FINAL TECHNICAL REPORT

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WORKSHOP TO DEVELOP A COMMUNITY STRATEGY FOR A BOREHOLE GEO-OBSERVATORY IN THE CENTRAL U.S.

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ABSTRACT

Information obtained from a deep borehole observatory would enhance our understanding of the enigmatic seismic hazard in the central US. Such an effort, with its inherent cost and risk, requires a coordinated, multi-disciplinary, multi-university and community stakeholder team approach. Therefore, as an initial step toward implementing a borehole geo-observatory this project organized and hosted a workshop to bring together regional scientists, industry and science stakeholders, instrumentation experts, and researchers with borehole experience. The goal of the workshop was to define scientific targets and priorities for a borehole geo-observatory in the central US and then to develop an implementation strategy. The outcome of the workshop was FOCUS, the Fault Observatory in the Central United States, which focuses on the causes and consequences of seismicity in the central US and the tools and techniques needed to improve our understanding of those causes and consequences. The workshop identified a mission, objectives, leadership team, lead scientist, organizational structure, and a strategy for implementation. A report for the workshop was submitted to EOS for publication and a webpage has been designed and disseminated.

INTRODUCTION

The workshop was organized by a multi-disciplinary organizing committee coordinated and led by faculty at the University of Memphis Center for Earthquake Research and Information (CERI) and the Department of Earth Science. The Organizing Committee (OC) included: Drs. Cramer, Langston, Powell, Johnston, Bodin, and Hill. Duties of the OC were to finalize the schedule, create a website, advertise for attendees, invite speakers, and facilitate the workshop.

Considerable effort was put into the website (http://www.ceri.memphis.edu/FOCUS) prior to the workshop to provide those interested in the project with background material (e.g. Memphis Old Hole Report) and a forum to develop the working concept for the observatory. The website was very useful and is something recommended for future workshops.

The workshop was hosted at the FedEx Institute of Technology at the University if Memphis on May 3-4, 2007. The event took place over the course of two days and followed the format of invited keynote speakers presenting technical issues related to the science and to the practice of

instrumenting a borehole. These keynote talks were intended to stimulate discussion and highlight scientific controversies or problems that a geo-observatory could address.

Workshop participants were invited directly and through an advertisement posted to the CEUS List serve hosted by the USGS. Approximately 35 professionals attended the workshop, representing multiple agencies, universities, states, countries, and disciplines. An additional dozen individuals were interested in the workshop but unable to attend. Workshop participants are listed in Appendix A.

WORKSHOP AGENDA

The two day agenda is summarized in the tables below. The first day focused on presentations and discussions of key topics. The activities of the second day sought to organize the goals and objectives of the observatory, identify participants, and determine a plan for the future.

DAY ONE: Thursday May, 3, 2007		
8:00	Call to Order: Welcome Meeting Goals and Overview	 A. Johnston C. Cramer
8:30	Keynote 1: Summary of Problems and Targets of Interest	C. Langston
9:00	Discussion of Problems and Targets	
9:30	Keynote 2: Dream Tools	P. Malin A. Lee
10:00	Discussion of Tools and Data Needed	
10:30	Break	
11:00	Keynote 3: Data Management Issues	J. Swift
11:30	Discussion of Data Management Issues	
12:00	Lunch (at the FIT)	
1:00	Keynote 4: SAFOD, Lessons Learned	S. Hickman
1:30	Discussion of SAFOD Lessons	
2:00	Current Initiatives and Possible Areas for Collaborations Geology University of Kentucky geotechnical hole Geotechnical/Earthquake Hazard GPS EarthScope Connection	 B. Hatcher E. Woolery C. Cramer B. Smalley C. Powell
3:30	Break	
4:00	Discussion on the Way Forward	A. Hill
5:30	Break for Dinner at 6:00 (Fogelman Executive Center)	

DAY TWO: Friday May, 4, 2007		
8:00	Outline of Topics for Plenary Sessions	C. Cramer
8:30	Plenary Session – The Way Forward: Discussions Geotechnical Aspects Expertise/Partnerships	

	Science Targets Organization	
12:00	Lunch (at the FIT)	
1:00	Plenary Session – The Way Forward, continued The Role of ICDP Action Items	
3:00	Adjourn	

HIGHLIGHTED MEETING DISCUSSIONS

Discussion of Targets:
The stage was set through discussion of general issues including the tectonic frame work, present day seismicity, seismic networks, GPS results, and current theories for earthquake activity in the New Madrid seismic zone. The agreed upon motivation for developing the observatory was increased knowledge of an intraplate seismic zone that would advance scientific theories for intraplate earthquake activity and provide a much clearer understanding of earthquake hazard.

The advantage of obtaining seismic observations below the Mississippi embayment sediments includes one to two orders of noise reduction, improved source spectra, and possible detection of episodic tremor. In addition, direct measurements of strain would be possible including strain transients and dynamic strain. Strain measurements would be made using "PBO" GPS and sensitive seismometry and "SAFOD" type measurements through the fault.

Several potential problems will have to be considered in designing the deep borehole part of the observatory. The objective is to drill into the active Reelfoot fault. Karst could be encountered and will affect our ability to drill deeper. Karst is a definite problem in the region and affected the recent deep hole in Kentucky. Drilling at depth will subject borehole seismic instruments to elevated temperatures. This could be a problem if drill holes exceed several kilometers. We will also have to find the fault at depth. The fault has very little surface expression and the geometry at depth is not well known. We will need high resolution imagining prior to drilling to optimize our chances of encountering the fault at depth.

The observatory will also have a surface seismic array to investigate wave propagation in the unconsolidated embayment sediments. Presently, basic questions regarding the response of the sediments to the passage of seismic energy are not answered. For example, it is not known if the sediments amplify or deamplify ground motions or, if they act as a waveguide. The extent of the nonlinear response is unknown as if the attenuation with distance. The surface array will provide critical information that can be combined with geotechnical information provided by the deep borehole and the Kentucky deep well to better specify the seismic hazard in the region.

The observatory will help resolve the geologic structure and history of the region. For example, the Reelfoot fault could be very old. More reflection data, obtained as part of the observatory mission, will help clarify structural trends, fault geometry at depth, etc. The observatory will also serve as a data depository for refraction, reflection, and potential field data.

Drilling:

Discussion centered on oil versus mining technology. The design of the hole must be considered very carefully to allow critical instrumentation packages to be installed and maintained. Coring will accompany drilling. How much is needed and for what purposes?

Additional Study Areas:
Several related projects were discussed that could integrate into the objectives of the observatory. In this sense, the observatory will serve as a broad umbrella fostering research efforts that, when combined, will provide a much improved determination of seismic hazard in the region. Heat flow is a critical parameter in our understanding of the active tectonics in the region. Heat flow measurements are very sparse. The general understanding is that heat flow is relatively high in the embayment and decreases to the east. Many more measurements are needed to develop an accurate picture of the heat flow in the region. The regional stress field is not well known. Additional in-situ stress measurements are needed to determine if important stress variations occur in the vicinity of the Reelfoot fault, as are observed along the San Andreas fault. Very little is known about fluid flow at depth. Yet, fluid flow could be one of the major factors influencing seismic activity in the New Madrid seismic zone. More continuous GPS stations are needed. The existing continuous network, GAMMA, is stable and is providing data that suggests that strain rates across the Reelfoot fault are comparable to those in active plate boundaries. More GPS stations will provide a better, more detailed picture of the regional displacement field.

Existing Wells and Data:
CERI New Madrid seismic network catalog
http://folkworm.ceri.memphis.edu/catalogs/html/cat_nm.html 1974-present

CERI GAMMA GPS data – available through unavco

Arkansas Core Repository – available for access
- Paleozoic cores
- New wells being drilled in Arkansas, S and SW of NMSZ

Kentucky Geotechnical Hole
- Drilled to 585 m into bedrock (10 m in)
- 4” cased hole
- Logged – many types

Memphis Old Hole Report – http://www.ceri.memphis.edu/FOCUS/discussion.html
A NEHRP Project final report showing locations of old drill holes in the embayment. Report recommends seven likely candidates for reentry with seismic instrumentation.

The Way Forward: Summary of Day One
A phased approach was suggested consisting of the following steps:
- Partnerships with industry
- Follow the ICDP process
- Determine what we know presently about the region from available data sources
- Determine what else we need to know to in order to establish the observatory
- Determine what additional data sets will be required

Establish how interested parties can become part of the effort

The major discussion points are as follows:

- Develop a shallow borehole seismic array as an initial effort.
- Need for an organizing committee (done later in the workshop by a committee of the whole).
- Need to develop scientific hypotheses that this project will address. Should define the ideal site; the ideal site description is an important step in developing search parameters to find actual candidate sites. Site selection should identify a site for both a 1 km intermediate hole and 5-6 km ultimate hole (possibly separate sites). Search should start with existing or currently being drilled wells before looking for sites for new holes.
- Panels of experts should be used for drilling advice and advice on other issues. ICDP provides many of these resources.

Possible Targets and Issues for project to address:

- Seismogenic Depth (5-6 km):
  Reelfoot Fault, Blytheville extension, Cottonwood Grove Fault

- Pascola Arch:
  Thermal History (cooling age), Uplift

- Drilling through the faults – Reelfoot easiest candidate; look at wall rock and fault zone

- Monitoring properties in the fault zone for a response to earthquakes: Heat flow, Fluids, Pressure, chemistry, permeability (hydrologic properties), Stress/Strain, Fault zone guided waves

- Issues of why intraplate earthquakes occur:
  Why this rift system and not other, more geophysically prominent rifts?
  Upper mantle link? – Forte et al., 2007
  What are the drivers of North America intraplate earthquakes?
  Time frame for deformation and activity?
  What are the geologic and geophysical conditions in the seismogenic zone?

- Quantify earthquake source properties:
  Differences from earthquakes near plate boundaries.
  Crustal attenuation different from western U.S.
  Embayment sediment properties – need to remove effects:
    Linear or nonlinear response
    Attenuation
- Look for presence of low-level non-volcanic tremor:
  Reduce detection threshold by placing instruments below sediments.
  Tie to GPS measurements

- Potential regional economic targets – oil, gas, water, waste injection sites.
  Deep stratigraphy of Reelfoot Rift, Cambrian structure, Oil exploration

- Outreach effort:
  Risk management, Policy decision support, Awareness/Preparedness

- Need to involve the following kinds of studies:
  Rheology
  Geochemistry
  Fluid inclusions
  Rock mechanics
  Downhole measurements

Second Day Discussion:
The discussion centered on the geotechnical aspects of a borehole through the embayment sediments, how the upper 100 m would be characterized, the kinds of instruments that would be placed in the borehole and what kinds of data they would supply, how to induce in situ nonlinearity, possible sidewall coring efforts, coordination of sampling and instrumentation, and how to get community involvement in the effort.

Needed Expertise:
Oil and Gas Commissions
Fluid Inclusion / Geochemistry
Deformation / Microstrain
Minerology
Rheology
Drilling Technology [Los Alamos, DOSECC (coring)]
DOE
Drilling Tool – Schlumberger
Industry Partners (instruments) – Sonde, others

Develop partnerships within the following areas:
Geographic Representation
Industry Parnters (imaging) – 3D seismic imaging
Community Partners
CUSEC State Geologists
FEMA and State EMAs
CUSEC
EarthScope

OUTCOMES

The workshop identified a mission, objectives, leadership team, lead scientist, organizational structure, and a strategy for implementation. A report for the workshop was submitted to EOS for publication and a webpage has been designed and disseminated. We named our effort FOCUS (Fault Observatory for the Central U.S.).

Mission Statement

The mission of Fault Observatory for the Central U.S. (FOCUS) is to drill a scientific deephole into the New Madrid seismogenic zone to better understand intraplate earthquakes.

Organization Chart

Leadership: Lead Scientist and the Steering Committee

Subcommittees:

- Geophysics and Monitoring
- Drilling / Holes of Opportunity
- Geology/Tectonics
- Geotechnical
- Community Partners / Outreach and Education

Committee members are given in Appendix B

GOALS

The ultimate goal of FOCUS is to drill a 5-6 km deep scientific hole into the Precambrian basement and into the New Madrid seismic zone. Additional scientific goals for FOCUS include a better understanding of why earthquakes occur in intraplate settings, a better understanding of the geological, geophysical, and geotechnical setting of the New Madrid seismic zone, an improved understanding of intraplate earthquake processes, and a better definition of seismic hazard to maximize public safety. To accomplish these goals short, intermediate, and long-term objectives were defined.

Short-term objectives include the preparation of an International Continental Drilling Program (ICDP) pre-proposal, initiation of site selection activities, communication with the international scientific community via scientific meetings and presentations, and development of funding strategies and proposals targeted at key agencies. A special session at the fall AGU is planned. An article for EOS has been published.

Intermediate-term objectives include developing an ICDP drilling workshop proposal investigating holes of opportunity and scientific characterization of alternative drilling sites, establishing an intermediate depth observation hole into the Paleozoic bedrock (~ 1k m), and preparing for an observatory dedication (not completion) on the 200th anniversary of the 1811-1812 earthquakes.

Long-term objectives include drilling a deep hole into the Precambrian basement (5 – 6 km) and into the New Madrid seismic zone.

REFERENCES

Cramer, C.H., and L.W. Wolf, 2007, Deep drill hole for the New Madrid seismic zone, borehole geo-observatory Workshop, Memphis, Tennessee, 3-4 May 2007, EOS, Transadtions, Am. Geoph. Union, vol. 88, no. 43, 444.

APPENDIX A
Workshop Attendees

List of Workshop Participants – September 25, 2007

Committee:

Arch Johnston, CERI
Chris Powell, CERI
Charles Langston. CERI
Arleen Hill, CERI
Chris Cramer, CERI

Keynote Persons:

Steve Hickman, USGS
Jennifer Swift, COSMOS
Allen Lee, Duke University
Peter Malin, Duke University

Others attending:

Buddy Schweig, USGS
Oliver Boyd, USGS
Bill Stephenson, USGS
Beatrice Magnani, CERI
Roy Van Arsdale, CERI
Brian Waldron, GWI, Univ. of Memphis
Mitch Withers, CERI
Bob Smalley, CERI
Ed Woolery, Univ. of Kentucky
Bob Hatcher, Univ. of Tennessee, Knoxville
Youssef Hashash, Univ. of Illinois, Urbana-Champaigne
Bob Bauer, Illinois Geological Survey
Melanie Barnes, Texas Technical University
Richard Ray, Univ. of South Carolina, Columbia
Shahram Pezeshk, Univ. of Memphis
Rick Howe, R.W. Howe and Associates, Memphis, TN
Jonathan Paauwe, Indiana DOT
Lorrie Wolf, Auburn Univ.
Scott Ausbrooks, Arkansas Geologic Commission
Bill Prior, Arkansas Geologic Commission
Ming-kuo Lee, Auburn Univ.
Richard Dart, USGS

Randy Cox, Univ. of Memphis
Behrooz Tavakoli, Univ. of Memphis
Gary Patterson, CERI
Rob Williams, USGS

Interested parties that could not attend:

Mark Zoback, Stanford Univ.
Kaye Shedlock, NSF
Bill Ellsworth, USGS
Rus Wheeler, USGS
Dave Applegate, USGS
Glenn Rix, Georgia Technical Institute
Gail Atkinson, Univ. of Carlton
Kate Miller, Univ. of Texas, El Paso
Jerry Hajjar, MAE Center, Univ. of Illinois, Urbana-Champaigne
Zhenming Wang, Univ. of Kentucky
Jim Beavers, Univ. of Tennessee, Knoxville
Guy Cobb, Federal Express, Memphis, TN
John Kiefer, Kentucky Geological Survey
Mike Bradley, USGS
Martin Chapman, Virginia Tech.
Dominic Assamaki, Georgia Technical Institute
Haydar Al-Shukri, Univ. of Arkansas, Little Rock

APPENDIX B

Committee Members

The Steering Committee will be composed of the Lead Scientist and a representative (and alternate) from each participating institution, organization, and agency.

Lead Scientist: Charles Langston, CERI

Steering Committee:

- CERI – Chris Cramer and Arleen Hill
- Auburn U. – Lorraine Wolf and Ming-Kuo Lee
- Texas Tech. – Melanie Barnes
- USGS – Bill Stephenson, Richard Dart, Oliver Boyd
- Arkansas Geological Commission – Bill Prior, Scott Ausbrooks
- U. of Kentucky (and KGS) – Ed Woolery
- Duke and Sonde – Peter Malin and Allen Lee
- U. of Tennessee – Bob Hatcher, Jim Beavers(?)
- UIUC – Youssef Hashash
- Georgia Tech – Glenn Rix
- Carlton U. – Gail Atkinson(?)
- Indiana U. – Gary Pavlis(?)
- SAFOD – Steve Hickman, Mark Zoback(?)

Geophysics and Monitoring Subcommittee:

- Charles Langston, Chair
- Bill Ellsworth(?)
- Ming-Kuo Lee
- Bob Smalley
- Mitch Withers
- Loraine Wolf

Drilling / Holes of Opportunity Subcommittee:

- Ed Woolery, Chair(?)
- Paul Bodin(?)
- Richard Dart
- Bill Prior
- Brian Waldron
- Mark Zoback(?)

Geology / Tectonics Subcommittee:

- Randy Cox
- Bob Hatcher
- Steve Hickman
- Arch Johnston

Beatrice Magnani
Chris Powell
Buddy Schweig(?)
Tish Tuttle(?)
Roy Van Arsdale

Geotechnical Subcommittee:
Chris Cramer, Chair
Dominic Assimaki(?)
Bob Bauer
Youssef Hashash
Shahram Pezeshk
Richard Ray
Glenn Rix(?)
John Scheider(?) - International
Bill Stephenson
Rob Williams

Community Partners / Outreach and Education Subcommitte:
Arleen Hill, Chair
Rick Howe(?)
Gary Patterson

CONCLUSIONS

Many questions persist in our multi-disciplinary endeavors to understand the causes and consequences seismicity in the central United States. In fact uncovering answers to these questions may be pertinent in other intra-plate regions. The purpose of this workshop was to initiate a regional, multi-university, multi-agency, multi-disciplinary dialog regarding a fault observatory at depth. The results of the workshop include: mission, objectives, leadership team, lead scientist, organizational structure, and a strategy for observatory implementation. The realization of a Fault Observatory in the Central United States will require sustained commitment of a diverse team. The team will necessarily be inclusive and engaged with multiple scientific communities. This workshop succeeding in meeting the goals of the funded project and most importantly established a lead scientist and a core of professionals committed to the research questions and to the borehole geo-observatory approach to addressing the fundamental research questions.

ACKNOWLEDGEMENTS
Project team gratefully acknowledges workshop logistical support provided by D. Greganti at the Center for Earthquake Research and Information (CERI) at the University of Memphis. Website development and maintenance was conducted by K. Tucker at CERI. The workshop was a success thanks to the participants and to those who though unable to attend provided data and support. Previous studies of holes of opportunity in the study area will continue to be valuable resources as the FOCUS project moves from planning into existence. This project was funded by the USGS through award number 06HQGR0146.

REFERENCES
EOS Article