposited on the Antarctic Margin? Where are they Deposited? In Part 8.1 students build their knowledge of specific sedimentary facies and depositional settings through diagrams, geological reasoning, and use of core images and core logs. They build skills to recognize ice-retreat and ice-advance facies.

Part 8.2: ANDRILL 1B – The Big Picture. In Part 8.2 students are presented with the core log (a graphical summary of the sediments) for the entire ANDRILL 1-B core (1285 m). Students characterize each of the key lithostratigraphic sub-units and use their knowledge of depositional facies to write a brief history of the climatic and environmental conditions in the Ross Sea region.

Part 8.3: Pliocene Sedimentary Patterns in the ANDRILL 1B Core. In Part 8.3 students use their core-log reading skills and facies knowledge to evaluate patterns in the Pliocene sediments from ANDRILL 1-B. They complete calculations to show correlations with 40-kyr cycles in insolation influenced by changes in the Earth‟s axial tilt (obliquity) during the Pliocene.

9. Past Arctic Climate. This set of short activities investigates the scientific motivation, logistical challenges, and drilling history of the Arctic.

Part 9.1: Going Polar. In Part 9.1 students articulate what they know about polar settings to draw out prior knowledge and potential misconceptions.

Part 9.2: Arctic Drilling Challenges and Solutions. In Part 9.2 students hypotheses about Arctic seafloor drilling challenges and potential solutions, and then compare their ideas to the challenges and solutions of the IODP Arctic Coring Expedition, which are presented in a short online video.

Part 9.3: Why Drill in the Arctic? In Part 9.3 students work with historical data on the spatial and temporal distribution of seafloor cores in the Arctic to consider the extent to which Arctic marine sediment records have contributed to the knowledge base of Cenozoic history. Students formulate a scientific rationale for drilling the seafloor in the Arctic to research past regional and global climate change.

10. Northern Hemisphere Glaciation. This exercise set serves as an introduction to the characteristics and possible causes of the Cenozoic Northern Hemisphere glaciation.

Part 1: Concepts and Predictions. In Part 10.1 students make predictions on where and why continental ice sheets form; this enables the instructor to gauge prior knowledge and flag misconceptions.

Part 2: What's the Evidence? In Part 10.2 students examine geological, geochemical, and paleontological data to infer the spatial extent and temporal history of this glaciation. **Part 3: What Caused it?** In Part 10.3 students critically assess abstracts from 7 peer-reviewed papers on different proposed mechanisms for the expansion of Northern Hemisphere glaciation at ~2.6 Ma.