SE02: The earthquake cycle: squaring the circle

Conveners: Edwin Nissen[1], and Kristin Morell[2]

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Session Description

In recent years the earthquake cycle model in its simplest form – the steady interseismic build-up of strain, released at regular intervals in an earthquake – has been challenged by new observations and interpretations. These include (1) apparent seismic and aseismic precursory activity before major subduction earthquakes; (2) a variety of transient fault slip phenomena including fault creep, slow earthquakes and postseismic after-slip; (3) complex fault interactions including earthquake clustering, compound ruptures and remotely-triggered seismicity; and (4) long-term waxing and waning of fault activity. This session provides a platform for work on all aspects of the earthquake cycle, and seeks contributions from studies of surface deformation (such as those using high-resolution imaging techniques like InSAR and pixel correlation); surface topography and geomorphology (such as those exploiting lidar or structure-from-motion); paleoseismic or sedimentary records of earthquake recurrence; laboratory experiments of fault mechanical behaviour; and related modelling and theory.

Primary Affiliation: Solid Earth/Geodesy

NOTE: THIS DOCUMENT CONTAINS INFORMATION FOR ALL SESSION SUB-SECTIONS. PRESENTER ABSTRACTS ARE FOUND AT THE END OF THE DOCUMENT.

SCHEDULE MAY BE SUBJECT TO CHANGE.

ORAL SESSION SE02a

Chairs: E. Nissen & K. Morrell **Room: ESB 2012**

Tuesday, May 30th

TIME	AUTHORS	TITLE
9:00	K. Wang, S. Li, Y. Jiang & S. Dosso	Using a viscoelastic Earth model to invert geodetic data to determine the locking state of the Cascadia megathrust
9:15	D. Li* & Y. Liu	Modeling slow slip events and their interaction with Megathrust earthquakes in Cascadia Subduction Zone
9:30	Y. Liu, D. Li, H. Yu & H. Yang *(Invited)*	Seismic rupture and slow slip events in a megathrust earthquake cycle model
9:45	K. F. Tiampo, J. Kazemian, W. Klein & R. Dominguez	The earthquake cycle in a simple earthquake asperity model
10:00	H. Yu, Y. Liu & H. Yang	Effects of fault geometry on earthquake ruptures: Modeling earthquake sequences along the central Chile subduction zone
10:15	E. Nissen	Recent observations and implications of a new class of cascading, multi-fault earthquake rupture

ORAL SESSION SE02b

Chairs: E. Nissen & K. Morrell **Room: ESB 2012**

Tuesday, May 30th

TIME	AUTHORS	TITLE
14:00	T. Mulder	Changing times, Meager Mountain Seismicity 1985 - 2017
14:15	C. Regalla, K. Morell, C. Amos, S. Bennett, L. Leonard & V. Levson	Tectono-geomorphic and paleoseismic evidence for Holocene surface ruptures along the Leech River fault near Victoria, British Columbia, Canada
14:30	L. Broom*, C. Campbell & J. Gosse	A high-resolution Holocene marine sedimentological record from Pond Inlet, Nunavut - Is there a paleoseismicity signal?
14:45	E. Kirby, J. Gosse, E. McDonald & J. D. Walker	Geomorphic evidence for co-seismic slip on an active low-angle normal fault: Panamint Valley, California
15:00	C. A. Paige*, J. C. Gosse, K. Taylor, A. Margreth, E. Kirby & E. McDonald	An in-situ cosmogenic ^{14}C erosion-rate method to improve the reliability of exposure dating strain markers, Panamint Valley, California

15:15	J. Gosse, E. Kirby, E. McDonald & J. D. Walker	Coupling cosmogenic nuclide ages and soils to constrain the interaction between multiple fault systems, Panamint Valley, California

POSTER SESSION SE02

Chairs: E. Nissen & K. Morrell Room: ESB Atrium

Wednesday, May 31st

Poster No.	AUTHORS	TITLE
P01-SE02	T. Hayward* & M. Bostock	Slip behaviour of the Queen Charlotte plate boundary before and after the 2012, M_W 7.8 Haida Gwaii earthquake: evidence from repeating earthquakes
P02-SE02	H. Yu, Y. Liu & Y. Huang	Constraining the frictional parameters used in an earthquake cycle modeling
P03-SE02	E. Nissen, E. Karasozen, E. Bergman & A. Ghods	Rupture directivity effects in large Iranian seismic sequences reassessed with calibrated earthquake relocations

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SUBMITTED ABSTRACTS

LIST SE02-01: Using a viscoelastic Earth model to invert geodetic data to determine the locking state of the Cascadia megathrust

Kelin Wang[1,3*], Shaoyang Li[2], Yan Jiang[1], and Stan Dosso[3]

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Abstract
Viscoelastic stress relaxation occurs not only right after an earthquake but also during the entire interseismic period. Stresses slowly built up due to fault locking are being relaxed at the same time, even when crustal deformation no longer changes with time. This interseismic stress relaxation causes crustal deformation far away from the locked zone, much farther than can be explained using elastic models which neglect the relaxation. In this work, we develop the first geodetic inversion model for Cascadia megathrust locking using a viscoelastic Earth model. We invert 514 horizontal velocity vectors based on continuous and campaign GNSS measurements over the past two decades. The vertical component has a very small signal-to-noise ratio and is used only for qualitative validation of model results. Ambiguities arising from long-term rotation of upper-plate crustal blocks are addressed by test-correcting the GNSS velocities with two different block-motion models. Fault back-slip (i.e., slip deficit) Green's functions are derived by running to nearly a steady state a Maxwell viscoelastic finite element model with realistic subduction zone structure and megathrust geometry. We use viscosity values 10^{19} and 10^{20} Pa s for the mantle wedge and oceanic mantle, respectively, but we also test other values. The preferred model features a narrow and shallow megathrust locked zone, consistent with earlier thermo-rheological reasoning. For an elastic model with similar constraints to fit the GNSS data to the same fidelity, the locked zone has to extend to much greater depths and with a lower degree of locking. However, even with the viscoelastic model, the GNSS data still cannot resolve whether there is some creep (or incomplete locking) in the shallowest part of the megathrust far offshore. Neither can they resolve along-strike variations of the locking state. These ambiguities can be resolved only when seafloor geodetic data become widely available at Cascadia.

Presentation type: Oral Presentation

SE02-02: Modeling slow slip events and their interaction with Megathrust earthquakes in Cascadia Subduction Zone

Duo Li[1*] and Yajing Liu[1]

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Abstract
We develop a 3-D episodic slow slip event (SSE) model for northern and central Cascadia, incorporating both seismic and geodetic observations to constrain the heterogeneities in the megathrust fault properties. The tremors epicenters are used to constrain the rate-state friction parameters. The effective normal stress at SSE depths is constrained by along-margin free-air and Bouguer gravity anomalies. The along-strike variation in long-term plate convergence rate is also taken into consideration. Simulation results show five segments of ~Mw6.0 SSEs spontaneously appear along the strike, correlated to the distribution of tremor epicenters. The segmentations of recurrence intervals of models constrained by both types of gravity anomalies are equally comparable to GPS observations. However, the model constrained by free-air anomaly does a better job in reproducing the cumulative slip as well as more consistent surface displacements with GPS observations. The modeled along-strike segmentation only represents the averaged slip release over many SSE cycles, rather than permanent barriers. Individual slow slip events can still propagate across the boundaries, which may cause interactions between adjacent SSEs, as observed in the time-dependent GPS inversions. We then incorporate the fault-couple pattern, inferred from long-term GPS obvervations, and historical coseismic subsidences in the seismogenic portion in our model. The along-strike variation of interseismic fault coupling and coseismic subsidence can help us to constrain the frictional heterogeneity in the seismogenic zone. We target to find the interaction between SSE and megathrust earthquake in the numerical modeling. [237]

Presentation Type: Oral

SE02-03: Seismic rupture and slow slip events in a megathrust earthquake cycle model

Yajing Liu[1*], Duo Li[1], Hongyu Yu[1] and Hongfeng Yang[2]

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Abstract
Mega-thrust fault geometry has long been postulated to influence the seismic and aseismic slip processes in subduction zones. In this study, we present numerical simulations in the framework of rate-state friction of earthquake cycle slip on megathrust faults with non-planar geometry, represented using triangular element meshes. We apply the model to investigate the fault geometrical effects on slow slip events (SSE) in northern Cascadia and earthquake rupture patterns along the Manila subduction zone. In both cases, we find that the "geometry parameter", defined to encapsulate the spatial variations in fault local dip and local strike angles, is critical in controlling the along-strike segmentation of slow slip (Cascadia) and seismic slip (Manila).
For the northern Cascadia model, without introducing any other type of along-strike heterogeneity, the central ~ 150 km segment beneath Port Angeles acts as a repetitive slip patch, with SSEs appear every ~ 1.5 years and a maximum slip of ~ 2.5 cm. Two minor slip patches with less cumulative slips straddle the central patch. The modeled slip patch distribution captures the major SSE characteristics revealed by GPS inversions. Earthquake cycle simulation for the Manila subduction zone demonstrates that first-order fault geometrical heterogeneity, i.e., transition from the steeper southern segment to the flatter northern segment due to the subducting Scarborough seamount chain, controls earthquake rupture behavior. Shear stress on the fault and coseismic rupture propagation speed are both clearly correlated with the along-strike profile of the geometry parameter. Modeled interseismic coupling state also is spatially consistent with the interplate seismicity distribution along the Manila Trench. Our modeling results suggest that megathrust fault geometry plays a key role in seismic and aseismic slip processes and needs to be incorporated in the mechanism studies of subduction zone deformation. [287 words]

Presentation type: Oral Presentation

SE02-04: The earthquake cycle in a simple earthquake asperity model

Kristy F. Tiampo[1], Javad Kazemian[2], William Klein[3] and Rachel Dominguez[4]

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Abstract
Natural earthquake fault systems are spatially heterogeneous, the result of inhomogeneities that are a function of the variety of materials and strengths. However, despite their inhomogeneous nature, real faults are often modeled as spatially homogeneous systems. Here we present a driven earthquake fault model, based on the Olami-Feder-Christensen (OFC) and Rundle-Jackson-Brown (RJB) cellular automata models with long-range interactions, that incorporates asperities, or stronger sites, into the lattice (Rundle and Jackson, 1977; Olami et al., 1992). Although these asperity cells are significantly stronger than the surrounding lattice sites, they eventually rupture when the external tectonic stress reaches their higher threshold stress. The introduction of these spatial heterogeneities results in spatial and temporal clustering in the model similar to that seen in natural fault systems. We observe sequences of activity that begin with a gradually accelerating number of larger events, or foreshocks, prior to a large event, followed by a tail of decreasing activity, or aftershocks. These recurrent large events occur at regular intervals and the characteristic time between events, sequence length and magnitude are a function of the stress dissipation parameter. We find that the scaling depends not only on the amount of damage, but also on the spatial distribution of that damage (Dominguez et al., 2011; Kazemian et al., 2014). This work provides further evidence that the spatial and temporal patterns observed in natural seismicity are strongly influenced by the underlying physical properties and are not solely the result of a simple cascade mechanism. Here we compare the modeled sequences to those of natural earthquake sequences from California and around the world in order to investigate the interplay between cascade dynamics and spatial structure.

Presentation type: Oral

SE02-05: Effects of fault geometry on earthquake ruptures: Modeling earthquake sequences along the central Chile subduction zone

Hongyu Yu [1*], Yajing Liu [1], and Hongfeng Yang [2]

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Abstract
Along the central Chile subduction zone, the segmentation of megathrust earthquakes, including the 2010 M_W 8.8 Maule and the 2015 M_W 8.3 Illapel earthquakes, spatially coincides with the subducting Juan Fernandez ridge (JFR; latitude ~ 33°S) and the along-strike bending of the trench (~ 30°S), respectively. To investigate the causal relationship between the subducting JFR or trench bending and earthquake rupture segmentation, we conduct numerical simulations of earthquake sequences on a 3D central Chile subducting plate boundary (27.5°S-38°S) in the framework of the rate and state friction law. Our modeling results successfully reproduce the megathrust ruptures that are stopped at ~30°S and 33°S. In our model, the geometrical effect of the subducting JFR is represented by an average fault dip angle varying from 20° in the north to 15° in the south, equivalent to the widening the seismogenic zone. When ruptures propagate through the subducting JFR from north to south, the decreased dip angle on fault more likely stops ruptures. In addition, the bending of trench shape at ~ 30°S mainly manifests as the deviation of local strike (up to 7°) on the subducting fault, which also plays a role of inhibiting the rupture propagation. The two geometrical anomalies jointly control the rupture segmentation along the trench. [207 words]

Presentation type: Oral Presentation

SE02-06: Recent observations and implications of a new class of cascading, multi-fault earthquake rupture

Edwin Nissen[1*]

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Abstract

Reliable earthquake forecasting hinges upon anticipating the likely length of seismic rupture, and thus, upon recognizing the role of fault segment boundaries in arresting slip. Past rupture forecast models have generally presumed that segment boundaries of a ~5 kilometres are sufficient to halt any earthquake rupture. However this inference, which is based upon compilations of historical surface rupture maps, has recently been challenged by new observations of earthquakes that bridge fault gaps or segment boundaries that are tens of kilometres wide, near-instantaneously. Here, I use the 27th February 1997 Harnai, Pakistan (M_w 7.1) earthquake – probably the earliest well-documented example of this new class of compound, multi-segment rupture – to illustrate. In this instance, dynamic stresses generated by seismic waves from the first fault rupture are the probable cause of slip initiation on the second fault. Other recent notable examples include the 14th November 2016 Kaikoura, New Zealand (M_w 7.8), 16th April 2016 Kumamoto, Japan (M_w 7.0), 7th December 2012 Sanriku-Oki, Japan (M_w 7.3), 11th April 2012 Indian Ocean (M_w 8.6), 2nd January 2011 Araucania, Chile (M_w 7.1), and 29th September 2009 Samoa-Tonga (M_w 8.1) earthquakes. This rapidly growing list – which now includes subduction zone, fore-arc, continental, and intraplate examples – implies that cascading multi-fault earthquakes are a common and global phenomenon whose recent discovery merely reflects advances in earthquake rupture imaging. These events expose a serious flaw in forecast models that disregard cascading, multiple-fault ruptures of this type. [236 words]

Presentation type: Oral Presentation

SE02-07: Changing times, Meager Mountain Seismicity 1985 - 2017

Taimi Mulder[1]

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Abstract

Meager Mountain, in southwestern BC, is the most recently active volcano in British Columbia, Canada. It last erupted 2360 years BP and the explosive eruption fractured the basement rock. During July 2016, three fumaroles were spotted on Meager, venting through the glacier covering the mountain. This activity, combined with increased seismicity in the vicinity of Meager Mountain and the high geohazard potential of the mountain (ranging from numerous historical landslides, to seismicity, to hot springs and fumaroles and associated glacial morphology) resulted in September 2016 of the installation of a seismic station to the east of Meager Mountain in order to monitor the mountain and its seismicity and to improve earthquake depth determinations. Seismicity clusters around the Meager volcanic complex. Seismicity rates since 1985 were low (≤ 10 events/year) until 2013, when the rates increased to more than 50 events in 2014 and died back down to previous background levels in 2016. The increased seismic activity clusters in time between July 2014 to October 2015. The events are all less than or equal to magnitude 2.5 and the majority of events are shallow, although depth determination of those events is poor as the closest seismic station, at that time, was located in Whistler, BC, approximately 100 km away. It appears unlikely that the earthquakes are due to magma movement as they are of small magnitude, are predominantly shallow, and have substantially lower seismicity rates than active volcanoes, which may have hundreds to thousands of earthquakes per day. It is more likely that the seismicity is due to hydrothermal fluid circulation in the region. Interestingly enough, the 2013-2016 earthquakes are predominantly situated within 10 km to the south of Meager Creek, which runs along the southern side of Meager Mountain.

Presentation type: Oral Presentation

SE02-08: Tectono-geomorphic and paleoseismic evidence for Holocene surface ruptures along the Leech River fault near Victoria, British Columbia, Canada

Christine Regalla[1], Kristin Morell[2], Colin Amos[3], Scott Bennett[4], Lucinda Leonard[2], Vic Levson[2]

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Abstract
Surficial and bedrock mapping and paleoseismic trenching provide the evidence for three late Holocene surface-rupturing earthquakes along the Leech River fault, southwestern British Columbia, Canada. The Leech River fault separates the Pacific Rim Terrane from basalts of the Eocene Crescent Terrane and extends ~60 km across southern Vancouver Island. The fault is not currently listed in an active fault catalogue for Canada, and post-Eocene-Oligocene slip had not been previously documented. However, based on new field mapping aided by lidar topography, we identify >60 individual, sub-parallel, linear scarps, sags and swales occurring in semi-continuous, enechelon arrays that offset bedrock and late Pleistocene-Holocene deposits. Field observations of these scarps confirm that they are not the result of anthropogenic, glacial or landslide processes. Scarps in several places are located above exposures of faulted bedrock with brittle fracture networks and gouge. At a site ~5 km west of Leechtown, British Columbia, we estimate ~6 m of dip-slip reverse displacement of a post-Last Glacial Maximum (<~15 ka) colluvial surface and ~4 m of displacement of intervening channels. Two paleoseismic trenches at this site reveal Jurassic Leech River Schist in fault contact with latest Pleistocene loess and colluvium, and latest Pleistocene till thrust over post-glacial colluvium. These trenches preserve a record of at least three earthquakes in the late Holocene, each with ~1 m vertical displacement. We interpret the Leech River fault as a 500–1000 m-wide, steeply dipping fault active zone that accommodates transpression across the northern Cascadia forearc. The onshore trace of the Leech River fault may continue offshore to the east, south of Victoria, and may be kinematically linked to active faults in western Washington. The Leech River fault is likely one of several active crustal faults that should be considered in seismic hazard assessments for southern British Columbia and northwestern Washington.

[299 words]

Presentation type: Oral Presentation

SE02-09: A high-resolution Holocene marine sedimentological record from Pond Inlet, Nunavut - Is there a paleoseismicity signal?

Laura-Ann Broom[1*], Calvin Campbell[2], and John Gosse[1]

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Abstract
Fjords often have high sedimentation rates sufficient to preserve a high resolution sedimentological record of the local and regional environment. Baffin Bay is one of the most seismically active areas in Canada and despite this, the region has a very limited instrumental earthquake record until the expansion of seismograph stations in the 1950s. Due to the limited instrumental record, the geological record must be studied to understand the recurrence of large earthquakes over a longer time scale. Pond Inlet, a fjord in Northern Baffin Island, has had high sedimentation rates since deglaciation (0.8 mm/a), which gives it the potential to preserve a paleoseismic record for the region. Relatively little is known about what depositional processes are responsible for the sedimentological record preserved in Pond Inlet. Mass transport deposits (MTDs) and turbidites were interpreted from newly acquired submarine sediment cores and geophysical data. These mass movement events could be sesimogenic though it is important to consider that climatic related events such as local glacial outbursts, storms or flood events could be possible trigger mechanisms. Detailed sedimentology on the cores, radiocarbon geochronology, multibeam bathymetry, and seismic stratigraphy of 3.5 kHz data will help test if these deposits are related to regional paleoseismicity, or if climate or storms are more likely triggers. This will involve i) comparing the sedimentology and grain size patterns of the MTDs within the basin and with other MTDs related to paleoseismicity, ii) determining if deposits show approximately synchronous deposition based on relative or radiocarbon dating, or iii) the MTDs were deposited during known Arctic Holocene paleoclimate anomalies. If linked to seismicity, the recurrence interval of large earthquakes may be evaluated, which will improve understanding of the seismic risk for the hamlet of Pond Inlet and contribute to improved assessment of the geological hazards in Baffin Bay.

Presentation type: Oral Presentation

SE02-10: Geomorphic evidence for co-seismic slip on an active low-angle normal fault: Panamint Valley, California

Eric Kirby[1], John Gosse[2], Eric McDonald[3], and J. Douglas Walker[4]

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Abstract

The mechanical feasibility of co-seismic displacement along low-angle normal fault systems remains an outstanding problem in tectonics. In the southwestern Basin and Range of North America, large magnitude extension during Miocene – Pliocene time was accommodated along a system of low-angle detachment faults. Whether these faults remain active today and, if so, whether they slip during co-seismic rupture or whether they creep asesimically remains uncertain. Here we evaluate the relationship between Late Pleistocene – Holocene fault scarps and a low-angle detachment system along the ~100km long Panamint Valley fault zone. We combine analysis of LiDAR-based topography with a detailed chronology provided by both directly dated deposits and a calibrated soil chronosequence to characterize the recent activity of the fault system. The range-front fault system along the eastern side of Panamint Valley is a low-angle (15-30°), curviplanar detachment fault that is linked to strike-slip faults at its southern and northern ends. Along the southern segment, a recent paleoseismic investigation revealed evidence for 3-4 surface ruptures during past ~4-5 ka, the most recent of which (MRE) occurred ~330-485 cal yr BP. Scarps related to the MRE can be traced for at least ~35 km northward along the range front, and reflect throw of ~2-3 m. The geometry of the rupture mimics range-scale variations in strike of the curviplanar detachment fault, suggesting that scarps merge with the detachment at depth. Moreover, rupture kinematics inferred from displaced geomorphic markers implies dextral oblique-normal slip, consistent with the long-term slip vector inferred from piercing lines across the Hunter Mountain fault. Thus, we conclude that the most recent rupture along the Panamint Valley fault system likely activated the low-angle normal fault beneath the valley. Displacement of older alluvium suggests at least 2-3 previous ruptures have occurred during the Late Holocene. [291 words]

Presentation type: Oral Presentation

SE02-11: An in-situ cosmogenic ^{14}C erosion-rate method to improve the reliability of exposure dating strain markers, Panamint Valley, California

CODY A. PAIGE[1*], JOHN C. GOSSE[1], KEITH TAYLOR[1a,] ANNINA MARGRETH[1,2], ERIC KIRBY[3], ERIC McDONALD[4]

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Abstract

Terrestrial cosmogenic nuclide (TCN) exposure dating is a widely used method to estimate slip-rates from alluvium strain markers, and the only option for Pliocene-Pleistocene surfaces not datable with radiocarbon, luminescence, or U-series techniques. Surface erosion reduces a TCN concentration since the cosmic ray flux attenuates exponentially with mass depth. Unlike boulders or bedrock surfaces, the erosion rate of unconsolidated landforms such as alluvial fans or terrace surfaces can range over two orders of magnitude. Direct measurement of surface erosion rates requires that a TCN concentration has reached saturation, or a second nuclide with a different production mechanism is used. Thus exposure ages of alluvial fans and terraces used as Quaternary strain markers are often reported as minimum dates making the slip rates too uncertain. Owing to a relatively fast decay rate of ^{14}C, in situ ^{14}C quickly reaches saturation at which time its concentration will be controlled by erosion rate. We hypothesize that a single measurement of in situ ^{14}C can reliably adjust exposure ages based on other TCN measurements in situations where high precision is critical. Deformed and non-deformed fans in Panamint Valley, CA will provide the test site. The four sample sites have been modelled with depth profiles yielding ages between 59.7 and 89.9 ka. At these relatively old ages ^{14}C has reached saturation. By measuring the ^{14}C saturation concentration at each site it is possible to (i) determine the erosion rate corresponding to the saturation concentration and thus (ii) more tightly constrain the age calculated from the ^{10}Be depth profiles. With a better control on the age these deformed paleo-shorelines and alluvial fans can serve as strain markers to examine and reconstruct the local tectonic history. We are currently testing and using the stainless steel UHV ^{14}C extraction line developed at the Cosmogenic Isotope Lab at Dalhousie.

Presentation type: Oral Presentation

SE02-12: Coupling cosmogenic nuclide ages and soils to constrain the interaction between multiple fault systems, Panamint Valley, California

Gosse, John[1], Kirby, Eric[2], McDonald, Eric[3], and Walker, J. Douglas[4]

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[3] Desert Research Institute, Reno, NV
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Abstract
Alluvial fans with a mixture of fluvial and debris-flow facies are prominent strain markers in divergent and convergent settings but their chronology is elusive. A typical strategy to minimize or constrain the affects of erosion and inheritance on cosmogenic nuclide ages involves combinations of measurements, e.g. five subsurface samples, to compute a single Bayesian most probable exposure age. The method uses depth-vs.-concentration curves fitted to measured ^{10}Be or ^{36}Cl of subsurface and surface amalgamated sand and pebble samples, but further constrained by limits of inheritance, erosion, and exposure age. To overcome the paucity of suitable sites and the prohibitive cost for a single age, we have developed a chronology-calibrated soils chronosequence for alluvial fans and shorelines throughout the Mojave Desert. The most prominent alluvial fan surface in Panamint Valley is the Qf3 unit, is dated with multiple cosmogenic nuclide ages ranging from 55 to 100 ka, consistent with oxygen-isotope stage 4 deposition, and with the Mojave-wide soils chronostratigraphy. The wide range in age may be related to uncertainty in erosion history. These and older and younger fan units, and their relationships with dated lake shorelines, and with debris flow levees dated with boulder exposure ages, have contributed a robust chronology for calibrating the soils chronosequence and slip rates of the dextral and high-angle normal fault systems in the valley. We also report the first age for a regional low-angle normal fault (LANF) cutting Pleistocene sediments. A burial age of 0.80 ± 0.13 Ma was determined on fan gravels offset by the LANF with an isochron constrained by multiple $^{26}Al/^{10}Be$ measurements on cobble clasts with different exposure histories but shared burial history. This maximum date for slip along the LANF suggests similarly-timed activity on the LANF and the Eastern California Shear Zone system.

Presentation type: Oral Presentation

P01-SE02: Slip behaviour of the Queen Charlotte plate boundary before and after the 2012, M_W 7.8 Haida Gwaii earthquake: evidence from repeating earthquakes

Tim Hayward[1*] and Michael Bostock[2]
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Abstract
The Queen Charlotte plate boundary, near Haida Gwaii, B.C., includes the dextral, strikeslip, Queen Charlotte Fault (QCF) and the subduction interface between the downgoing Pacific and overriding North American plates. In this study, we present a comprehensive repeating earthquake catalogue that represents an effective slip meter for both faults in the area. The catalogue comprises 730 individual earthquakes ($0.3 < M_W < 3.5$) arranged into 224 repeating earthquake families on the basis of waveform similarity. We employ and extend existing relationships for repeating earthquake magnitudes and slips to provide cumulative slip histories for the QCF and subduction interface in 6 adjacent zones within the study area between 52.3ºN and 53.8ºN. We find evidence for creep on both faults, however the creep rate is significantly less than plate motion rates, which suggests partial locking of both faults. The QCF exhibits the highest degrees of locking south of 52.8ºN, which indicates that the seismic hazard for a major strike-slip earthquake is highest in the southern part of the study area. The October 28, 2012, M_W 7.8 Haida Gwaii thrust earthquake occurred in our study area and had a significant effect on the plate boundary. The QCF is observed to undergo accelerated, right-lateral slip for 1-2 months following the earthquake. The subduction interface exhibits afterslip thrust motion that persists for the duration of the study period (i.e., 3 years and 2 months after the Haida Gwaii earthquake). Afterslip is greatest on the periphery of the main rupture zone of the Haida Gwaii event.[260 words]

Presentation type: Poster

P02-SE02: Constraining the frictional parameters used in an earthquake cycle modeling

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Abstract
Numerical modelings in the framework of rate- and state-dependent friction have been successful in reproducing a broad spectrum of plate boundary fault deformation modes, from dynamic rupture to aseismic slip, at various stages of an earthquake cycle. However, there is substantial uncertainty in the empirical parameters used in this model, including the key frictional stability parameters *a*, *b* and characteristic slip distance d_c, and their extrapolation from laboratory experimental conditions to natural tectonic faults. In this work, we investigate the feasibility of constraining these parameters using long-term geodetic observations along major subduction margins. In order to apply our tests into a wide range of the loaded slip rate (i.e., plate convergent rate) and rock rheology, we adopt the dimensionless quantities for our equations, thus consist the influence of the loaded slip rate, the characteristic distance and effective normal stress. An iterative optimal estimation scheme is constructed to estimate the values of *a* and *b* by validating the simulated moment release rate and surface displacement against GPS measurements. We systematically examine the sensitivity of the aforementioned observables to *a* and *a-b*, varying respectively in the order of O(100 kPa) and O(10 kPa). The sensitivity is a unimodal distribution with variation smaller than one order. Using computed sensitivity kernels, we assess the information content in the measurements that can be used for constraining these empirical parameters. In particular, we focus on subduction margins, such as northeast Japan and central Chile, where decadal geodetic dataset is available to constrain the fault acceleration process toward the magnitude 8-9 megathrust earthquakes. Observation simulation experiments are also conducted to test the performance of the optimal estimation scheme in estimating the parameter value from synthetic measurements.
[279 words]

Presentation type: Oral Presentation / Poster

P03-SE02: Rupture directivity effects in large Iranian seismic sequences reassessed with calibrated earthquake relocations

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Abstract
Iran offers great potential for studying a range of earthquake phenomena, due to (1) its rich historical record of damaging earthquakes, extending back several centuries, (2) an abundance of instrumental seismicity, with >40,000 events from 1960 onwards in the ISC bulletin, and (3) more than thirty events with mapped surface ruptures and several others imaged with radar interferometry, which is more than any other comparably-sized region globally. However, due to unknown Earth structure and uneven station coverage, catalog earthquake locations are subject to up to ~50 km of location bias, making it challenging to interpret this wealth of data. To overcome this limitation, we are using a new multi-event calibrated relocation procedure – based upon the hypocentroidal decomposition technique – to reduce the location uncertainties of past earthquakes down to a few kilometers or better. Calibrated relocations of this quality have been made possible in Iran only within the past few years, through rapidly densifying station coverage and increased availability of near source data. The multi-event relocations can encompass early instrumental earthquakes, extending as far back as the 1950s and 1960s, so long as they share readings with nearby, well-recorded modern events. We are using the new high quality locations, in combination with independent constraints on rupture extents and fault geometry from field and InSAR mapping, to reexamine several large earthquake sequences and assess patterns of seismicity and triggering. Here, we address whether large earthquakes have a preference for rupturing unilaterally rather than bilaterally, and whether aftershocks concentrate in the direction of unilateral rupture propagation, favoring a significant role for dynamic triggering over static stress changes. [264 words]

Presentation type: Poster Presentation