EXECUTIVE SUMMARY: WORKSHOP RESULTS

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Earth Cube Workshop Title: EarthCube Domain End-User Workshop for Structural Geology and Tectonics

Introduction: The areas of Structural Geology and Tectonics are at the core of the modern Earth Sciences. For example, the Structural Geology and Tectonics (SG&T) Division is the largest division in the Geological Society of America, and Tectonics is one of the principle foci of the American Geophysical Union. This domain group strives to understand Earth's structural state and deformation processes at all spatial and temporal scales. In addition, much of the motivation for endeavors in the geological sciences is framed in the plate tectonic paradigm.

Workshop participants (35 in total) were all from the US. They represented a variety of disciplines from neotectonics and deformation of the Earth's surface to researchers specializing in ductile deformation. Participants from computer science areas (9%) and students (18%) made important contributions to the effort. The main outcomes of the EarthCube workshop discussions are summarized below.

SCIENCE ISSUES AND CHALLENGES

1. **Important science drivers and challenges:** Participants identified several high-priority science questions that will be the focus of interdisciplinary efforts during the next 5-15 years.

   - What is the evolution of geological structures in three dimensions and at all spatial scales?
   - How can we use the rock record of deformation to better assess the rheology of the crust and upper mantle in different tectonic settings and over different spatial and temporal scales?
   - What are the timescales of different geological processes (fault motion, magmatism, landscape development, etc.) and how do they interact with each other?
   - How do we integrate between short-term (e.g., earthquakes) and long-term (e.g., mountain building) geological processes?
   - How do landscape development and other processes at the Earth's surface relate to geological structures and processes within the Earth's lithosphere?
   - How do mantle processes influence crustal deformation, and what is the dynamic interplay between magmatism, deformation, and mantle flow?

2. **Current challenges to high-impact, interdisciplinary science:** Several themes emerged as consistent challenges faced across disciplines.

   - The Structural Geology community has not adopted conventions for publishing and interchanging digital information, nor has it determined how the data will be archived. Further, primary structural geology data is typically published as derived products. For example, many structural measurements are reported as stereonets, which do not provide information about spatial position, observation quality, or provenance. Consequently, it is difficult for members of the Structural Geology and Tectonics community to collectively share data with each other or even rigidly adhere to NSF's data-gathering requirements. The ability to make primary data (field and laboratory) universally available would be beneficial to both the current and future researchers.

- Researchers and research groups collect data for use as individuals or a small research group, generally using a wide variety of data acquisition workflows and technology. The result of this individualistic approach to data collection is inconsistent formatting, no standard file types, and a complete lack of metadata. A community effort to establish a data standard is needed, together with development of tools to allow multiple data collection schemes to be modified to conform to the data standard for broader data sharing.

- Although researchers are generally willing to share data, data sharing typically requires a trip to the researcher's home institution to gather hard-copy maps and field notes. The ability to access data from diverse sources will greatly enhance efficiency, by allowing researchers to integrate and build on existing knowledge and new results from distant researchers. This approach may require a change in culture within the community concerning an overall willingness to share data.

- Structural geologists typically use a wide variety of data (e.g., field, microstructural, experimental, and modeling) and across a wide variety of disciplines within the geosciences (e.g., geophysics, sedimentology, petrology, etc.) and external to it (e.g., material science, engineering, etc.). Databases in these other fields (e.g., geophysics) typically require both knowledge and computer skills that are often too technical for use by anyone not in that specific subfield. Finally, structural geologists often integrate data over a wide variety of spatial and temporal scales, and numerical modeling is a powerful technique to facilitate this synthesis. Most numerical modeling resources, however, require a significant level of knowledge and background to be used appropriately, which precludes them from being used routinely to test new hypotheses.

- The Structural Geology and Tectonics community has a strong tradition of collaborative science and of community. What is only beginning to be developed, however, is a community of practice to build shared resources and conventions that take advantage of technological advances of the last 20 years. This situation is a result of historical development of structural geology, which has typically relied on researchers working in isolation without needing advanced technology for data collection. Thus, the big challenges are: 1) Community building to support development and adoption of new technology-based approaches to conducting science; and 2) Development and adoption of technology (software and hardware) to enable standardized data interchange by supporting standardized framework for data acquisition and management.

TECHNICAL INFORMATION/ISSUES/CHALLENGES

1. Desired tools, databases, etc. needed for pursuing key science questions with brief elaboration:

- Workshop participants considered developing conventions and technology for data interchange and documentation to be the highest priority component of cyberinfrastructure needed by the community. This system should be web accessible and allow discovery, access, and reuse Structural Geology data. The scope of such a SG&T Database (or Dataspace) was not developed in detail, although it was recognized that field and microstructural observations would be need to be geospatially referenced. Standards and technology developed by various groups (OpenGeospatial consortium, IUGS Commission for the Management and Application of Geoscience Information (CGI), W3C) were mentioned, and these approaches could be used in the development of such a system.

- There was agreement that analytical tools routinely used to evaluate structural data should be developed in the context of this SG&T Database. These tools include - but are not limited to - stereonet plotting, shape preferred orientation analysis, rotation of data, calculation of finite strain, vorticity analysis, spatial error analysis, three-point problems, etc.. A specific set of new tools would be focused on processing map data. If convenient and powerful tools were available for compiling and analyzing geologic maps and map data, workers would have a natural incentive to use the tools. At the same time, the map tools could serve as a front end for larger map databases. Maps could be designated as “private” until publication, but once public, they would be available to researchers around the world.

- A vast amount of Structural Geology data already exists in the form of geologic maps. These maps contain primary data and are at the very core of the field. Most of these are not in digital form, and the workshop participants considered the digitizing of these legacy data to be very important to the community. This task was considered to be a potentially high impact investment in digital conversion. Semi-automatic to rapidly guided digitizing is considered by the group as an appropriately challenging endeavor for EarthCube. The use of cross-sectional data is particularly challenging, because cross sections involve increased interpretation and their vertical orientation is poorly handled in existing map-based approaches.

- Development of innovative methods to build and visualize interpreted structural histories would be very useful to the structural geology and related geoscience communities.

- Because Structural Geology and Tectonics relies on integration across the Earth Sciences, scientists and students in this area must use data and tools from other fields in the geological sciences. For example, many structural geologists working in neotectonics need access to GPS and LiDAR data. In practice, it can be difficult to find the appropriate data; when found, the user may not be aware of, or how to use, the appropriate tools to solve their structural problems. At a minimum, maintaining a listing of tools and data is critical. More significant advances would involve cataloging resources for best practices and tool use, in addition to making more accessible interfaces for data from other domains.

- There was a keen interest in developing digital laboratory/field notebook software for wide adoption to increase efficiency in the field and facilitate data integration. The concept of the science workbook would be to allow a researcher real-time (or pre-loaded) access to all the geological data from a specific region. This science workbook would form the basic cyberinfrastructure for interacting easily and seamlessly with the database noted above. If well designed and made sufficiently adaptable, the software could be tailored in part to be the front end for the structure database; data collected to be immediately uploaded to the structural geology database (although the data might not become publicly available immediately, to allow for field re-checking, etc.). This software would be platform independent and would have to run on devices from smart phones to pads to tablets to desktops. The development of this type of science workbook would be an important step in developing a cyberinfrastructure for Structural Geology as well as all field-based sciences. Various existing software provides a starting point for defining the functionality and implementation of the science notebook.