ISES

Integrated Solid Earth Sciences

2002/03 Report

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Introduction and Mission of ISES

The solid Earth sciences (SES) are concerned with the characterization, origin and evolution of our planet's continental and oceanic lithosphere. Investigation of the processes that modify the lithosphere requires studies of both active environments and the geologic record of past events. Research in SES is inherently multidisciplinary and increasingly interdisciplinary, and effective communication between and integration of SES is necessary for future research advances. An intellectually vibrant community of SES researchers is essential to the future our discipline, because central elements of the Earth System will otherwise be missing from a systematic approach to understanding our planet. SES are also an essential core of Earth Science education, so educational programs in solid Earth science should reflect the increasingly interdisciplinary nature of geoscience research, and the foundation it provides for other component of the Earth System.

The mission of the Integrated Solid Earth Sciences (ISES) initiative is to change the research and education culture in solid Earth sciences through communication and integration, and to stimulate the articulation of and approach to the next generation of solid Earth research. This will be accomplished by developing specific plans for:

1) Mechanisms to synthesize and integrate across fields.
2) Developing cyberinfrastructure.
3) Supporting integrated research equipment facilities.
4) Educating the next generation of solid Earth scientists.

The ISES initiative takes a two-prong approach. First, it will facilitate integration among the current cadre of scientists through topical, annual ISES Forums that will be held at large national meetings. Secondly, to foster a cultural shift for the next generation of scientists through ISES Summers Schools for senior graduate students and ISES Summer Retreats for junior, research-oriented faculty. Following a description of outcomes from the Fall 2002 ISES workshop, these proposed elements of the ISES initiative will be described in this document.

ISES Workshop 2002

Approximately 90 scientists from various geological disciplines, including structure, petrology, sedimentology, stratigraphy, geophysics and geochemistry, met on October 26, 2002, to discuss priorities in Solid Earth Sciences. This one-day workshop met before the Denver Geological Society of America Annual Meeting and was supported by a grant from the National Science Foundation. An additional Town Hall discussion was held at the 2003 AGU Fall Meeting.

The workshop was motivated by two complementary needs. First, a realization by the solid Earth sciences community that for the 21st Century an examination of priorities is necessary. This sentiment is in line with a recent NSF Advisory Committee Report, in which the Geosciences goal is stated as "To benefit the nation by advancing the scientific understanding of the integrated Earth systems through supporting high quality research, improving geoscience education and strengthening scientific capacity." (NSF Geosciences Beyond 2000). Second, a desire by the Solid Earth Sciences community to contribute fully to EarthScope and future Geo-Facilities plans.

The goals of the workshop were:

1. To recognize the importance of the Solid Earth Sciences to understanding Earth processes in order to facilitate future support for work in the Solid Earth Sciences
2. To provide a Forum for the generation of ideas about directions that the Solid Earth Sciences community should take, to organize the community to achieve these goals, and to inform funding agencies, such as NSF, of these goals
3. To initiate change within the community to enable integration of different approaches, data sets and disciplines, and to emphasize the natural partnership between research and education.

Particularly encouraging at the workshop was the collective agreement among scientists in a range of disciplines in Solid Earth Sciences that such a Forum is needed to advance our research goals, as well as have a clearly identifiable voice among initiatives in the geological sciences.

This interim report presents the main outcomes of our workshop discussions on Research and Education, but particularly serves as a platform for discussion of proposed near-term activities that, we believe, will advance the shared goals of scientific integration and provide the best opportunity for future progress in this direction.

Workshop Structure

The workshop was organized around three breakout sessions that discussed Research, Teaching and Infrastructure. The topics, subgroups and their respective leaders are described below.

Breakout Session 1: Research priorities

Goal: Assessment of research priorities - integrating the Solid Earth Sciences by defining common research priorities by type of geologic setting.

1. Active Margins. Leaders: K. Cashman, H. Tobin.
2. Ancient Orogens. Leaders: C. Teyssier, A. Glazner.
3. Mid-continent, Precambrian, and deep lithospheric processes. Leaders: R. Rudnick, S. Bowring.
4. Basins and Extensional Regimes. Leaders: L. Goodwin, B. Wernicke.

For each of four geologic setting breakout groups, we discussed:

a. the identification of major research problems;
b. an integrated approach at studying these research problems;
c. the processes involved, in order to compare with processes in other regions.

Breakout Session 2: Integrating Teaching and Research

Goal: To identify priorities for education and outreach derived from breakout session 1; to identify synergisms among research, education and outreach in the Solid Earth Sciences. The research agenda formed the foundation for developing priorities for facilities and education activities.

1. Active Margins. Leaders: T. Gardner, K. Furlong.
2. Ancient Orogens. Leaders: S. DeBari, K. Hodges.
3. Mid-continent, Precambrian, and Deep lithospheric processes. Leaders: D. Mogk, S. Marshak.
4. Basins and Extensional Regimes. Leaders: L. Goodwin, B. Wernicke.

For each research priority area, we discussed:

a) integration of research and teaching in order to 'lower the boundary' between the two;
b) identification of critical barriers (if any) to teaching topics identified as research priorities at the upper division/graduate level, what is needed to eliminate them, and how to use an integrated approach to facilitate teaching students to solve open-ended problems
c) consideration of which of these research priorities should be included in introductory level undergraduate courses, and what is needed to make this possible given the large number of people teaching out of field at this level
d) consideration of whether the answers to these questions change the way we look at research priorities and facilities

Breakout Session 3: Facilities and Equipment

Goal: To identify infrastructure requirements and research facilities to support research and education priorities, and enable participation by scientists in the full range of academic institutions; moreover, to evaluate technology and IT needs, both for field-based activities as well as for mathematical modeling and computational science in support of Solid Earth Sciences.

1. Geochemistry and Geochronology (including instrumentation, facilities & experimental requirements). Leaders: L. Farmer, K. Hodges.
2. Petrology, Rock Mechanics, and High P/T experimental deformation (including instrumentation, facilities & experimental requirements). Leaders: W. Carlson, D. Whitney.
3. Active Tectonics/Geomorphology and Geological Geophysics (including field-based activities). Leaders: R. Arrowsmith, D. Burbank.
4. Field-oriented Petrology, Sedimentology, and Structural Geology. Leaders: B. Dorsey, K. Klepeis.
5. Mathematical modeling and computational science in Solid Earth Sciences. Leaders: G. Bergantz, P. Koons.

Workshop Outcomes - Highlighted Discussions

During the course of the workshop, it became clear that integration among subdisciplines is a critical component of most future work in the Solid Earth Sciences. We highlight three topics – integrated field work, numerical modeling, and geochronology – that typify the challenges facing the Integrated Solid Earth Sciences (ISES) community.

These summaries also address questions concerning the need for facilities in the Solid Earth Sciences (SES). In particular, a major issue of centralization of tools is included, with significant tradeoffs between the distributed vs. centralized approaches. This is addressed more fully below.

Integrated Field Work

The integration of field, laboratory and numerical approaches to research and education in the SES fosters new ideas, leads to unique scientific breakthroughs, and commonly provides new insights into areas that are of interest to a broad range of scientists, teachers and the public. Much of this effort is conducted by small groups of investigators who work together using well-established networks and support systems. Field-based research forms the basis of many such projects, and commonly involves collaborations among geochemists, geophysicists, experimentalists, geochronologists and modelers. Pooling resources from multiple institutions enhances this effort by reducing costs and increasing opportunities for research, education and student training. The value of synergistic activities that result from integrative research programs cannot be overstated. Thus, enhancing the quality and frequency of interdisciplinary, collaborative research is a priority in a SES initiative and in any new consortium of facilities that supports field-based research.

Field-based research commonly provides the basis for testing numerical models and determining the ages and rates of geologic processes. The future success of field-oriented research and education requires that practitioners be fluent both in traditional skills and concepts as well as emerging new technologies and tools. The current trend toward the use of new technologies (e.g., GPS, GIS and other types of computerized surveying and mapping tools) and digital data (e.g., DEMs, LIDAR, InSAR) to supplement traditional approaches needs to be managed. For instance, knowledge of new technologies should not result in the loss of essential skills such as ability to read topographic maps, trace complex structures in deformed terranes, and properly identify rocks and minerals in the field. This presents a challenge to educators who may wish to incorporate both traditional and new skills into courses that are limited in time and resources. It is also a challenge to the research community, which risks relying increasingly on remotely collected digital data while neglecting essential aspects of field-based geology and basic geologic mapping. Thus we recognize the need to utilize emerging new technologies in teaching and research while remaining firmly grounded in the traditional skills and concepts of field-based research.

Another priority in SES is to balance the need for large, centralized laboratories and research centers with the small to intermediate-sized labs that are run by single (or a few) investigators and their students. Eloquent arguments have been put forward on both sides of this question. One argument in favor of centralized facilities is that many field-based programs require access to expensive, specialized analytical tools (TEM/SEM, microprobes, LA-ICPMS, XRF, chemical labs, paleomagnetism, all types of geochronology) that aid in the evaluation of hypotheses. Large centralized facilities may allow more investigators and educators access to much needed analytical tools. In addition, the costs of operating state-of-the-art laboratories that conduct modern research in, for example, geochronology and isotope geochemistry have increased dramatically in recent years, yet during this same period it has become increasingly difficult to obtain the funding needed to maintain these facilities and encourage innovation. These problems indicate a need to consolidate some resources and funding into specialized labs that can provide access to large groups of investigators and that can efficiently turn out large volumes of high-quality data.

However, it also is critical that we maintain small, single-investigator laboratories to discourage a "black-box" approach to science where technicians, rather than the scientists involved in the research, analyze samples that they are not familiar with. Because rocks and minerals are complex systems, they continually pose new problems that require the development of new and different strategies for resolving unique problems. A case-by-case approach to problem-solving during data collection in the lab might be discouraged in large research labs that service a large number of clients and that focus on producing large volumes of data efficiently. In addition, the replacement of smaller labs with large centralized research centers could limit student access to lab facilities, thereby reducing our ability to teach and train new young scientists in these areas. While strong support exists in the community for funding of centralized labs, it is also important to maintain or increase support of small, single-investigator labs where the pursuit of unexpected problems can be encouraged and where the bulk of student training and education is most likely to occur.

In summary, most field programs require support for and access to modern surveying equipment and laboratory facilities that incorporate tools such as SEM, LA-ICPMS, XRF, microprobe, mass spectrometers, paleomagnetics. Field-based structural programs also require access to new 3-D and 4-D data sets and new technologies for visualizing and displaying these data. One potential solution to these nearly universal needs is to have a few centralized national facilities and data repositories that could rent equipment and provide data to investigators and educators involved in field-based research and teaching. One model that seems to work well is employed by NSF's Division of Polar Programs, which provides support for Antarctic research. We envision a network of national facilities and data repositories that could supply funded programs with shared state-of-the-art equipment and digital data. We also recommend that large laboratory facilities that support field-based research be consolidated because they are expensive. However, small and intermediate-sized laboratories also are highly valued and may serve different needs, so they too must be maintained.

Numerical Modeling

Many of the exciting challenges in solid earth geosciences relate to the discovery of the processes that produce time dependence. However, characterizing the deterministic template that underlies time dependence can be difficult. Mathematical (analytical), numerical and analog modeling provides a vehicle for understanding parameter sensitivity, for exemplifying behavior not available to direct observation, for negative tests of hypotheses, and consequence modeling. Despite the range of possible applications to the intellectual activity of discovery in Solid Earth Sciences, many workers are unaware of the opportunities that modeling can provide. This is the result of both a lack of training in the fundamentals of transport theory and related supporting sciences, and a misunderstanding of how models are best used and their limitations. We note that this is in contrast to other fields of Earth science and engineering, such as atmospheric sciences, where modeling is a core component of both undergraduate and graduate training. Hence we see a danger that Solid Earth Sciences are falling behind peer sciences, especially in a time where computational resources are growing in speed and decreasing in cost.

Based on our group experience, we suggest that modeling is usually concerned with, 1) systems with known physics but whose degrees of freedom and interactions can produce unexpected outcomes and, 2) systems with unknown physics, where the modeling is used in an exploratory capacity to identify the possible range and scale of processes at play. The group was in agreement that both uses of modeling must be conditioned on observation, which requires a dialog between modelers and observationalists at all steps of the process.

How to Advance a Modeling Framework in Support of Solid Earth Sciences?

There is growing frustration with the basic curriculum in Earth science in that there is a need for increased "numeracy." This refers to a need for more training in quantitative problem solving skills, problem identification and solution techniques, especially in the context of Earth sciences. Thus there are issues of academic culture as well as specific training in supporting sciences. Improving numeracy is seen as a precondition to progress in facilitating modeling as a research and education tool. One way to implement this might be the development of a hierarchical 'user toolbox' linking modules in geo-informatics, transport modeling, geostatistics, perhaps with a common format and through a web-based environment.

More advanced approaches might be implemented through an 'expert system' approach (e.g., MELTS code of Mark Ghiorso), supported by short courses that could have both generic and user-specific training (an example being the NASA High Performance Computing Camp), including aspects of both hardware and software, problem and solution design. So government agency funding (DOE, NSF, DOD, NASA, etc.) will need to be directed to community-wide training as well as to individual investigators.

New Directions

Geological systems are granular (in the information theory sense) in that they are usually composed of interacting objects with many scales, and it is the interactions across these scales that produce the structures in time and space that are interesting. Developing both continuum (or quasi-continuum) theories and modeling strategies is a state-of-the-art process where solid earth geosciences can play a leadership role in the general fields of solid and fluid mechanics. Examples include multiphase flow and reaction (volcanic systems, debris flows, sedimentation), discontinues or discrete particle methods (plastic, plate-scale deformation, fault zone rheology and behavior), or a mix of both (melt migration in a deforming media). So funding will be needed to allow investigators to develop innovative tools for these interesting problems, as nothing that is currently 'on the shelf' is entirely appropriate.

The pervasive feeling was that the need for increased access to modeling and quantitative expertise could best be met by a multi-tiered and distributed approach.
The requirements identified were:

- Increasing numeracy among undergraduates and graduates through exposure to quantitative methods in all facets of their education.
- Modeling of well-understood phenomena using robust solutions for application to commonly encountered problems in the earth sciences. Problems in this class are those similar to and including linear and slightly non-linear heat conduction in the solid earth, diffusion, reaction dynamics, kinematic analysis and geochemical modeling.
- Quantitative calculations usually performed by specialists at identified centers with interest to a broad range of earth scientists. This class includes solutions to typically non-linear, coupled partial differential equations such as those that describe convective transport, earth deformation, and magma mixing.
- Development of new algorithms, hardware, and theory to address emerging and poorly understood phenomena described by highly non-linear equations such as those

encountered in modeling of chaotic systems, and mixed continuous-discontinuous processes.

Clearly there is a continuum among these classes, but the above discretisation lends itself to a strategy that can fit within present funding schemes. The individual needs can be met by:

- Providing clearly identified, lesson-specific modules for K-12 and undergraduate education that demonstrate physical and chemical behavior, and that require simple manipulation of controlling equations. The role of modern visualization techniques, integrated within the teaching modules, should be emphasized and strongly encouraged.
- Collection and maintenance of commonly used software into a single directory for downloading and operating on remote locations. Obvious links here could be established with other initiatives.
- Support of investigators and numerical facilities that will permit non-specialists to travel and work for specified periods at these facilities. The expertise contained at each facility could then be exploited by a wide group of scientists who wish to explore some phenomena, but are unlikely to develop and support their own numerical facilities. The facilities will serve as centers for numerical calculation and, perhaps more importantly, as nodes for communication and cross-fertilization among researchers working on similar problems. In many respects, these facilities are directly analogous to those that provide geochemical analytical support to the earth science community.
- Support for numerical modeling facilities intended to identify new quantitative directions where theory and methods can evolve together.

Geochronology

Of major concern in the U.S. geochemistry and geochronology community are the issues of how to best support existing and new analytical facilities nationwide, and how to promote the development of novel analytical techniques and instrumentation. There is considerable support in the geochemistry community for the current U.S. paradigm, in which numerous, widely distributed analytical facilities are developed and maintained by individual investigators. Such a distributed network of small, generally University-based facilities, as opposed to large “national” analytical centers, is generally favored because it allows numerous individuals to pursue simultaneously the development of creative and innovative geochemical techniques, provides a proven training ground for both undergraduate and graduate students, and is perceived by many to allow better access to various analytical techniques for the geochemistry community as a whole. National analytical centers may be required for large and/or difficult to maintain instruments, such as accelerator mass spectrometers and ion microprobes, but these centers can lead to the “fossilization” of analytical techniques and to the disenfranchisement of scientists who are not directly involved in the centers’ operation and scheduling.

While the above arguments favor continued strong support of PI-driven analytical facilities by scientific funding agencies, some aspects of the “distributed infrastructure” model are problematic. It is generally conceded, for example, that any analytical facility, whether large or small, requires adequate technical personnel in order to ensure its smooth operation and maintenance. Unfortunately, long-term institutional or federal funding of laboratory technicians is rare in the U.S. and many small university laboratories function instead with soft-money technical personnel whose salaries are recovered, at least in part, from user-fees. In this circumstance there is an incentive to operate the analytical facility principally as a "data mill" and not as an engine of either innovation or education. A lack of technician support has been an important impediment to the proactive design and development of new instrumentation in geochemistry and geochronology.

We believe that the National Science Foundation should consider a two-pronged approach to supporting analytical research infrastructure in geochemistry. First, we recommend that geochemists lobby NSF to endorse a new model of direct operational support for analytical facilities that does not depend on a steady flow of "contract" work and frees up individual investigators to focus on innovation. Second, we recommend that a committee of representative members of the geochemistry community and non-specialist collaborators be engaged to design, in concept, one or more national research laboratories that would focus on the education of visiting specialists in state-of-the-art analytical techniques, serve as a training ground for those specialists who are too early in their careers to have laboratories of their own, and provide access to visiting non-specialists who wish to employ geochemical techniques in support of research in other fields.

Notable methods relevant for the timescales of our interest include ^{14}C, cosmogenic radionuclides, U-series, and low temperature thermochronometers (fission tracks and U-Th-He). Continued development of these tools should be supported. For some, it may be possible to achieve the ease and confidence and price of ^{14}C with time. Such development should include further precision testing and cross-calibration (e.g., CHRONUS effort). Required throughput to expand research is on the order of 10^3—10^4 dates/year. The experience of Southern California Earthquake Center and Bay Area Paleoseismic Experiment (BAPEX) colleagues with ^{14}C dating has been excellent when larger volumes of dates were negotiated with the AMS labs and a bridging person was hired to help shepherd the samples, and educate the users and the geochronologists while also improving the method in its particular application. The near real time dates were invaluable in guiding research while trenches were still open, for example. This is an excellent model that could be expanded, but requires significant commitment of support for such professional level staff. The rate limiting step for cosmogenic dating is sample processing. AMS facilities can support the throughput requirements, but we would need to build a number of processing labs.

A second priority for the geochemistry community should be to establish modern, Internet-based, geochemical databases. At present, much existing data exists only in paper form and is not compiled in electronic databases where is can be easily accessed and queried. Electronic geochemical databases, particularly when combined with Geographic Information Systems (GIS), will provide the means of manipulating and investigating large geochemical datasets in a manner that has not been possible in the past. It is essential that such databases be established, both as repository for geochemical data and as the springboard for new and innovative geochemical research.

In summary, the priorities are:

- Continue to maintain a distributed network of geochemical facilities operated by individual principal investigators, but investigate the establishment of a few "national" centers to support advanced education and to ensure broad access to new analytical techniques.
- Work to better establish the level of funding required to allow individual geochemical facilities to develop innovative instrumentation. A high priority should to increase the number of long-term, "hard-money" technical personnel positions nationwide.

- Establish geochemical databases, to improve access to existing data and as a repository for data produced in future studies.

Education and Outreach

The research agenda for the solid Earth sciences can be achieved only if there is concomitant development of the knowledge base (i.e., new research discoveries), infrastructure (i.e., facilities, instrumentation, databases, and information technologies), and human resources (i.e., through education and outreach, professional development opportunities). "Basic Research Opportunities in the Earth Sciences" (NRC, 2001) has clearly identified emerging areas where there is a compelling need to focus research activities, and the solid Earth sciences play an essential role in each: integrative studies of rocks, soils, water, air, and organisms in the near-surface "critical zone"; geobiology; Earth and planetary materials; investigations of the continents; studies of the Earth's deep interior; and planetary geology. Research in these areas is increasingly adopting an Earth systems approach, emphasizing the processes and feedback mechanisms among and between components of the Earth system.

It will be important to foster new collaborations and partnerships across the geoscience disciplines, and to sister disciplines in the sciences, mathematics and engineering. Datasets, and the tools needed to render and represent data, must become universally accessible, and data providers should anticipate and support uses of their data beyond a specific targeted clientele (e.g., Geochemical Earth Reference Model, Geoinformatics/GEON). New information technologies provide the means to aggregate, organize, and disseminate information to broad audiences, and to create networks in support of virtual communities (e.g., Digital Library for Earth System Education or DLESE). In addition, use of instrumentation must be optimized to support basic research, to address problems and issues of import to society, and for educational purposes. Beyond existing facilities, it may be desirable to develop national consortia to prioritize and operate next-generation facilities for the benefit of all.

Advancing the interests of solid Earth sciences also requires a concerted, coordinated education and outreach effort. Research and education share the common values of inquiry and discovery. Education is intrinsic to all of our professional research activities: in our scholarly publications, in presentations at national meetings, in field trips, workshops and short courses (e.g., the NAGT "On the Cutting Edge" professional development workshop series). The solid Earth sciences research agenda is sustainable only if researchers continue to learn about the Earth and to share that information with each other. At the same time we must adequately prepare future generations of scientists (and citizens). The health of the solid Earth sciences is largely dependent on the effectiveness of educational activities that a) translate new advances in science to colleagues, students, and society; b) provide training in the appropriate use of analytical instruments, databases, and interpretive tools; and c) inculcate "scientific habits of the mind" in students and citizens. The solid Earth sciences will further benefit from coordinated outreach efforts to other related disciplines and to the public (such as, policy planners, journalists, teachers). Solid Earth scientists have a shared responsibility to proactively represent our science to these diverse audiences. To prosper, the solid Earth sciences must effectively integrate knowledge, education and human resources.

Other Approaches

Database population and manipulation

We recognize that high resolution imagery and topographic data remain essential for addressing the research topics outlined above. GEO-PBO discussions emphasized the need/opportunity for LIDAR acquisition across the western US with a price tag of ~$15M. Whether or not acquiring such a dataset is feasible, support of imagery and topographic data acquisition must be supported on a continuing basis. Furthermore, the IT infrastructure (processing and archiving facilities and software) must be in place to help earth scientists work with earth science and other data and model results. To some extent, development in this regard is ongoing with the GEON and other related efforts, but that is a very small part of a much more extensive and sustained effort that will have to be undertaken. This approach will be critical to change the culture of earth science research to include and enable data fusion, etc.

Microstructural imaging

With respect to many areas in the SES, microstructural imaging (e.g., SEM/TEM) is underutilized and under exploited. This is an important area of research and has obvious connections to Material Sciences and Engineering.

Field geology

Digital field data collection schemes are becoming more common and improving data location precision, visualization, quantity, and possibly quality (see for instance http://web.mit.edu/dtfg/www/). Expansion of access to these tools, possibly with an IRIS/ PASSCAL /UNAVCO model with summer workshops, is an important goal. Such expansion has significant ties to education.

Geophysics

Important aspects of the geophysics infrastructure are:

- Additional Earthscope seismometers and strain gauges.
- Shallow imaging tools such as Ground Penetrating Radar should be established as pools for the community.
- The USArray needs a clear seismic reflection component. For many integrated geological and geophysical studies, active source seismology is a central tool. For example, it is a major component of many Continental Dynamics proposals. These tools allow for the scale penetration and imaging necessary to compliment geological studies. They require significant technical support.

The outcomes of the various breakout groups are presented under several heading that mix the breakouts groups, reflecting the desire and need for integration of research, infrastructure and teaching. These narratives are not a complete representation of the topics and issues discussed, but offer a first insight into the thinking of the community. Based on the discussions and comments, as well as reading recent reports on priorities and targets in the Solid Earth Sciences, it is clear that follow-up workshops are needed to identify and enunciate the community's goals and needs. This follow-up is part of the ISES plan (below).

Scientific Objectives

The following scientific objectives were recognized during the course of the workshop:

- Identifying the characteristic length and time scales, and bridging the gap in length scales and timescales. Spatial scales of interest vary from the grain-scale (mm) to fundamental hillslope lengths (m) to large fault ruptures (10s of km) to mountain belt and plate tectonic scales (100s-1000s of km) – some 10^{18} orders of magnitude. The timescales of tectonics are such that we study processes from earthquakes and impacts (seconds) to plate motions and mantle convection (10^8 years), and from orogenic heating and cooling (10^6 years) to melt segregation, ascent and emplacement (10^2-10^5 years) – some 10^{16} orders of magnitude.
- Understanding the dynamics of coupling within the lithosphere. What is the importance of lower crustal flow in continental deformation? How well coupled is the upper brittle crust with the rest of the lithosphere (see next question as well)?
- Characterizing the rheologic behavior of the lithosphere. One of the major areas of research in continental dynamics is the relative roles of distributed versus localized deformation; i.e., the importance of faults as major lithospheric scale discontinuities along which most regional deformation is accommodated versus distributed flow (mostly by lower crust; see above).
- Understanding the geodynamics of mountain building and interactions among climate, surface and tectonic processes. Numerous modeling, geological, petrological, thermochronological and other studies address this exciting research topic.
- Determining the linkages from modern earth to the rock record and ancient orogens. This is basically a uniformitarian view of how we go back and forth between the record of geologic processes and active manifestations of them.
- Understanding hazards related to processes in Solid Earth Sciences. For example, large magnitude surface displacements can occur with magma movement in volcanic systems, which may enable better predictive capability of eruptions, and understanding earthquake histories and manifestations of repeated earthquakes in the landscape might enable better predictive capability.
- Understanding the structural geology of the upper 10 km or so of fault zones. Can we differentiate between creeping and seismogenic rock fabrics?

Proposed ISES Activities

Based on the workshop outcomes and subsequent discussions with scientists and NSF officers, the steering committee proposes three main activities:

- ISES Forums (annual, starting Fall 2003)
- ISES Summer Schools (annual, starting Summer 2004)
- ISES Summer Retreats (annual, starting Summer 2004)

These activities and associated budgetary needs are described below. Note that a funding request for the first ISES Forum has been submitted to NSF, and is planned just before the Fall 2003 Seattle meeting of the GSA.

ISES Forum

A one-day forum for up to 100 members of the Solid Earth Sciences community is proposed to precede the Fall GSA or AGU meetings. Each ISES Forum will start with a series of updates and presentations that serve as a platform for discussion of research facilities and equipment, and identification of emerging needs to support research and education in the SES.

Examples of ISES Forum topics are:

- GeoInformatics, cyber-infrastructure (ISES-CI): database building and tools
- High-precision geochronology (ISES-CHRON); techniques and infrastructure
- Numerical modeling of lithospheric processes (ISES-CALC)
- Continental evolution (ISES-CE); emphasis on experimental deformation of rock materials and the derivation of constitutive relations applicable to earth materials

The first Forum, preceding the Fall 2003 GSA meeting in Seattle, will focus on CyberInfrastucture and Geochronology. The facilities and equipment goal is to ensure sufficient infrastructure in geochemistry, particularly geochronology, to support the increasing needs of ISES research, including research by students. This first forum is one step down the road of synthesis and integration among the SES disciplines. Additionally, the forum will discuss the ISES Coordinating Group's proposal to sponsor further Forums, Summer Schools (part of the goal of educating the next generation of solid Earth scientists within the new integrated science culture), and Summer Retreats (for junior Assistant Professors (APs) and senior Post-Doctoral Fellows (PDFs)), to enable successful development of and collaboration among the next generation of leaders in SES).

A primary goal of "ISES Forum I: CyberInfrastructure and Geochronology" is to stimulate the articulation of and approach to the next generation of Solid Earth Sciences research, and to ensure that the culture of integration pervades the education of the next generation of Solid Earth Scientists. Another important element of planning for the future in SES is the need to stimulate and support the development and dissemination of next-generation instrumentation and multi-user facilities, including the maintenance of facilities that house mass spectrometers, electron microprobes, ion probes, accelerators, etc. Additionally, the Solid Earth Sciences community should develop activities that ensure multi-user facilities are sites of technological breakthroughs in instrumentation and also sites of research and mentoring for science students.

The tentative schedule for ISES Forum I (2003) is:

07.30 Continental breakfast available
08.00 Introduction and goals: Ben van der Pluijm (ISES Coordinating Group)
08.20 EarthScope update: Rick Carlson (DTM)
08.40 The National Center for Earth-Surface Dynamics (NSF Science and Technology Center): Chris Paola (Scientific Co-Director)
09.10 ISES-CI (Cyberinfrastructure for the Solid Earth Sciences): Doug Walker (Co-Chair ICES-CI)
09.30 Coffee Break
10.00 PetDB: Kerstin Lehnert (LDEO)
10.30 CHRONOS: Bruce Wardlaw (USGS)
11.00 Geoinformatics: John Oldow (U Idaho)
11.30 Geochemistry of metamorphic rocks and metamorphic petrology: Frank Spear (RPI)
11.40 Structural Geology: Jeff Lee (Central Washington University)
11.50 Physical properties of rocks and minerals: Tracy Rushmer (U Vermont)
12.00 Lunch
13.15 The geochemistry and geochronology infrastructure: Sam Bowring and Lang Farmer
13.35 Opportunities in Solid Earth Sciences: Walt Snyder (NSF)
13.45 High temperature geochronology: Jonathan Patchett (U Arizona)
14.15 Low temperature geochronology: Farley
14.45 Breakout groups
15.45 Tea Break
16.15 Reports from Breakout discussions
16.45 ISES Summer Schools, Retreats and Forums(ISES Coordinating Group)
17.30 ISES continuation and operation (ISES Coordinating Group)
18.00 Cash bar

The annual ISES Forums will promote the cultural revolution of communication and integration in SES, a cultural change that we anticipate will generate other activities that will arise naturally through increased communication and the need for greater integration in the SES.

ISES Summer School

Each summer a one-week workshop for senior graduate students (PhD) will be organized that focuses on topics that emphasize integration of geological disciplines. These workshops will initially be coordinated by Tikoff and Rushmer.
The first three Summer School topics we propose for community review are:

- Rheology (2004)
- Geochronology (2005)
- GeoInformatics (2006)

We envision 20-25 students per Summer School and a small number of faculty (~5) who may be teaching outside their training or who justify a refresher course on the subject. The format is based loosely on a European Summer School held annually in the Czech Republic. Each invited expert scientist will give 1/2 day overviews, using a combination of lectures, computer demonstrations and/or hand-on demonstration. The emphasis will be on integrating between disciplines.

The first Summer School on "Rheology of Earth Materials" is tentatively planned for August 2004 at Colorado College (coordinated by Dr. Christine Siddoway, Colorado College). The Summer School will use at its core a GSA Short Course given by Drs. Jan Tullis (Brown University) and Christian Teyssier (University of Minnesota), who have tentatively agreed to participate. We foresee the following topics in the first summer school: "integration of experimental and fieldwork", "numerical modeling of microstructural development", "petrological insight concerning rheology", "physical properties and lower crustal constraints", "analytical solutions of rheology and flow", "numerical simulations of bi-phase flows", and "numerical modeling of rheology". Dr. Christine Siddoway (Colorado College) has agreed to lead fieldtrips during the Summer School, to facilitate discussion and application of the concepts.

In general, Summer School topics will be solicited from the various sections and divisions in professional organization (notably, but not exclusively, GSA and AGU). Geochronology and Geoinformatics are included as timely examples. Student participation is by invitation, based on an application that includes a statement of purpose and recommendations by one research advisor and one other referee. Special attention will be given to underrepresented students in research tracks.

ISES Summer Retreat

Each summer, a three day retreat will be organized that brings together young tenure-track faculty with senior, NSF-funded faculty and NSF Program Directors. The Summer Retreats will be designed as a research-oriented complement to workshops offered under the NAGT/DLESE "On the Cutting Edge: Workshops for Geoscience Faculty" workshop entitled "Early Career Faculty: Teaching Research and Managing Your Career". To ensure no unintentional overlap, particularly with the NAGT/DLESE "Preparing for an Academic Career in the Geosciences" workshop, the ISES Steering Group will interact with the NAGT/DLESE group concerning content. These Summer Retreats will initially be coordinated by van der Pluijm and Brown.

The motivation of the retreat structure is to train and support young faculty who are increasingly overwhelmed by funding and publications pressures, as well as encourage an integrated science approach among the new generation of research leaders and foster collaborations. We envision annual participation of ~30 Assistant Professors (APs) and Post-doctoral Fellows (PDFs), generally from within the first three years of tenure-track appointment or who have a minimum of two years research, ~10 Senior Scientists (mostly at Professor level), and ~5 coordinating persons and NSF staff, particularly program officials in areas related to the solid Earth sciences.

Participation to the retreat is by invitation, based on an application process that includes a statement of purpose and CV. Participants will be selected from across all disciplines in EAR and OCE. This purposely contrasts with the topical approach of ISES Forums and ISES Summer Schools. The selection committee will be made up of retreat hosts (2) and funding agency representatives (2). Recently NSF-funded, senior scientists are invited and “encouraged” to participate. The retreat will be fully supported for all participants, in a location that is both convenient to reach and geologically attractive (such as Snowbird, Boulder). Activities will include learning how to balance the conflicting requirements of research with other demands, feedback on processes such as proposal writing and reviewing, information about funding sources, discussion of the benefits of collaborative proposals vs. individual proposals, etc. The ISES Coordinating Group will evaluate whether special mentoring programs for Post-doctoral Fellows and Assistant Professors should be established.

Example Outline of ISES Summer Retreats

Arrival late pm evening before Day 1 and retreat dinner.

Day 1
Introductions and goals of retreat
Information session with representatives of funding agencies: NSF, ACS (”how research works”); for example, presentations on I&F program, IODP, etc.
Research presentations by 5-6 invited senior faculty, emphasizing integrated aspects within individual’s interests.
Lunch
Early pm: community building activities, such as geology fieldtrip, topical workshop (e.g., data management, numerical tool set).
Late pm: breakouts on topics for next day’s experiences panel.
Dinner
After dinner: preparation of summary reports of breakout discussions.

Day 2
“Experiences” panel (examples of topics):

- Development of successful research projects. Pre-circulate ~5 successful proposals from among the group of senior scientists present (maintain all aspects, but exclude budgetary details, such as salary).
- Research and tenure-track demands. Mentoring from senior colleagues (research feedback, inside teaching evaluation). Portfolio development, activity recording.
- Advising student research and thesis (BS/honors, MS, PhD).

Lunch
Early pm: free for informal discussions and one-on-one appointments for advice
Late pm: meet with evening speaker (special invitee; typically non-North American).
Dinner, followed by lecture.

Day 3
Plenary session, and research posters and brief group presentation.
Lunch and depart.

ISES Operation and Funding

The ISES Coordinating Group proposes to support the activities outlined above as part of a 5-year ISES plan that is yearly adjustable. The ISES initiative will be formally reviewed during its 5th year, after which a recommendation will be made for continuation. Details of the organizational structure are subject to annual review, so that participation arrangements can be optimized and NSF insight in the progress is guaranteed. The ISES Coordinating Group commits to the execution of this plan for a minimum of 3 years, after which others will be asked to lead ISES. Broad access and wide participation is the key to the success of ISES, which is the primary motivation to limit the terms of Coordinating Group members; departures will be phased, to allow continuity of activities.

We estimate that a fully funded scenario (up to 50 summer school attendees, and up to 50 summer retreat attendees, including all participants) will cost approximately $150,000 per year ($1,500 per participant), to be shared among NSF programs in EAR, OCE and Polar. In addition to travel and hosting support, we will offer a stipend for invited core faculty or keynote speakers (~$500/person), and seek minor office staff support. The ISES initiative will be formally reviewed during its 5th year, after which a recommendation will be made for continuation. Details of the organizational structure are yearly reviewable, so that participation arrangements can be optimized and NSF insight in the progress is guaranteed. The coordinating committee will offer annually alternating town hall-style updates on the ISES initiative at GSA and AGU, which will include presentations by officers and brief testimonials by past participants.

Coordination with other workshops

New Departures in Structural Geology and Tectonics

A separate workshop was organized by David Pollard of Stanford University in September 2002, in Denver, concerning "New Departures in Structural Geology and Tectonics". During this two-day workshop, twenty members of the community presented brief overviews of topics related to their research specialties. A major theme of the workshop was building upon the integrated nature of work in the structural geology and tectonics community, and the implications this has for future funding of the research and teaching we do as a community. Four topical areas of research came into focus at the workshop:

1. Beyond Plate Tectonics: Rheology and Orogenesis of the Continents.
2. The Missing Link: From Earthquakes to Orogenesis.
3. Dynamic Interactions between Tectonics, Climate, and Earth Surface Processes.
4. Co-evolution of Earth and Life.

Details on this workshop were presented to the NSF in April 2003, and are listed at the following website: http://pangea.stanford.edu/%7Edpollard/NSF/main.html. That fact both workshops were independently conceived indicates the desire for members of the Solid Earth Sciences community to be more pro-active in integration within the larger geosciences community. No further activities derived from this workshop are anticipated.

Workshop on CyberInfrastructure (CI) for the Integrated Solid Earth Sciences (ISES)

This Workshop derived from the alliance formed during the Fall of 2002 within the Solid Earth Science community to coordinate and articulate common community visions for science, research, and participation in the Cyberinfrastructure revolution. The last aspect, which is termed ISES-CI, was the focus of a NSF-funded workshop organized by J. Douglas Walker of the University of Kansas and Rick Carlson of the Department of Terrestrial Magnetism, and held at the University of Kansas on March 28 and 29, 2003. The workshop's website is at: http://www.geo.ukans.edu/TectonicsWorkshop/main.html. The development of an ISES-CI organization follows on the community consensus built at this workshop. The ISES-CI effort is ongoing, and is separate from, but coordinated with, the ISES role in helping to create a science vision for the contributing domains. Thus,

> *ISES-CI is the vehicle for participation of ISES domains in the CI revolution. Several working groups have been formed to take advantage of community consensus reached at the ISES-CI workshop. These working groups will foster new areas of effort, help nurture nascent areas, and work to solidify collaborations among mature endeavors.*

The ISES-CI workshop concluded that there is a pressing need to develop databases and tools, and to ensure interoperability of ISES datasets and tools in keeping with other disciplinary CI efforts at NSF. At present, there are many ongoing collaborative efforts that need to be fostered, there are natural collaborations that need to be cultured, and there are others that have yet to be organized but are identified. The process evaluating needs, developing consensus, and building community support started during the ISES-CI workshop by selecting key scientists to serve as steering committee leaders for each of these areas. The resulting working groups will help facilitate the ISES communities through ISES-CI in the overall GeoInformatics efforts in the Geoscience community.

The ISES-CI workshop identified ten priority areas that are critical to the future progress of the ISES and their integration into the broader spectrum of Geosciences and other related areas of science. Provisional steering committee leaders in most of the following areas have been identified and contacted. The leaders will establish working groups to start, nurture, or conclude community efforts on CI needs, participation, and protocols. The working groups will make presentations at the ISES meeting to be held at the Geological Society of America meeting in Fall, 2003. The specific areas are:

1. Geochemistry of igneous and sedimentary rocks
2. Geochemistry of metamorphic rocks and metamorphic petrology
3. Geochronology and thermochronology of the Earth
4. Structural geology
5. Physical properties of rocks and minerals
6. Maps
7. Stratigraphy
8. Field data acquisition techniques
9. Tools for data integration and exploration
10. Creating the *ISES Collaboratory* and archiving structure.

On the Cutting Edge: Workshops for Geoscience Faculty

The ISES Summer Retreats will complement the workshops offered under the NAGT/DLESE "On the Cutting Edge: Workshops for Geoscience Faculty" program. The ISES summer retreats will focus primarily on the research and scholarly aspects of academic life. To ensure that there is no unintentional overlap, particularly with the NAGT/DLESE "Preparing for an Academic Career in the Geosciences" workshop, the ISES Steering Group will coordinate with Heather Macdonald concerning content.

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