G22D MCC: 2010 Tuesday 1340h

Insights Into the Earthquake Cycle II

(joint with OS, S, T)

Presiding: **I Shennan,** University of Durham**; J T Freymueller,** University of Alaska, Fairbanks

G22D-01 1340h INVITED

Secular Subsidence and Deep Basal Subduction Erosion at the Northeastern Japan Forearc

Kosuke Heki (+81-197-22-7139; heki@miz.nao.ac.jp)

Div. Earth Rotation, National Astron. Obs., 2-12 Hoshigaoka, Mizusawa-city, Iwate 023-0861, Japan

Subduction erosion has two basic mechanisms, (1) material collapsed from the landward slope is trapped in horst-graben structure of the subducting plate (frontal erosion), and/or (2) materials at the base of the upper plate are scraped off by the subducting slab (basal erosion). These processes let the upper plate material subduct with the slab, and make the trench retreat landward and cause forearc subsidence. Subduction erosion in Northeast Japan (NEJ) has been investigated by many geologists since ocean drilling at the continental slope of the Japan Trench discovered evidence of past erosion, i.e. unconformity over Cretaceous subaerial strata several kilometers deep. Tide gauge data of the last few decades in NEJ forearc also show that both interseismic and coseismic vertical movements are downward, suggesting secular subsidence of the forearc currently goes on. On the other hand, subduction erosion does not take place in Southwest Japan (SWJ); it has a well-developed accretionary prism, and sediment accretion is considered to occur there. Direct observation of the erosion has been difficult as it leaves little geological and geophysical evidence. In the present study, we compare horizontal and vertical velocity profiles across NEJ and SWJ, and investigate geodetic signatures of subduction erosion and accretion with modern satellite geodesy. The horizontal velocities agree well with those predicted by the elastic loading of the subducting slabs. However, vertical velocities in the NEJ forearc show significant negative deviation (subsidence). This may indicate loss of material at the plate interface, due to the erosion of the upper plate by the slab (basal subduction erosion). The estimated rate (15 mm/yr down to 90 km) is somewhat faster than the geological average, and the erosion speed may be variable being controlled by the surface roughness of subducting slabs.

G22D-02 1355h

Recurrent Coastal Uplift Events in Eastern Hokkaido, along Kuril Subduction Zone, as Inferred from Litho- and Biostratigraphy

Yuki Sawai[1] (yuki.sawai@aist.go.jp); Hiroo Nasu[2] (nhiroo@nichibun.ac.jp); Kenji Satake[1] (kenji.satake@aist.go.jp); Masanobu Shishikura[1] (m.shishikura@aist.go.jp); Takanobu Kamataki[1] (t.kamataki@aist.go.jp); Benjamin P Horton[3] (b.p.horton@durham.ac.uk)

[1] Active Fault Research Center, GSJ/AIST, Site C7 1-1-1 Higashi, Tsukuba 305-8567, Japan

[2] Department of Japanese Studies, The Graduate University for Advanced Studies (Sokendai), 3-2 Oeyama-cho, Goryo, Nishikyo-ku, Kyoto 610-1192, Japan

[3] Department of Geography, University of Durham, South Road, Durham DH1 3LE, United Kingdom

Litho- and biostratigraphy beneath coastal salt marshes in eastern Hokkaido record at least six emergence events during the past 4000 years, probably resulted from deep aseismic slip following infrequent unusual earthquakes along the Kuril subduction zone. The stratigraphy in Akkeshi and Onnetoh marshes was studied using over 50 cores. Four emergence events in Akkeshi were marked by estuary-wide stratigraphic contacts between mud and peat layers, and by diatom assemblages in the deposits. Sharp peat-over-mud contacts clearly separate the diatom dominance: salt-tolerant diatoms in lower mud and freshwater diatoms in upper peat. Radiocarbon ages of plant macrofossils and tephra show the dates of these four events are 2300-1700, 1300-1000, 700-500 and ca. 300 cal yr B.P. In Onnetoh, about 70 km east, six similar emergent events were identified. They provided contrasting diatom and plant macrofossil assemblages. Salt-tolerant diatoms and vascular plants dominated in mud below the contact, whereas a conifer Picea glehnii and freshwater-aerophilous diatoms dominate in peat above the contacts. Radiocarbon ages and tephra show that these six events, characterized by gradual changes in environment from brackish water to freshwater forests, date to 3900-3600, 2700-2400, 2000-1700, 1400-1000, 700-500, and 300 cal yr B.P. Such emergence events may solve a conflict of vertical crustal movement in eastern Hokkaido. This tectonically active area, where the Pacific plate subducts at 8 cm/yr, has been steady submerging at fast rate of 8-9 mm/yr in the twentieth century as recorded by tide gauges. Pleistocene marine terraces, however, imply 0.3-0.5 mm/yr of net uplift during the past 125,000 years. To balance these two opposite movements, emergence events as found this study were needed. The coastal uplift, the most likely cause of the emergence in this area, might be generated by infrequent a-seismic slip in the Kuril subduction zones, although such large-scale emergence events have not been recorded in interplate earthquake cycle of 19-20th century. Unusual tsunami deposits, recently found along the Pacific coast of eastern Hokkaido (Nanayama et al., 2003) support this hypothesis. The tsunami deposits indicate that unusual earthquake occurred every about 500 years over the past 7000 years. The interval of the unusual earthquake coincided with the emergence events of this study.

G22D-03 1410h

The seismic cycle on intracontinental megathrusts

Jean-Philippe Avouac[1] (avouac@gps.caltech.edu)

Hugo Perfettini[1]

Laurent Bollinger[1]

Olivier Beyssac[2]

[1] Caltech, California Boulevard, Pasadena, CA 91125, United States

[2] Ecole Normale Superieure, rue Lhomond, Paris 75252, France

Our understanding of the mechanics that relates crustal deformation and seismicity remains crude. The "seismic cycle" concept does provide some useful and physically sound rationale, but many basic questions remain open. To state a few: What proportion of crustal deformation is taken up by large earthquakes? How co-seismic deformation does relates to stress and strain accumulated since the last large earthquake having ruptured the same fault? What mechanism drives aftershocks and background seismicity in the interseismic period? Is interseismic straining a stationary process? These questions are addressed here from investigations focused on some major intracontinental thrust faults in the Himalayas and Taiwan. In such settings, the analysis of the fault geometry and properties at depth are facilitated by the shallow dip angles and also because deep rocks are ultimately brought to the surface providing a way to assess thermal conditions at depth. These case examples provide insight on the factors, and associated physical processes, which control the geometry and mechanical behavior of the fault portion capable of producing larges earthquakes (such as the 1999 M=7.6 Chichi, in Taiwan, or the 1934, M=8.5, Bihar-Nepal earthquakes). The thermal structure is a key factor because it determines the transition with depth from a locked seismogenic fault portion, to a zone undergoing predominantly strain strengthening brittle creep, and finally to a zone of aseismic ductile flow at depth. Some simple model is derived that can be used to analyze jointly seismicity rate and crustal strain in the interseismic period and during post-seismic relaxation, and assess the possibility for non-stationary straining in the interseismic period.

G22D-04 1425h

Multi-cycle Dynamic Models of Thrust Faulting and Normal Faulting

Benchun Duan[1] ((909)787-3434; benchun@namazu.ucr.edu)

David D. Oglesby[1] ((909)787-2036; david.oglesby@ucr.edu)

[1] Department of Earth Sciences, University of California, Riverside, 900 University Avenue, Riverside, CA 92521, United States

Using the two-dimensional dynamic finite element method, we compare the behavior of thrust faults and normal faults over multiple earthquake cycles. The earthquake cycle is simulated by an inter-seismic loading phase and a dynamic rupture phase. The earthquake fault is loaded by a constant slip velocity at the base of the fault. The coefficient of friction drops from a static level to a sliding level over a critical slip distance during dynamic rupture, and recovers to the static level after dynamic waves die out. The transition from the loading phase to the dynamic phase can be accomplished spontaneously, rather than introducing an artificial triggering procedure. We conduct numerical simulations for faults of various dip angles. The results demonstrate that both thrust and normal faults tend to develop a stable event pattern: a large event, which ruptures the whole fault, is preceded by several small events that rupture about 1 km length of the fault, and one or more moderate events that rupture several km along the fault. During the stable event pattern, the stress evolution and slip evolution for thrust and normal faults are quite similar. However, normal faults develop a stable event pattern more rapidly than thrust faults, when they start from the same initial preset stress level. The results also demonstrate that variation of normal stress on faults plays an important role not only during the dynamic rupture phase, but also during the loading phase. The normal stress at the lower end of faults, where rupture usually starts, increases on normal faults during the loading phase, whereas it decreases on thrust faults. This variation of the normal stress during the loading phase has several important implications for the behaviors of these two fault types, given similar initial stress level and frictional properties on faults. First, normal faults take a longer time to reach the failure level than thrust faults, due to the above variation of normal stress on faults. Second, the shear stress level on the whole fault just before the onset of dynamic rupture is higher for normal faults than thrust faults, due to the longer loading time. Third, for an event that ruptures the whole fault, normal faults typically have larger slip than thrust faults, due to a larger stress drop. However, peak slip rates on thrust faults are larger than those of normal faults, possibly due to the amplifying effects of the free surface interaction.

G22D-05 1440h

Reassessment of the 2001-2002 Aseismic Slow Slip Event in Mexico

Vladimir Kostoglodov[1] (525 55 622-4138; vladi@servidor.unam.mx); Sara Ivonne Franco[1] (525 55 622-4138; ivonne@ollin.igeofcu.unam.mx); Shri Krishna Singh[1] (525 55 622-4138; krishna@ollin.igeofcu.unam.mx); Kristine M Larson[2] (303 492-6583; Kristine.Larson@colorado.edu); Anthony R Lowry[3] (303 735-4892; arlowry@brennan.colorado.edu); Jose Antonio Santiago[1] (525 55 622-4138; santiago@ssn.ssn.unam.mx)

[1] Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, IGF UNAM, Ciudad Universitaria, Coyoacan, Mexico, DF 04510, Mexico

[2] Department of Aerospace Engineering Science, University of Colorado, Campus Box 429, Boulder, CO 80309-0429, United States

[3] Department of Physics, University of Colorado, Campus Box 390, Boulder, CO 80309-0390, United States

In 2001-2002 a network of continuous GPS stations in Mexico recorded an unexpectedly large aseismic slow event (equivalent Mw 7.4) in Guerrero and in western Oaxaca. This event lasted more than six months and the area involved in the aseismic motion was initially estimated as 500x250 km2. The event produced a slow thrust slip of 13-15 cm on the subduction plate interface below the central part of the State of Guerrero. Elastic dislocation models, which fit the observed data, restrict the width of the slip to 150-200 km along the plate interface. This interface was partially locked before, during the steady state interseismic phase associated with the continental plate compression. Unfortunately the GPS network coverage was not sufficient to resolve an important question: Was the seismogenic part of the plate interface involved in the slow thrust slip? A long term record from a permanent GPS station located on the Popocatepetl volcano, POSW, shows unambiguous displacements corresponding to the aseismic slip events of 1997-1998 and 2001-2002. Recent data analysis of 2001, 2002, and 2003 GPS occupation campaigns on 16 sites in Oaxaca reveals that the 2001-2002 slow aseismic slip may have extended SE along almost the entire Pacific coast of Oaxaca. These observations indicate that the total area affected by the last slow aseismic slip event is greater than 300x700 km2. Most likely the same area was involved in a previous aseismic event of 1972, which is discovered from the analysis of tide gauge data. Frequently occurring aseismic transients should have an important bearing on the recurrence period of large subduction thrust earthquakes in Mexico.

G22D-06 1455h

Sea Level Changes and Active Tectonics of the Guerrero Coast, Mexico

M. Teresa Ramirez-Herrera[1] (ramirezt@csulb.edu)

Andrew B. Cundy[2] (A.B.Cundy@sussex.ac.uk)

Matt Sedor[1] (SedorM@aol.com)

Vladimir Kostoglodov[3] (vladi@servidor.unam.mx)

[1] Geological Sciences, California State University Long Beach, 1250 Bellflower Blv., Long Beach, CA 90840, United States

[2]Centre for Environmental Research,, University of Sussex, Brighton BN1 9RH, United Kingdom

[3]Instituto de Geofisica, UNAM, Circuito de la Investigacion, CU, Mexico 01000, Mexico

Understanding the interaction between sea-level changes and tectonic activity during the Holocene is essential in determining long-term tectonic deformation rates and in identifying prehistorical earthquake events along active margins. The Guerrero coast extends along the active Pacific margin of southwest Mexico and parallels the trench where the Cocos Plate subducts beneath the North American Plate. The last major earthquakes occurred in Guerrero in 1899, 1907, 1909, 1911, and 1957, but none have occurred since the major 1911 (Ms=7.6) earthquake in the northwest segment of the Guerrero seismic gap. The Guerrero gap is currently considered to be matured for a severe earthquake of estimated Mw= 8.1 to 8.4. We present preliminary results of geomorphic field surveying, sediment coring, and geochemical and microfaunal analyses of cored sediments on the Guerrero coast. The Coyuca lagoon strip of the Guerrero coast consists of long barrier beaches, behind which extends a lagoon, beach ridges, extensive swamps, mangrove swamps, salt pans, floodplains, alluvial plains, fluvial terraces, and abandoned meanders. Abandoned meanders and fluvial terraces indicate that the Coyuca River has migrated to the southeast. This migration, and changes in hill elevations near the coast, suggest a southeast tilting of this coastal segment. The morphology of the Guerrero coast has no evidence of long-term coastal uplift. This is consistent with short- term tide gauge measurements (1953-1999) and GPS data (1992-2000) indicative of subsidence rates of 3 mm/yr (Kostoglodov et al., 2001) in this area. Five cores up to 5.5 m depth were taken nearby the Mitla, Coyuca, Tres Palos and Tecomate lagoons. Core stratigraphies show clear sequences of interbedded peats and clays, interspersed with sand units. The peat-clay sequences are similar to those observed along active margins elsewhere, and indicate fluctuations between marine and brackish/freshwater conditions. Two cores included sediments with archeological remains (pottery). The stratigraphic data, coupled with geomorphic evidence, indicate changes in relative sea-level associated with long-term tectonic deformation. On-going radiocarbon dating of shells and charcoal, and detailed geochemical and micro-faunal (i.e. pollen, ostracod and foraminiferal) analyses are being used to constrain the timing and confirm the nature of these sea-level change events.

URL: http://seis.natsci.csulb.edu/tramirez/tramirez.html

G22D-07 1510h

Characteristic and Uncharacteristic Earthquakes as Possible Artifacts: Applied to the New Madrid and Wabash Seismic Zones

Seth Stein[1] (seth@earth.northwestern.edu)

Andrew V. Newman[2] (505-665-3570; anewman@lanl.gov)

[1]Department of Geological Sciences, Northwestern University, 1850 Campus Drive, Evanston, IL 60208

[2]Earth and Environmental Sciences, EES-9, Los Alamos National Laboratory, MS-D462, Los Alamos, NM 87545

Generally, the largest events, characteristic earthquakes (CE), appear more often than expected from the Gutenberg-Richter relation. Whether this effect is real or apparent is an interesting question since apparent differences can arise from several possible situations. If the known history is shorter than or comparable to the recurrence time of largest events, apparent CEs can occur because sampling bias allows anomalous short recurrence to be observed more frequently (fractions of earthquakes cannot be observed). Alternatively, apparent CEs can occur if paleoseismic data overstimate magnitudes or underestimate recurrence. In the New Madrid Zone (NMSZ), simulations suggest that because the 2000 year paleoseismic record is 4× the accepted recurrence for CEs, there is a small probability of observing apparent CEs. A more significant effect is that paleoliquifaction data regionally appear to overestimate magnitudes. It is commonly assumed that the distribution of liquifaction, used for paleomagnitudes, near the NMSZ is smaller that seen globally. Liquefaction features extending 250 km from an earthquake in the NMSZ are interpreted as evidence for an M 8.3 event, rather than an M 7.6 as would be inferred from the global curve. This practice arose because the curve was calibrated assuming an M 8.3 for the 1811-12 events whereas more recent analysis finds M$\sim$7.4. Hence either the largest earthquakes are CEs or the paleoevents were smaller than those in 1811-12. The opposite effect occurs in the Wabash Valley Seismic zone, where the paleoearthquakes appear "uncharacteristic", less frequent than would be inferred from instrumental seismicity. The paleoseismic record is long enough that the discrepancy is unlikely to be a sampling artifact. Hence either the uncharacteristic behavior is real, or the paleoseismic record captures only a small fraction of the large preinstrumental earthquakes.

G22D-08 1525h

The Evolution of the Seismic-Aseismic Transition During the Earthquake Cycle: Constraints from the Time-Dependent Depth Distribution of Aftershocks

Frederique Rolandone[1] (510-642-8374; frede@seismo.berkeley.edu)

Roland Bürgmann[1] (burgmann@seismo.berkeley.edu)

Robert Nadeau[1] (nadeau@seismo.berkeley.edu)

Andrew Freed[2] (freed@purdue.edu)

[1]UC Berkeley Seismological Laboratory, 215 McCone Hall, Berkeley, CA 94720, United States

[2]Earth and Atmospheric Science, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, United States

We have demonstrated that in the aftermath of large earthquakes, the depth extent of aftershocks shows an immediate deepening from pre-earthquake levels, followed by a time-dependent postseismic shallowing. We use these seismic data to constrain the variation of the depth of the seismic-aseismic transition with time throughout the earthquake cycle. Most studies of the seismic-aseismic transition have focussed on the effect of temperature and/or lithology on the transition either from brittle faulting to viscous flow or from unstable to stable sliding. They have shown that the maximum depth of seismic activity is well correlated with the spatial variations of these two parameters. However, little has been done to examine how the maximum depth of seismogenic faulting varies locally, at the scale of a fault segment, during the course of the earthquake cycle. Geologic and laboratory observations indicate that the depth of the seismic-aseismic transition should vary with strain rate and thus change with time throughout the earthquake cycle. We quantify the time-dependent variations in the depth of seismicity on various strike-slip faults in California before and after large earthquakes. We specifically investigate (1) the deepening of the aftershocks relative to the background seismicity, (2) the time constant of the postseismic shallowing of the deepest earthquakes, and (3) the correlation of the time-dependent pattern with the coseismic slip distribution and the expected stress increase. Together with geodetic measurements, these seismological observations form the basis for developing more sophisticated models for the mechanical evolution of strike-slip shear zones during the earthquake cycle. We develop non-linear viscoelastic models, for which the brittle-ductile transition is not fixed, but varies with assumed temperature and calculated stress gradients. We use them to place constraints on strain rate at depth, on time-dependent rheology, and on the partitioning of deformation between brittle faulting and distributed viscous flow associated with the earthquake cycle.

G22E MCC: 2010 Tuesday 1600h

Insights Into the Earthquake Cycle III *(joint with OS, S, T)*

Presiding: **S L Hamilton,** University of Durham**; W Thatcher,** U.S. Geological Survey

G22E-01 1600h INVITED

Incubation of Chile's 1960 Earthquake

Brian F Atwater[1] (206-553-2927; atwater@u.washington.edu); Marco Cisternas[2] (marco.cisternas@ucv.cl); Ignacio Salgado[2] (nachosalgado@123.cl); Gonzalo Machuca[3] (gmachuca@udec.cl); Marcelo Lagos[4] (malagoslo@puc.cl); Annaliese Eipert[5] (eiperta@carleton.edu); Masanobu Shishikura[6] (m.shishikura@aist.go.jp)

[1]U.S. Geological Survey, University of Washington Box 351310, Seattle, WA 98195, United States

[2]Facultad de Agronomia, Universidad Catolica de Valparaiso, Valparaiso V, Chile

[3]Departmento de Cs. Historicas y Sociales, Universidad de Concepción, Concepcion VII, Chile

[4]Instituto de Geografia, Universidad Catolica de Chile, Santiago Metro, Chile

[5]Department of Geology, Carleton College, Northfield, MN 55057, United States

[6]Active Fault Research Center, GSJ/AIST, Site C7 1-1-1 Higashi, Tsukuba 305-8567, Japan

Infrequent occurrence of giant events may help explain how the 1960 Chile earthquake attained M 9.5. Although old documents imply that this earthquake followed great earthquakes of 1575, 1737 and 1837, only three earthquakes of the past 1000 years produced geologic records like those for 1960. These earlier earthquakes include the 1575 event but not 1737 or 1837. Because the 1960 earthquake had nearly twice the seismic slip expected from plate convergence since 1837, much of the strain released in 1960 may have been accumulating since 1575. Geologic evidence for such incubation comes from new paleoseismic findings at the Río Maullin estuary, which indents the Pacific coast at 41.5° S midway along the 1960 rupture. The 1960 earthquake lowered the area by 1.5 m, and the ensuing tsunami spread sand across lowland soils. The subsidence killed forests and changed pastures into sandy tidal flats. Guided by these 1960 analogs, we inferred tsunami and earthquake history from sand sheets, tree rings, and old maps. At Chuyaquen, 10 km upriver from the sea, we studied sand sheets in 31 backhoe pits on a geologic transect 1 km long. Each sheet overlies the buried soil of a former marsh or meadow. The sand sheet from 1960 extends the entire length of the transect. Three earlier sheets can be correlated at least half that far. The oldest one, probably a tsunami deposit, surrounds herbaceous plants that date to AD 990-1160. Next comes a sandy tidal-flat deposit dated by stratigraphic position to about 1000-1500. The penultimate sheet is a tsunami deposit younger than twigs from 1410-1630. It probably represents the 1575 earthquake, whose accounts of shaking, tsunami, and landslides rival those of 1960. In that case, the record excludes the 1737 and 1837 events. The 1737 and 1837 events also appear missing in tree-ring evidence from islands of Misquihue, 30 km upriver from the sea. Here the subsidence in 1960 admitted brackish tidal water that defoliated tens of thousands of trees. We sampled 45 such trees, some of them completely dead and the rest surviving only from shoots near the ground. One-third of these trees lived through the 1837 earthquake; they contain over 180 annual rings. Five of the trees also contain rings earlier than 1737. From this evidence, we tentatively infer that the islands underwent more subsidence in 1960 than they did in 1737 or 1837. Comparisons with old Chilean documents for the estuary further suggest that subsidence in 1837 did not approach that of 1960. In their depiction and description of the Misquihue islands in 1874, surveyor Francisco Vidal and botanist Carlos Juliet show nothing like the ghost forests seen today. Twice in the first 37 years after the 1837 earthquake, surveyors mapped as emergent several islands that the 1960 earthquake would lower into tidal water. Today, 43 years after they subsided in 1960, these islands remain submerged as barren intertidal flats. Research supported by Fondecyt 1020224.

G22E-02 1615h INVITED

Elastic and Viscoelastic models of Crustal Deformation in Great Earthquake Cycles

Kelin Wang[1,2] (250-363-6429; wang@pgc.nrcan.gc.ca)

Jiangheng He[1] (he@pgc.nrcan.gc.ca)

Yan Hu[2] (yhu@pgc.nrcan.gc.ca)

[1]Geological Survey of Canada, Pacific Geoscience Centre, 9860 W Saanich Rd, Sidney, BC, V8L 4B2, Canada

[2]School of Earth and Ocean Sciences, University of Victoria, Victoria, BC, V8W 3P6, Canada

Ideally, a model of subduction zone earthquake cycles should include tectonic loading, fault friction, and viscoelastic stress relaxation. Such a model is not yet available. The loading mechanism is rarely addressed. A model does not address tectonic loading if some part of the fault is assigned a slip rate. Models based on rate and state dependent friction laws are useful in demonstrating how seismic fault slips may occur and stop as a result of the interplay between fault frictional behavior and system rigidity. For comparison with geodetic observations, however, the most widely used models treat the fault motion in a purely kinematic fashion, that is, the fault slip (or state of locking) is estimated from surface observations regardless of the loading mechanism and friction properties. These include the forward and inverse elastic dislocation and viscoelastic models. Without addressing the loading mechanism, extra care should be taken to ensure that the assigned or estimated fault motion is physically valid. It is often difficult to distinguish between contributions to surface deformation from fault motion and from stress relaxation of the rock material. The same deformation observations can be explained by different models, and any published model merely portrays one particular understanding of the processes being studied. It is usually assumed that aseismic slip of the fault, such as "afterslip" and interseismic silent slip, is of the time scale of days to years, but viscoelastic stress relaxation of the system has a time scale of decades to hundreds of years. On the basis of the time scale argument, we modeled earthquake cycles at the Cascadia and Chile subduction zones using a 3-D spherical finite element viscoelastic