Seismology

S13A CC: 516 D Monday 1330h

Seismicity and Geodynamics of Eastern North America and Other Midplate Environments I *(joint with G, T)*

Presiding: **S Mazzotti,** Geological Survey of Canada Natural Resources Canada**; G Sella,** Northwestern University

S13A-01 1335h INVITED

Science, hazards, and policy questions for intraplate earthquakes in eastern North America

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Intraplate earthquakes in eastern North America and similar continental interiors pose unresolved scientific and societal issues. Resolving these issues will be challenging, and bears on our understanding of lithospheric and mantle rheology, continental evolution, and the earthquake process. Their causes can be viewed as some combination of two end-member models. In one, earthquakes occur almost randomly in a continent containing many long-lived fossil weak zones. Minor stress variations stress due to platewide driving forces and local stresses such as from glacial-isostatic adjustment and other density variations cause transient seismicity as the locus of strain release migrates. If so, present regions of seismicity do not significantly differ from similar weak zones that are less active. Alternatively, seismicity concentrates on long-lived weak zones. For example, if such a zone under the New Madrid area relaxed recently, transient release of accumulated stress could cause large earthquakes more frequently than implied by geodetic or earthquake frequency-magnitude data. Such models can explain the lack of surface strain accumulation shown by GPS data, but there is little evidence for such weak zones or their recent initiation. Assessing the resulting hazard requires assumptions about the size, recurrence rate, and ground motion resulting from the larger earthquakes, none of which is well known. Hence hazard estimates have large uncertainties and, at least for New Madrid, are near the high end of possible estimates. The uncertainties also make choosing mitigation strategies challenging. For example, the proposed upgrade of New Madrid zone building codes to California-level seems likely to impose societal costs significantly exceeding the benefits.

S13A-02 1355h INVITED

Seismicity and Seismic Hazards in Eastern Canada: Needs from Crustal Deformation Studies

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The historical earthquake catalog is the basis for many hazard assessments that explicitly use the pattern of past earthquakes to assess hazard - the current USGS maps for the eastern U.S. rely heavily on smoothed seismicity rates and even classical seismic source zones give a similar smoothing, albeit with non-objective human insight. However, past southeastern Canadian activity has been a poor indicator of future large earthquakes. Though Charlevoix represents the site of repeated M>6 earthquakes, other M circa 6+ earthquakes in eastern Canada (Grand Banks, Timiskaming, Cornwall, Saguenay) appear to be one-off events (albeit with long aftershock sequences). Saguenay, the last large earthquake south of 60N, occurred in an essentially aseismic region (no M>3 event for over 40 years). To address the problem, Canada's 4th generation seismic hazard model, intended for the 2005 National Building Code, uses two models for Canadian earthquakes "H" and "R". "H" describes the earthquakes in their historical clusters while "R" associates seismicity clusters with continent-scale seismotectonic features like the passive Atlantic margin and the ancient margin of Iapetus. It expresses the alternative hypothesis that future large earthquakes (comparable to those named above) could occur anywhere along these features. The modeling of postglacial rebound data (to understand the relative roles of rebound and plate tectonic stresses) together with paleoseismological studies to establish the locations and rates of pre-historic earthquakes could help decide between the models. Direct horizontal strain measurements in eastern Canada will also help, but come from an extremely short period and need to be reconciled with the circa 350 year historical earthquake record. That record is, however, both (i) too short relative to likely earthquake occurrence rates and (ii) flawed by inaccurate and incomplete information especially regarding the magnitudes for the oldest, largest events. Those events are the most important for deciding the hazard and also contribute almost all of the seismic deformation. The pattern of contemporary crustal deformation could be definitive, and furthermore its rates could constrain the frequency of large earthquakes and their maximum size, both key factors in assessing the seismic hazard.

S13A-03 1415h INVITED

Effects of lateral variations in lithospheric thickness and mantle viscosity on glacially induced surface motion and seismotectonics in Eastern Canada

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Eastern Canada is supposedly in a stable continental region, yet it experiences intraplate earthquakes with magnitude as high as M6. Earlier investigations (Wu & Hasegawa 1996, Wu 1997, Wu & Johnston 2000) have shown that the relaxation of stress induced by late Pleistocene deglaciation events could have triggered present-day earthquakes by the reactivation of faults created by past tectonic processes. The predicted mode of failure and onset timing of paleo-earthquakes near Charlevoix and Wabash Valley was found to agree well with the observed. However, these models all assume that mantle properties vary in depth only. The purpose of this paper is to investigate the effects of lateral variations in lithospheric thickness and mantle viscosity on earthquake potential and surface motions in Eastern Canada. The input of this model consists of ice thickness history and mantle viscosity models. Here a realistic ice deglaciation model (ICE4G) with cycles of loading and unloading is used. Different viscosity models are constructed so that the individual effects of lateral lithospheric thickness variation, lateral asthenospheric viscosity variation and three-dimensional viscosity variation in the upper and lower mantle as inferred from seismic tomography, or their combination can be studied. It will be shown that lateral heterogeneity do affect surface motion and thus the strain rates in Eastern Canada. In order to study the effects of lateral heterogeneity on earthquake potential, the evolution of stress induced by deglaciation is superposed on tectonic stress and overburden stress to give the spatial-temporal variation of total stress, which is used with Mohr's failure criterion to calculate the changes in Fault Stability Margin in Eastern Canada. The effects of lateral heterogeneity on the onset timing of earthquakes will also be studied for Charlevoix and Wabash Valley where paleoearthquakes have been dated.

S13A-04 1435h

Evidence of Neotectonic Activity in the Lakebeds of the Lower Great Lakes and Possible Relation to Postglacial Isostatic Rebound

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Over the past 25 years the Geological Survey of Canada has conducted regional investigations of lakebed surficial geology and geomorphic features using high-resolution acoustic sources including sidescan sonar and subbottom profilers and bottom sediment corers. More recently new multibeam mapping techniques have been employed to generate high-resolution detailed 3D imagery of the lakebed. Key features regarded by most investigators to indicate neotectonic activity in the lake basins include bedrock pop-ups and sediment pockmarks. Pop-ups occur in areas of exposed bedrock in western Georgian Bay, eastern Lake Ontario and eastern Lake Erie. These linear bedrock ridges predominantly strike NW with conjugate sets occurring to the NE. Both fresh and oxidized surfaces along ridge crest fractures with non-existent to discontinuous sediment infill, and undisturbed sediments overlying buried pop-ups indicate these features have occurred over geologic time. Greater numbers appear to be older. Pockmarks or fluid vent features occur in areas of postglacial sediment cover in central Georgian Bay, eastern Lake Ontario and eastern Lake Erie as single features or as linear arrays of vents. Some pockmarks are still active although a greater number have mid to late Holocene sediment infill suggesting an older age of formation. A recently updated model of postglacial rebound indicates a negative exponential uplift curve with associated rapid initial crustal rebound in the early Holocene followed by declining rates that continue today. The more frequent occurrence of older pop-ups and pockmark features and the more rapid early Holocene glacial rebound would suggest these neotectonic features may be linked to glacial unloading when the crust experienced the highest rate of deformation.

S13A-05 1450h

Postglacial Faulting Within the Temiskaming Graben of Quebec and Ontario; Evidence from Lake Temiskaming

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Lake Temiskaming is a long (100 km) deep (220 m) lake within the Temiskaming Graben of Ontario and Quebec. The graben is an extension of the St. Lawrence Rift System (SLRS) that underlies the St. Lawrence and Ottawa valleys. The SLRS first formed as a Paleoproterozoic failed rift' and was reactivated during regional extension during Neoproterozic breakup of Rodinia when the Iapetus Ocean opened, and later during the Late Jurassic breakup of Pangea and the opening of the North Atlantic Ocean. The Temiskaming district lies within the Western Quebec Seismic Zone one of the most active in eastern North America characterized by frequently occurring moderate to large magnitude earthquakes such as in 1732 (M5.8; Montreal), 1935 (M6.2 Temiskaming) and 1944 (M5.6; Cornwall). Earthquakes of M> 3 occur every other year in the Temiskaming area and M6.5 temblers have a 500 yr recurrence interval. High-resolution seismic profiling of the floor of Lake Temiskaming shows that much of the bathymetric relief throughout the lake basin is the product of postglacial neotectonic faulting of the late Pleistocene and Holocene sediment fill. The onshore continuation of prominent faults is marked by linear fault scarps and by straight river valleys. The scale of neotectonic activity is highly unusual for an intracratonic setting, with implications for seismic risk analysis and public safety.

S14A CC: 516 D Monday 1530h

Seismicity and Geodynamics of Eastern North America and Other Midplate Environments II *(joint with G, T)*

Presiding: **S Stein,** Northwestern University**; T Dixon,** University of Miami

S14A-01 1530h

Characteristic and uncharacteristic earthquakes as possible artifacts: what does the seismic history actually tell us?

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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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