State of Stress in Intraplate Regions

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Session Chairs: Charles Langston and Christine Powell

State of Stress in Central and Eastern North America Seismic Zones

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We use a Bayesian analysis to determine the state of stress from focal mechanisms in ten seismic zones in central and eastern North America, and compare it with regional stress inferred from borehole measurements. Comparison of the seismologically-determined azimuth of the maximum horizontal compressive stress (SHS) with that determined from boreholes (SHB) exhibit a bimodal pattern: In four zones, the SHS and regional SHB orientations are closely parallel, whereas in the Charlevoix, Lower St. Lawrence and Central Virginia zones, the SHS azimuth shows a statistically significant 30–50° clockwise rotation relative to the regional SHB azimuth. This pattern is exemplified by the northwest and southeast seismicity clusters in Charlevoix, which yield SHS orientations respectively strictly parallel and strongly oblique to the regional SHB trend. Similar ~30° clockwise rotations are found for the North Appalachian zone and for the 2003 Bardwell earthquake sequence north of the New Madrid zone. The SHB/SHS rotations occur over 20–100 km in each seismic zone, but are observed in zones separated by distances of up to 1500 km. A possible mechanism for the stress rotations may be the interaction between a long-wavelength stress perturbation source, such as postglacial rebound (PGR), and local stress concentrators, such as low-friction faults. The latter would allow low-magnitude (<10 MPa) PGR stresses to locally perturb the pre-existing stress field in some seismic zones, whereas PGR stresses have little effect on intraplate state of stress in general.

Seismogenic Yield Stresses in an Intraplate Region Estimated Using Laboratory Friction Experiments to Interpret Earthquake source Parameters

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"Stick-slip often accompanies frictional sliding in laboratory experiments with geologic materials. Shallow focus earthquakes may represent stick-slip during sliding along old or newly-formed faults in the earth." (Brace and Byerlee, Science, 1966) We pursue this hypothesis, proposed 44 years ago, by applying two techniques, based on laboratory stick-slip friction results, to investigate the crustal yield strength within earthquake rupture zones in the stable continental region of North America. The first approach (McGarr *et al.*, Bull. Seismol. Soc. Am., 2009) uses the maximum slip within the rupture zone of an earthquake and its seismic moment, in conjunction with results from laboratory friction experiments, to estimate the yield stress. The second approach is based on the observation that for stick-slip friction experiments, the apparent stress is about 5 % of the yield stress. We applied these two methods to nine earthquakes with reverse or thrust fault mechanisms, and moment magnitudes from 4 to 6.8, to sample seismogenic yield stresses over depths between 1 and 26 km. The resulting yield stresses range from about 30 to 300 MPa, increase approximately linearly with depth, and are generally consistent with the deepest available in situ stress measurements. Nearly all of the yield stresses suggest that these earthquakes are the result of frictional sliding involving pre-existing faults with pore pressures that are close to hydrostatic. The yield stress at the shallowest depth, however, is too high to be consistent with frictional sliding and may indicate fresh rock fracture. Applying the same analyses to three earthquakes in California, with thrust or reverse mechanisms and moment magnitudes between 6.5 and 7, revealed no significant differences in yield stress as a function of depth compared to their counterparts in the intraplate region.

Passive Margin Earthquakes as Indicators of Intraplate Deformation

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Mysterious large earthquakes occur at passive continental margins. The continent and neighboring seafloor are part of the same plate, so these earthquakes reflect deformation within the plate. The most plausible mechanism is reactivation of faults remaining from continental rifting by the modern stress field. As a result, the nature and distribution of passive margin earthquakes is a primary constraint on the stress field.

A crucial question is whether all such earthquakes reflect tectonic faulting. For example, the 1929 M 7.2 earthquake on the Grand Banks of Newfoundland triggered a landslide of thick continental slope sediments, resulting in a tsunami. However, investigators differ as to whether a tectonic earthquake nucleated the landslide, or whether it resulted from slope instability but released enough energy to appear as an earthquake. We approach this issue using a new result that aftershocks following a large (M~7) earthquake in this tectonic setting should continue for a very long time due to the slow deformation rate. Because large landslides should not be followed by a long aftershock sequence, it is possible to distinguish landslides that result from tectonic activity from those that result from slope instability. We find that both the Grand Banks earthquake and the analogous M 7.3 event in Baffin Bay in 1933 have similar aftershock sequences that continue today, suggesting that both were tectonic earthquakes.

The location of these events suggests that the primary influence is flexural stresses produced by removal of the Laurentide glacial load. Recent GPS data showing that the primary deformation within eastern North America results from deglaciation support this hypothesis. To assess this issue we compare the seismic moment release in earthquakes on the deglaciated portion of the coast to that on the remainder of the coast and on other passive margins.

Reservoir-Triggered Seismicity in the Canadian Shield

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The International Commission on Large Dams (ICOLD) has recently published a Bulletin on Reservoir-Triggered Seismicity (RTS). The Bulletin, in its rough draft stage, reviews the state of knowledge on this phenomenon, and suggests a methodology to assess its likelihood in various tectonic contexts. In light of future development of hydro-electric reservoirs, we examine how this Bulletin applies to the Canadian Shield environment, *i.e.* a mostly seismically quiescent region that contains some active areas and five documented cases of RTS. We find that some generalizations contained in the Bulletin should be refined in light of the known RTS history in the Canadian Shield. According to the Bulletin, for example, the thrust faulting environment and the quasi absence of background seismicity make RTS unlikely in the Canadian Shield, in contradiction to the known RTS history. Another example is that the Bulletin describes reservoir-triggered earthquakes as tectonic events that occur prematurely because of the increase in pore-fluid pressure. Based on this, one could consider the regional earthquake activity representative of the potential for RTS, even though tectonic earthquakes in the Canadian Shield generally occur much deeper (5–30 km depth) than RTS (upper 1–2 km depth). We present some preliminary ideas on the assessment of RTS potential in the Canadian Shield, keeping in mind the difficulty in forecasting the impact of increased pore fluid pressures on faults that are generally unmapped, have an unknown neotectonic history and lack sufficient knowledge of their permeability. The problem of defining a representative RTS event (location, magnitude, depth) for the design of dams and appurtenant structures is also examined. We also present some shallow earthquakes near reservoirs in Quebec that are now recognized as small magnitude RTS.

On the New Madrid Strain Rate/Release Discrepancy: Reexamining the Observational Underpinnings of Sacred Exotic COws

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At the heart of the conundrum of seismogenesis in the New Madrid Seismic Zone is the apparently substantial discrepancy between low strain rate and high recent seismic moment release. GPS data reveal a strain rate not resolvably different from zero. Previous modeling of post-glacial rebound predicts a strain rate of ~10–9yr^{-1} over a region of ~20,000 km^2, with the rate predicted to remain nearly constant for the next few millennia. Along the St. Lawrence Seaway, where the strain rate associated with rebound is stronger, previous studies have shown that post-glacial rebound can plausibly account for the historic seismic moment release rate. In the New Madrid region, post-glacial rebound provides sufficient strain to produce a sequence with the moment release of one Mmax6.7–6.9 every 500 years, a value that is lower than most published estimates but at the low end of the range inferred from a recent analysis of consensus intensities. One can also construct a range of consistent models that permit a higher Mmax, with a longer average recurrence rate. For example, post-glacial strain rate can produce one Mmax6.9–7.1 event every 1000 years. If one assumes this mean rate and with a coefficient of variation of 0.5, the observed historic/prehistoric clustering has a 10–20% probability. The probability of recent clustering is higher if we assume a Poissonian rate. It is thus possible to reconcile predicted strain and seismic moment release rates with alternative models: one in which 1811–1812 sequences occur every 500 years, with the largest events being ~Mmax6.8, or one in which sequences will occur on average less frequently, but with Mmax close to or slightly higher than 7.0. Both models assume that seismicity follows standard statistics given a strain signal controlled by post-glacial rebound, with magnitude values on the low end of recently derived estimates. Neither model predicts that New Madrid sequences will shut off any time soon.