PROJECT SUMMARY
Tectonic Targets for EarthScope in the Ozark Plateau / Illinois Basin Region of the U.S. Midcontinent

This proposal seeks funding for a two-day workshop to develop a coordinated multi-institutional effort that can utilize *EarthScope* resources to address first-order questions concerning the character and tectonic evolution of a particularly interesting block of cratonic-platform lithosphere and underlying mantle in the Midcontinent of the United States. The specific region of focus includes the Ozark Plateau and the Illinois Basin. The proposed workshop will foster partnerships among researchers familiar with the tectonic context of this region (which encompasses Illinois, Indiana, Missouri, and Kentucky), those familiar with existing geophysical data sets covering the region, and those with experience in design and implementation of geophysical experiments that can take advantage of the transportable and flexible arrays and other instrumentation associated with *EarthScope*. The workshop organizers will strive to bring together individuals from research universities, state geological surveys, four-year colleges, and the U.S. Geological Survey. The transportable array of *EarthScope* will arrive in the Midcontinent in 2011, so time is running short to set a scientific agenda—a focused approach is needed now.

Intellectual Merit: Cratonic platforms are long-lived continental provinces in which a veneer of sedimentary strata overlies Precambrian crystalline basement. The proposed workshop will focus on a block of the U.S. Midcontinent that provides one of the most fascinating examples of cratonic-platform lithosphere in the world. Specifically, this block includes a major intracratonic uplift (the Ozark Plateau), and a major intracratonic basin (the Illinois Basin). Notably, the structural relief between the Cambrian-Precambrian unconformity at the crest of the Ozarks and the comparable horizon at the base of the Illinois Basin (< 100 km to the east) is over 7.5 km, comparable to orogenic relief. This block also includes the northern end of the Mississippi embayment (a region that remained anomalously low during the Mesozoic and Cenozoic), three major Proterozoic lithosphere accretionary boundaries (borders of the Yavapai, Mazatzal, and Grenville belts), one of the world's largest anorogenic igneous provinces (the 1.47 Ga Eastern Granite-Rhyolite Province), and the intersection of several significant fault-and-fold zones that possibly represent inverted Proterozoic rifts (Nelson and Lumm, 1992; Marshak and Paulsen, 1996). The target region is also one of the most seismically active regions of cratonic platform lithosphere anywhere. Similar, though perhaps not as dramatic, lithosphere-scale features occur in craton platforms worldwide, so study of the proposed target block will potentially provide insight into first-order issues of continental tectonics in general. For example, work in the area can address issues of craton formation and evolution, intraplate seismicity, and the formation of intracratonic epeirogenic structures (regional basins and domes). In cratonic platforms, coherent and coupled motions have continued from the Precambrian to the present (e.g., Park and Jaroszewski, 1994; van der Pluijm and Catacosinos, 1996; Howell and van der Pluijm, 1999). Surprisingly, decades after the advent of plate tectonics, we have no universally accepted theory to explain controls on tectonism in cratonic platforms, even though these regions account for over 25% of continental lithosphere. The limitation on understanding comes largely from lack of data on the deeper character of the crust and mantle beneath these regions. Such data may become available through *EarthScope*, so the unique opportunity to organize a coordinated scientific agenda for studying a particularly illustrative example of cratonic platform is not to be missed.

Broader Impacts: The target area addressed by this workshop encompasses large populations (both urban and rural), including under-represented groups, who traditionally have not had strong connections to geoscience. Projects that may nucleate at this workshop have the potential to stimulate interest among these populations. The target area also contains major energy resources (and may be the site of FutureGen) and has hard-to-assess but significant seismic risk. Projects that may come out of the workshop could provide needed tectonic context for understanding Midcontinent resources and risk. Also, the workshop will explicitly address opportunities for outreach, and discuss how existing outreach programs (including those at Indiana University, Purdue University, and Illinois State University) can connect to potential new scientific discoveries about the Midcontinent cratonic platform.

PROJECT DESCRIPTION

OBJECTIVES

The purpose of this proposal is to obtain funding for an *EarthScope*-sponsored workshop addressing first-order tectonic-related problems of Midcontinent cratonic-platform lithosphere (Figs. 1 & 2; e.g., Park and Jaroszewski, 1994). The target of the workshop is a region in Illinois, Indiana, Kentucky, and Missouri that includes prominent examples of all major features characteristic of cratonic platform lithosphere—in effect, it is a "type specimen" of a type of lithosphere that accounts for over 25% of continental areas, yet remains incompletely understood. Specifically, the block includes the Ozark Plateau (a major intracratonic uplift), the Illinois Basin (a major intracratonic basin; Leighton et al., 1991; McBride et al., 2003), the northern end of the Mississippi embayment, and intersecting fault-and-fold belts (Marshak et al., 2000), some of which pose significant seismic risk (e.g., Hamburger and Rupp, 1988; Bear et al., 1997; McKenna et al., 2007; Tuttle et al., 2002; Stein and Mazzotti, 2007). Beneath its veneer of Phanerozoic strata, the "OPIB block" (for Ozark Plateau and Illinois Basin) also contains intriguing lithospheric features, such as: structural relief of over 7.5 km, defined as the vertical difference between the elevation of the Cambrian/Precambrian boundary in the Ozark Plateau and depth of this unconformity in the Illinois Basin (Marshak et al. 2005); important Proterozoic sutures such as the boundaries of the Yavapai, Mazatzal terranes, and Grenville belts (Van Schmus et al., 2007; Holm et al., 2007; Sims et al., 2008), and the possibility of significant Proterozoic rift basins (McBride et al., 2007). Study of the succession of progressively younger terranes may provide insight into the cratonization process. Finally, the region hosts the Eastern Granite-Rhyolite province (e.g., Van Schmus et al., 1996), the result of an immense felsic igneous event whose cause and consequences remain incompletely understood.

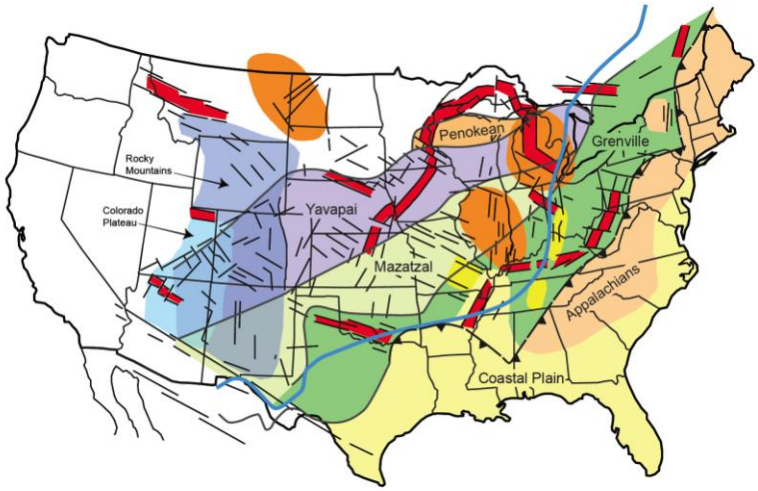


Fig. 1: Simplified tectonic map; orange=basin; yellow=dome; red=rift.

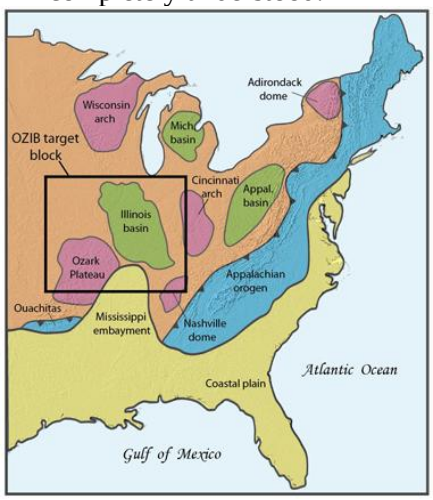


Fig. 2: Basins and arches, eastern U.S.

The OPIB block remains mysterious because it does not contain extensive surface exposures, and has not been extensively studied using modern geophysical techniques. The long-standing challenge of unraveling its character and evolution can only be addressed with new geophysical data, so the sweep of *EarthScope* instrumentation into the region provides a compelling opportunity for study. A fundamental understanding of the OPIB block will provide key insight into similar lithosphere blocks worldwide, and will provide a valuable basis for comparison with other types of lithosphere.

By focusing the workshop on a specific target block, we anticipate that the event will lead to submission of a set of linked proposals that can take optimal advantage of the deployment of instruments in the Midcontinent, set for 2011 and 2012. The workshop will bring together geologists and geophysicists with interest and knowledge of tectonics in the target region with researchers skilled in the set-up of

EarthScope experiments, in deployment of *EarthScope*-related instrumentation, and in the interpretation of *EarthScope* data. During the course of the meeting, we will discuss the geological-geophysical background of the area (from the surface down into the underlying asthenosphere) and will refine the nature of specific scientific problems to be addressed. We will then develop a set of experiments designed to test hypotheses about these problems. Also, we will establish a time frame for work, a strategy for proposal submission, and a means to make appropriate linkages between projects within the target block with projects that may develop in adjoining areas. Finally, we will address the important issue of outreach, and develop a preliminary strategy for bringing the new results of proposed studies to a broader population.

The meeting will be designed to improve communication and interaction among geoscientists who could contribute to the understanding of cratonic platform lithosphere and underlying mantle. Thus, an effort will be made to attract faculty from research universities, researchers at state geological surveys and the USGS, faculty at undergraduate institutions, and researchers from industry.

NEED FOR A WORKSHOP / LIST OF TOPICS

Introduction

The *EarthScope* transportable array sweeps into the Midcontinent (Long 94ºW to 85°W) in 2011 and 2012 (Fig. 3). During these years, the array will span a swath of North America's craton, ranging from the southern edge of the Canadian shield (on the north), across the basins, domes, and arches of the cratonic platform, and onto the coastal plain (on the south). Measurements made with the array, if supplemented by those of additional instruments, provide an ideal opportunity to address first-order problems of an important region of continental lithosphere, the cratonic platform. In many ways, less is known about the tectonic evolution and behavior of cratonic platforms than about Phanerozoic orogenic crust. Indeed, geoscientists have not agreed on a theoretical framework to describe intracratonic processes, because key structures lie buried beneath younger strata and glacial deposits (Fig. 4), GPS site velocities remain less than measurement error in most locations, and significant existing geological and geophysical data have not yet been integrated into widely available publications. Major scientific questions about the cratonic platform lithosphere of the Midcontinent remain unresolved.

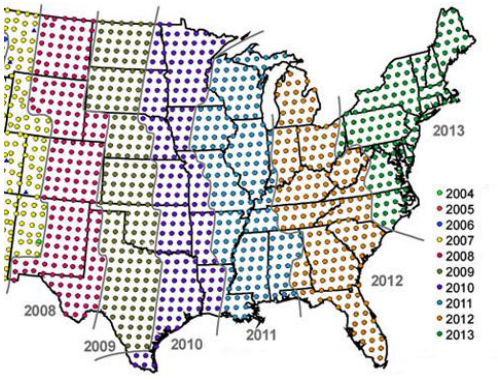


Fig. 3: *EarthScope* transportable array.

Fig. 4: Lack of outcrop—the Midcontinent challenge!

EarthScope provides an amazing opportunity to address these scientific questions concerning the Midcontinent cratonic platform. Yet as of now, the scientific community has not developed an integrated and comprehensive strategy to take advantage of new data to address these questions. Part of the reason for this is that relatively few geoscientists have actively worked on tectonic issues in the region during recent decades, and relatively few researchers adept at using *EarthScope* data are aware of the first-order

problems related to the region. Considering the timing of the *EarthScope* instrumentation deployment, it is urgent that a coordinated scientific agenda be established in advance of the July, 2010 proposal submission deadline.

This proposal seeks funding for a workshop that will address the application of *EarthScope* resources to solve tectonic-related problems in the OPIB block, a "type specimen" of cratonic platform lithosphere. This block was targeted because it contains excellent examples of the key elements characteristic of cratonic platforms, so information gained by studying this region can be used to interpret similar lithosphere elsewhere, and can provide a basis of comparison for shields and orogens. Not only does the OPIB block encompass the Ozark Plateau, the Illinois Basin, and the northern part of the Mississippi embayment, but it includes major Proterozoic lithospheric boundaries, several active intracratonic seismic zones, and a perplexing anorogenic granite province. It was identified as a key area of interest in the context of the *GeoFrame* initiative in 2006.

The proposed workshop will be held at the University of Illinois. It was motivated by a self-funded half-day meeting held in Urbana on June 5, 2009, attended by researchers from four universities and two state surveys. The participants identified a preliminary list of important issues and delineated a target area that could be appropriate for discussion in more comprehensive workshop. Discussions by the PI with Dr. Greg Anderson on June 18, 2009 confirmed that a request for a workshop could be considered by NSF. We propose that the workshop be held in early March, 2010, to provide sufficient advance time for science proposal submission in July, 2010.

Because the OPIB block is not familiar to a broad audience, we begin this proposal by briefly reviewing its key tectonic elements. Then, we justify the need for a workshop, the topics to be addressed at the workshop, and the logistics of the meeting.

Geological Context of the Ozark Plateau / Illinois Basin Block

North American continental lithosphere can be divided into two fundamental provinces. (1) *Craton* refers to the part of the lithosphere that is relatively stable and has not been affected by penetrative deformation and/or metamorphism for at least the last 1 billion years. North America's craton grew in the Precambrian by the collision and suturing of Archean blocks, by accretion of crustal slivers, oceanic blocks, and volcanic arcs between 1.8 and 1.6 Ga, and by formation of the Grenville orogen at 1.1 Ga. Various processes, which remain incompletely understood, contributed to the cratonization of this region (e.g., Hinz, 1996). One phase of cratonization may have led to the intrusion and extrusion of vast volumes of felsic igneous rocks between 1.5 and 1.3 Ga in a region now known as the Eastern Granite-Rhyolite province. (2) *Phanerozoic orogens* are regions that have been involved in rifting, convergence, and/or collision at discrete times during the Phanerozoic. They have been penetratively deformed and/or metamorphosed during this time, and thus remain relatively warmer and softer.

North American's craton consists of the Canadian shield, where Precambrian terranes are largely exposed in a broad region of low relief, and the cratonic platform, where a cover of Phanerozoic strata unconformably overlies Precambrian basement. The sedimentary cover of the platform varies in thickness from 0 km in the St. Francois Mountains of the Ozark Plateau to 7.5 km in the Illinois Basin depocenter (Marshak et al., 2005). Within the platform, there are two orders of structure. (1) Regional-scale epeirogenic structures are broad areas of lithosphere (on the order of 200-500 km in diameter) that have undergone gentle subsidence or uplift during the Phanerozoic (Heidlauf, et al., 1986; Bond and Kominz, 1991; Kolata and Nelson, 1991)—examples include the Ozark Dome (topographically, the Ozark Plateau), and the Illinois Basin. Subsidence analysis indicates that the basin regions have undergone both long-term thermal subsidence and discrete pulses of tectonic subsidence temporally

linked to Appalachian tectonic events. In contrast, arches and domes have remained relatively high throughout the Phanerozoic, and may rise at times when basins subside. Despite this apparently coupled behavior, the long-lived geologic contrasts between subsiding and uplifting regional features imply that the lithospheric provinces have remained fundamentally different. Significantly, structural relief of about 7.5 km exists between the Precambrian-Cambrian unconformity at the center of the Illinois Basin and the same contact at the peak of the St. Francois Mountains. (2) Numerous Midcontinent fault-and-fold zones (Fig. 5) occur within and bordering epeirogenic structures (Braile et al., 1986; Marshak and Paulsen, 1996; McBride and Nelson, 1999). These zones are as large as 100 km by 500 km, and consist of faults (typically steeply dipping in the upper crust), some of which intersect the land surface and some of which die out up-dip in monoclinal folds. In effect, these zones are subdued versions of Laramide-style basement-involved uplifts typical of the Rocky Mountains and Colorado Plateau. A number of zones are clearly associated with narrow sediment and/or volcanic-filled troughs, and have been interpreted as Proterozoic rifts. Some of the fault-and-fold zones remain seismogenic, capable of generating > M = 7 events. Fault-and-fold zones within the proposed study area (e.g., Wabash Valley; NE Missouri; New Madrid) are among the most active intracratonic seismic zones worldwide.

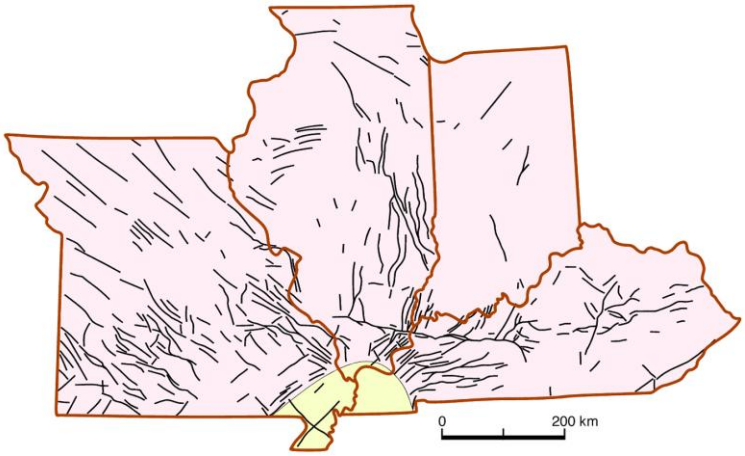
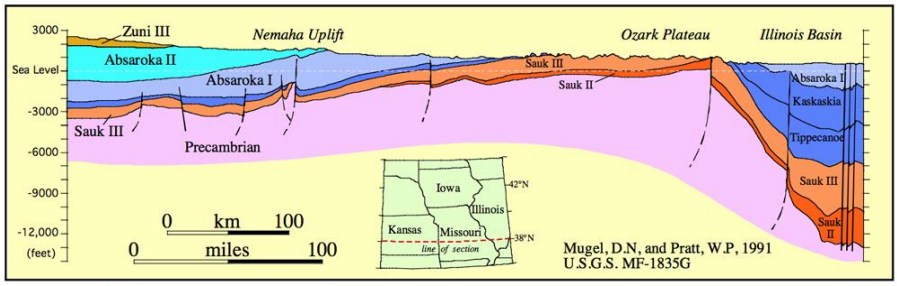


Fig. 5: Fault and fold traces of the OPIB target block. Three trends dominate (NW; NNE; E-W).



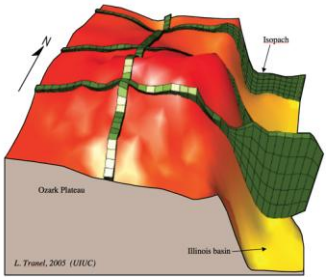


Fig. 6: Vertically exaggerated cross section, Ozark / Illinois Basin boundary. **Fig. 7:** 3-D model of the boundary.

Workshop Justification

Previous *EarthScope* workshops addressing the Midcontinent covered the entire continental-interior region. These meetings consistently pointed to the OPIB block as a high-priority target, because of the number of major tectonic features that it contains. These features include:

- the largest, and topographically most prominent, epeirogenic dome (Ozark Plateau);
- the deepest intracratonic basin (Illinois Basin);
- structural relief of about 7.5 km;
- several of the most prominent fault-and-fold zones (Reelfoot rift; Rough Creek graben; northeast Missouri fault zone; Wabash Valley fault zone; La Salle belt; Fluorspar district fault system);
- several active intracratonic seismic zones (e.g., NE Missouri; New Madrid; Wabash Valley);
- the NE-SW-trending boundary of 1.7 Ga crust;
- the NE-SW trending boundary of Paleoproterozoic crust;
- the buried Grenville front;
- the Mississippi embayment;
- possible Proterozoic rift and foreland basins.

Despite the high priority of the OPIB block, earlier meetings did not yield a specific, workable scientific agenda designed to study it. The *EarthScope* transportable array is now approaching the Midcontinent and will sweep through the region in 2011-2012. Considering this temporal context, and the important opportunity that study of the OPIB block provides for increasing our understanding of continental assembly and evolution, it is urgent that research plans for study of the OPIB block be established now. With this goal in mind, we propose a focused workshop designed to lay the foundation for development of *EarthScope-related* research proposals that specifically address the OPIB block. By narrowing the scope of the meeting to address a specific target whose dimensions are compatible within the scale of *EarthScope* experiments, we anticipate that meeting will nucleate a set of strong, linked proposals. The workshop setting is needed to bring researchers with expertise in utilizing *EarthScope* data together with researchers who have expertise on tectonic issues of OPIB block.

In order to assess the potential of our proposed focused approach, and to establish a preliminary scientific rationale for study of this region, a small group of researchers met, at their own expense, at the University of Illinois on June 5, 2009. The meeting, organized by Stephen Marshak, included:

- Stephen Marshak, Xiaodong Song, Alison Anders, and Jonathan Tomkin (Univ. of Illinois),
- Michael Hamburger and Gary Pavlis (Indiana Univ.),
- Seth Stein (Northwestern Univ.),
- Hersh Gilbert and Eric Calais (Purdue Univ.),
- Mary Parke (Indiana Geological Survey), and
- Timothy Larson (Illinois State Geological Survey).

In addition to those in attendance, Suzan van der Lee (Northwestern Univ.), John McBride (Brigham Young Univ.), and Scott and Beth Wilkerson (DePauw Univ.) contributed ideas. The group concluded that the OPIB block warrants intense study, and that a focused workshop would be needed to stimulate development of research proposals concerning the block. Mary Parke, Scott Wilkerson, Seth Stein, Mike Hamburger, Tim Larson, John McBride, and Gary Pavlis assisted in preparation of this proposal for a workshop.

Topics to be Addressed

Considering the diversity of tectonic features within the OPIB block, work in the region could address many questions, including:

- What are the differences between basin lithosphere and dome lithosphere?
- What is the cause of cratonization, and what is the nature of North America's cratonic roots?
- What is the origin and evolution of cratonic basins?
- Are there Proterozoic accretionary tectonic boundaries at depth?
- Does lithosphere of a cratonic platform differ from that of shields or orogens?
- Do mantle features influence distinct provinces within the platform (e.g., Bedle and van der Lee, 2006; Forte et al., 2007)?
- What makes Mississippi embayment behave differently from adjacent lithosphere?
- Did the formation of the granite-rhyolite province leave residuum at depth?
- Are there deep manifestations of Proterozoic rifts?
- What factors driver the subsidence of basins?
- Can discrete, independently moving crustal blocks be delineated?
- How does the Moho vary with location?
- Do deep crust or mantle features control seismicity (e.g. Hildenbrand, et al., 2002)?

Participants in the proposed workshop will develop testable working hypotheses pertaining to these problems that can be resolved by a well-planned configuration of geophysical (seismic; GPS; and magnetotelluric) experiments. Of note, some geophysical data for the target block already exist. But these data, archived in state geological surveys and in industry files, have not been available broadly. As part of the *EarthScope* projects that will evolve from our proposed workshop, we will develop a strategy for accessing these data.

The answers to the problems that we will address in the context of *EarthScope* will be of global interest, because comparable lithospheric provinces occur on all continents. Further, because we are examining an important specimen of cratonic platform lithosphere, results from work in the proposed OPIB target block could serve as a basis for comparison with other types of lithospheric provinces, and could be used to address such questions such as: How does the lithosphere of platforms, shields, and orogens differ at depth?

Need for a Tectonic Framework GIS Map

Our preliminary workshop also determined that in order for science planning concerning the OPIB block to be successful, there is a need for a GIS-based compilations of key existing geological and geophysical data pertaining to the block. Such compilations do not currently exist, except in a rudimentary form assembled for this proposal (Fig. 8a-f; these images are courtesy of Curtis Abert, ISGS), so there is no way to visually examine spatial relationships among faults, folds, crustal provinces, potential field data, seismicity, basement structure, and existing reflection profiles. Thus, as part of this workshop proposal, we request funds to develop a preliminary geo-referenced compilation of the above data on a DEM base for a region that includes Illinois, Indiana, Kentucky, and Missouri. Some of the information needed for this compilation is available through state geological surveys, so part of the funding will be used for travel to state survey offices. Specifically, in preparation for the meeting, we will make preliminary compilations of the following:

- bedrock geology,
- DEM of surface topography,
- DEM of the sub-Pleistocene surface,
- structure contour maps on the Tippecanoe and the Kaskaskia sequence boundaries,
- structure contour map on the Precambrian basement surface,
- earthquake epicenter map,

- gravity anomaly map,
- aeromagnetic map,
- fault and fold distribution map.

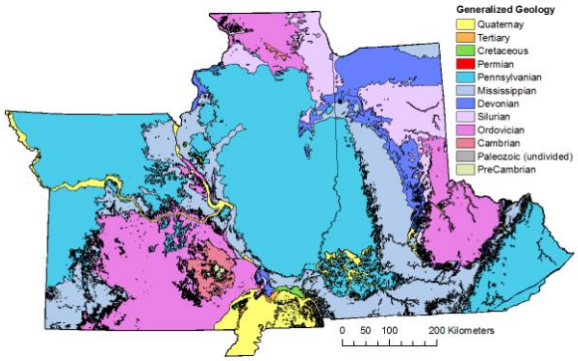


Fig. 8a: Simplified bedrock geology, OPIB block.

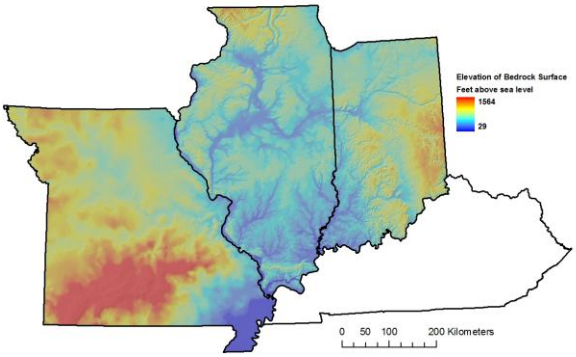


Fig. 8b: Topography of the bedrock surface, OPIB block.

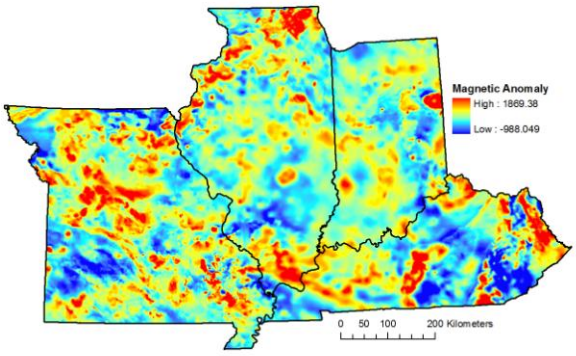


Fig. 8c: Magnetic anomaly map, OPIB block.

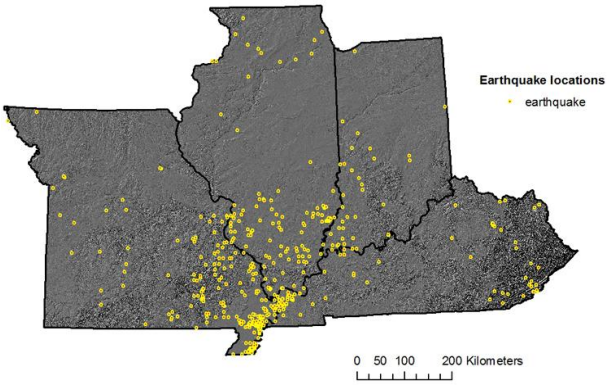


Fig. 8d: Epicenters of post-1973 earthquakes, OPIB block.

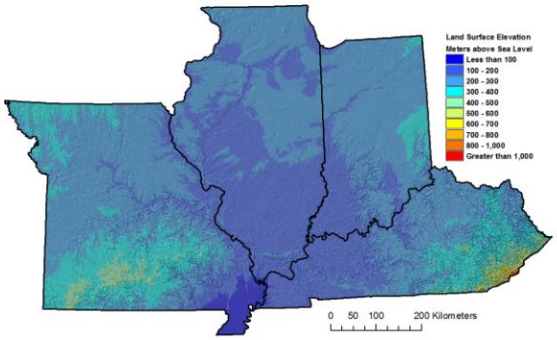


Fig. 8e: Land surface DEM, OPIB block.

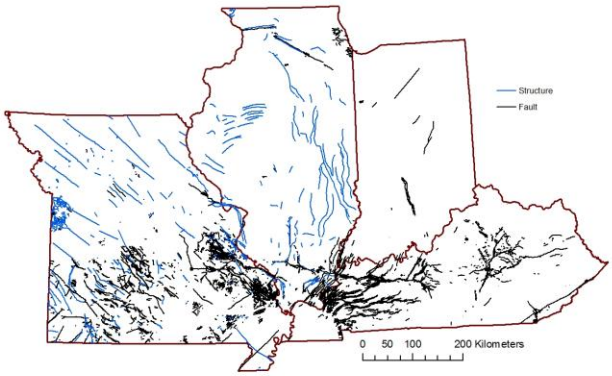


Fig. 8f: Known faults and folds (surface and subsurface).

Potential for Outreach

There is excellent potential for significant outreach concerning *EarthScope*-related work in the Midcontinent. For example, the region of interest and surroundings include several major cities, with museums and science centers. Because the region, part of the Great Plains, is not one of visible geologic splendor, there is a strong need to provide opportunities for increasing geologic literacy. Our workshop will define outreach opportunities explicitly, especially those that can leverage substantial efforts already underway at state geological surveys and by Skip Nelson of Illinois State University. The ISU group already has *EarthScope*-related teacher-training programs under way with funding from the Illinois State Board of Education. Participants in the workshop will be asked to discuss unique facilities of their home institutions that might be available. For example, the University of Illinois is particularly strong in development of data visualization (through NCSA, the National Center for Supercomputing Applications, on campus), and in STEM educational development (through the College of Education), and also is the base for the Mid-America Earthquake Center.

RECENT RELATED MEETINGS

In the past five years, three large meetings have included coverage of Midcontinent tectonic issues in the context of *EarthScope*. These were:

- *USArray and the Great Plains,* organized by M. Hubbard at Kansas State University in 2004.
- The *GeoFrame Workshop,* organized by van der Pluijm et al. in St. Louis in 2006 (Tikoff et al., 2006). This meeting was followed by *EarthScope*-sponsored theme sessions at both AGU and GSA.
- *EarthScope Science for Mid-America,* organized by P. Bodin et al. at Memphis State University in 2004.

Each of these meetings addressed very broad areas. Considering the rapidly decreasing lead time, it is now appropriate to focus on a detailed research agenda for the OPIB block. We recognize, of course, that other groups will be exploring other important areas in the Midcontinent—we will work towards developing connections with the other groups to avoid duplication of effort and to leverage results.

MEETING LOGISTICS

Organizing Committee

Stephen Marshak (Univ. of Illinois) will serve as the PI of the workshop proposal. Marshak, Mary Parke (Indiana Geological Survey), and Tim Larson (Illinois State Geological Survey) will coordinate the logistics of running the workshop. John McBride (Brigham Young Univ.), Tim Larson (ISGS), as well as geologists and GIS specialists at state geological surveys and participating universities, will join in coordinating producing of Tectonic Framework maps for the meeting. The organizing committee to recruit and select participants for the workshop will include John McBride (Brigham Young Univ.), Gary Pavlis and Michael Hamburger (Indiana University), and Seth Stein (Northwestern University). Other participants of the June 5, 2009 preliminary meeting (Hersh Gilbert; Eric Calais; Xiaodong Song) will be available for consultation.

Invitations and Participant Selection

Upon approval of the proposed workshop, the organizing committee, in consultation with other participants of the June 5 meeting, will identify individuals to be invited. Organizers will seek to attract under-represented groups. In addition, a general advertisement of the meeting will be posted through the *EarthScope* website and other outlets (e.g., EOS; USGS) to attract other participants.

Proposed Meeting Schedule and Logistics

We will plan the meeting for two days in early March. The tentative schedule is as follows:

Thursday
- Participants arrive by mid-evening.
- Group reception for early arrivals.

Friday
- Morning 1: Introduction and goals; discussion of background tectonics and implications of the Tectonic Framework map.
- Morning 2: Presentations of results from related research by participants to serve as examples of work that can be done.
- *Lunch*
- Afternoon 1: Development of a list of specific priority science issues and associated testable hypotheses.
- Afternoon 2: Design of experiments appropriate for addressing these issues.
- Dinner
- Evening: Breakout groups to refine experiments.

Saturday
- Morning 1: Plenary group to share results of breakout sessions; discussion of opportunities to link projects, both within region and with other regions; discussion of outreach opportunities
- Morning 2: Subgroups begin to outline proposals
- *Lunch*
- Afternoon: Proposal development continued; discussion of whether to consider a broader project incorporating linked proposals to continental dynamics or other NSF programs; wrap-up
- post-4:00 departure

Workshop Products

The workshop will lay out a clear scientific agenda for *EarthScope*-related research in the OPIB target block, a plan for associated outreach, a plan for interaction with working groups in related areas, and the production of preliminary Tectonic Framework maps of the region. The workshop should lead to the production of a specific set of proposals. The results of the workshop will be presented at the national *EarthScope* meeting, and will be submitted for publication. The maps will be made available in open-file format through the state geological surveys.