GROUNDWORK
Furthering the Influence of Earth Science

Advancing Geoscience Research through CIDER

Barbara Romanowicz, *Dept. of Earth and Planetary Science, Univ. of California Berkeley, 301 McCone Hall, Berkeley, California 94720, USA;* ***Marc Hirschmann,*** *Dept. of Earth Sciences, Univ. of Minnesota, 310 Pillsbury Drive SE, Minneapolis, Minnesota 55455, USA;* ***Louise Kellogg,*** *Dept. of Earth and Planetary Sciences, Univ. of California Davis, One Shields Ave., Davis, California 95616, USA;* ***Michael Manga,*** *Dept. of Earth and Planetary Science, Univ. of California Berkeley, 301 McCone Hall, Berkeley, California 94720, USA;* ***Sujoy Mukhopadhyay,*** *Univ. of California Davis, Dept. of Earth and Planetary Sciences, One Shields Ave., Davis, California 95616, USA; and* ***Bruce Buffett,*** *Dept. of Earth and Planetary Science, Univ. of California Berkeley, 301 McCone Hall, Berkeley, California 94720, USA*

With growing technical sophistication in the earth sciences and increasing specialization within its subdisciplines, geoscientists face an organizational problem when we want to tackle grand research challenges that span many disciplines. How do we bring the various fields together to leverage their individual strengths and create something more than the sum of the parts? This is the problem that CIDER (Cooperative Institute for Dynamic Earth Research) attempts to solve.

CIDER is an institute "without walls" that brings together experts from a wide range of disciplines with the goal of advancing understanding on grand challenges that require a multidisciplinary approach and engages geoscientists at all levels to look at the entire Earth as a system. It has been funded by the National Science Foundation (NSF) since 2003, most recently through the Frontiers in Earth Systems Dynamics (FESD) program.

Why CIDER? Even though almost half a century has passed since the acceptance of the plate tectonics theory, many fundamental components of Earth's dynamic systems remain poorly understood. Some examples of questions that CIDER addresses include (a) connections between mantle convection and the forces that drive plate motions; (b) coupling between the dynamics and geochemical fluxes of Earth's surface and interior; and (c) Earth's evolution from its early violent beginnings to its modern state. Significant progress on these questions can only be achieved through efforts involving several fields (e.g., seismology, geodynamics, mineral physics, petrology, geochemistry, geomagnetism, geology), which provide complementary constraints on Earth's structure, dynamics, and evolution. All these fields have evolved to very high levels of specialization, making the latest research presented at conferences and in publications less accessible to non-specialists. Appreciating the robustness but also the uncertainties in a field other than one's own presents a growing challenge.

In establishing its format, CIDER was initially inspired by the Kavli Institute for Theoretical Physics (KITP) in Santa Barbara, California, USA, which provides an immersive environment for informal interactions among researchers in physics. KITP has a dedicated building, where each visitor has office space and access to research and information infrastructure. There are few formal activities, but interactions among participants are facilitated by the building layout, with many open areas for meetings equipped with blackboards and chairs and abundant access to coffee and tea.

Adapting this model to the specific needs of the geoscience community, and specifically to provide an intellectual framework for integrated multidisciplinary research and education, was the work of a pioneering group of enthusiasts, including Adam Dziewonski and Stan Hart, and evolved over several years by successive approximations to its present steady state.

CIDER activities are organized around a five- to six-week–long summer program, the core of which is a four-week tutorial aimed at advanced graduate students, post-docs, and faculty. CIDER encourages sustained, in-depth interactions among participants. To achieve this, senior participants are required to spend at least two weeks on site, while students and post-docs commit to the entire tutorial session.

The four-week tutorial includes two weeks of structured and intense lectures and tutorials, designed to bring both junior and senior participants up to speed in the different disciplines, with a focus on a particular "theme." The lectures and hands-on exercises target the non-specialists in a particular discipline and progressively build from basics toward current research questions and multidisciplinary challenges. All the lectures are recorded and posted publicly on the CIDER wiki (see http://www.deep-earth.org/wiki_cider/CIDER_Lecture_Collection). Lectures are designed so that informal interruptions are encouraged, inviting questions that frequently lead to unexpected discussions involving both students and senior participants. Cross-disciplinary education across generations is a valued aspect of the summer program. Most senior participants attend most of the lectures, which frequently results in stimulating discussions among several experts in the same discipline. This open environment means that the lectures differ from conventional teaching environments, providing different points of view and a better sense of the challenges and state of knowledge in a given discipline, and how the different disciplines complement each other. Assessments and evaluations by participants are administered and collected by an independent team (see http://www.deep-earth.org/wiki_cider/CIDER_Program_Evaluations).

As the tutorial session progresses, time is set aside for several plenary sessions, in which junior and senior participants together are encouraged to propose topics for multidisciplinary research projects. Their relevance to CIDER and to the annual theme, as well as timeliness and feasibility, are discussed. This is a remarkable self-organizing process—while nothing is planned or preprogrammed, it always seems to work!

By the end of the two-week lecture session, five to seven research topics emerge, each involving groups of about five to eight participants, balanced in disciplinary

GSA Today, v. 27, https://doi.org/10.1130/GSATG329GW.1.

expertise, composed of individuals at all stages of their career. Examples of such projects include evaluation of the possible processes leading to growth of the inner core, assessment of the global scales of mantle heterogeneity, and evaluation of fluxes of subducted volatiles.

Once the groups are formed, they spend the following two weeks working on the selected research topics (Fig. 1). Typically, a group will start by reviewing the relevant literature and performing simple computations. In two weeks, there is rarely sufficient time to complete the research, but many of the groups are able to identify a roadmap for future steps, and continue working together over the following year, with modest support from CIDER. This can have various outcomes, ranging from presentations at American Geophysical Union (AGU) to publications and collaborative proposals.

The progress of the research groups is presented to the community at a one-day workshop held at The University of California Berkeley right before or after the meeting of the AGU each December. In addition, CIDER provides support for two or three multidisciplinary working groups each year (see reports at http://www.deep-earth.org/wiki_cider). These working groups, formed independently of the summer programs, bring together 10–20 scientists from different disciplines to advance the understanding of, or define research goals for, specific topics or concepts. For example, a working group was formed in 2013 to define what is needed to construct the next seismological global Reference Earth Model (REM), with input from the mineral physics and geodynamics community. It was decided that the next REM should include long-wavelength 3D structure, which is by now well constrained. An international effort to construct the REM is now under way, supported by the NSF.

Most importantly, CIDER provides a platform for successive generations of very early career scientists to encounter their peers from different disciplines, forming lasting professional relationships, and to interact with some of the leading senior experts in our field. Conversely, for the senior participants, it is an opportunity to get to know the upcoming generations. CIDER summer sessions include many opportunities for informal interactions, such as joint lunches and twice-weekly dinners/barbecues. Also, because CIDER is such a long program, we make all possible efforts to be family friendly. Numerous dual-career couples with young children have participated in the CIDER programs. Many former CIDER students have gone on to faculty jobs and are now returning, five or more years later, as lecturers, substantially improving the age and gender distribution of the latter. Such was the case for six of the lecturers in the 2016 CIDER program. Other alumni have gone on to successful careers in business, politics, or government, benefiting from CIDER through experience in building and leading teams, working on open-ended problems, thinking about complex multidisciplinary problems, and learning how to communicate across disciplines. A future challenge is to assess and quantify how CIDER experiences have impacted the careers of participants, the nature of their research, and the impact on interdisciplinary collaborations, over both short and long time scales.

Summer programs on topics related to the deep Earth have been held every two years at KITP since 2004. CIDER participants take advantage of exposure to concurrent KITP programs with some relevance to geoscience, such as, for example, a program on "Dynamos" in 2008 and the "Physics of Glasses" in 2010. The FESD funding has allowed CIDER to broaden its scope and, in alternate years, include themes related to research questions at the interface of the solid Earth and the fluid envelopes (e.g., "Mountain Building" or "Solid Earth and Climate").

Many of the same "grand challenge questions" have been brought up repeatedly in discussions at CIDER, and progress is tangible over the past 12 years; for example, the stated goal of our first program in 2004 was to combine information from geochemistry and seismology to better constrain deep Earth dynamics. This is an extremely ambitious goal, because geochemistry samples the Earth locally and global coverage is spotty, whereas at the global scale, seismic tomography best constrains long-wavelength structure. In the past decade, tomographic resolution has improved significantly, as has global coverage of geochemical sampling. Geochemists and seismologists understand each other better and, together with geodynamicists, are now better poised for such multidisciplinary analysis. Several such efforts are under way, and CIDER will revisit the questions of the origin and implications of mantle heterogeneity in its 2018 summer program, to be held at KITP.

Judging by the momentum gained over the past decade, CIDER helps fill an important need for the geoscience community, stimulating research on outstanding interdisciplinary geoscience problems and engaging geoscientists at all levels in this effort. This need, as discussed at the community workshop held at the Marconi Conference Center (Marshall, California, USA) from 5–8 May 2016, will continue with the arrival of successive new generations of early career geoscientists. We are looking forward to continuing CIDER for the foreseeable future and to broadening international participation.

For more information about CIDER, visit http://www.deep-earth.org.

ACKNOWLEDGMENTS

CIDER is funded through the Frontiers in Earth Systems Dynamics program of the National Science Foundation (NSF) under grant EAR1135452. We also acknowledge support from the Kavli Institute of Theoretical Physics under NSF grant PHY-1125915.

Manuscript received 29 Dec. 2016
Revised manuscript received 10 Apr. 2017
Manuscript accepted 10 Apr. 2017

Figure 1. Research group at work during the 2016 CIDER summer program at KITP.