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A challenge for tectonic studies and seismic hazard analysis is that the rates and sizes of the largest observed earthquakes in an area may differ significantly from their true long-term values. This especially likely for intraplate areas or others where recurrence intervals are long, so the earthquake record length is comparable to the mean recurrence time of large earthquakes. In many areas, the largest earthquakes - termed characteristic - appear more common than expected from the log-linear frequency-magnitude relation observed for smaller earthquakes. In others, large earthquakes which we term "uncharacteristic" appear less frequently than expected from the small earthquakes. These effects may be real, or may arise from several possible situations. Apparent characteristic earthquakes can occur if earthquake recurrence intervals are distributed about the mean for that magnitude range, because sampling bias makes those with shorter intervals more likely to be observed than those with longer ones (fractions of earthquakes cannot be observed). A second possibility is suggested by the fact that characteristic earthquakes are often inferred because paleoseismic data are discordant with instrumental or historical data. Hence apparent characteristic earthquakes would occur if paleoseismic data overestimate earthquake magnitudes. This appears to have occurred for the New Madrid zone, because paleoliquification data were calibrated assuming the 1811-12 earthquakes were M 8.3 events, whereas more recent analyses find that these earthquakes were low M 7. Conversely, paleoearthquakes in the Wabash seismic zone appear "uncharacteristic", perhaps because or the paleoseismic record captures only some of the large earthquakes.

S14A-02 1545h

Crustal strain rates and seismic hazard from seismicity and GPS measurements along the St Lawrence Valley, Quebec

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The St Lawrence Valley, Quebec, presents one of the largest concentration of earthquakes in eastern North America. Background seismicity extends over 900 km from the Gulf of St Lawrence to Montreal following the Paleozoic Iapetan Rift system. Two main seismic zones are defined along this trend: Charlevoix, the most active in eastern Canada and the locus of at least five M6+ earthquakes in the last 350 years; and Lower St Lawrence, where the largest known earthquakes are about M5. Integration of earthquake statistics in both zones indicates that the equivalent seismic deformation rates are 1.0 +/- 0.5 mm/yr and 0.2 +/- 0.3 mm/yr, respectively. Based on high-precision GPS measurements at 16 sites surrounding the St Lawrence Valley, we estimate the current rate of crustal strain across both the Charlevoix and Lower St Lawrence seismic zones. Our GPS results are based on 3-4 campaign occupations over the last 7-9 years. On a regional scale, horizontal strain rates are 0.5-2 nanostrain per year of roughly NNW-SSE shortening. This strain pattern agrees well with earthquake focal mechanisms. Horizontal velocity vectors on both sides of the St Lawrence River suggest that this shortening corresponds to a maximum convergence of 0.5 +/- 0.5 mm/yr between the north and south shores, in general agreement with the rate from earthquake statistics. Assuming that seismicity in Charlevoix follows typical b-value statistics, our GPS results constrain the maximum magnitude of large earthquakes to be less than or equal to M7.6. Alternatively these strain rates are equivalent to one characteristic M7 earthquake per 170 years.

S14A-03 1600h INVITED

Geophysical and Geodetic Evidence for Active Crustal Deformation in the Southern Illinois Basin

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We examine geophysical and geodetic evidence of active crustal deformation associated with the Wabash Valley Seismic Zone (WVSZ) in the southern Illinois Basin. The area is associated with a concentration of historical earthquakes, paleoseismic evidence of repeated, large-magnitude earthquakes, and possible Quaternary faulting. Seismic data in the vicinity of the Wabash Valley Fault System (WVFS) show that the WVFS is rooted in basement-penetrating, high-angle transtensional faults that define a narrow, elongate graben, with normal displacements reaching >600m, and sinistral strike-slip displacements of 2-4 km. Regional seismic network observations indicate diffuse, moderate-magnitude seismic activity in the Wabash Valley region, notably the June, 2002 Darmstadt, Indiana earthquake (m_b5.0). In addition, small-magnitude earthquakes recorded by a temporary seismic array deployed in the WVSZ in 1995-1996 show a concentration of activity in and around the WVFS. Evidence of geodetic strain was obtained from a 56-station regional GPS geodetic network in the southern Illinois Basin, observed in GPS campaigns in 1997-2003. The network includes observations at a dense 22-station geodetic array in the Shawnee National Forest of southernmost Illinois, in the Hicks Dome/Fluorspar area. The individual site velocities, while highly variable, suggest a systematic pattern of shear strain that may be interpreted either as sinistral shear along the NNE-trending Wabash Valley Fault System or as dextral shear along the NE-trending Commerce Geophysical Lineament. While most of our local strain estimates remain statistically indistinguishable from zero, the averaged shear strain for the entire network is estimated at $1.7 \pm 1.2 \times 10^{-9}$ yr^{-1}, oriented 130.6° ± 9.4°. Strain estimates from the Shawnee network suggest higher strain rates, but still close to the margin of their larger error estimates. The maximum compressional strain is estimated at $26.9 \pm 26.1 \times 10^{-9}$ yr^{-1}, oriented 107.2° ± 26.3°. The location, depth, and mechanism of the 2002 Darmstadt earthquake provides evidence for ongoing deformation along reactivated Precambrian and Paleozoic basement structures, in a zone of recurring seismic activity, and in an area of heightened neotectonic strain.

S14A-04 1620h

Are SCR Earthquakes Caused by Tectonic Stresses Acting in the Shallow, Strong Crust?

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We present the following testable model to explain the genesis and location of the current seismicity in SCR regions. SCR earthquakes occur due to localized stress build-up in the vicinity of stress concentrators located in a pre-existing zone of weakness in response to plate tectonic streses. These stress concentrators are suitably oriented intersecting faults (or kinks), buried plutons, and rift pillows. Unlike plate boundary earthquakes, these earthquakes tend to be spatially clustered in relatively small regions which are locations of very local stress build-up and higher strain rates. We illustrate these ideas using a two fold approach to explain the current seismicity in the New Madrid and the Middleton Place Summerville seismic zones. First is from the results of a simple two-dimensional numerical model using the Distinct Element Method, with model geometry and properties developed to represent the known geological setting. Second is from the results of GPS observations in the two regions. The results of the 2-D modeling show that shear stresses developed in the model blocks successfully predict the observed horizontal motions in the two regions and the locations of elevated strains along the faults are consistent with the locations of the current seismicity. At Charleston the earthquakes occur in a 20 km x 30 km Middleton Place Summerville Seismic Zone (MPSSZ). The results of reoccupation of GPS sites inside and outside the MPSSZ in 1993, 1997, and 2000 suggest that strain is accumulating in the region of active seismicity at a rate of approximately 10^{-7} per year. Outside the MPSSZ in an area of about 5000 km^2, it is accumulating at approximately 10^{-8} per year, and outside that it reverts back to approximately 10^{-9} per year consistent with other observations for the North American plate. These observations support the idea that SCR earthquakes occur near stress concentrators in response to tectonic stresses in the shallow crust.

S14A-05 1635h

Role of Pan-African Structures in Intraplate Seismicity in Ghana

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The setting for intraplate seismicity in southeastern Ghana has been cited as an analog to the even more destructive earthquakes in eastern North America such as at Charleston 1886 (Sykes 1978). Although located far away from any plate boundary, major earthquakes have occurred near Accra, the capital of Ghana in 1939 (M6.4), 1964, 1969, and most recently in 1997 (M4.8) and 2003 (M3.8). The setting for this seismic activity, near the eastern termination of the Romanche Fracture Zone (RFZ), presents the opportunity to investigate the relationship among Pan-African (Neoproterozoic) orogenic structures, transform tectonics, and neotectonic activity. Across the Ghana seismic zone prominent structures of the Pan-African orogen include: i) the Pan-African front (PF) representing the western limit of deformation, ii) the Pan-African suture zone (PS) represented by a ductile shear zone at the base of mafic granulites which comprise the suture zone nappes, and iii) a dextral shear zone that projects into the RFZ represented by a prominent submarine canyon. Epicentral data compiled from local and teleseismic networks reveal clusters along the PF, a remarkable alignment of epicenters along the PS, and events along the coastline parallel Accra fault. Seismic reflection data offshore Ghana confirm active displacement along the Accra fault and, for the first time, provide direct evidence for neotectonic activity along the Pan-African front. The normal sense of displacement along the PF, inferred from the seismic sections, suggests that reactivation of the Pan-African structures involved inversion. The available data provide no support for active tectonics associated with the termination of the RFZ. However, reported seismic activity along the conjugate margin in northeastern Brazil suggests that far-field stresses related to active plate displacements in the Atlantic may contribute to the intraplate seismicity on these nominally passive paleo-transform margins.

S21A CC: 220 C-E Tuesday 0830h

Seismicity and Geodynamics of Eastern North America and Other Midplate Environments III Posters

(joint with G, T)

Presiding: **S Mazzotti,** Geological Survey of Canada Natural Resources Canada**; T Dixon,** University of Miami

S21A-01 0830h POSTER

Catalog of Historical Seismicity in the Central United States

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Modified Mercalli intensity assignments were used to estimate source locations and moment magnitude M for eighteen 19th-century and twenty early- 20th-century earthquakes in the central United States (CUS). These solutions, comparable solutions for historical M > 6.0 CUS events (Bakun, Johnston, and Hopper, BSSA, 2003; Bakun and Hopper, BSSA, 2004), and instrumental solutions for late-20th-century events provide a uniform catalog of historical M > 5.0 CUS earthquakes. The 1811-1812 New Madrid, Missouri, (NM) earthquakes apparently dominated CUS seismicity in the first two decades of the 19th century. M5-6 NM earthquakes occurred in 1843 and 1878, but none have occurred since 1878. There has been persistent seismic activity that can be associated with faults in the Illinois Basin in Illinois and Indiana, with M > 5.0 earthquakes in 1895, 1909, 1917, 1968, and 1987. Four other M > 5.0 CUS historical earthquakes have occurred: in Kansas in 1867, in Nebraska in 1877, in Oklahoma in 1882, and in Kentucky in 1980. Ohio has also been seismically active with several 4.5 < M < 5.0 events.

S21A-02 0830h POSTER

Structure of the Crust and Mantle of Central and Eastern Canada From Teleseismic Receiver Functions

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Teleseismic receiver functions have been used to determine the crustal and upper mantle structure beneath twenty-one three-component broadband seismograph stations of the Canadian National Seismograph Network (CNSN) located in central and eastern Canada. Receiver functions were produced from the waveform data of earthquakes of magnitude 6.5 or greater located at distances of 30 to 90 degrees from each station. When appropriate, receiver functions from similar azimuths and distances were stacked to enhance the signal to noise ratio. Preliminary models for each station were determined by inversion using a generic Canadian Shield model as the starting point. The models were further refined and constraints placed on them by employing the Neighborhood Algorithm. All stations show some evidence for structural layering within the crust. Depths to the Moho range from 35 to 45 km. The average depth to the Moho is 40-42 km, somewhat deeper than the 36 km depth currently assumed for routine earthquake locations in eastern Canada. Most stations show some evidence for 3D structure, which is most probably related to dipping layers. In addition to providing a better understanding of the velocity structure beneath eastern Canada, the improved models should lead to improved earthquake locations, which may help delineate the structures on which the earthquakes occur. An example from the station ICQ in eastern Quebec shows significantly lower RMS errors in the locations of aftershocks of the 1999 Cote-Nord earthquake using the model determined from receiver functions than with the generic model.

S21A-03 0830h POSTER

POP-UP FIELD IN LAKE ONTARIO SOUTHEAST OF TORONTO, CANADA: INDICATORS OF LATE GLACIAL AND POST-GLACIAL STRAIN

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A field of pop-ups in the Upper Ordovician Georgian Bay Formation is located in Lake Ontario south of Toronto Canada. A 1 km x 5 km area of these pop-ups (79o18'W to 79o26' W, 43o33'N to 43o36'N) has been surveyed extensively by high resolution boomer, side scan sonar, multibeam, and submersible. The pop-ups strike primarily NNW, WNW, ENE, NS and EW. The most prominent pop-ups have straight axes 1+ km long. The bathymetric relief across the axial zones is generally about 1-2m, although the structural relief at depth can be 5m+. Many of the narrow axial zones of the surficial pop-ups are located on deeper structural fractures at edges of structural blocks where the bedrock has undergone rigid body rotations. These blocks form much wider structures than the surficial pop-up, and include open anticlines, monoclines, thrusts and high angle faults. Pop-ups are generally younger than the last ice age, but post-glacial sediment onlaps the flanks of many of the pop-ups and larger structures, suggesting that some motion on these structures is not recent, and glacial till may be involved with a few of the pop-up structures. However, several pop-ups do not have a sediment veneer thick enough to be observed seismically. Submersible observations showed that bedrock pop-ups were covered by only a thin veneer of sediment. The pop-ups display master-abutting relationships similar to joint sets mapped onshore, suggesting that preexisting joint sets were utilized. That the sediment onlaps the flanks, but the axial zone appears relatively free of sediment, may indicate multiple motions on some of the pop-up structures, culminating with relatively recent strain. Other pop-ups are apparently relict (those with thick sediment across both the flanks and axial zone). The pop-ups appear to document ongoing deformation beginning with the end of the last ice age and continuing to relatively recently.

S21A-04 0830h POSTER

Use of Subaqueous Slope Failures to Study the Paleoseismicity of Eastern North America

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The identification, dating, and back analysis of subaqueous slope failures can provide useful information about the history and reoccurrence intervals of large, intraplate earthquakes. Such a failure was discovered in the Rochester Basin of Lake Ontario using HUNTEC seismic reflection data and an analysis of piston cores. Historic variations in the earth's magnetic field were measured in the cores within the failures' debris flow and in adjacent unfailed areas, and these variations were compared to a paleomagnetic reference curve developed for the region from three lakes in New York and Pennsylvania. The age of the failure was estimated to be 7,900 yrbp based on the paleomagnetic dating techniques. Using infinite slope stability analyses, measured values of the undrained shear strength, and slope geometry from a GIS elevation model and the HUNTEC records, the minimum ground acceleration needed to fail the slope ranged from 0.01 to 0.03 g. Based on published attenuation relationships for intraplate earthquakes, an earthquake of Magnitude 5 or greater located 150-200 km from the site could have generated such a ground acceleration, and caused the failure. The Niagara-Attica, 1000 Islands, and western Lake Ontario seismic zones are all within this distance. There is currently no known earthquake of this magnitude in the seismic record that occurred 7,900 years ago. This analysis does not prove conclusively that a seismic trigger is responsible for the failure, but rather identifies a starting point for further research. Other possible failure mechanisms that need to be investigated include rapid changes in lake levels that affect the gas phase in the sediments and bedrock "pop-ups" caused by large horizontal stresses beneath Lake Ontario. However, the results of this study do show the promise of this approach for studying paleoseismic events and earthquake hazards in Eastern North America. The next step in this research is to search for similar features in other lakes in the region to see if their ages and locations can verify the existence of past earthquakes.

S21A-05 0830h POSTER

Resolution Constraints on the Use of Regional Aeromagnetic Data for Mapping Basement Faults: An Example from Lake Simcoe, Canada

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Regional airborne magnetic data (line spacings > 500 m) are frequently used as a basis for mapping basement faults for seismic risk assessments, but the resolution limitations of these data are often not considered. In this study we compare a high-resolution lake-based magnetic dataset with low-resolution (800 m line spacing) airborne magnetic data acquired over a well-defined Grenville-age (1.2 Ga) shear zone (Go Home Domain boundary) in southern Ontario, Canada. The shear zone forms part of a broader zone of northwest-trending magnetic anomalies (Georgian Bay Linear Zone) that have been interpreted as zones of basement faulting. Lake-based data were acquired in Lake Simcoe using an Overhauser marine magnetometer with 75-100 m line spacings and 4Hz sampling (ca. 1 m inline sampling). Both airborne and the lake-based datasets identify a series of prominent(> 200 nT) northwest-trending magnetic anomalies that define a 2.5 km wide shear zone. Lake-based data show a significant enhancement in structural detail over the airborne data and identify previously unrecognized northeast-trending brittle faults that cross-cut and offset the Grenville shear with an apparent left-lateral displacement of 250 m. The faults parallel a system of northeast-trending fractures in overlying Paleozoic strata and are spatially coincident with several linear embayments in the modern shoreline. These results show that interpretations based on low- or medium-resolution aeromagnetic data may significantly underestimate the basement structural complexity and occurrence of brittle faulting.

S21A-06 0830h POSTER

Interpretation of Local Gravity Anomalies in Northern New York

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About 10,000 new gravity measurements at a station spacing of 1 to 2 Km were made in the Adirondack Mountains, Lake Champlain Valley, St. Lawrence River Valley and Tug Hill Plateau. These closely spaced gravity measurements were compiled to construct computer contoured gravity maps of the survey areas. The gravity measurements reveal local anomalies related to seismicity, faults, mineral resources and gas fields that are not seen in the regional gravity mapping. In northern New York gravity and seismicity maps indicate epicenters are concentrated in areas of the most pronounced gravity anomalies along steep gravity gradients. Zones of weakness along the contacts of these lithologies of different density could possibly account for the earthquakes in this high stress area. Also, a computer contoured gravity map of the 5.3 magnitude Au Sable Forks earthquake of April 20, 2002 indicates the epicenter lies along a north-south trending gravity gradient produced by a high angle fault structure separating a gravity low in the west from high gravity in the east. In the St. Lawrence Valley, the Carthage-Colton Mylonite Zone, a major northeast trending structural boundary between the Adirondack Highlands and Northwest Lowlands, is represented as a steep gravity gradient extending into the eastern shore of Lake Ontario. At Russell, New York near the CCMZ, a small circular shaped gravity high coincides with a cluster of earthquakes. The coincidence of the epicenters over the high may indicate stress amplification at the boundary of a gabbro pluton. The Morristown fault located in the Morristown Quadrangle in St. Lawrence County produces both gravity and magnetic anomalies due to Precambrian Basement faulting. This faulting indicates control of the Morristown fault in the overlying Paleozoics by the Precambrian faults. Gravity and magnetic anomalies also occur over proposed extensions of the Gloucester and Winchester Springs faults into northern New York. Gravity and magnetic surveys were conducted at the closed Benson Mines magnetite mine and the Zinc Mines at Balmat, New York. The gravity and magnetic anomalies at Benson Mines indicate that significant amounts of magnetite remain in the subsurface and the steep gradients indicate a shallow depth. A gravity high of 35 gravity units in the Sylvia Lake Zinc District at Balmat, New York occurs over the upper marble and a 100 gu anomaly occurs just northeast of the zinc district. Abandoned natural gas fields exist along the southern and southwestern boundary of the Tug Hill Plateau. Gravity surveys were conducted in the vicinity of three of these gas fields in the Tug Hill Plateau (Camden, Sandy Creek and Pulaski). The Tug Hill Plateau is thought to be an uplifted-fault-bounded block which, if correct, might account for the existence of those gas fields. The trends of the gravity contours on the gravity maps lends credence to the fault interpretation. Also gravity and magnetic traverses were conducted across faults in the Trenton-Black River. These traverses show gravity anomalies across the faults which indicate control by faulting in the Precambrian.

S21B CC: 516 A Tuesday 0830h

Insights Into Earthquake Nucleation and Rupture I *(joint with G, T, NS, MR)*

Presiding: **E Richardson,** Pennsylvania State University**; K Mair,** University of Edinburgh

S21B-01 0835h INVITED

Fracture Surface Energy of Mature Fault Zones From Structural Observations of the Punchbowl Fault, California

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