S23A CC: 220 C-E Tuesday 1330h

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

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

S23A-01 1330h POSTER

Acoustic Emission Analysis of Stick Slip Behaviour in Faulted Westerly Granite

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Recent debate has focused on understanding the initial stages of earthquake rupture and whether this is a scale dependent process that varies with magnitude. As a first step in addressing this issue, we present results from stick slip experiments on a smooth fault in a cylindrical sample of Westerly granite, during which ultrasonic Acoustic Emission (AE) data were monitored. One goal of this project is to explore the extent to which the high-frequency radiated energy, as well as premonitory AE, scales with rupture dimension. In our experiments, we use continuously recorded AE to examine the radiated energy accompanying dynamic rupture nucleation of the macroscopic stick-slip events. The artificially prepared fault consisted of a sawcut inclined at 30 degrees to the sample axis. The fault surface was surface ground and then lapped with 220 grit SiC. The sample was loaded at a strain rate of 5.0 x10-6 /s at constant confining pressure of 150 MPa, undergoing a series of three slip events. Fault slip for each event was a few millimeters. Continuous AE data were acquired using a Giga RAM Recorder, which enables five minutes of uninterrupted ultrasonic waveform data to be recorded at 5 MHz sampling frequency, on 16 channels. The AE monitoring system also records triggered data throughout the test cycle. The first motion of each of the three large scale slip events was captured in the triggered AE record. A comparison of the triggered data to locations and waveforms from the continuous recording for the third stick-slip event confirmed that the triggered AE record for this event did indeed represent the initiation of macroscopic rupture. Although the waveforms on the continuous recording saturate following rupture initiation, we were able to identify the position of initiation of each stick-slip event by inversion of first motion arrival times. Focal mechanisms as calculated from first motion polarity, are in agreement with slip in the plane of the fault. Less than one hundred premonitory AE events were recorded in the time intervals leading up to the three macroscopic slip events. We located these AE source events and used moment tensor inversions to calculate AE focal mechanisms. Many premonitory AE events have mechanisms consistent with the large scale fault orientation.

S23A-02 1330h POSTER

Dimensional Analysis in Granular Mechanics: The Role of Surface Properties and Material Properties

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Understanding the mechanical properties of granular material is a central problem in deciphering the frictional characteristics of active faults. In order to isolate frictional processes in layers of granular fault gouge, we designed laboratory experiments to focus on three primary mechanisms of strain accommodation: sliding, rolling, and dilation. Our experiments were conducted on samples composed of rods of differing compositions in a variety of geometric configurations. In each run, a sample, consisting of two approximately 6-mm thick layers sandwiched between steel forcing blocks, was sheared in a biaxial double-direct-shear hydraulic press. Experiments were run under a constant normal load of 1 MPa and at a constant shear velocity of 10 μm/s. Temperature and humidity were not directly regulated, but environmental conditions were consistent over the course of the experiments, with temperature of 22 degrees and relative humidity ranging from 5 to 10 %. To evaluate the effects of particle surface roughness and material properties, we studied dried semolina pasta, alloy 260 brass, and 1/16" hardwood dowels, with particle diameters of 1.86 mm, 1.59 mm, and 2.06 mm, respectively. By restricting particle motion to one or two dimensions, we produced experimental results that can be compared directly with numerical modeling techniques. Following Frye and Marone [2002] we studied shear within a 2-D particle configuration, in which rods are sheared perpendicular to their long axes, and within a 1-D configuration in which shear is parallel to rod axes. Layers sheared within the 2-D configuration involve all three components of strain accommodation. The 1-D configuration allows only sliding parallel to applied shear. We also studied a rolling-only configuration, in which a layer of rods oriented perpendicular to shear is sandwiched between rods oriented parallel to shear. The pasta samples had mean sliding friction coefficients of 0.24, 0.11, and 0.02 in 2-D, 1-D, and rolling configurations, respectively. The brass rods had an average coefficient of 0.23, 0.15, and 0.01, respectively; and the wood samples had average coefficients of 0.18, 0.19, and 0.09, respectively. The evolution of the layer's strength during each experiment corresponded to the displacement derivative of the layer thickness. Each material displayed a distinctive and consistent pattern of strengthening and weakening under shear, particularly in the 2-D experiments. SEM images reveal significant differences in surface finish between the materials. We find a systematic relationship between the mean coefficient of friction of each granular material and its surface finish, as well a correlation between friction and the number of contact sliding dimensions in each sample configuration. Our data provide important constraints on the fundamental parameters used in numerical models of tectonic faulting.

S23A-03 1330h POSTER

Moonquakes and Low Frequencies of Earthquakes

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Some new results concerning moonquakes are included in this study. According to F. Duennebier and G. H. Sutton, 'Thermal moonquakes', J. of Geophysical Res., 79, 4351-4363, 1974, the moonquakes occur primarily during the early hours of the moon day. The frequency of these acoustic emissions is about 5 Hz and their duration is more than 60 s. There are interruptions in the emissions about every 10 cycles, similar to those seen in the acoustic emissions from granular media when they are forced to flow between the walls of the plunger and the container. The latter can be seen in a paper by H. Takahara, 'Sounding mechanism of singing sand', J. Acoustical Soc. Am., 53, 634-639, 1973. In a recent paper by A. J. Patitsas, 'Booming and singing acoustic emissions', J. of Fluids and Structures, 17, 287-315, 2003, the origin of the moonquakes is sought in the granular flow in the crevices of the craters during the early hours of the moon day when the rock masses tend to expand due to the relatively steep rise in the temperature on the surface of the moon. In order to render credibility to such a scenario, several simple experiments were done involving the squeezing and shearing of granular media between stone plates. The results of these experiments and the mechanism responsible for the low frequencies of the moonquakes and also for the very low frequencies associated with earthquakes will be discussed.

URL: http://www3.sympatico.ca/tpatitsas

S23A-04 1330h POSTER

The Tidal Triggering of Earthquakes Under Certain Circumstances

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Although it would be lunacy to claim that all earthquakes are triggered by the motions of the Moon and Sun, there are certain circumstances where these celestial bodies might play a role. This would especially be the case where pre-existing, nearly vertical zones of weakness are present and, hence, the solid-earth tidal stresses would have maximum effect. I have investigated two possible areas: i) the Charlevoix seismic region of Québec along the St. Lawrence River and)ii the San Andreas and Calaveras Faults in California. In the Charlevoix region there a few suites of earthquakes, recognized by Maurice Lamontagne and lying mainly beneath or at the edge of the St. Lawrence River, in which the events in each suite occur in a relatively small volume of rock and produce similar waveforms characteristic of the particular location involved. This sort of repeated rupturing suggests the possibility of triggering by solid-earth and/or marine tides. In one sequence of 9 events (2 of which are left out of the analysis because they are aftershocks) it appears that there is only about one chance in ten that this sequence occurred at random. Unfortunately, there are no fault-plane solutions for any events in this particular set of earthquakes and so it is difficult to comment on failure mechanisms. However, in the case of the Calaveras and San Andreas Faults of California where fault-plane solutions are often available, if we restrict our attention to the larger, strike-slip earthquakes, it appears that lunar and solar tides (both solid-earth and marine) do, in fact, play a role in the timing of these events and the triggering mechanism may involve the amount of incremental normal stress acting upon these two faults.

S23A-05 1330h POSTER

The Role of Pore Fluids in the Mechanism of Seismic Sequences

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It is generally agreed that the occurrence of seismic sequences implies a kind of interaction between different fault segments. The coseismic stress transfer produced by each dislocation is the most obvious component of such an interaction. However the time intervals elapsing between subsequent events in a sequence indicate that the coseismic stress is not sufficient to trigger other seismic events by itself. We investigate the possibility that the coseismic stress field may induce flow of pore fluids, altering the pore pressure distribution in the region. The flow velocity depends on the pressure gradient and the permeability of the medium. We consider a porous, elastic medium and study under which conditions the change in pore pressure induced by a fault dislocation may lead to a significant decrease in friction on adjacent fault segments. A gradual decrease of friction on a fault segment, which was already loaded as a consequence of stress transfers by previous dislocations in the seismic sequence, might lead to the failure of the segment itself, after the time required for pore fluid diffusion to take place.

S23A-06 1330h POSTER

Duration-Amplitude Distribution of Tremor Associated with Slip Events Along the Cascadia Subduction Zone, Vancouver Island, Canada

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Tremor activity associated with slip events along the Cascadia subduction interface can be identified in the continuous seismic data collected by the Canadian National Seismic Network (CNSN) in western Canada. A tremor sequence that occurred in the spring of 2003 (February 25 - March 26) corresponding to a slip event along southern Vancouver Island is selected for further analysis. By adapting the method developed by Benoit et al. (2003) using volcanic tremor, a duration-amplitude distribution of slip-associated tremor can be found. Since tremor is a continuous signal, the duration is taken as the frequency of occurrence and the size is measured as the amplitude (Benoit et al., 2003). By plotting the duration-amplitude distribution, we hope to determine whether the source mechanism of tremors is scale dependent. If the distribution is found to fit a power-law curve, the source process is scale-invariant; however, if the distribution fits an exponential curve, it follows that the tremor source process is scale-bound. Initially, one hour of continuous data from the spring 2003 sequence is analyzed for one CNSN station on southern Vancouver Island. Preliminary results show that the duration-amplitude distribution of tremor appears to be best-fit by a power-law model. Upon successful completion of the initial stage, the data set will be expanded to include a longer time period across multiple stations. The goal of this work is to shed some light on the properties of the source mechanisms involved with slip-associated tremor.

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S23A-07 1330h POSTER

Source Fault of the Dec.26, 2003 Bam Earthquake (Mw6.5) in Southeastern Iran Inferred From Aftershock Observation Data by Temporal High-Sensitive-Seismograph Network

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The Bam earthquake occurred in southeastern Iran at 05:26 A.M.(local time) on December 26, 2003 (epicenter: 29.010N, 58.266E, Mo=6.6x10**18Nm, Mw=6.5; ref.1). The earthquake had strike-slip mechanism (strike=175, dip=85, slip=153; ref.2) and source parameters (focal depth=4km, fault dimension=20kmx15km, Dmax=1.0m, stress drop=3.7MPa; ref.2). The earthquake struck the ancient city of Bam and killed more than 40,000 people. It shows that one third of about 120,000 in population in and around Bam city were killed. The main reason of such a big damage may be caused by weak adobe and brick houses; even so, the damage was too much big. We, therefore, are researching other cause of such a big damage. Taking instruments from Japan for this aim we installed 9 high sensitive seismographs and one accelerograph in and around Bam city on February 6-8, 2004. And we observed aftershocks and continue during one month. Reading P and S arriving times of about 100 aftershocks occurring from February 6 to 10, we determined those preliminary hypocenters and magnitudes. Those epicenters (errors<500m) distribute mainly from northeastern Bam city to south direction with about 20km length. It means that the fault of the main shock passed just under eastern half of Bam city where most of houses and buildings were heavily damaged. This fault is about 4 km away west from Bam fault which is presented in geological map (ref.3). A north-south vertical cross-section of the hypocentral distribution (maybe errors < 1km) shows that most of their depths are shallower than 14km and a seismic gap exists in the laterally middle part of their distribution and shallower than 6 km in depth. The shallow seismic gap may correspond to a main fracture zone as shown in the slip distribution figure proposed by Yamanaka (ref.2). This main fracture occurring shallower than about 6 km in depth must be one of causes of the big damage in Bam. (Reference) ref1:USGS,http://neic.usgs.gov/neis/FM/, ref 2: ERI, U. Tokyo, http://wwweic.eri.u-tokyo.ac.jp/EIC/EIC_News/031226f.htmlref 3: National Geoscience Database of Iran, http://www.ngdir.ir

URL: http://www.gaea.kyushu-u.ac.jp/research/iran2004/iran2004_1.html

S23B CC: 516 B Tuesday 1330h

POLARIS: Lithospheric Structure in North America *(joint with G, GP, T, SEDI)*

Presiding: **D Eaton,** University of Western Ontario**; C J Thomson,** Queen's University

S23B-01 1330h INVITED

Possible Uses of POLARIS Data: From Subasthenospheric Mantle Flow Beneath Plate Boundary Zones to the Fabric of Archean Lithosphere

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The POLARIS program provides an opportunity to explore a variety of first order problems, making use of both seismic and geodetic networks that are either installed or in the planning stages. The area that POLARIS will cover ranges from the actively deforming plate boundary zone in the west to the long-stable terrains of the Archean Canadian Shield. I will discuss a few studies that have made use of techniques that could be successfully utilized in the analysis of POLARIS data. In the case of actively deforming regions, we have shown (Silver and Holt, 2002) that the simultaneous inversion of surface deformation observations from GPS and mantle deformation data inferred from seismic anisotropy, provides an estimate of the mantle flow velocity field at the base of the asthenosphere, under certain simplifying assumptions. In that study, the mantle beneath westernmost North America south of the Mendocino triple junction was found to be moving to the east at 5cm/yr in a hotspot reference frame, and likely due to the sinking of the Farallon slab through the mantle. The nature of this flow field north of the triple junction and into Canada, in particular the influence of the subducting Juan de Fuca slab on this flow field, constitutes an important scientific problem that could be attacked with data from POLARIS. A second study, relevant to the Canadian Shield, involves the analysis of the anisotropic properties of the lithosphere beneath cratonic southern Africa. That study of 80 broadband transportable stations from the Southern African Seismic Experiment revealed the existence of anisotropy restricted to the mantle portion of the lithosphere, based on the study of both splitting in core phases and radial anisotropy in surface waves. This anisotropy was generated by Archean tectonic events and the corresponding mantle fabric appeared to have controlled the subsequent magmatic evolution of the region over the next subsequent billion years (Silver et al., 2004). The strength of mantle anisotropy (based on delay-time size) beneath the Superior Province of the Canadian Shield is greater than any stable continental region globally, and is at least double that found for the mantle beneath Southern Africa. Yet the size of the relative contributions of lithosphere and asthenosphere in the mantle beneath the Canadian Shield remain unresolved at this point. The combined study of splitting and surface wave radial anisotropy provides a means of placing more precise limits on depth, as in southern Africa, and thus a stronger constraint on the underlying physical process.

S23B-02 1355h INVITED

Kimberlite Trends at the Surface and at Depth

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Although the focus of much study as the host rock for diamonds, the emplacement mechanisms and structure of kimberlite deposits remains only poorly perceived. Recent application of geochronological and seismic techniques to the Lac De Gras kimberlite field that is home to the world's newest diamond mines in NW Canada revealed unexpected correlation in structural trends. The best fitting patterns for the variation in SKS splitting delay times for the Lac de Gras teleseismic stations are consistently those of two horizontal layers. The fast axis of each lower layer trends $045-050^{\circ}$ and delay times are 0.9-1.0 seconds. Upper layers show greater variability; beneath the Ekati Diamond Mine, the fast axis trends 012° with a delay time of 0.45 seconds. At depths of about 120 km, the radial component of receiver functions from this same station has maximum amplitude at $285-290^{\circ}$ and the transverse component at about 320°; together these indicate a horizontal symmetry axis for hexagonal anisotropy at $108/288^{\circ}$ and an associated fast axis at $018/198^{\circ}$. The 120 km depth is the top or bottom of the mantle layer containing this anisotropy; the large maximum amplitudes observed suggest it is here the bottom of the upper layer. Precise ages of over 40 kimberlites in the Lac de Gras field were constrained using standard Rb/Sr and U/Pb isotopic dating techniques correlated with a local geomagnetic polarity timescale; they indicate that one kimberlite group erupted from 75 to 64 Ma along a generally east-west $(100-110^{\circ})$ trend. Another 58.9 ± 1.2 Ma group has a similar trend, whereas younger 55.4 ± 0.5, 53.2 ± 0.3 and 47.5 ± 0.5 Ma clusters show tighter grouping along northeast $(37-45^{\circ})$ trends. The inferred age and direction of trends at both the surface and at > 120 km depth suggests that kimberlites erupt along fractures controlled by continental stress fields related to global plate motions. This provides important clues about where to search for additional diamond deposits, but also about past plate motions.

S23B-03 1415h

Identification of Upper–Mantle Velocity and Anisotropy Structures Beneath the Archean Superior Province Using Surface Waves

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The Canadian Archean Western Superior Province (WSP) is composed of a number of east–west trending subprovinces progressing in age from south to north. Lithoprobe's Western Superior Transect aimed to better understand the significance of such geological architecture for Archean tectonics and included a portable broadband teleseismic array to complement conventional crustal geophysical studies. This N–S array of 17 instruments traversed subprovince boundaries and involved two more stations further north in the Trans–Hudson orogen (THO). Body wave teleseismic tomography and shear–wave splitting analysis have suggested the existence of laterally–varying lithospheric–mantle structures that may be associated with frozen Archean oceanic lithosphere and a high degree of anisotropy. In order to acquire additional constraints on this interesting lower–lithospheric environment we have examined surface waves from high–magnitude teleseismic events in two stages: a standard dispersion analysis along two near–orthogonal paths and a Love and Rayleigh polarization study. The W–E path was examined by incorporating data from CNSN station ULM. Variations in 15–80s Rayleigh fundamental mode group and phase velocities for S–N propagation indicate that the linear profile is best treated in three segments reflecting changes in lithospheric structure. Corresponding shear–wavespeed models inferred from independent isotropic inversions of Love (20–70s) and Rayleigh fundamental phase velocity are broadly coherent with the coincident R/WAR model of Musacchio et al. (in press, JGR, 2004). Both studies indicate crustal thinning moving northward (from 45 to 39 km), faster velocities in the E–W direction and the presence of a thin anisotropic high–velocity layer just below the Moho. While this layer is detected along the E–W path and in the middle and northern parts of the N–S line, there is no surface–wave indication of it in the southern section. It has been interpreted as a relic of oceanic lithosphere accreted during the Kenoran orogeny. Anisotropy is suggested both by comparing the observed Rayleigh phase velocities along the orthogonal paths and by a Rayleigh/Love discrepancy in each of the N–S and E–W isotropic inversions. In fact, inspection of the Rayleigh/Love particle motions in various frequency bands for surface–waves arriving from various azimuths brings into question the assumptions in isotropic analysis. Indicators such as quasi–Love waves and Love elliptical particle motion are seen at most of the stations. Numerical modelling indicates that plausible uppermost–mantle anisotropy has the potential to explain such observatons, especially given the large SKS splitting along the main array. Interestingly, despite a null SKS splitting result at the far north THO station BPW, surface–wave polarizations there provide evidence of significant anisotropy. Overall, the surface–wave data reinforce other techniques suggesting significant lateral variations and anisotropy in the WSP, with the upper 200km of the lithosphere capable of accounting for most of the