DEVELOPING THE U.S. INITIATIVE IN CONTINENTAL SCIENTIFIC DRILLING
Front cover: Drilling at Lake El’gygytgyn, Siberia, early 2010. This project required many years of maximum effort at planning, arranging funding from numerous agencies, developing cooperation with local scientific bodies and getting approval from appropriate political and administrative agencies, design and fabrication of specialized equipment, and eight months of transport of equipment and supplies to the lake before on-site operations could begin. Then the ice had to be thickened to support the weight of the rig, rods, and equipment. The project was a triumph, but required dedication of the PIs and their institutions, funding agencies, Russian and provincial entities, and the implementing agencies for its successful completion. While the Lake E project was unusually complex, without infrastructure and management capabilities, no drilling project beyond the most elementary will be possible. Photo courtesy of Julie Brigham-Grette.

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EXECUTIVE SUMMARY

Core samples and downhole measurements, obtainable only through drilling, are essential when approaching many exciting and transformational questions in science. Drilling into the ocean crust has revolutionized the Earth sciences, but its scope does not provide insight into continental processes and configurations, early history of the Earth, or detailed temporal records, such as those in lake sediments. Nor does ocean drilling address questions relevant to society that are common to continents and oceans as inexpensively as drilling on land does. For these reasons, continental scientific drilling (CSD) is a necessary tool for the Earth sciences.

Over the past several decades, the United States geological community has been among the intellectual leaders in identifying key problems that require drilling and in mobilizing the human and financial resources needed for a successful program. CSD has produced much insight into these problems over the years. A number of sources, notably the National Science Foundation (NSF), currently provide several million dollars annually to support projects where drilling is essential.

It is appropriate to pause to examine the state of the program from time to time. For this reason, an NSF-sponsored workshop convened in Arlington, Virginia, in June 2010 to review and consider the US CSD program and recommend a change in its organization and financing for the future. This session followed a 2009 workshop that identified many key scientific questions that could be answered only by drilling into continents and other land areas. The 2009 workshop made specific recommendations about building the CSD community.

One such recommendation was addressed when DOSECC, Inc. expanded the membership in its Science Planning Committee (SPC) and broadened its mandate to serve as the organizing focus and communications hub for the CSD community. The 2010 workshop, following the earlier recommendations, gave guidance to the SPC and made specific recommendations concerning funding, organization of the community, and planning.

Workshop participants believe that the U.S. community could be better organized to address key problems of the CSD effort, and that the funding structure could be coordinated and simplified to strengthen both a U.S.-led effort and participation by U.S. scientists in the international effort. A strong US CSD program would require funding not only for drilling and scientific investigations of the resulting core or other samples and data, but also for project-development, community-building, and topical-planning activities; for long-term archiving of data and samples; and for outreach to the scientific community and the general public. The overwhelming sense of the workshop participants is that facility funding would be necessary to carry out the drilling, community-development, and project-development activities, and that a formal program at NSF—with a designated director and a budget—would most effectively manage the overall effort.

A successful CSD effort requires a developed infrastructure rather than dependence on individual investigators to develop the expertise and equipment necessary to implement the program one project at a time. A developed infrastructure assumes a strong community to ensure effective use of that infrastructure through thoughtful planning, effective communication among various specialties, and strong proposals to address exciting and transformational questions of science. A strong U.S.-based CSD program would encourage U.S. investigators to participate in international projects while developing U.S.-based projects open to international participation, thus strengthening the existing international program.
RECOMMENDATIONS: THE ESSENCE OF THE WORKSHOP

1. Funding
   - Base funding for continental drilling operations and community development and support should be centralized at The U.S. National Science Foundation, either as a stand-alone program or under a designated program. Science operations on drilling projects would continue to be funded through core programs.
   - A CSD facility, perhaps the existing facility that DOSECC, Inc. operates, should be funded to support the community, assist PIs in developing projects, and provide a base level of drilling annually. Workshop participants recommended an initial target of $1.5 million for drilling operations with a possibility to adjust the amount of support as proposal pressure dictates or special opportunities develop. Appropriate funding for community activities and support of investigators should also be granted to the facility.
   - A clear pathway should exist to acquire additional funding for necessary preliminary activities, including site characterization on a project-by-project basis.
   - NSF should continue to support the International Continental Scientific Drilling Program (ICDP).
   - The Interagency Coordinating Group required by the Continental Scientific Drilling and Exploration Act of 1988 should be reconstituted and perhaps enlarged, even informally, to coordinate CSD related activities among several funding agencies with shared interests.

2. The US CSD Community
   - The DOSECC Science Planning Committee (SPC) or a similar, broad-based group, with staff support from the CSD facility, should oversee a planning process, development of protocols, formulation of positions on issues facing the community, organization of communication within the community and with external stakeholders, both domestically and internationally, and otherwise ensure the interests of the CSD community are met.
     - Each of the component communities of the CSD community should periodically work with parallel groups and overlapping communities, to develop science plans. Plans should review the state of the science and the results of any previous plan and look to both long-term goals and those approachable over the next three to ten years. Plans should emphasize exciting and transformative science and identify the means necessary to achieve it.
   - An occasional but key community-wide activity would entail planning for the overall US CSD effort, generalizing and summarizing the topical science plans. A mission statement, vision, and strategic plan for the overall community also should be developed.
     - The SPC should oversee an improvement in communications within the CSD community and with parallel groups and overlapping communities using a combination of workshops, newsletters, electronic communications, and other means.
     - The CSD facility should provide support for the administration and implementation of SPC activities through base funding of the facility and the SPC should seek grants for specific additional activities.

3. Cores, Samples, and Data
   - Each project should include a comprehensive procedure for data-management and archiving that is in conformance with protocols developed by the community and that meets guidelines and policies of the U.S. National Science Foundation and other agencies. The system of data archiving...
should be made accessible, easy to use, and valuable through tools that allow the summarizing, manipulating, and displaying of information.

- Cores and samples
  - The community should review protocols for core handling and initial description or develop suitable protocols where necessary. Protocols can be informed by existing standards from IODP, ICDP, LacCore, and other organizations.
  - Containerized, transportable, on-site laboratories are necessary for certain investigations (e.g., deep biosphere) and desirable for all projects where core can be described immediately on site. Planning should address the needs for and design of such laboratories.
  - The community should recommend steps that would provide long-term storage of cores and other samples.

4. Education and Outreach

- DOSECC, or a successor facility, should continue the programs of distinguished lecturers, town halls, newsletters, and booths at appropriate professional meetings.

- Students
  - The existing internship program should be expanded to include ways for student volunteers and paid student workers to participate on site drilling projects, especially in the United States, through a community-wide program or on a project-by-project basis.

  - The CSD facility should take steps to provide meaningful material for K-12 education.
  - Projects should develop websites where students in colleges and K-12 schools can follow progress and see the results of drilling projects.
  - Exhibits of drilling-related equipment, samples, and data would be useful for primary-secondary and college-level instruction.
  - Small, portable drilling rigs should be available for use at field camps for undergraduate geology students and for student research projects.

- The CSD facility should have materials suitable for distribution to the press and video media about CSD in general, including a roster of contacts on various topics related to active CSD programs. The facility also should work with PIs to develop project-specific materials and media contacts.
INTRODUCTION

Drilling into the crust of continents and other land areas is the only means available for collecting key data needed to address many critical problems in the Earth sciences (Harms et al., 2007; Walton et al., 2009). Drill cores contain information on fault zones and volcanic conduits in full geologic context and in active or near-active conditions (Brodsky et al., 2009; Ito et al., 2007; Tobin et al., 2007; Zoback et al., 2007; Reches and Ito, 2007; Eichelberger and Uto, 2007); provide unweathered time-series records at annual to millennial scale (Brigham-Grette et al., 2007; Miller and Clyde, 2009); and detail stratigraphic relationships that are not exposed at the surface, and explore impact structures as analogs for elucidating the most important surficial process on most planetary bodies (Koeberl and Milkreit, 2007; Koeberl and Plescia, 2009). Drill bits even reach into magma chambers (Elders and Fröilífsson, 2009).

Drill holes can provide high-resolution views of the processes that affect and control climate change and paleobiologic processes at all time scales. Wells provide the only samples of water and gasses from the lithosphere for which the origin is documented. The deep biosphere was discovered through drilling and can only be explored through drilling (Horsfield et al., 2007, Walton and Kief, 2009). Instruments placed downhole, either permanently or not, are uniquely sited to sense pressure, temperature, strain rate, and seismic shocks. Downhole measurements and samples are essential ground truth for the interpretation of many remotely sensed data. In many fields of the Earth sciences, samples, and measurements are essential for continued advance.

The geological community has engaged in drilling campaigns into both oceanic and continental environments for decades. The Integrated Ocean Drilling Program (IODP) is currently reviewing its progress and laying out plans for its future. Ocean drilling is vital for exploring certain processes and relationships preserved only in oceanic environments, and some that are expressed in both continental and oceanic environments. However, much history and many processes and relationships are either unique to continents or precede the extensive records of the oceans (pre-Jurassic events or even pre-Cretaceous ones for large parts of the ocean basins). Continental scientific drilling (CSD), which here includes specialized campaigns in such places as Hawaii, Iceland, and Antarctica as well as drilling into the continental masses themselves, can expose phenomena expressed in both the oceans and continents more economically than ocean drilling programs that require drill ships. Both land-based and ocean drilling are necessary tools for obtaining samples and data for many exciting, fundamental, and even transformational scientific studies.

A LITTLE HISTORY5

Scientific drilling dates back to explorations of coral reefs at the end of the 19th century (Cohen, 2010, workshop presentation). Systematic drilling of the ocean basins began with the abortive Project Mohole and the wonderfully successful Deep Sea Drilling Project in the 1960s followed by the ODP and the IODP. During the 1970s several efforts were initiated to explore the depths of the continents at the limit of drilling technology, notably the Kola deep hole in the former Soviet Union and the KTB boring in Germany (Harms and Emmermann, 2007).

Early on, the U.S. geoscience leadership established the need for a continental scientific drilling program, developed intellectual support, gained institutional participation, and arranged for legal mandates. They then set to work drilling holes, collecting cores, making downhole measurements, and studying the samples. Later, the U.S. community was a leading participant in building an international program. Beginning with the Carnegie Institution’s Ghost Ranch workshop in 1974 (Shoemaker, 1975) and continuing with a U.S. Geodynamics Committee workshop in 1978 (U.S. Geodynamics Committee, 1979), the community defined the objectives of a drilling program and argued for its implementation. In 1977 the Panel on Continental Drilling of the Federal Coordinating Council of Science, Engineering and Technology (FCCSET) recommended establishment of a drilling program. In 1980, a Continental Scientific Drilling Committee (CSDC) was established by the National Research Council (NRC) to guide the planning for a national program of scientific drilling. This committee set up several panels to plan programs exploring thermal regimes, basement structure, deep continental basins, active fault zones, and downhole measurements, and mineral resources. The CSDC also set up panels on drilling, logging, and instrument technology and sample curation and data Management. Subsequently, the Board on Earth Sciences (1983) recommended a program of deep continental drilling in 1983.

The following efforts came to fruition in 1984:

- Reviewing the findings of its panels, the CSDC

5 Much of the information in this section came from a revised copy of Dennis Nielson’s brief manuscript on the History of DOSECC, Inc., which he had published in the DOSECC newsletter in 2004, the 20th anniversary of the founding of the corporation.
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recommended that a “continuing National Program of Continental Scientific Drilling is required, extending over a period of decades.” (NRS CSDC, 1984). Subsequent NRC reports explored objectives for scientific investigation, such as the structure of the southern Appalachians, volcanic activity and hydrothermal activity at Yellowstone National Park, active fault zones, and hydrocarbon resources (NRC CSDC, 1987a, b, c; Committee on Hydrocarbon Research Drilling, 1988).

- Federal agencies had already recognized the need to oversee and fund a continental scientific drilling program. The National Science Foundation (NSF), the Department of Energy (DOE), and U.S. Geological Survey (USGS) established their Interagency Coordinating Group (ICG) on continental scientific drilling in April 1984.

- The Office of Basic Energy Sciences (OBES) of the Department of Energy undertook a study of thermal regimes and heat transport in the Earth’s crust, especially in magma-related hydrothermal systems. To implement that study, OBES set up a Geothermal Research Drilling Office at Sandia National Laboratory. This program was very successful (Wollenberg et al., 1989).

- The founding in May 1984 of DOSECC (originally Deep Observation and Sampling of the Earth’s Continental Crust; now Drilling, Observation, and Sampling of the Earth’s Continental Crust), marked the beginning of a major operational effort in the United States.

- In July 1984, DOSECC proposed that it plan and manage the US CSD effort. When funding the proposal, NSF recommended that DOSECC establish a management structure suitable to oversee a drilling program with an annual budget of $20 Million.

At this point, a number of large-scale projects were proposed in the United States, including the Salton Scientific Drilling Project that drilled 3.2 km into a geothermal field reaching temperatures of 355°C; the Cajon Pass boring into the San Andreas Fault that tested hypotheses about strength of faults, stress fields, and heat flow at an active fault; and the never-drilled ADCOH (the Appalachian deep core hole) that was suppose to test models of structure and history of a major orogen (Hatcher et al., 1988; Rosen, 1991). Simultaneously, a model of shallower, more targeted coring programs emerged during the 1980s in conjunction with efforts to explore the Precambrian of the interior of North America by deepening planned oil exploratory wells (Van Schmus et al., 1988) and the early 1990s detailing of the history of the Triassic of the Newark Basin of eastern North America (Olsen et al., 1996).

1988 was the best and worst of times:

- Congress formalized the IGC and the US CSD program when it passed PL 100-441, the Continental Scientific Drilling and Exploration of 1988.

- The budget limitations of expensive science changed NSF’s view of the future of CSD and DOSECC’s role. DOSECC closed its Washington office and science planning office in 1989, became primarily a drilling entity, and moved to College Station, Texas.

Drilling projects that address problems of global interest are commonly best approached by combining the scientific and financial resources of several nations (Zoback and Emmermann, 1993). With the advent of International Continental Scientific Drilling Program (ICDP) in 1994 (formalized in 1996), scientific drilling of the continents became organized and active internationally. Over the past quarter century, a balanced program has used shallow holes (1500 m or less) where possible and deep holes (up to a few km) where necessary as exploratory science or to get data to test hypotheses (Harms and Emmermann, 2007). As drilling activity has accelerated, new fundamental and potentially transformative areas of investigation have emerged: mantle plumes and large igneous provinces, Plio-Pleistocene and deep-time paleoclimate records, impact structures, stratigraphic architecture, rates and history of evolution, the geobiosphere, and even dynamics of the solar system (Walton et al., 2009).

MOVING AHEAD

Each major human effort should periodically consider where it has been, where it stands, where it could or should go, and how it is to get there. The ICDP report on its 2005 review of a decade of continental drilling considers the past and looks into the future of the international program (Harms et al, 2007). The US CSD community participated heavily in that effort but also has its own parochial outlook and concerns. In June 2009, the U.S. community met in Denver, Colorado, to consider the key scientific areas where drilling provides vital data for significant advances (Walton et al., 2009). The resulting document lists themes and topics that rely on drilling samples or data (Table 1). The document also made several recommendations that reflect the sense of the meeting (Table 2).
One of the recommendations was followed when the Board of Directors of DOSECC, Inc. took action to expand its Science Planning Committee (SPC) and open its membership to individuals within the continental scientific drilling community regardless of whether they are employed by DOSECC member institutions (see sidebar). This committee now comprises a diverse group of eleven Earth scientists (listed in sidebar), including international members, and is chaired by Mark Abbott and Julie Brigham-Grette. With three-year term rotations, the committee will serve as the voice and organizing focus of the US CSD in the future. To accomplish its charge, it must get input from the community.

**TABLE 1. Themes and Topics for Continental Scientific Drilling (Walton et al., 2009).**

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<tr>
<th>Themes</th>
<th>Topics</th>
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<tr>
<td>Global Environmental and Ecological Change</td>
<td>Plio-Pleistocene climate records</td>
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<td>Evolution in isolated lake systems</td>
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<td>Climate and evolution of hominins and associated faunas</td>
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<td>(History of the magnetosphere)</td>
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<td>Deep-time records</td>
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<td>Paleoclimatology</td>
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<td>Atmospheric history</td>
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<td>Cryospheric history from near-field sub-ice records</td>
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<td>Stratigraphic architecture and crustal deformation</td>
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<td>Evolution and extinction</td>
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<td>Dynamics of the Solar System</td>
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<td>Continents as the only source of information for pre-Late Jurassic</td>
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<td>(Antarctic deep-time records)</td>
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<td>Geodynamics</td>
<td>Crustal evolution</td>
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<td>Hotspots, mantle plumes, and large igneous provinces</td>
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<td>Processes and hazards at volcanoes</td>
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<td>Fault mechanics</td>
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<td>History of the magnetosphere</td>
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<td>Ice sheet history and dynamics</td>
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<td>Geobiosphere</td>
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<td>Ichnofossils</td>
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<td>Natural resource systems and related environmental concerns</td>
<td>Hydrothermal resources and ore deposits</td>
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<td>Ground water</td>
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<td>CO₂ sequestration</td>
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The continental drilling community must broaden itself by educating other geoscientists on the advantages of drilling as a means of getting key samples and data for important projects.

The community must develop a broadly based science advisory committee that acts as a focus for the community, provides scientific leadership and invites participation by all interested parties within the Earth sciences.

The science advisory committee must encourage disciplinary planning workshops with strong participation by parallel groups not traditionally involved in drilling in addition to members of the continental drilling community.

The community should identify general needs for technological advances in capabilities or facilities and work together to meet those needs.

The community should develop instrumentation and protocols for the use of drill holes in long-term monitoring on active processes at depth.

There should be well-established routes to carrying out preliminary site characterization studies to facilitate development of scientific and operational plans for drilling projects and to verify that the sites selected for those projects are optimal for achieving their scientific objectives.

The community must provide open and ready access to all data, cores, and publications that result from drilling (after appropriate moratorium periods), through public databases, repositories, site reports, and publications in the general literature.

A facility is needed to assist PIs in preparing realistic drilling plans and cost estimates for proposals. This facility should also have the capabilities to carry out successful drilling campaigns, including operational and support staff, logistics, drilling equipment, and suitable on-site laboratories. Such a facility could provide staff support for community activities and should be managed in coordination with technological, database, and other support capabilities currently provided by the ICDP and IODP.

The Science Planning Committee

The 2009 CSD workshop recommended that a committee of community members serve as the focus of community activities, guide the process of developing plans and protocols, and speak for the community as follows:

Develop a science planning and advisory group that represents the entire U.S. CSD community. The DOSECC Science Planning Committee is currently a membership committee that advises the Board of Directors on scientific matters. It is possible that this committee could be reconstituted to represent the entire community and serve as a focus for identifying goals, fostering collaboration, and speaking out on community needs and accomplishments as well as advising DOSECC. Alternatively, the committee can be otherwise constituted. The science planning and advisory committee would include active participants from several fields of interest. This committee can sponsor efforts by various interest groups to define their goals and identify their needs…. It, or a specialized technical advisory committee, can also develop means of identifying technical and infrastructure needs and the means to fulfill them…. (Walton, et al., 2009)

In response to this recommendation, the DOSECC Board of Directors revised its charge to reflect the recommendation of the Workshop. The minutes from the DOSECC Board of Directors Meeting on December 14, 2009 state that charge to the committee is to
- Develop a long-range science plan that spans the scientific disciplines represented by DOSECC.
- Assist President in developing proposals to provide support for workshops, planning groups, site surveys, safety and pollution panel, a DOSECC lecture series, etc.
- Encourage continental scientific drilling proposals with a defined scope and scale.
- Evaluate proposals and make recommendations to the BOD [Board of Directors].
- Provide guidelines and procedures for publication and data repository.
- Evaluate the status of core archiving within continental drilling and recommend improvements in core archiving.
- Liaise with other appropriate scientific organizations, including drilling and coring efforts, such as ICDP, IODP, Arctic, and PAGES.

In addition to modifying the charge to the committee, the DOSECC increased the membership of its Science Planning Committee (SPC) from seven to a minimum of eleven members. It also broadened its membership, opening it not just to employees of DOSECC member institutions but to any community member. The Board advertised the revised committee through its mailing lists and in EOS. In April 2010 it accepted the recommendation of its Committee on Committees to appoint a slate of new members to the SPC. The committee met for the first time at the 2010 CSD workshop in Arlington, Virginia, and elected Julie Brigham-Grette of the University of Massachusetts, Amherst, and Mark Abbott of the University of Pittsburgh as co-chairs. Christian Koeberl of the University of Vienna will serve as vice chair.

Members of the Committee

Co-Chairs
  - Julie Brigham-Grette, University of Massachusetts, Amherst
  - Mark Abbott, University of Pittsburgh

Vice Chair
  - Christian Koeberl, University of Vienna

Members
  - Andrew Cohen, University of Arizona
  - Christopher Campisano, Arizona State University
  - David Dinter, University of Utah
  - Wilfred A. Elders, University of California, Riverside (Emeritus)
  - Torsten Halbersattl, Fridrich-Schiller-Universität Jena
  - Linda Hinnov, Johns Hopkins University
  - Kenneth Miller, Rutgers University
  - Walter Snyder, Boise State University

A second workshop took place June 2–3, 2010 at the Ballston Campus of Marymount University in Arlington, Virginia, with the aim of implementing other recommendations from the 2009 workshop. The meeting provided for a dialog between the CSD community and NSF and sought to empower the US CSD community through planning, nurturing, and developing interaction among the topical communities, in short, to provide the grist for the mill of the SPC. The workshop was funded by the National Science Foundation and, to a lesser extent, by DOSECC, Inc. Forty-nine individuals attended, including several beginning professionals, participants from Germany and the United States, and a number of NSF employees (Appendix 2). This document summarizes workshop deliberations and recommendations, considers the state of the CSD enterprise in the United States today, and recommends some possible paths forward.
CURRENT STATE OF US CSD ACTIVITIES

Successes of Continental Scientific Drilling

Scientific Progress

Continental scientific drilling has provided significant advances in the understanding of structure, processes, and history of the Earth. Following are samples of some notable results and opportunities:

- Drilling is the only method used to explore impact structures to shed light on the processes that form them. Despite the comparative rarity of such structures on the surface of the Earth, bolide impact is the major surface process throughout the solar system. It has shaped many celestial bodies in addition to affecting the history of life on Earth. Exploration of the Chicxulub structure in Mexico, the Chesapeake Bay impact, and the Bosumtwi crater in Ghana has provided information on structures at various scales. We await the results of drilling into the Lake El’gygytgyn impact structure in northeastern Russia in 2009 (Koeberl et al., 2007; Koeberl and Plescia, 2009).

- Investigations of the continuous, high-resolution sediment record in lakes, such as Bear Lake in Utah, Lake Baikal and Lake El’gygytgyn in Russia, Bosumtwi in Ghana, Laguna Potrok Aike in Argentina, Lake Malawi in Africa, Petén Itza in Guatemala, and, in the near future, Lake Van in Turkey, are necessary to determine the history of global climate change across spatial and temporal scales back into the Pliocene, potentially at a decadal or even annual resolution. Assessing regional versus global climate systemic processes and feedbacks spanning the spectrum of orbital forcing frequencies is important for understanding the stability of interglacial periods and warmer-than-present scenarios over the length of the Cenozoic.

- Investigations of lake deposits can also provide data on the rates and patterns of evolution of other organisms where endemism is pronounced (Cohen et al., 2009a, b). Paleoclimate fluctuations in Africa may have profoundly affected the course of evolution there, including that of hominins.

- A deep-time investigation of the Newark Basin established Milankovitch periodicities for the Triassic and showed the relationship between such orbital parameters and local climate. Furthermore, the record has been interpreted to display cycles that reflect the long-term resonances among the planets of the solar system and to show that those resonances have changed their period, perhaps in a catastrophic manner (Olsen and Kent, 1999). Investigations along a broad transect from the New Jersey Coastal Plain into the continental shelf have verified models of subsidence and sea-level history (Browning et al., 2008). Further investigations of deep time will soon explore the Mesozoic of the Colorado Plateau and the Paleogene of the Big Horn Basin of Wyoming (Olsen, personal communication, 2010; Clyde, personal communication, 2010).

- Only drilling efforts can recover unweathered records of really deep time, the Archean and Proterozoic. FAR-DEEP and the Astrobiology Drilling Program sampled the ancient record to explore the evolution of the Earth, the history of life, and development of the atmosphere. This was done mainly by examining organic and inorganic geochemical and isotopic records in cores from key, well-preserved sections in Fennoscandia and Australia, respectively (Melezhik et al., 2008; Anbar et al., 2010).

- The Chelungpu-Fault Drilling Project sampled a recently active fault zone (Ma et al., 2006), while the SAFOD Project sampled the San Andreas Fault and allowed the installation of instrumentation, both at seismogenic depth (Zoback et al., 2010). Such investigations test hypotheses about the strength of faults and the process of initiation of earthquakes.

- The Unzen drilling project has provided otherwise unavailable samples from an active volcanic conduit and demonstrated that each eruption followed a separate dike-like conduit. Cooling time of the conduit system much shorter than the recurrence interval of eruption events. (Nakada et al. 2005).

- The Hawaii Scientific Drilling Project has led to a new understanding of the structure of the mantle and the processes of melting in mantle plumes as well as the growth of Hawaiian volcanoes. It also serendipitously identified potentially significant new sources of fresh water in Hawaii and a unique record of the deep biosphere (Stolper et al., 2009; Fisk et al., 2003; Walton, 2008). The soon-to-be-drilled Project Hotspot in the Snake River Plain will extend understanding of plume-related volcanism to the continental realm, investigating the influence of continental...
crust on magma generation and evolution (Shervais et al., 2006).

- Investigation of the deep biosphere has only begun, despite the fact that it contains somewhere between 30% and 50% of the total biomass on Earth (Whitman et al., 1998). Many current efforts have emphasized work in mines, and dedicated drilling projects in the oceans have begun. Only two CSD projects specifically included sampling of the deep biosphere: the Chesapeake Bay project in the USA (Cockell et al., 2009) and the Laguna Potrok Aike project in Patagonia.

- Deep drilling in the Ross Sea region of Antarctica via the ambitious ANDRILL program has provided new insights into the tectonic, paleoclimate, and paleoglaciological history of that continent. The new data revise earlier summaries, based on drilling results in dry valleys, concerning the Cenozoic history of the continent as well as the dynamics of the West and East Antarctic ice sheets and their vulnerability to climate change.

**Operational Capabilities**

These scientific successes indicate that a substantial capability in continental scientific drilling exists. Some drilling projects contract with local providers for drilling services and others make use of facilities designed to facilitate and operate drilling projects. These dedicated entities provide equipment and supporting facilities, but more importantly they offer skilled and experienced personnel.

**ICDP.** The International Continental Scientific Drilling Program (ICDP) is a funding agency supported by 19 nations, one corporate member, and one organizational member. ICDP draws funding from the science funding agencies of the several member nations. The National Science Foundation annually contributes $700,000 to ICDP on behalf of the United States. This money is commingled with other ICDP funds to support projects all over the world. Drilling funds from ICDP defray only a portion of project costs—ICDP grants typically provide about 17% of total project costs—so matching funds are required to complete projects. ICDP does not pay salaries for investigators or provide funding for scientific studies or planning.

The ICDP organization also maintains several operational-support and equipment services for drilling projects, specifically its drilling engineering capability; its Drilling Information System (DIS) for recording real-time drilling data and basic sample and laboratory data on projects; a system for on-site geophysical borehole logging, i.e. spectral gamma, resistivity, sonic, and borehole imaging with necessary surface equipment for transporting equipment and recording data; and various downhole sensors and core scanning and imaging equipment (Hickman, 2010, workshop presentation). The Glad 800 system for lake drilling was funded by ICDP and is operated by DOSECC. Project support includes the GeoForschungsZentrum’s Innova drilling rig, an automated system with 5000 m capability. ICDP also provides training in planning, proposing, and conducting drilling projects and sponsors project-specific planning workshops (Hickman, 2010, workshop presentation).

**DOSECC.** DOSECC, Inc. is an international consortium of 57 universities and research institutions that has the mission of promoting CSD (http://www.dosecc.org). In this role, DOSECC can ensure that planning and community-building activities take place and that the message of the CSD community reaches the appropriate audience. The consortium operates a facility in Salt Lake City, Utah, where it provides design services for drilling projects and budgets for proposals that require drilling. It is important to differentiate between the consortium and the facility; they are closely connected, of course, but the facility is intended to implement the mission of DOSECC while participants in consortium activities make up a large but active subset of the CSD community.

The DOSECC facility maintains an inventory of specialized equipment, including drilling rigs of several different capacities, modular barge systems for lake drilling (the GLAD 800 system and, for larger lakes, an enlarged system with 1500 m of total drill-string length), an active heave-compensation system, a dynamic-positioning system, and the DOSECC Hybrid Coring System. It also has drilling tools, drill rods, and all supporting equipment; a permanent staff of drilling supervisors, superintendents, and administrative workers; and drillers on call. The facility is a one-stop shop where investigators can have all the drilling-related operations of their project implemented and also get help making arrangements with funding agencies and DOSECC. The DOSECC facility has historically been funded by grants from the National Science Foundation of about $500,000 annually, and its office supports community development and education and outreach activities.

Both the DOSECC facility and ICDP provide consulting services for design and implementation of drilling operations and have expertise in drilling techniques. They can supply cost-of-hole estimates for proposal budgets and assist in permitting activity for projects.
As an operating agency that actually drills, DOSECC in particular has established a system of project management to track activity and funding for drilling projects.

**Specialized Tools for Specific Tasks**

A significant area of activity over the past two decades has been the development of tools and equipment capable of taking cores very efficiently in extreme conditions. The DOSECC Hybrid Coring System, a hydraulic top drive system for deep drilling, was an incremental improvement on existing technology of the 1990’s. It was successfully employed in three projects—Long Valley, Chicxulub, and both phases of the HSDP #2 well in Hawaii. The modular barge system developed by DOSECC, the GLAD-800 system, met many of the goals of the lake drilling community for a decade. To make this system work, DOSECC commissioned a set of coring tools that has been successfully used to sample lake sediment successions and return high percentage core recovery despite the variation in sediment properties with depth. These tools have been used in several projects and sold to other drilling consortia. To meet the needs of drilling projects in deeper, larger lakes, DOSECC has adapted a system of modular barges, which will be employed initially in the Lake Van drilling project (Fig. 1).

![Figure 1. The DOSECC modular drilling barge at Lake Van, Turkey, preparing for its initial drilling operations. This system was developed by DOSECC for use in lake drilling projects worldwide. The next planned deployments for the system are ICDP drilling projects in the Dead Sea and Lake Ohrid, Macedonia.](image)

The Iceland Deep Drilling Project, which undertook an investigation of the supercritical zone of a geothermal groundwater system, developed special coring equipment that would withstand up to the 450°C anticipated at the bottom of the 4.5 km boring (Skinner et al., 2010). Unfortunately, the IDDP boring was terminated when it encountered rhyolite magma at a depth of 2.5 km. The Lake El’gygytgyn project (2008–2009) required drilling through ice in the Siberian winter. DOSECC had to adopt special procedures and equipment to ensure the ice would not give way under the weight of the drilling rig and design a suitable tent to resist the local winds and provide a heated workspace for the drillers and scientists. Such innovations by various individuals around the world indicate that most technological demands can be met and continuous cores can be extracted under difficult circumstances.

**CSD: What Works and What Does Not**

Large, complex projects are never easy to implement, especially when they involve a set of specialized skills not in the project leaders’ area of expertise (Brigham-Grette, 2010, workshop). Even without this difficulty, the workshop presentation believed drilling projects are especially difficult to initiate and conduct despite the good will and thoughtful support of the community, facilities, and funding agencies and the attainment of some excellent outcomes. This perception is based on several factors: inadequate community for guidance and synergistic interaction, a lack of some necessities in the supporting infrastructure and management, inadequate or missing direction on procedures in dealing with outcomes of the projects—both physical products and data; and, above all, a fragmentary funding system ill-equipped to meet the needs of various steps along the way. This section reviews the structure and operation of the CSD effort in the United States and points out the difficulties that community members perceive.

The overall CSD effort encompasses developing and maintaining a community of interested workers, scientific planning, and the scientific investigations themselves. CSD investigations have a pre-operational phase, an operational phase, and a post-drilling phase.
The pre-operational phase includes planning, project identification and management, team building, site survey and operational feasibility studies, and proposal development. A data-management system should begin collecting information as the project takes concrete form. The operations phase includes operational planning, project management, logistics, drilling, initial sample characterization, and instrument installation, if any. Data management here emphasizes collection of drilling, imaging, and whole core or downhole measurements as well as the initial core description. At the conclusion of the drilling phase, data will begin to flow from any sensors placed in the hole. The post-operational phase includes sample distribution, study and measurement of the samples, analysis of the data, publication of results, collection and archiving of all data produced, and archiving of cores and samples. Archived data and cores should be thoughtfully catalogued and made available to future investigators. These phases are not sharply differentiated and, to some extent, overlap. Because the most pressing problems are those related to the scientific projects themselves, they should come first in the discussion.

**Participation in CSD Projects**

Many CSD projects involve international teams of collaborators investigating key problems at world-class sites. Other projects are implemented entirely by participants from a single nation that address similarly major questions at ideal sites. The workshop participants saw both arrangements as desirable, i.e., they supported projects with only U.S. participants funded exclusively by U.S. agencies as well as a strong U.S. program with international funding and the full participation of U.S. scientists in international programs. They also noted that it was important for international investigators to participate in U.S.-based projects.

A strong national U.S. program that funds parochial projects as well as international ones is a benefit for the entire international CSD community, in fact the entire Earth science community. A strong overall program creates opportunities to investigate key topics and for individual participation in all funded projects.

Over the history of the ICDP, CSD has become a truly international activity, as Cohen (2010, workshop presentation) has pointed out in his keynote presentation at the workshop. While nearly 75% of the lead PIs in the 15 ICDP drilling projects from 1998 to 2004 lived in the United States, U.S. PIs were leads on only 5 of the 12 (or just over 40%,) of the projects implemented between 2005 and 2010 (Fig. 2). Other countries, especially Germany and China, had become major players; together German and Chinese PI’s led half of the funded projects during that period. Of the 25 projects currently in various stages of development, U.S. investigators are lead PIs in 5 (20%) while German scientists are leaders of 6.

One can alternatively argue that the data compiled by Cohen (2010) show that U.S. PIs are not competing effectively or that they face difficult challenges in developing projects where drilling is necessary for getting the crucial data. One of the themes that came forward clearly from the community during the workshop was that U.S. investigators face real obstacles to developing successful proposals.

**Identifying the Targets**

Some targets are selected simply because they stand out. The San Andreas Fault is an obvious target for exploring how faults work because it is a very hazardous type of fault common in many parts of the world, some densely populated; it is easily accessible; and it is well known geologically, seismically, and by the general public. Similarly, the Hawaiian mantle plume...
is perhaps the best example of its kind. Hawaiian volcanism has been extensively studied, attracting the early attention of investigators seeking to understand the dynamics of plume magmatism. Other targets are developed through an organized planning process, such as the PEP (pole-equator-pole) transects of lake sedimentary records developed by the Quaternary paleoclimate community to provide global-scale information on past climate (Colman, 1996). Topical scientific planning is a key activity that warrants its own discussion (see “Topical Science Planning” below). Obscure, but highly significant targets may come to the attention of investigators as a matter of chance; when the Bosumtwi and Lake El’gygytgyn impact structures were being drilled for their lake sediment record, the opportunity to explore the structure formed during impact process was simply too good to pass up. As the science develops, the need to identify key questions and experiments that could answer them becomes more important. An example of such tropical planning is the 1995 PAGES workshop. However, no plan should be allowed to dictate exact courses of action or preclude other views and projects.

Preparing Excellent Proposals

Drilling projects arise out of the need to test important hypotheses or the need to explore certain key aspects of the configuration or history of the Earth. Individual projects are designed to investigate sites likely to contain vital information, wherever they may be. Because of the expense of drilling, investigators must build a multidisciplinary team to address a variety of problems or a single problem from a variety of directions. The process of developing drilling programs is well laid out in the DOSECC Best Practices manual (Cohen and Nielson, 2007; Cohen, 2010, workshop presentation). Funds are available for some of the activities needed to build strong teams and gather support from programs of the ICDP or NSF EARly-concept Grants for Exploratory Research (EAGER) grants, but not for all of them.

Good proposals require much background investigation, including field studies to characterize geology and geophysical attributes of specific sites. Hickman (2010, workshop presentation) emphasized the importance of pre-drilling investigations, both geophysical and geological. Some lake projects, in particular Lake Titicaca and Lake Qinghai, have not had adequate geophysical investigation. As a result, drilling was terminated above key objectives because of unanticipated conditions in the sediment. However, proposals for preliminary studies alone that do not pursue such goals as testing hypotheses or promising results for inquiries in and of themselves do not review well. Hence funding for background and site investigations necessary for preparing sound proposals is difficult to come by. Site surveys and other preliminary investigations may have budgets large enough to require review before funding. Workshop participants found this lack of funding for preliminary investigations a serious obstacle to preparing successful proposals.6

Building the Project Team

Because the proposal process begins after a target is identified and appropriate preliminary investigation are complete, investigators should select a group of collaborators at the earliest possible stage. If a project’s drill site is outside the investigators’ home country, it may be necessary to engage local geoscientists who could potentially become full participants through extensive contacts, possibly including exchange visits.

A project team is generally built through personal contacts followed by a workshop to broaden the group of investigators. Such project-specific workshops can receive funding directly from ICDP or from NSF and be supported with NSF or other funds administered by DOSECC as some have been in the past. Generally this process works well, although PIs must actively avoid project bloat if investigators with overlapping interests add to project costs. Because the workshop step and other preparatory steps are very important in project development, continuing support for them is necessary.

Mentoring the Nascent Proposal

First proposals for drilling projects commonly need constructive input before being submitted for review. A pre-submittal reviewer may expose obvious gaps in the proposed science, suggest new participants, or even suggest corollary investigations that complement the proposed project. ICDP invites pre-proposals that receive careful evaluation and input (Hickman, 2010, workshop presentation). A comparable stage of nurturing would greatly assist U.S. scientists not looking toward projects with international scope and could provide additional resources for U.S. scientists wanting to develop international projects. To the extent that projects cannot take advantage of the ICDP process or other resources, and if demand warrants, such a process might be established in the United States.

6 In Germany, the DFG-ICDP program funds site surveys, including those for international drilling projects based in Germany, including those that involve US investigators (Torsten Halberstatt, personal comm., 2010).
While samples and data from boreholes are absolutely necessary for certain classes of projects, the broader geological community and specifically reviewers of proposals may balk at the substantially increased costs of drilling to get essential information. The NSF review process, which currently includes information on the costs of drilling, thus may stand in the way of funding excellent proposals. Directors of NSF core programs report that if their relatively small budgets were disproportionately committed to grants requiring drilling, other excellent proposals would be excluded. In contrast, some facilities have equipment or other resources provided by funding agencies for the use of funded investigators at little or no cost to budgets of core programs. Investigators who require costly drilling should not have to compete for funding with investigators whose science does not require such high expenses for gathering data.

Funding drilling and funding science. Several sources of funds for drilling programs exist. ICDP provides partial support for drilling operations, averaging about 17% of the overall operational budget (Detrick, 2010, workshop presentation). National science agencies, such as NSF in the United States, are called upon to provide additional drilling funds plus the funds for scientific investigation. This arrangement creates a disconnect between funding for drilling and science, especially in international programs where drilling money comes from ICDP and a non-U.S. science agency but where U.S. investigators seek funds for scientific investigations from NSF. The situation is compounded for U.S. investigators because it is also possible to get support for either drilling or science, or both, from other agencies, including NASA (especially for study of impacts and aspects of the deep biosphere), the Department of Energy (DOE); and even the Department of Defense, IODP (Integrated Ocean Drilling Program) has funded projects that investigate continental margins or structures crossing from the continental to the ocean realm. Industry has been a significant source of funding for some projects.

It is worth reviewing examples of projects involving U.S. investigators, or conducted in the United States, that have substantial resources for drilling but inadequate, or potentially inadequate, science funding. Drilling for the Newark Basin Project was funded almost entirely by Amoco, which had an interest in shaking down a mobile drilling rig and investigating petroleum source rocks in a rift setting. While some spectacular results have been achieved during the project, limited science funding has prevented many in-depth studies of the 10 km of core recovered. In another case, drilling for the Iceland Deep Drilling Project was largely, but not entirely, funded by geothermal energy interests in Iceland who sought information on supercritical steam as well as a potential production well. This would have provided holes and cores for study if, unfortunately, the drilling hadn’t been terminated 2 km above the target when the borehole encountered rhyolite magma. However, even if the project had not been terminated, the science still might not have been done if funding for it had not become available. In an upcoming example, DOE, ICDP, and the U.S. Air Force are funding coring operations in the Snake River Plain in 2010–2011, with drilling expected to start about August 15, 2010. However, the scientific study of the cores by U.S. investigators may be incomplete because of lack of funding for scientific studies from NSF. A revised proposals for funding is being submitted.

These examples highlight two concerns. First, building a funding program from multiple sources requires separate proposals, in different formats, and with different submission deadlines. When matching funds are required, a funding decision by one agency may depend upon that of another. A higher level of coordination among the funding agencies (NSF, DOE, USGS, ICDP, etc.) might smooth the inconsistencies. Coordination among the NSF, DOE, and USGS is already required by Public Law 100-441, the Continental Scientific Drilling and Exploration Act, but it has not occurred for several years.

The second and greater problem is that drilling funds may be available while science funding is not, or possibly vice versa. This has been a significant barrier for U.S. investigators wanting to participate in international projects funded by ICDP and other nations. It is also an issue when drilling funds for U.S.-led projects come from non-NSF sources that do not fund laboratory analyses of cores and other samples, data, or possibly initial core description.

Current funding (Fig. 3). NSF-EAR (Earth Sciences) has historically provided $1.2 million in baseline support for CSD. This includes $500,000 for support of the DOESCC facility and $700,000 as its contribution to ICDP. Over the past decade (1999–2008) NSF has provided an average of $800,000 annually to DOESCC for drilling operations either directly or through subcontracts with other institutions. Other projects may receive additional support from NSF notably Lake El’gygytgyn and SAFOD, which received significant funding from EarthScope. Total funding averages several million dollars per year. In addition,
NSF-OPP has funded parallel drilling organizations, such as ANDRILL and SHALDRIL.

The equivalent of most or all of the $700,000 that NSF has provided to ICDP has come back to U.S. investigators as support for their own drilling projects and international drilling projects in which they participate; annual ICDP funding to DOSECC for drilling and equipment has averaged about $1 million, although that includes international projects that may have little or no U.S. participation. The actual amount of drilling funds from NSF to DOSECC, including pass-through funds awarded to other institutions, has ranged from zero in 2009 and 2010 to an annual maximum of $2.9 million, which came during the peak of the HSDP drilling in Hawaii. ICDP funding fluctuated from just over $400,000 to nearly $3 million between 2000 and 2009 (figures from Nielson, oral and written comm., 2010).

The funds from ICDP and NSF to DOSECC include directed purchase of some equipment. Equipment purchased for particular projects can be used for other projects without capital cost to the later investigations. Other equipment has been purchased by DOSECC from its own resources. Because DOSECC charges depreciation on that equipment to drilling projects, cost for that equipment is also included in the NSF and ICDP support. In 2009, DOSECC received no money from NSF, and no NSF-funded drilling projects occurred. These figures do not include funds for scientific research on cores, nor do they include funding for LacCore or other repositories that receive CSD cores. With about $2 million per year (to DOSECC, to ICDP, and for drilling), not to mention the increments for specific projects such as that for SAFOD, which as a portion of the EarthScope program, the total expense shows that agencies have been funding a substantial effort in continental scientific drilling over the past decade. Furthermore, that effort has triggered contributions from other sources, both governmental and private (Detrick, 2010, workshop presentation). However, the workshop participants believe the funding needs to be coordinated more closely and regularized.

### Getting from a Funded Proposal to Drilling

Local connections and final preparations must be made between the time necessary grants are approved and the onset of operations. When several sources of funds are involved, all parties must understand who is paying for what, and the commitments and expenditures must be coordinated. Brigham-Grette (2010, workshop proposal) emphasized the importance of making high-level agreements with political and scientific authorities when developing international drilling programs. It is necessary to have reliable contacts in foreign countries who can smooth the way for permitting, making local arrangements for support services, and transferring funds. This issue plagued the Potrok Aike (PASADO) project when the local support had not anticipated and solved the many problems that arose (Nielson, personal communication, 2009). In another situation, the Lake El’gygytgyn project required permission to import foreign equipment and to bring foreigner visitors into the Chukotka province (Table 3). Even in areas where local officials understand the importance of scientific investigation, rules, laws, and procedures must be observed and all

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[7] No depreciation is charged to drilling projects for use of equipment purchased with funds provided by NSF, ICDP, or other granting agencies.
TABLE 3. Permitting for the El’gygytgyn drilling project (Brigham-Grette, 2010, workshop presentation)

(1) Permission for Scientific Drilling from Russian Ministry of Natural Resources (MNR) through Rosnedra (Russian Geological Committee).

Requires: Permission from association of native people
           Permission from administration of Anadyr District
           Permission from landowner (an agricultural cooperative)
           Support letter from Chukotnedra (Chukotka Geol. Comm.)
           Permission from Government of Chukotka
           Permission from Department of Water Resources of Chukotka
           Support letter from North-East Science Center (ichthyologists)
           Permission of Chukotka Government Ecological Commission

(2) Permission from an agency of the Russian Federation for use of foreign equipment

Requires: Separate applications for every expedition
           Very detailed logistical and technical information

(3) Permission for foreigners to visit Chukotka

Requires: Passport and personal data from participants
           A minimum of 45 days to get approval

appropriate steps taken. Commonly, the process of moving from successful proposal to drilling involves travel to the area for negotiating arrangements in person. In many cultures, email and attachments are not valued as a means of developing partnerships. Efforts may need to include forays into local culture to get the blessings of individuals, as they did with the Bosumtwi drilling project.

The amount of effort needed for complex international projects can be astounding; the run-up to the Lake El’gygytgyn project required frequent coordination among an international set of central parties, trips to Moscow for one-hour meetings at a few days’ notice, and long lead times for getting equipment and supplies to a remote area accessible only part of the year (Brigham-Grette, 2010, workshop presentation).

At the time a project is funded, a formal project management program is needed to track tasks, timetables, and expenses. Such was the case for the Lake El’gygytgyn project, which involved several funding streams, some mingled by ICDP and others moving independently from and to different agencies. Before the project could really begin, it was necessary to secure the cooperation of Russian science authorities, people on the ground in Pevek (a port city on the Arctic coast of Siberia), and the various support groups and investigators.

Investigators and funding agencies should remember that making arrangements, permitting, coordinating, and sophisticated project management are all required expenses for successful projects. Those activities frequently require skills or knowledge that many science investigators do not have and divert PIs from more appropriate tasks. Funding agencies must expect and fund project management activity in the run-up to a large international project. They should also be cognizant of the fact that many preparatory activities cannot be predicted in advance. Funding must be available to carry out such activities in real time, i.e., without returning to the granting agency for permission or additional funding.

Drilling Operations

The drilling phase, including mobilization of rigs, tools, spares, and supplies to the project site; the drilling process; and demobilization back to base has generally gone well. While few projects reach the most optimistic goals of the PIs, nearly all produce a larger than adequate amount of cores and other data with which to make important conclusions. Cores commonly, or even normally, are continuous and of excellent quality. While not all projects have gone smoothly, not all investigators are entirely happy with the results, and some projects drilled into unanticipated difficulties, the workshop participants did not identify the drilling operations phase as a significant problem.

Gathering, Archiving, and Distributing

The essential products of a drilling program are the core or other samples (fluids, gasses, cuttings) and various data gathered before and during drilling and
in subsequent studies of the materials. NSF is moving toward requiring a data-management plan with every proposal (Mervis, 2010). Publication of results also needs to be a requirement of funding. Similarly, the samples recovered in drilling projects have continuing value for future investigators because cores would be very costly to reproduce, if they can be reproduced at all. It is vital that protocols be established for data gathering and management for CSD projects. Use of protocols could be strongly encouraged by requiring inclusion of plans in proposals and making plans for data management and archiving of cores and samples a criteria for review. Wide application of protocols on description and archiving probably depends most on making the systems easy to use and useful in terms of manipulating, imaging, combining, distributing, and communicating the results. Thus, any data-management system must provide online tools for analyzing and visualizing data, must convert data into widely usable formats, and must support the publication of data sets, including DOI identifiers and citations (Snyder et al., 2010, workshop presentation).

Data management. Data comes as a continuous stream from drilling projects. Long before drilling begins, the stream begins with preliminary geological and geophysical investigations at the site and planning and preparation activities that produce designs, costs, budgets, summaries, and descriptions. It may be desirable to capture pre-project legacy data for any data edifice developed during the project. During the operational phase, gathering drilling data—tools employed, depth, inclination, weight on bit, rate of penetration, mud pumping rates, log measurements made while drilling, if any, and costs—is followed by the recording of downhole logs and initial description, measurement, and imaging of cores or samples, and distribution of samples. The tracking of samples is vital, both those samples distributed immediately after drilling and initial description and those distributed to become the basis for additional investigations over time. Any instrument placed downhole also produces a data stream. Laboratory investigations produce sample descriptions, mineralogical compositions, chemical and isotopic analyses, and a wealth of metadata, such as images, data tables, graphs, and plots. Ultimately, the project itself and subsequent investigations lead to publications that can be tracked through an online, searchable catalog, and available for downloading through a digital library (e.g., the DIS of the ICDP).

Comprehensive data management, from project inception to resulting publications, must be a cornerstone for any CSD initiative. It must be an integral part of all phases of study associated with continental drilling and must include a distributed, web-based, open, and easily accessible system able to capture data when they are generated, or as soon as possible thereafter, to help insure their acquisition into the system. The data management system must accept a variety of forms of data, including legacy data and various information gathered during the investigation.

The cost of data management, which extends beyond the end of any individual drilling project, is not trivial, but baseline costs can be minimized through incremental funding to existing databases. Funding for U.S. data management in partnership with ICDP efforts must be included in project budgets and be an on-going service to communities requiring separate funding.

Core and sample description. As cores are recovered, or before they can be subdivided and sampled, they should undergo initial description and measurement, i.e., marked for depths and up direction, verbal description, imaging, and some whole core measurements (Ito and Noren, 2010, workshop presentation). Cores from lake drilling projects are initially described at LacCore in Minneapolis, Minnesota, according to established procedures. Currently, no common protocol exists for such routine initial description of other cores, although several projects have developed their own protocols.

Core and sample archives. They should undergo initial description and measurement, i.e., marked for depths and up direction; verbal description; imaging; and some whole-core measurements (Ito and Noren, 2010, workshop presentation). This is true for cores, samples, and data from Earth sciences research in general (NRC committees, 2002), but CSD cores are particularly valuable because they meet several criteria established by Maples et al. (NRC committees, 2002). That is, they are well documented and accurately located and characterized, and they have been more or less extensively studied with published results in the public domain. Most CSD cores are continuous; they contain information from most or all of the depth drilled in addition to that about any particular targets at depth. While most CSD cores are not irreplaceable or unique, strictly speaking, replacing them with closely similar material from the same location would cost about as much as their initial acquisition, adjusted for inflation, and the values measured on the new cores might not match those from the originals. Individual samples of rocks or fluids from drilling projects also have value and might be costly or impossible to replace.

Cores of lake sediment are archived at LacCore in Minneapolis (Fig. 4), but no single facility has accepted all hard rock cores collected. Cores from Phase 1 of
the Hawaii Scientific Drilling Program (HSDP) were donated to the American Museum of Natural History and are stored in a warehouse in New York City with little facility for study and sampling. Those from HSDP phase 2 are in the steam tunnel beneath the geology building at Cal Tech. Cores from the Snake River Plain drilling project will go to the USGS repository in Denver. They will not be with a number of legacy cores stored at the Idaho National Laboratory and elsewhere in southern Idaho and cores from nearby geothermal and thermal-gradient holes, which are stored at the University of Utah’s Geothermal Sample Library. At some repositories, new cores will displace cores already in storage. These facilities do not provide permanent storage, which is not a satisfactory arrangement in the long run. Other facilities are full and do not accept new material. Finally, no single protocol exists for granting access to cores or samples for additional study by other investigators.

The possibility of supporting a single repository for hard-rock cores is attractive because such a facility could provide substantial resources for initial description, whole-core measurements, and imaging and house a large number of cores in one well-known and easily accessible location. The Houston Science Center of the Texas Bureau of Economic Geology (formerly the core repository for Amoco) with its excellent facilities for study of cores is one facility that could be considered. However, several factors deserve consideration when determining the best way to store cores. First, various nations might wish to retain cores collected within their boundaries during international projects. Second, even assuming cores can be removed from their sites of origin permanently, it might be useful to have them close to the site of origin, rather than at some arbitrary site, or close to the investigators who are most interested in studying them, at least for a period of time. Workshop participants strongly favor a single destination for cores. Whether a single facility receives all cores or whether they are distributed to appropriate local sites, a readily accessible, on-line record of the location of all CSD cores and samples must be available along with information on criteria and procedures for sampling them.

Protocols for description and archiving of cores and samples and for data management. The CSD community has the responsibility to develop protocols for data management and for core and sample description, imaging, and logging. Monitoring of systems and planning for their improvement should also be a community activity. The DOSECC Science Planning Committee (SPC) is a logical organization to organize development of such protocols. LacCore has already developed protocols for initial core description of lake-bottom sediments and their imaging and sampling (Ito and Noren, 2010, workshop presentation). These protocols might offer guidance for creating protocols for hard-rock cores, although the situations can vary greatly, eg., lake cores are perishable and different kinds of data from the initial description are being sought. The community can also evaluate existing systems of data collection and management when establishing protocols. GeosciNET (collaboration of CoreWall, Geoinformatics for Geochemistry (GfG), SESAR, GeoStrat, and the ICDP Digital Information System) provides an existing, web-based data management system that could serve initial needs and be broadened as needs dictate (Snyder et al., 2010, workshop presentation). It is crucial to collect the data and archive the cores and also to prevent investigators from having to deal with a difficult system or, worse, having to invent and fund their own systems.
Nurturing the US CSD Community

A strong CSD community in the United States could make the most of opportunities for collaboration, make decisions on policy issues, engage in scientific planning, develop procedures and protocols, and keep funding agencies informed of community needs and priorities (see breakout report by Zur and Snyder below). DOSECC was formed over 25 years ago to represent the community. Although the organization has grown over the years from the original 11 to 57 institutional members, the community is not just those institutions but also comprises many individuals, a good portion of whom are not associated with DOSECC member institutions. Because the founding individuals have aged or shifted their interests, the community must continue to welcome new recruits in order to avoid entropy and, ultimately, dissociation.

To thrive, the CSD community must have ready means of communication and exchange of ideas. DOSECC has worked to maintain the community through its annual membership meetings with general or topical workshops, newsletters, and display booths at large professional meetings such as GSA and AGU. It also sponsors an annual town-hall meeting at the Fall AGU meeting jointly with ICDP. However, the community needs to develop additional infrastructure such as websites, discussion groups, and electronic mailing lists (the so called “listservs”) for rapid dissemination of information and opinion. The community also could sponsor or co-sponsor topical sessions at professional meeting on areas of investigation or on individual projects. Such sponsored topical sessions would be in preference to general sessions that draw talks from across the width and breadth of CSD investigations, where each successive talk has a scarcely overlapping audience with the others. Most facilities have support for community activities, and the CSD community should seek such support.

An important CSD activity is educating the broader community about the impact drilling could have on their research and, especially, its importance to the science as a whole. Many students and beginning professionals are not aware of the potentials of drilling or are inhibited by the perceived cost and difficulty of meeting that cost. Several outreach and community-enhancement programs exist to smooth the path for these new community members. One DOSECC program uses corporate funds to provide internships for students and others to engage in research using results of drilling projects, including cores. This small program, which funds three to five summer-long positions annually, is not well known and draws only about ten applicants each year. DOSECC also provides a list of distinguished lecturers willing to visit colleges, universities, and research institutions to publicize drilling projects, making them more accessible to faculty and students. The organization pays the visiting lecturers transportation costs. DOSECC’s Best Practices Manual (Cohen and Nielson, 2007) guides PIs and others through the process of developing and implementing drilling projects. ICDP sponsors training workshops and short courses for beginning investigators engaged in drilling projects. Such efforts to bring new members into the community and educate neophytes should be maintained and could be expanded with additional workshops, internships, and other programs. They also should be reviewed and perhaps enhanced.

Many of the scientific problems studied by CSD investigators are also under investigation by other groups who have overlapping memberships with CSD. These communities may be part of an organization parallel to DOSECC. The CSD community should take advantage of shared members to engage such parallel organizations and overlapping communities in developing joint meetings, coordinated planning efforts, and enhanced communication (see breakout report by Kaufman and Kieft below). Overlapping exists with IODP and PAGES, for example, and with communities such as fault mechanics and impact structures and processes. However, more complete channels of communication and coordination of activities would be favorable for all concerned. EARTHSCOPE, IRIS, and MARGINS (GeoPRISMS) are umbrella organizations with overlapping interests but little overlap in membership. ANDRILL, SHALDRIL, and the Astrobiology Drilling Program have overlapping interests as well. A vibrant CSD community would be the ideal group to coordinate all of the appropriate groups.

Topical Science Planning

The US CSD community comprises a number of groups engaged in different aspects of Earth science who may have independent (or partly overlapping) goals but who all use drilling to get samples and data. This arrangement has three implications for science planning. (1) Objectives, goals, and projects are best undertaken by individual segments of the overall community, which can come together to focus on specific topics. The CSD community should encourage each intellectually coherent segment to conduct its science planning independently, to set its own agenda, and to outline steps to achieve its objectives. (2) In addition, some of the objects thus outlined can further the agenda of other communities or can catalyze and facilitate their pursuit of goals within their area.
of interest. Communication is vital among the various
groups across the CSD community and with outside
groups and entities. (3) The overall CSD effort should
incorporate the activities of the component groups, but
there must be a comprehensive aspect as well; that is,
a CSD community plan must recommend the facilities,
equipment, arrangements, and other aspects of infra-
structure necessary to accomplish its goals.

A compelling example of the interplay between topi-
cal planning and developing opportunities for other
communities within CSD comes from the lakes pa-
leoclimate community. In 1995, this community had
a planning workshop under the guidance of PAGES,
the organization that investigates past global changes.
This workshop laid out a drilling program to explore
Plio-Pleistocene climate using proxy records in lake
sediments. The report proposed three pole-equator-
pole transects of lakes through the Americas, Europe
and Africa, and Asia-East Indies-Australia (Colman,
1996). In response to this interest, DOSECC devel-
oped the GLAD 800 modular drilling system, which
has been successfully used in several lakes in North
America, Central and South America, Asia, and Af-
rica. This system is limited to lakes where anchoring
is possible and to a total drill-string length of 800 m. A
larger system, capable of reaching deeper, will be used
to drill Lake Van in Turkey in Summer 2010 and in the
Dead Sea and Lake Ohrid in Macedonia in the future.
All in all, that PAGES workshop report and the plan it
endorsed have led to successful, but still incomplete,
exploration of a long segment of the Earth’s climate
history at an annual to decadal scale of resolution.

But that is not all. The lake paleoclimate effort has
permitted exploration of impact structures in Lake Bo-
sumtwi, Ghana, and in Lake El’gygytgyn in Siberia,
establishing a tradition in the lake community of coor-
dinating targets with different communities. The Lake
Malawi drilling project, by identifying evidence of se-
vere drought in Africa over the late Pleistocene and
focusing interest in exploring the effect African paleo-
climate may have had on human evolution, reached out
to a quite different community, one that lies on the
boundary between geology and anthropology. Projects
now in planning would study African climates, espe-
cially of the late Pleistocene, through further drilling
of African lake sediments and sediments of dry lake
beds to elucidate climate and its effect on human evo-
lution. Lakes record rates of evolutionary changes in
organisms, making it possible to answer fundamental
questions of biology, perhaps with methods and data
unanticipated by the biological community itself,
through the paleoclimate exploration of lakes, such as
the planned Lake Ohrid project.

While overall planning of the CSD effort is neces-
sary, most planning for the future of scientific drill-
ing should be organized at the topical level, perhaps
as topics are laid out in the earlier workshop (Table 2;
Walton et al., 2009; see breakout report by Shervais
below). Planning should be inclusive in that it should
be international and open to the entire intellectual
community that investigates a particular topic. Groups
engaged in planning should be cognizant of the inter-
ests of other topical groups within the CSD commu-
nity. However, and this is important to keep in mind,
topical planning leads to long-range science plans that
should be supported by the subject disciplinary com-
unities. Specific drilling project proposals should be
developed within the guidance of the program plan.
However, the process should allow for opportunities
to develop ideas that have not been anticipated in the
planning process. These long-range plans are vital;
they describe the current state of the art, propose hy-
potheses and tests, and identify facilities and equip-
ment necessary for further advance.

Specialized Laboratories and Advanced Equipment

In addition to identifying hypotheses or their tests, and
setting other goals for scientific advances, the CSD
community and its components must identify equip-
ment necessary for accomplishing its ends. For ex-
ample, critical components of scientific investigations
on many drilling projects must be done on site, some-
times in specialized laboratories that are in contain-
ers for easy transportation. The most obvious example
of such a laboratory is one for geomicrobiological
studies of cores and waters recovered during drilling
(Walton and Kieft, 2009). Two other examples would
be an appropriate laboratory for gathering paleomag-
etic data that might be lost rapidly after recovery
and facilities for rapid on-site mineralogical analysis
that might capture such ephemera as the rapidly fad-
ing blue mineral found in HSDP basalt cores that may
provide clues to down-hole conditions at the moment
of recovery. Overall, on-site mobile laboratories with
core description facilities and core scanning and imag-
ing equipment would make it possible to study cores
almost immediately upon recovery (See breakout re-
port by Brigham-Grette and Nielson below). In addi-
tion, some projects require special equipment during
the drilling process, such as the Iceland Deep Dril-
ling Project (IDDP) and other projects that attempt to
drill into hotter rocks. (Elders and Friðleifsson, 2009).
Similarly, drilling into core friable rocks between re-
sistant layers may require new or improved technol-
gy. Here, as in several other areas, facility operators
and funding agencies should have input from the com-
munity in assessing the need for and design of equipment or laboratories.

**The View from ICDP**

At the workshop, Hickman (2010, workshop presentation), as Chairman of the ICDP Science Advisory Group (SAG), presented his view on how the US CSD effort could become more effective in the overall international drilling program (Table 4). He called for a reliable path to site characterization, a coherent approach to funding both drilling operations and scientific studies, better coordination among the several U.S. funding agencies, and a dedicated facility for studying and archiving samples.

**A WELL-FUNDED US CSD EFFORT**

*Cost Components*

A well-funded US CSD effort would include several elements: (1) funding for community nurturing and investigator development, (2) funding for a facility to manage the overall CSD effort and services to investigators on a project-by-project basis, (3) funding for planning at the community level and for science planning within topical areas, and (4) project-specific funding. Project-specific funding has three parts: (a) planning and site characterization, (b) drilling, including on-site studies and archiving, and (c) post-drilling scientific studies. For each project, planning of logistics and additional site-characterization studies are critical to success. The drilling phase should include initial core description, data entry and archiving, some sample distribution and summary analyses, and core or sample archiving, as well as the actual drilling operation. The science phase must be adequately funded to ensure maximum potential return is extracted from the investment in acquiring samples and data, including return from investigations that will continue for years.

**Drilling Cost on Science Proposals**

Drilling-based projects may require substantially higher costs than research projects with more conventional modes of acquisition of field data or samples. Pre-drilling planning, site characterization, and preparatory activities of coordination and site-specific permitting or logistics involve significant costs, not to mention the operational funding needed to obtain the cores, samples, and down-hole data of the drilling activity itself. Initial core description and archiving of cores, samples, and data add to the overall expense. These are separate issues from the scientific investigations themselves.

Proposals for drilling projects submitted to NSF, and some to other agencies as well, now request funds for pre-drilling activities as well as for the drilling phase, disposition of materials from the project, and the effort required for analysis and publication. Many drilling proposals include a large budget for mobilization of equipment to and from remote sites. The mobilizations to Lake Potrok Aike in southern Argentina and to Lake El’gygytgyn in eastern Siberia, for example, required shipment of several containers of equip-

<table>
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<tr>
<th>TABLE 4. What is needed to take better advantage of U.S. membership in ICDP? (Hickman, 2010, workshop presentation)</th>
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<tbody>
<tr>
<td>1. A more reliable way to fund pre-drilling site-characterization studies, as needed to present a compelling case for a full drilling proposal. Currently, such studies must be sold on their own scientific merits to existing scientific programs (e.g., NSF, USGS, NASA) without regard to the merits of an eventual drilling proposal.</td>
</tr>
<tr>
<td>2. A more unified and coherent approach to obtaining co-funding from multiple U.S. funding agencies in support of drilling operations and for essential science investigations. If one or more of these “legs of a stool” falls through, then the project has to be significantly de-scoped, delayed, or cancelled. <em>(Average ICDP support is 17% and is for operations only.)</em></td>
</tr>
<tr>
<td>3. Better coordination among U.S. agencies (NSF, USGS, DOE, DOD, NASA) in support of scientific drilling, both during evaluation of proposals and during project implementation. This might also help build strong interagency support for new scientific drilling programs in the United States.</td>
</tr>
<tr>
<td>4. A dedicated facility for sample handling and long-term curation. Except for LacCore, there is no centralized core facility in the United States for continental scientific drilling and each project has</td>
</tr>
</tbody>
</table>
Drilling and supplies over sea routes and roads in remote areas over several months. Program directors are led to choose between funding expensive projects that would disproportionately deplete the budgets of core programs and funding several other excellent proposals. Workshop participants perceived drilling costs are a great burden to any proposal during the review and funding process, no matter how excellent the science, unless the higher costs can be addressed outside of the budget of core programs.

**Drilling Support as the Key Resource**

Other areas of scientific research where the data collection is expensive or requires specialized equipment offer a comparison to the situation faced by CSD investigators. In many instances, the equipment or facility is funded independently of the science in anticipation that science proposals will lead to efficient utilization. There are numerous examples of this: IRIS’s (Incorporated Research Institutions for Seismology) equipment inventory, ships of the UNOLS (University-National Oceanographic Laboratory System) and IODP fleets, support for investigators in the Arctic and Antarctic through Polar Programs, telescopes used by astronomers, and specialized high-level computer facilities, to name just a few. To some extent, funding from ICDP can be envisioned as support for a certain amount of drilling, if not a certain number of drilling days (see breakout report by Brigham-Grette and Nielson below).

Drilling equipment and crews, or rather *drilling time*, is analogous to the equipment, ships, and telescopes of other initiatives. If drilling time were funded, based upon anticipated demand from a number of investigations, individual proposals could be funded on their scientific merit and worked into an optimized schedule. Drilling time in the instance of non-lake projects would include onsite initial core description, imaging, and data entry. For lake drilling projects, the existing LacCore arrangements would suffice as the site of core description as well as being the ultimate destination of the archived materials.

Many factors complicate the simple calculation of cost of drilling time. Some projects require shallow drilling and low-capacity equipment while others require larger equipment capable of drilling to depths of a several hundred or a few thousand meters. Furthermore, for deeper holes already requiring bigger, more expensive equipment, the rate of penetration generally declines with greater depth due to longer trip times so that drilling time is equivalent to some exponential of depth, where the exponent is somewhat larger than one. In addition, rigs in transport are not available for other uses, and mobilization time can be substantial, especially when it includes transportation across the sea and through customs at international boundaries.

These circumstances led the workshop participants to conclude that core-drilling activity should be supported by a block grant, and that a drilling facility and the CSD community should optimize the return on that investment through careful coordination of project schedules (see Brigham-Grette and Nielson breakout report below). A block grant would allow the facility to develop operational and staffing plans on an annual, or even longer term, basis while providing for maintenance of the equipment. Such scheduling might result in some efficiencies, such as the execution of several projects being carried out in the same region of the Earth during a set time frame. As an example, DOSECC has shipped its expanded lake drilling system to Turkey and plans to leave it in that area for subsequent projects in Israel and Macedonia. With appropriate advance announcements of such scheduling, investigators could submit proposals or reschedule projects to take advantage of specific time frames. Funding based on a block grant would allow investigators to schedule their activities several months to a year or more in advance to take advantage of favorable weather windows, based upon records of past climate. The concept of funding block grants would allow funding agencies to evaluate the project stream and adjust the budget for drilling, especially if it is part of a cooperative agreement, within the annual budget. Finally, if multiple sources of drilling funds are available, they could effectively extend the amount of drilling either for the whole community or for specific projects, as desired or as structured by the funding agency.

**Multiple Funding Sources**

Multiple potential funding sources besides NSF and ICDP exist for projects. Other federal agencies, such as USGS, DOE, and NASA, have funded drilling at some level, as have and other facilities, such as the Mission Specific Platform element of the IODP (De-trick, 2010, workshop presentation). USGS studies in particular are crucial to pre-drilling site surveys in many projects in the United States. The explorations of the Astrobiology Drilling Project in the Pilbara craton of Western Australia have been funded in part by a private foundation (Anbar et al., 2010), much as Darwin wished a rich man would fund drilling to test of his hypothesis of formation of coral atolls (Cohen, 2010, workshop presentation). For some projects, industry can be a major contributor. Energy interests in Iceland contributed much of the drilling for the recent
the potential for exciting and transformative science with samples and data from drilling projects. With funding for science and drilling linked, proposals must overcome formidable obstacles in the funding process to compete successfully. Tying drilling money to specific projects has also created a boom and bust situation for DOSECC, the drilling facility, which prevents optimizing personnel, equipment, and scheduling to allow the most efficient use of resources. If proposals do survive review, program directors are commonly at a loss to fund them without gutting the program’s budget to the dismay of other investigators who get their samples by less costly means.

In addition, without a firm commitment of community-development funds, the diverse community lacks cohesion. Without a strong community, the planning process is haphazard, that is to say, virtually non-existent. This overall situation appears to have discouraged U.S. investigators from developing proposals requiring drilling and has left the leadership in CSD to investigators from better-funded nations. The current situation does not fulfill NSF’s mandate to foster scientific investigation, at least in areas where CSD provides essential materials. Workshop participants concluded that the current funding arrangement is not suitable.

**Funding a Facility**

Because the status quo is not in the best interest of the community or of NSF, it is necessary to re-arrange the funding of the US CSD effort substantially. A facility that has funding not only for base operations but also for the drilling component of successful proposals may be a viable alternative. This arrangement would continue to provide base support for DOSECC or a similar organization and have funding for drilling operations and important related services (logging, data and sample archives) in a pool separate from core programs. Proposals would go to the core programs for review and funding of science operations. Separate operational funding would reflect anticipated demand. Base funding for a facility and the community would remain steady. This arrangement is more costly than the current one and does not deal with the issue of funding for pre-proposal site evaluation and on-site feasibility investigation (Detrick, 2010, workshop presentation).

The main advantage of a facility-based re-arrangement would be the availability of funds for a predictable amount of drilling annually, based on the stream of suitable proposals, realistic costs of drilling, mobilization, administration, and management. The levels
and history of funding, as reviewed above, and neglect of special items such as SAFOD, would suggest an initial drilling fund on the order of about $1.5 million per year from NSF would be appropriate. It is worth asking what that commitment would buy. Costs would vary depending on a large number of factors, but just to begin with, a small to intermediate size rig, such as the CS-14 in DOSECC’s inventory, would have an operating cost of approximately $8,000/day. Not counting mobilization costs, $1.5 million could fund drilling for some 185-190 days, or some 4500 m of drilling (Niel-son, personal communication, 2010, who cautions that costs and amount of drilling are estimates suitable for back-of-the-envelope calculations only). Several recent lake projects have run about 90 days of drilling, with mobilization and de-mobilization for projects in remote areas taking up to 6 months, total. Allowing for drilling, mobilization, de-mobilization, and maintenance, $1.5 million would more or less fund a CS-14 class rig for two projects a year. This level of activity would be adjusted based upon the actual project demands and the availability of drilling money from other sources, including, but not limited to, ICDP.

Providing a base level of funding would meet the goal of separating drilling costs from the costs of scientific investigation and permit drilling proposals to NSF to compete on a more level field during review and funding by core programs. This arrangement would make funding for drilling activity parallel position with support for other NSF-funded facilities because a pre-determined amount of money would be allocated annually for drilling. With such a commitment, the schedule for completion of projects could be optimized in terms of space, time, and expense. Staff could become permanent, rather than contracted for individual jobs. Grants or contracts from DOE and other agencies would increase the amount of drilling possible. Over time, the level of NSF support could be adjusted annually through a cooperative agreement with the facility to reflect proposal pressure and the stream of projects or particular high-cost efforts, such as HSDP or SAFOD.

With an allocation of resources for drilling, a reasonable extension would be to fund other vital project-related activities through a facility. Currently, DOSECC is charged with developing budget estimates for drilling programs and providing other aspects of support for principal investigators. That must continue. Project management is necessary to plan project activities most effectively, control costs, allocate costs among several sources of funding correctly, and provide timely information on the funds expended and remaining (Rack, 2010, workshop presentation). A drilling facility should also have a formal program for project management because many of the funds for the project will pass through the facility. Workshop participants recommended that proposals for site characterization and other preliminary studies, vital to successful drilling projects but that otherwise might not successfully compete for funding, should be funded through the facility.

Any facility should also receive funds that could be used to nurture the community and conduct planning efforts. This would greatly strengthen the overall US CSD effort. The main agency of community nurturing is the DOSECC Science Planning Committee (SPC). This committee will need funding for meeting-related expenses and such efforts as publicity and other communication with the community. The SPC has been charged with catalyzing and overseeing planning for the US CSD effort and science planning of individual topical communities. These efforts could be funded through a facility, either as base funding or as special purpose add-ons.

The sum of drilling, nurturing, and planning, would make the CSD facility parallel with other facilities in the Earth sciences. Such a facility should probably enter into a cooperative agreement with NSF that would specify various tasks. Money could be allocated through annual negotiations.

A CSD Program Parallel to NSF-ODP

This option envisons an NSF-EAR similar to the ODP in Ocean Science, with an operator and a budget for number of drilling projects per year and full support for all aspects of the US CSD effort. It would offer one-stop shopping for PIs, have continuous support for the infrastructure, and enable the community to develop a science-driven plan. However, a division-level program is costly and must have a substantial flux of projects to justify the cost, including the opportunity cost to other programs. Also, the science could potentially take on a life of its own that would be out of line with overall EAR goals and those of individual programs (Detrick, 2010, workshop presentation)

Workshop participants believe that a major reason the US CSD effort faces perceived obstacles is lack of a central focus at NSF, its key source of funding. In the current arrangement, the DOSECC facility is funded through the EAR-IF and funds for projects come from various core programs. No one individual at NSF or other U.S. agency is committed to the overall CSD
effort; some program directors are very cognizant of the need for a drilling program but are apprehensive about the effects of drilling projects on their program budgets. The workshop participants believe that a formal program with a director and a budget would successfully address the various issues the community faces. We should work toward this type of program over time, as it becomes obvious that this would be the most efficient arrangement.

RECOMMENDATIONS: THE SENSE OF THE WORKSHOP

Funding

A strong US CSD program requires funding for not only drilling and scientific investigations of the resulting core or other samples and data, but also for project-development, community-building, and topical-planning activities. The unanimous sense of this workshop is that facility funding is needed to carry out drilling and community-development and project-development activities, and that a formal program—with a designated director and a budget—at NSF would most effectively manage the overall effort.

Program. NSF should develop a program in continental scientific drilling that will hold money for drilling, planning, and community activities, and jointly review proposals for drilling projects with appropriate core programs that provide for science activities. Although NSF program directors communicate about various issues related to funding projects and are effective at working together, the community believes that a common point of reference would serve the interests of the community. If the level of activity warrants, the program could be independent with its own director.

Facility. A facility for continental scientific drilling would receive an annual budget through a cooperative agreement for expenses directly related to drilling operations, including transportation, crews, and expenditures. It would also receive necessary funds for project management and administration related to drilling activities as well as funds for administration of the US CSD effort and general support of the international effort where U.S. investigators are involved. Historically, NSF has provided $500,000 for support of the facility plus and an average of $800,000 for drilling operations annually. These figures need to be adjusted in light of the level of activity of the community, the flux of proposals, and inflation. A figure of $1.5 million for drilling operations plus about $500,000 for facility operations, community support, and other activities is an initial working target.

ICDP. NSF should continue to contribute to the ICDP and be active in its management. Continued close involvement of members of the CSD community in ICDP activities is essential.

Interagency coordinating group. The Interagency Coordinating Group (USGS, NSF, and DOE) should be reactivated, as required by the Continental Scientific Drilling and Exploration Act of 1988, and possibly enlarged (at least informally) to include agencies such as NASA who support science where drilling is necessary. Any revival should ensure that effective communication is maintained with such parallel agencies as ICDP and IODP.

The US CSD Community

Representing the community. With staff support from a CSD facility, the DOSECC Science Planning Committee (SPC) or a similar, broad-based group could serve as the organizing entity and voice of the community. The committee could oversee a planning process and development of protocols, formulate positions on issues facing the community, organize communication within the community and with external stakeholders, both domestically and internationally, and otherwise see that the interests of the CSD community are met.

Planning. Each of the intellectually coherent components of the CSD community should work with parallel groups and overlapping communities, nationally and internationally, to develop its own science plan. Such efforts should include reviewing the state of the science and results of any previous plan and establishing long-term goals as well as those attainable over the next three to ten years. Plans should emphasize exciting and transformative science and the means to achieve it.

Planning for the overall US CSD effort should be a key community activity. The community should meet periodically to identify key scientific questions that could potentially be answered based on the results of drilling projects and to determine how samples and data should be made available. To some extent, such plans would have be generalized and, in many respects, would summarize the more specific topical-science plans. However, one of the most important objectives of community-wide planning would be to develop a mission statement, vision, and strategic plan for the overall community.

The SPC is the logical group to organize and oversee the planning process and to ensure that the process is open, comprehensive, and sound, and that the results are published in accessible forms. Neither the overall CSD plan nor the individual topical science
plans should be rigid guides to what can and cannot be done. Instead they should be open to changes in whatever agenda they set as ideas emerge and the situation changes.

**Communications.** Communications within the US CSD community and with external groups could be overseen by the SPC and implemented by the CSD facility. Current forms of communication (newsletters, workshops, publications, booths at scientific meetings) could be supplemented with the diverse electronic media that are available now and those that will become available in the future.

**Support.** Activities of the SPC would require financial and administrative support. The administrative activity should be the focus of the CSD facility, with financial support coming from funds available to the facility and from grants for specific activities.

**Enlarging the community.** By engaging college and graduate students and encouraging neophyte investigators, the US CSD community can ensure that drilling will remain a viable means of addressing appropriate scientific questions in the future. By reaching out to the general public and especially primary and secondary educators and students, the US CSD community will enhance the understanding of its mission, the Earth sciences, and science as a whole.

The community should encourage further involvement of undergraduate and graduate students in the various projects as visitors, volunteers, and research assistants. DOSECC should also continue and expand its program of CSD internships to sponsor further research on new and legacy data from drilling projects (see sidebar).

The SPC should consider ways to expand to neophytes the existing support, such as the DOSECC best practices manual and the ICDP short courses for investigators of drilling projects.

### DOSECC Internships and Research Grants

Since 2000, DOSECC, Inc. has sponsored a competitive program of internships and grants for students and teachers to study cores and other materials collected from drill sites. Most recipients have been graduate students at U.S. universities, but some have been undergraduate students or from non-U.S. institutions. The program was intended to be open to primary and secondary teachers as well, but no funds for them have been awarded. Funding comes from income on the money institutions have paid into DOSECC as they join. Awards range from $2000 to about $5,000 annually, with each year’s total budget being $8,000 to $15,000, depending upon the income on the funds. Since 2000, DOSECC has awarded $110,710 in support for investigations of materials from drilling projects. The recipients are invited to the annual DOSECC workshop to make an oral or poster presentation.

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<thead>
<tr>
<th>Year</th>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
<td>2000</td>
<td>Angelique Emerson</td>
<td>South Dakota School of Mines and Technology</td>
</tr>
<tr>
<td>2001</td>
<td>Richard Hermance</td>
<td>Utah State University</td>
</tr>
<tr>
<td></td>
<td>Amy Gaffney</td>
<td>University of Washington</td>
</tr>
<tr>
<td></td>
<td>Rebecca Carey</td>
<td>University of Hawaii at Manoa</td>
</tr>
</tbody>
</table>

Figure 5. Kelly Bradbury, 2008–2009 DOSECC intern from the Utah State University, describes a segment of the SAFOD core as part of her research.
Cores, Samples, and Data

Much of the physical results and the numerical, verbal, or graphical products of each project have continuing value and should be available for future investigators. The community, probably under leadership of the SPC, should develop protocols that guide material handling and data management. Protocols should give guidance on what to save, how to preserve it and how to make it accessible. A CSD facility would be a logical clearing house for operation and management of any system of archiving cores, samples, and data.

**Data Management.** Each project should propose a data-management procedure in conformance with protocols developed by the community. The system should be comprehensive in that it would include or be linked to pre-drilling information, drilling data, and post-drilling scientific studies, including publications. It also should be accessible, easy to use, and provide enhanced value because of tools that allow summarizing, manipulating, and displaying data. Funding for immediate costs of data management should come with funding for a project or through the CSD facility, but system development and long-term maintenance of the data archive should be funded directly.

**Core handling and initial description.** The protocol for core handling and description should include the current procedures followed by LacCore and new procedures for hard-rock cores, including marking, description, imaging, and making whole-core measurements before sampling. Most or all of the hard-rock core work could be done on site. Specific protocols would be necessary for geomicrobiological investigations. Protocols could be informed by existing standards from IODP, ICDP, LacCore, and other organizations.

**On-site Laboratories.** Cores should be described as close to their time of extraction as possible and in a suitable laboratory. This would require developing a number of mobile laboratories for specific tasks in the process of core description, measurements, and imaging. For deep biosphere sampling, immediate sam-

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<th>Institution</th>
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<tr>
<td>2002</td>
<td>John Solum</td>
<td>University of Michigan</td>
</tr>
<tr>
<td></td>
<td>Greg Balco</td>
<td>University of Arizona</td>
</tr>
<tr>
<td></td>
<td>Debbie Balch</td>
<td>University of Arizona</td>
</tr>
<tr>
<td></td>
<td>Holly Godsey</td>
<td>University of Utah</td>
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<tr>
<td>2004</td>
<td>Angela Isaacs</td>
<td>Utah State University</td>
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<td></td>
<td>Anna Leigh Wagner</td>
<td>University of Colorado</td>
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<td></td>
<td>Jason Ressler</td>
<td>University of Rhode Island</td>
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<tr>
<td>2005</td>
<td>Sarah Draper</td>
<td>Utah State University</td>
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Plying under suitable conditions is especially pressing and needs to be addressed before serious exploration of this important component of the biosphere can be attempted.

**Core archiving.** A core and sample task force should examine the current options for core storage and develop recommendations on a central or dispersed core-storage capability and about providing samples to future investigators. A readily accessible listing of archived cores, their location, and the procedures used to obtain samples should be made available.

**Education and Outreach**

*Continuing programs.* DOSECC should continue its programs of student internships, distinguished lecturers, newsletters, and booths at appropriate professional meetings. The DOSECC internship program has always been open to K–12 teachers as well as undergraduate and graduate students. These programs should be made more visible through handout material, prominence on the website, mailing and e-mail distributions, and occasional advertisements in appropriate printed media.

*Undergraduate and Graduate Students.* The existing internship program should be expanded to include ways for student volunteers and paid student workers to participate on site at drilling projects, especially in the United States. Such a program could be a CSD community-wide program or part of each individual program.

*K–12 Education.* A CSD facility should take steps to provide meaningful material for K–12 education. This could include project-specific material about the goals, procedures, and accomplishments of CSD activity. Materials must be grade specific and tailored to science objectives on a state-by-state basis.

*Web-based interaction for Students.* Projects should develop web sites so that college and K–12 students could follow progress and see the results of drilling projects. This would be especially interesting for students at institutions and schools near a site, where field trips would be possible.

*Exhibits for students.* Exhibits of drilling-related equipment, samples, and data would be useful for primary-secondary and college-level instruction. Small, portable drilling rigs should be available for use at field camps for undergraduate geology students to educate them concerning the utility of drilling and to provide additional information to help them resolve geological problems or test hypotheses, perhaps even hypotheses they develop themselves.

**Press and media.** A CSD Facility should have general materials about CSD available for distribution to the press and video media and a roster of contacts for various topics where CSD programs have been active (e.g., earthquakes, volcanoes, CO₂ sequestration, geotechnical investigations, deep time, deep biosphere, paleoclimate, impacts). It should also work with PIs to develop project-specific materials and media contacts.

**Two Final Thoughts**

First, the CSD community should provide input to ongoing NRC studies about the unique capability of drilling to provide samples, measurements, and instrument placement for solving key problems of the Earth and biological sciences. These studies are (1) “New Research Opportunities in the Earth Sciences at the National Science Foundation” and (2) “Review of the Scientific Accomplishments and Assessment of the Potential for Future Transformative Discoveries with U.S.-Supported Scientific Ocean Drilling” (Olsen, personal communication, 2010).

Second, when making decisions about format and levels of funding, funding agencies should seek and respect thoughtful input from the CSD community. At the same time, the community must understand the need to justify its requests for support and the limitations faced by funding agencies.

**CONCLUSION**

Cores, subsurface rock samples, fluids and gases, and data from instruments placed downhole are unique sources of information used to address a number of key scientific questions in the Earth sciences, microbiology, evolutionary biology, and possibly other sciences as well. Some questions can only be answered by drilling into continental masses; for others, drilling experiments on the continents are equally as informative as drilling more expensive holes in the ocean floor and provide necessary and complementary information. Scientific drilling on land began over a century ago but became an organized multi-project whole with the founding of DOSECC in 1984. The current model focuses on specific drilling projects designed to answer important scientific questions at crucial locations. The model envisioned at the workshop advances community efforts to define topical issues of timely societal and scientific importance (such as paleoclimate studies, CO₂ sequestration, hominid evolution, earthquake mechanics);
topical (disciplinary) workshops to establish science plans that review the current state of knowledge and establish a comprehensive drilling and science program for projects that may require multiple holes at different locations over a number of years;

individual drilling and science proposals that would achieve the objectives of the science plans;

a facility that could support the community, assist in the design and implementation of projects, and conduct drilling operations;

coordination among the various funding agencies; and

a stable funding stream for drilling operations.

Historically, NSF has contributed $700,000 to ICDP, granted some $500,000 in baseline funding for DOSECC, and granted an average of $800,000 in drilling funds annually for CSD through DOSECC. It also provides substantial additional funds for parallel organizations and individual projects in addition to funds for scientific studies of cores, samples, and data from drilling projects and individual grants for various community activities. Other agencies have provided a great deal of funding for specific CSD projects. CSD is a multi-million-dollar-per-year venture in the United States.

U.S.-based investigators perceive significant obstacles to participating in international projects and to developing projects of their own, whether international in participation or not. Including drilling costs in budgets of research-grant proposals, as well as funds for scientific study of the materials collected on projects, raises the costs disproportionately compared to the costs of investigations that make use of resources from funded facilities or do not require expensive processes to gather materials for study. If funds for drilling are requested, and they must come from budgets of core programs, those programs will be disproportionately depleted. Preliminary site investigations are necessary to develop excellent proposals and verify actual drill sites but commonly lack the scientific justification to survive the review process in their own right. Proposals for large, complex projects usually are not funded on first submission; in fact, commonly they need to pass through a pre-proposal stage of review and comment before final revisions, review, and ultimate funding.

The 2010 workshop participants concluded that a CSD facility, such as the existing DOSECC, Inc. facility in Salt Lake City, should receive funds for drilling, based upon maintaining an appropriate level of activity, as well as for various other CSD-related activities, including those for which DOSECC has historically been funded. As funds become available from other agencies for specific projects or continuing funding, the drilling program can be optimized in terms of cost and schedule to accomplish the goals of the community and individual PIs.

The report from the 2009 CSD workshop recommended specific steps to reinforce the CSD community in the United States. One of these steps was taken when DOSECC recharged, expanded, and broadened the membership of its Science Planning Committee (SPC). This committee is viewed as the organizing entity in CSD and its voice with supporting constituencies. The 2010 workshop recommends that the SPC encourage planning for CSD as a whole, promote topical-scientific planning by intellectually coherent components of the broader CSD community, develop protocols for CSD data management and study and archiving of cores and samples, and foster the CSD community through various means. These activities will require funding for travel and publicity, perhaps through a CSD facility or through direct grants to the committee.

Several steps, by the DOSECC facility, the SPC, or funding agencies, will help with fostering the community. The Interagency Coordinating Group (DOE, USGS, NSF) on continental scientific drilling should be revitalized and perhaps expanded, or at least should include conferees from other key groups. Education and outreach should become more aggressive, with attention paid to neophyte investigators, college students, and primary and secondary education. Enhanced communication within the community and with other interested parties should bring the advantages of cooperation in setting goals for the sciences, using multiple tools to get the most out of the investigations, and opening projects to appropriate other communities, who can advantageously make use of the opportunities presented.

An appropriate US CSD effort with clear routes for funding of excellent projects would be important for several branches of the Earth and biological sciences both nationally and internationally. This effort must include planning to define overall goals and steps to achieve them as well as topical-scientific planning for particular components of the community. A strong CSD community, well informed about its own activities and well connected with parallel organizations and overlapping communities, is in the best interest of all.
“Every time we drill a hole we find the unexpected. That’s exciting, but disturbing.”—Un-named scientist referring to results of the Kola deep hole quoted at http://www.damninteresting.com/the-deepest-hole

ACKNOWLEDGEMENTS

This workshop was funded by NSF EAR grant 1039441 to the University of Kansas with supplemental funds and sponsorship from DOSECC, Inc. Casey Etzel and the conference staff at Marymount University were most helpful in arranging for the meeting and accommodating in providing support during it. Discussions with Dennis Nielson brought the wisdom of his experience to the report.

WORKSHOP PROCEEDINGS

Breakout Reports

How Should We Organize Continental Drilling in the U.S.?
Ken Miller and Frank Rack

How to Plan Continental Scientific Drilling
John Shervais

How Should We Reach Out to Parallel Groups and Overlapping Communities?
Alan J. Kaufman and Tom Kieft

How Can We Make Continental Scientific Drilling Cheaper, Quicker, and More Productive?
Julie Brigham-Grette and Dennis Nielson

Fostering the Continental Scientific Drilling Community
David Zur and Walt Snyder
HOW SHOULD WE ORGANIZE CONTINENTAL DRILLING IN THE U.S.?1

Ken Miller2 and Frank Rack3

Successful continental scientific drilling projects require three levels of activity: pre-drilling, drilling, and post-drilling. Pre-drilling activities include planning and community development, pre-proposal evaluation and mentoring, budgeting, safety, and predrilling survey. DOSECC provides budgeting and safety functions, but a means of funding pre-drilling surveys and community development is needed. Many drilling activities are handled well by DOSECC for logistics, equipment, and drilling. Drilling activities left to the PIs include logging, defining standard measurements, data management, sample distribution and drilling information, though some of these activities can be handled by ICDP. Post-drilling activities that are poorly supported in U.S. continental scientific drilling (US CSD) include funding of data analyses, publication, data dissemination, and core archiving. A broad consensus was reached that the United States must find means to fund pre-drilling, drilling, and post-drilling for continental scientific drilling or face falling behind the international community.

Three models of funding US CSD (listed above) were discussed. The current model of funding through core NSF programs is a failure; not only are many activities neglected with this method of funding, basic drilling costs for highly ranked proposals have proven difficult, if not impossible, to obtain (e.g., Colorado Plateau drilling proposal). The United States must break from this mold and start supporting drilling activities of top-ranked proposals.

The ideal solution would be to establish a continental scientific drilling program within NSF analogous to NSF/ODP, with an implementing organization (TAMU in the ODP case, DOSECC in the CSD case), an NSF program office (analogous to NSF/ODP’s), and a central management office (analogous to that of COL(Consortium for Ocean Leadership)/USSP). It is critical that someone at NSF have a vested interest in fostering CSD. Central management would provide better and simpler coordination, allow evaluation of pre-site surveys, and establish standards for measurements, data management, publications, and core archiving.

One of the models discussed would provide a start toward establishing a viable CSD activity for programs not presently achievable. Following this model, NSF would establish facility support for drilling. Analogous to provisions in the UNOLS/IRIS model, NSF would supply drilling funds and predrilling to an implementing organization through internal process, and core programs would fund post-drilling studies.

Additional recommendations included re-establishing the interagency coordination group with USGS, NSF, and DOE; sponsoring short courses in drilling, proposal preparation, and project management; broadening of student interns programs; and establishing a school of rock for teachers.

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1See also PowerPoint presentation by Miller and Rack (2010).
2Rutgers University
3University of Nebraska.
HOW TO PLAN CONTINENTAL SCIENTIFIC DRILLING

John Shervais

This breakout session dealt with the question of how to plan for continental scientific drilling within the U.S. geoscience community. The breakout leader was John Shervais (Utah State University igneous processes); participants included Julia Wellner (University of Houston, Shaldril), Alexander Van Geen (Columbia University LDEO, arsenic in groundwater), Tom Kieft (New Mexico Tech, deep biosphere), Alan Kauffman (University of Maryland, biochemistry), Lucy Edwards (USGS, Chesapeake Bay Drilling project), Torsten Haberzettl (Friedrich-Schiller-Universität Jena, DOSECC Science Planning Committee), Scott Wing (Smithsonian Institution, Big Horn Basin PETM (Paleocene-Eocene thermal maximum) Drilling), and Amy Chen (Ludwig Maximilians University of Munich, PEMT and DOSECC intern).

The primary focus of our discussions was on how to improve internal communications among investigators already involved in Continental Scientific Drilling, or those seeking to become involved, so that expertise and experience could be shared and each project did not have to “reinvent the wheel.”

It was observed that different projects with different objectives require different approaches to be successful. Nonetheless, because a sufficient number of common problems may arise among projects, shared experience is a valuable commodity. All of the participants agreed that sharing early information on new or proposed projects was critical in order to involve the community in planning. It is important that diverse communities learn about projects before they mature and become less flexible in their goals. It was also observed that students in particular needed to find out about new or proposed projects at an early stage so that they could participate through cooperative or add-on studies; without such partnering, they could not carry out their own work. This is also true for early career faculty, who cannot afford to spend ten years nurturing a continental scientific drilling project if they wish to obtain tenure.

A central problem addressed in this session was that drilling is expensive yet the results from a drilling project are often not shared with other investigators who could benefit from the results. In most cases, a single hole or drilling project produces results applicable to diverse areas of inquiry, such as meteorite impacts and climate change. Broad community involvement could strengthen proposals that begin with a single target if projects are able to overcome funding barriers and be allowed to seek funding from diverse sources. Another issue discussed at length was that investigators working on similar topics do not always know each other or know who is doing what in their field that pertains to Continental Scientific Drilling. Thus, different investigators with the same goals may not be aware of the efforts of others, weakening the community response to similar proposals.

Suggestions for improving this aspect of planning included (1) web-based community building using tools such as Listservs or social media websites, (2) expanded use of the DOSECC-ICDP community Town Hall at AGU through more presentations and information sharing, (3) special drilling-themed sessions at GSA or AGU, which could be informal with no abstract submission required, and (4) an expanded DOSECC or US CSD Program Annual Meeting where mature or active projects would present formal project reports and nascent proposals could make short project pitches to get feedback on both science and operations from the drilling community.

Incubation funding for development of new ideas and drilling proposals was seen to be a most important issue. This funding could be staged with successive funding opportunities that would be awarded based on the success of the original funded work, which would move projects forward incrementally. The participants felt that funding for these incubation grants could be based in part on very short project pitches (e.g., 3–5 slides for nascent proposals) made at the DOSECC Annual Meeting during an open forum set aside for pitching new ideas. Community feedback on the scientific basis of a proposal, and on the drilling operations side, would allow proponents to refine and improve their proposals, making them viable for workshop funding.

It was also felt that more mature proposals would benefit from access to expertise on project management and planning. This expertise should be housed within DOSECC so that PIs could get all of their planning needs addressed centrally, and so that operational support for projects would be fully coordinated with drilling operations. DOSECC should offer not only dedicated consulting on project management and organization but provide short courses on the theory and practice of project management within the context of scientific drilling projects.

1Utah State University
Finally, it was observed that good planning requires an informed community. Thus, DOSECC should offer workshops and short courses on scientific drilling practice, from drilling and logging to sample handling to data systems and management. These would be enormously useful to the community and would give investigators interested in pursuing scientific goals through drilling the knowledge needed to make informed decisions about how to structure their project. It would also foster better communication between the drilling operations staff and scientists.
HOW SHOULD WE REACH OUT TO PARALLEL GROUPS AND OVERLAPPING COMMUNITIES?

Alan J. Kaufman¹ and Tom Kieft²

This breakout session focused on means by which to promote wider participation in DOSECC by reaching out to parallel groups and overlapping communities interested in continental drilling. The breakout leaders, Alan J. Kaufman (Maryland, scribe) and Tom Kieft (New Mexico Tech), were specifically chosen because they represent a spectrum of new investigators who wish to promote continental drilling for studies of the deep biosphere as well as biological, environmental, and climatic events in very deep—Archean and Proterozoic—time. Session participants included Ken Miller (Rutgers), Steve Hickman (USGS, Menlo Park), Julia Wellner (University of Houston), and Paul Olsen (Columbia University LDEO).

Breakout discussions focused on three specific initiatives that could be instigated by DOSECC with the direct participation of the NSF. These included: (1) organization and advertisement of thematic workshops, (2) wider distribution of ICDP scientific goals, and (3) development of new educational tools.

Thematic workshops may be the most likely target for new NSF support of continental drilling initiatives. Of particular interest would be a workshop designed to build a community of researchers interested in deep-time drilling who are focused on understanding the co-evolution of Precambrian life and environment. Although broad aspects of global biological and climatic change in Earth's ancient past fit well with the existing ICPD agenda, a workshop is desired in order to flesh out specific targets, technological hurdles, and unanswered scientific questions identified by the new community. At present, Precambrian deep-time scientific drilling activities are led by the NASA Astrobiology Institutes in Australia (for an example based on time-series elemental and isotopic analyses of a deep time drill core through the Neoarchean Mount McRae Shale, see Fig. 6) and the private Agouron Foundation in Australia and South Africa. Adding NASA as a DOSECC partner in continental drilling is desirable because it would further expand the breadth and depth of the community.

A second workshop focused on the deep biosphere was also discussed in the breakout session. Recent drilling activities in the Chesapeake Bay provide a model for integrating deep biosphere studies with ongoing continental drilling. Because of the special requirements needed to minimize contamination of core materials, deep biosphere experts need to be included in the planning stages of drilling, rather than be added on later after the main scientific objectives are codified. Putting the cart before the horse adds both complexity and costs to an integrated drilling program. DOSECC added the Deep Biosphere to its list of scientific themes following the 2009 annual meeting. The breakout panel also noted that there was a recent ICDP workshop on the deep biosphere. A new workshop should further refine the scientific drivers for deep biosphere drilling. It could include quantification of economic resources, effects of carbon sequestration, and the metabolic activities and size of extremophile communities driven by the release of hydrogen deep in the crust. The workshop also could investigate the possibility of funding a deep biosphere observatory, perhaps in conjunction with a new Sloan Foundation initiative with the Carnegie Institution of Washington, to study deep carbon storage and cycling.

The breakout panel discussed the need to reach out to parallel communities by widely distributing DOSECC goals tailored to the scientific interests of these groups, including a white paper, portfolios, and information on the structure of continental drilling proposals. The ICDP goals laid out in 1995 and revised following a 2005 workshop may be a useful guide for further development of DOSECC efforts. All breakout panelists agreed that the creation of a new umbrella program for continental scientific drilling at the NSF would best serve the DOSECC community. Such a program would protect existing EAR programs, which are not able to bear the cost of funding continental drilling or site surveys on top of funding detailed scientific studies of newly acquired core materials.

Breakout panelists acknowledged that for the success of this workshop and future efforts to reach out to parallel groups and overlapping communities, interagency coordination of efforts and funding needs to be renewed. Principle investigators should nucleate the scientific ideas that would be served by continental drilling, and program managers should make the umbrella contacts between agencies that facilitate these activities.

¹University of Maryland
²New Mexico Tech
Figure 6. Lithologic and time-series elemental (C and S) and isotopic (δ13C, δ18O, δ34S, and D33S) trends in the ~2500 million-year-old Mount McRae Shale from samples taken from the ABDP-9 (NASA Astrobiology Institutes Archean Biosphere Drilling Program) core. Trends in D33S in the lower Mount McRae Shale are correlated with equivalents in a separate core drilled some 300 km away from the core in this study. VPDB, Vienna Pee Dee belemnite; TOC, total organic C; VCDT, Vienna Canyon Diablo Triolite. Trace element and isotopic studies of this core were published in three separate reports in Science magazine (Kaufman et al., 2007; Anbar et al., 2007, and Garvin et al., 2009) all indicating that the oxygenation of the surface ocean at the end of the Archean Eon—and at least 100 million years before oxygenation of the atmosphere—stimulated the release of metals through weathering processes and the onset of aerobic microbial ecosystems.

Finally, a new educational outreach activity was discussed in the breakout panel involving the creation of a DOSECC Office of Geotechnical Information. This office would purchase small scale Winkie-type drills, a commercial product that can create a small core 100 m feet deep, and provide technical support for drilling activities for field camps and university projects (Fig. 7). Such a drilling apparatus, with secure technical support, would be less intimidating to investigators and more practical for smaller projects. It was envisioned that DOSECC would develop a proof-of-concept for the drilling community, but once this was in place, individual scientists would be responsible for funding an engineer to run the core and for transportation costs. These outreach activities would stimulate interest in continental drilling and provide experience for both graduate and undergraduate students, who would ultimately become part of the larger DOSECC community. The small-scale operations would become the stimulus for larger long-term projects.
HOW CAN WE MAKE CONTINENTAL SCIENTIFIC DRILLING CHEAPER, QUICKER, AND MORE PRODUCTIVE?

Julie Brigham-Grette\textsuperscript{1} and Dennis Nielson\textsuperscript{2}

Scientific Drilling is challenging because, simply put, its risky, expensive, and extremely time consuming to plan and execute. Figure 8 demonstrates that sometimes the planning stages overwhelm the final operations, drawing to question how we might improve on this status quo.

The purpose of this breakout group was to explore a variety of ways the science community could decrease risk while shortening the planning stages that often result in cost escalation and less time dedicated to scientific outcomes. Our discussions focused on seven themes largely focused on planning efficiencies.

\textbf{1. Partnerships with Industry}

A small range of potential projects targeted for CSD could be effectively partnered with industry when the science objectives are not necessarily the proprietary interest of the industrial partner. For instance, areas where there might be “holes of opportunity” include regional stratigraphy, basin history, geothermal resources, hydrothermal fluid geochemistry, and hydrogeology. Effectual cost sharing for science and logistics would have some tradeoffs related to timelines and data access but may still well suit the program design. An excellent example of such a partnership is the Iceland Deep Drilling Project in which NSF was a contributor (along with ICDP), but most of the funding came from industry.

\textbf{2. Establishing fixed drilling days or annual budget}

An idea that surfaced several times during the workshop was development of a drilling program within NSF that would fund a fixed number of continental drilling days per year. Alternatively, instead of days, a fixed pool of funds could be set aside. In a given year, science groups could write targeted proposals to compete for a portion of the days or funds in the fixed pool, which would be similar to the funding of a fixed number of ship days for marine operations via the UNOLS model. CSD could only benefit from the investment of NSF (perhaps partnered with DOE, USGS, or other agencies) by having an infrastructure in place for managing this fixed funding.

\textsuperscript{1}University of Massachusetts
\textsuperscript{2}DOSECC, Inc.
This type of investment could be leveraged with ICDP funds if a program met the international criteria necessary for such a partnership. It would likely require a dedicated drilling program manager and perhaps even a program office and outreach staff if the program were to ramp up in parallel with other operations planning, for example, the ice coring office or ANDRILL office run by OPP.

3. State Department and Department of Agriculture assistance with core import and export

A common lament for many projects was the frustrations associated with importing and exporting equipment and core materials in and out of the United States and other countries. At the very least, the participants felt that much would be improved by developing a centralized website with links to facilitate the movement of cores, permitting, and other shipping needs. Such a site might also provide instructions to PIs developing cost estimates for transportation and import–export taxes. The CSD community might be better served if a committee of individuals developed a liaison with the U.S. State Department, and especially with the US Department of Agriculture (USDA), to facilitate core movements, forms for core documentation, and so forth in a manner common at all ports of entry where USDA is involved. A better relationship between the USDA, Customs, and a DOSECC committee could provide the strategic outreach to head off problems locally and regionally.

4. Improving efficiency in core handling

Once a project has obtained cores, the next big hurdle is to get them split open, documented, described, and sampled. LacCore is an outstanding and essential resource for the CSD community but several people suggested some additional ideas to make this work more effectively and to shorten the time to publication.

First, some projects might benefit from hosting a containerized core-processing lab directly on site. This would not work for many international projects but ideas for more on-site processing could be developed for projects of different sizes and scope. Secondly, short courses for PIs in initial core description (ICD) might be useful where the home institution or young PIs are less experienced. This would be especially important for long-term core documentation and for ramping up a crew of international graduate and undergraduate students who the work but have different backgrounds. Finally, it was suggested that some CSD projects include funding for technical assistance with core opening in grant proposals.

5. Short courses on all aspects of the drilling process

Over the past decade or more, every CSD project has paved the way for the next CSD project, but many PIs still have felt that they were reinventing the learning process and the necessary administrative infrastructure for effective planning and management. The DOSECC Best Practices document has been an outstanding step in the right direction toward laying out the requirements for potential PIs. However, because experience is the best teacher, the participants felt that, in addition to the Best Practices, a full short course was needed in CSD management and operations from initial concept to core processing and ego management. Such a course could be developed by DOSECC and offered at regional GSAs or other national meetings with keynote speakers and instructors who have experience with large projects and can speak from the heart about proper planning. A short course would require the development of a manual, PowerPoint slides, and short course notes that could be publicly available. Everyone agreed that practical field experience also should be an important part of the educational aspect for future PIs.

6. Regional drilling programs planned out years in advance

As the drilling community and the science matures, opportunities may arise in the near future for developing regional drilling targets—that is, nested sets of separate drilling operations in a particular area. Regional coordination would reduce costs because drill rigs would not have to be shipped halfway around the world (or across the country) and back for each project. While this would not work for many programs, where it was possible, investigators could take advantage of the shared shipping and import of equipment and the decreased burden associated with the steep learning curve of adapting to national and cultural issues. The negative aspect of such regional drilling campaigns would be the risk of letting the tail wag the dog; i.e., funding weak or immature science simply because it is convenient. All projects of a nested set would have to be strong and mature at the same time.

7. Post-drilling project reviews

A final suggestion from the breakout group called for a formal periodic synthesis of CSD projects—a self-evaluation among accomplished drilling programs that would inform future projects on ways to improve management and incorporate new technologies. This could be done through DOSECC.
What is “fostering?” The breakout session participants defined it as (1) communication within the scientific community (subcommunities); and (2) outreach to early career scientists.

We must reach out to subcommunities and early career scientists. Communication should be increased by combining disciplines in individual drilling projects and providing forums for project planning, such as an annual DOSECC Workshop and an annual CSD Town Hall Meeting at AGU. This would take much forethought by project proponents during the conceptual stage. In addition, members of the CSD community should consider involving others at their institutions (the subcommunities) who might be interested in joining a project team.

Communication within the existing scientific community is essential for creating a growing awareness of the value of scientific drilling. Most subsurface investigations collect cores and rock samples and perform wireline logging; some collect fluids and gases or install monitoring instruments. Drilling, however, isn’t just about collecting core and conducting downhole logging, it can also include collecting data beneficial for synergistic activities across a range of subcommunities within the Earth Sciences such as

- global environmental and ecological change (climate change records, evolution in isolated lake systems, climate and evolution of hominins, stratigraphic architecture and crustal deformation);
- geodynamics (impact processes and structures, crustal evolution, ice sheet history and dynamics, processes and hazards at volcanoes);
- geobiosphere (microbiology, biogeochemistry, ichnofossils), and;
- natural resource systems an related environmental concerns (hydrothermal resources and ore deposits, groundwater, hydrocarbons, CO₂ sequestration).

Educating those in our own community and parallel subcommunities is the logical first step to fostering CSD. A second step would be to involve early career scientists in drilling, which is essential for the future of CSD projects. The opportunity to build contacts and network with established researchers is of great interest to students. Encouraging students to attend workshops, conferences, and symposia would help shape their career paths and make them aware of the power of drilling.

Ideas for outreach to early career scientists include

- conducting a two-day drilling short course at the GSA or other national meeting;
- including a CSD component or workshop at the 2011 GSA Cordilleran meeting in Logan, Utah, and similar future meetings;
- using the IRIS Young Investigators program as a model for a DOSECC workshop for young investigators, which could be held annually at DOSECC’s Salt Lake City location;
- conducting an afternoon CSD session before or after the annual DOSECC Workshop;
- continuing to sponsor the very successful DOSECC Grant Program and DOSECC Distinguished Lecture Series and reach out to oil companies for additional funding;
- reaching out to early and mid-career researchers who may not know about the benefits of drilling.

Breakout participants agreed that most or all of these elements for involving early career scientists should be incorporated into DOSECC’s July 2010 Proposal to NSF. That’s all great, but who is going to do it? The DOSECC Science Planning Committee, as an umbrella group, could be the lead proponents for CSD to promote all of the action items listed above.

Other ideas from the breakout session included:
• Reports from DOSECC Workshops containing summaries of CSD projects (“one pagers”)
• Informal get-togethers to discuss future projects
• Involving young investigators with future project ideas
• Topical workshops and overarching plenary workshops such as this workshop
• A USCSD website/blog/discussion groups/Wiki site/forum site
• Partnerships with industry (the mining industry is very similar to CSD, geothermal and oil and gas drilling less so)
• A central repository or portal for one-stop-shopping for project samples (geoinformatics)
• Continued participation as an exhibitor at the annual GSA and AGU conferences and international conferences as appropriate
• Increased linking capabilities/one pagers on DOSECC website
• Links with state surveys, which do a lot of drilling
• Revisiting the DOSECC membership dues and consider charging an annual due (this could fund more student grants although it may not foster community because of institutions’ budget limitations)
• Maintaining and growing the intellectual ties between subcommunities
• Adding project management aspects to class projects
• Invigorating the scientific drilling lecture series
• Greater use of list serves

Finally, the breakout participants agreed that the biggest step toward fostering the CSD community would be an NSF Program for continental scientific drilling.
REFERENCES CITED


NRC CSDC (Continental Scientific Drilling Committee), 1987a, The scientific value of coring in the proposed southern Appalachian research drill hole: Washington, D.C., National Academy Press, 45 p.


Appendix 1: DOESCC Science Planning Committee

Co-Chairs
Julie Brigham-Grette
Mark Abbott

Members
Chris Campisano
Andy Cohen
David Dinter
Wilfred Elders
Torsten Haberzattl
Linda Hinnov
Christian Koeberl
Kenneth Miller
Walter Snyder
Dennis Nielson, ex officio

Appendix 2: Workshop participants

Members of the Organizing Committee
Julie Brigham-Grette University of Massachusetts, Amherst
John Shervais, Utah State University
Walt Snyder, Boise State University
Anthony Walton, The University of Kansas

Keynote Speakers
Julie Brigham-Grette University of Massachusetts, Amherst
Andy Cohen, University of Arizona
Robert Detrick, NSF EAR
Stephen Hickman, USGS, Menlo Park
Emi Ito, University of Minnesota, Twin Cities
Frank Rack, University of Nebraska
Walt Snyder, Boise State University

Breakout Leaders
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Tom Johnson, University of Minnesota, Duluth
Jay Kaufman, University of Maryland
Tom Kieft, New Mexico Tech
Ken Miller, Rutgers
Dennis Nielson, DOSECC
Frank Rack, University of Nebraska
John Shervais, Utah State University
Anthony Walton, The University of Kansas
David Zur, DOSECC

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Sheldon Alexander Penn State University
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David Dinter, University of Utah
Lucy Edwards. USGS, Reston
John Eichelberger, USGS, Reston
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Torsten Haberzettl, Fridrich-Schiller-Universität Jena
Donna Jurdy, Northwestern University
David Lambert, NSF EAR
Rich Lane, NSF EAR
Kerstin Lehnert, Columbia University LDEO
Anders Noren, University Minnesota, Twin Cities
Paul Olsen, Columbia University LDEO
Bob Phinney, Princeton University
Alexander Prokopenko, University of South Carolina
Jim Russell, Brown University
Mairi Sherman, DOECC
Joseph Stoner, Oregon State University
Tom Torgerson, NSF EAR
Alexander Van Geen, Columbia University LDEO
Dick Van Klaveren, DOECC
Stefan Vogel, Northern Illinois University
Julia Wellner, University of Houston
Jim Whitcomb, NSF EAR
Scott Wing, Smithsonian Institution
Philippe Wyffels, DOECC
Back cover: Continental scientific drilling (CSD) is the only way to approach many topics of the Earth sciences and other sciences as well. An active, US-based CSD effort is a necessary part of the overall research spectrum in the Earth sciences, both nationally and internationally. Two issues in particular concern the US CSD community.

(Top) The lead-time between project inception (as indicated by the first contact between investigators and the DOSECC drilling support facility) and onset of drilling operations ranges up to a almost a decade, several times the duration of actual drilling operations. The community would like to promote means of moving more quickly from first defining of the project to its implementation.

(Bottom) One is that participation by US scientists in international projects seems to be declining, at least relative to that of scientists from other nations. Figures from Cohen (2010, Workshop presentation) indicate that US leadership as PI’s in developing international drilling projects (right) is noticeably less than in past projects (1998-2004 on left and 2005-2010 in center). The community believes that some of this decline is traceable to institutional obstacles to developing competitive proposals. The community hopes to encourage young investigators to participate in drilling projects and to promote arrangements that will reduce obstacles to success for drilling projects that approach questions of exciting and possibly transformative science.

Figure from Dennis Nielson, see breakout report in this volume.