SE06: Solid Earth Geophysics: General Contributions

Co-convenors: Andrew Frederiksen, Sam Butler, Phil McCausland
Chairs: Andrew Frederiksen, Sam Butler, Phil McCausland

This session invites contributions from all areas of study investigating the origin, evolution and structure of the Solid Earth, ranging in scale from microscopic to planetary. Topics can take the form of new laboratory or field observations, methods, applications, theory and modelling studies drawn from all areas of solid earth geophysics, including tectonophysics, lithospheric and mantle dynamics, passive geophysical techniques (e.g. seismology, heat flow, potential fields), active source geophysical techniques, petrophysical properties, mineral physics and also the history of geophysical research.

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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 SE06a

Chairs: Andrew Frederiksen, Sam Butler, Phil McCausland **Room: ESB 2012**

Wednesday, May 31st

TIME	AUTHORS	TITLE
11:00	L. Chuang*, M. Bostock, A. Wech & A. Plourde	Plateau subduction, intraslab seismicity and the Denali volcanic gap
11:15	J. M. Gosselin, J. F. Cassidy, S. E. Dosso & Camille Brillon	Earthquake site response characterization in Kitimat, BC, via Bayesian gradient-based inversion of surface-wave dispersion
11:30	M. D. Cambaz & A. Mutlu	Investigation of the Bimaterial Interface Velocity Contrast along the North Anatolian Fault Zone
11:45	A. Plourde* & M. Bostock	Multichannel deconvolution for earthquake apparent source-time functions
12:00	T. K. Asafuah* & A. J. Calvert	Shallow tomographic velocity estimation across the Mariana island arc
12:15	F. A. Darbyshire	Crustal Structure from Craton to Margin in Eastern Canada From Receiver Function Studies

ORAL SESSION SE06b

Chairs: Andrew Frederiksen, Sam Butler, Phil McCausland **Room: ESB 2012**

Wednesday, May 31st

TIME	AUTHORS	TITLE
16:45	S.L. Butler	Shear induced porosity bands in Earth's upper mantle: do they exist and if so, what do they do?
17:00	A. Schaeffer, S. Lebedev, J. Fullea & P. Audet	Seismic Tomography of the Circum-Arctic Lithosphere and Asthenosphere
17:15	A. W. Frederiksen	Transfer-Function Analysis of Teleseismic P and S

POSTER SESSION SE06

Chairs: Andrew Frederiksen, Sam Butler, Phil McCausland **Room: ESB Atrium**

Tuesday, May 30th

Poster No.	AUTHORS	TITLE
P01-SE06	J. Onwuemeka*, Y. Liu, R. Harrington, A. Pena-Castro,	Events Relocation and Stress Inversion for Charlevoix Seismic Zone using Recent

	A. Martell & F. A. Darbyshire	Earthquake and Newly Recorded Waveform Data
P02-SE06	A. Pena-Castro*, J. Onwuemeka, Y. Liu, R. Harrington, A. Martell & F. Darbyshire	Earthquake Focal Mechanism solutions in the Charlevoix Seismic zone suggest stress heterogeneity in the impact structure
P03-SE06	A. Esmaeilzadeh, G. R. Brooks & C. Samson	Evidence of synchronous mass transport deposits from sub-bottom profiling at Lac de l'Argile, Quebec
P04-SE06	J. Hutchinson*, H. Kao, K. Obana & G. Spence	Initial results from the SeaJade 2 project: Characteristics of the April 2014 Nootka sequence and the corresponding seismogenic structures
P05-SE06	G. Savard* & M. G. Bostock	Updated 3D Seismic Model of southern Vancouver Island and Earthquake Relocations Using Double-Difference Tomography and Low Frequency Earthquakes
P06-SE06	T. Akuhara, M. Bostock & A. Kato	Low velocity zones along subducting plates: comparative study between southwest Japan and Cascadia subduction zones
P07-SE06	R. Campbell* & A. W. Frederiksen	Layer Stripping the Effect of Sedimentary Basins on Teleseismic Data Using Transfer Functions
P08-SE06	F. Vervaet* & F. A. Darbyshire	Moho depth and bulk crustal properties in northern Quebec and Labrador
P09-SE06	A. Foster, F. A. Darbyshire & A. Schaeffer	Preliminary phase-velocity structure of the central Canadian Shield
P10-SE06	A. P. Kuponiyi*, H. Kao, J. Cassidy, F. Darbyshire, S. E. Dosso & J. Gosselin	Broadband Dispersion Measurement and Implications for Constraining Deep Earth Structures
P11-SE06	P. J.A. McCausland, M. Deng, J. Umoh & D. W. Holdsworth	Reliable, non-destructive bulk volume and density determination of meteorites using medical X-ray micro computed tomography (microCT)
P12-SE06	B. Lynch, C. McAnuff, C. Samson	Computing synthetic 3D images of rock walls for various sensors and mobile platforms
P13-SE06	C. McAnuff, C. Samson, D. Melanson & C. Polowick	Imagine rock walls with a Lidar mounted on an unmanned aerial vehicle

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SUBMITTED ABSTRACTS

SE06-01: Plateau subduction, intraslab seismicity and the Denali volcanic gap

Lindsay Chuang[1*], Michael Bostock[1], Aaron Wech[2], and Alexandre Plourde[1*]

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Abstract

Tectonic tremor in Alaska is associated with subduction of the Yakutat plateau, but its origins are unclear due to lack of depth constraint. We have processed tremor recordings to extract constituent low frequency earthquakes (LFEs), and generated a set of 6 high signal-to-noise ratio waveform templates via iterative network matched filtering and stacking. Timing of impulsive P- and S-arrivals on template waveforms places LFEs between 36 and 53 km depth, 5–10 km above the envelope of intraslab seismicity and immediately updip of increased levels of intraslab seismicity. S-waves at near-epicentral distances display polarities consistent with shear slip on the plate boundary. We compare characteristics of LFEs, seismicity and tectonic structures in central Alaska with those in warm subduction zones, and propose a new model for the region's unusual intraslab seismicity and the enigmatic Denali volcanic gap. We argue that fluids in the Yakutat plate are confined to a (meta)basaltic upper crust, and that shallow subduction leads to hydromechanical conditions at the slab interface in central Alaska akin to those in warm subduction zones where similar LFEs and tremor occur. These conditions lead to fluid expulsion at shallow depths, explaining strike-parallel alignment of tremor occurrence with the Denali volcanic gap. Moreover, the lack of double seismic zone and restriction of deep intraslab seismicity to a persistent low velocity zone are natural consequences of anhydrous conditions prevailing in the metagabbroic lower crust and upper mantle of the Yakutat plate.

Presentation type: Oral

SE06-02: Earthquake site response characterization in Kitimat, BC, via Bayesian gradient-based inversion of surface-wave dispersion

Jeremy M. Gosselin[1,2], John F. Cassidy[1,2], Stan E. Dosso[1], and Camille Brillon[2]

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Abstract
Earthquake ground motions at a particular site are strongly influenced by local geology, specifically the geophysical properties of the upper 10s of metres of the soil/sediment column. Displacement is amplified as seismic waves propagate through material of decreasing impedance, such as soft, unconsolidated sediments. Hence, knowledge of the local, near-surface geophysical conditions, particularly the shear-wave velocity (Vs) structure, is important for characterizing and predicting the ground response to earthquake shaking at a particular site. Passive, non-invasive methods for estimating Vs based on recordings of ambient seismic noise are becoming increasingly popular. This study develops an inversion methodology for estimating Vs structure from surface-wave dispersion extracted from passive seismic recordings. In the inversion, the one-dimensional Vs structure is described using a Bernstein polynomial model, which efficiently represents smooth gradient structure in the geophysical properties of the sediment column. The inversion is performed within a Bayesian (probabilistic) framework in which the solution is defined in terms of the marginal posterior probability profile of Vs, which provides a quantitative measure of uncertainty in the inversion results. The approach considered here is better suited than uniform layered modelling approaches in applications where smooth gradients in geophysical properties are expected. The Bernstein polynomial is more general than other gradient-based models such that the data information constrains the form of the gradient Vs structure. This methodology is applied to dispersion data processed from passive seismic recordings collected in Kitimat, British Columbia, a region of significant proposed infrastructure development. Bayesian inversion results are compared to results from other geophysical methods, and are used in probabilistic earthquake site response characterization.

Presentation type: Oral

SE06-03: Investigation of the Bimaterial Interface Velocity Contrast along the North Anatolian Fault Zone

Musavver Didem Cambaz[1] and Ahu Mutlu[1]

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Abstract
Recent field studies revealed that the main fault is surrounded by micro-fractures under stress and shear fault branches. The main fault and the damaged area around it are characterized by this micro-fractures and cracks. Recently, new attitudes on fault rupture modeling studies are started to use in order to eliminate these errors and residuals. Asymmetrical distribution of micro-fractures across the fault is the result of repeated occurrence of earthquakes on active fault zones. These earthquake sequences generate bi-material interfaces that separate elastically different materials from each other. It is known that geological fault with long slip history is likely to locate on bi-material interfaces. Bi-material interface causes existence and evaluation of strike slip fault zones and effects fault plane mechanism solutions directly. Velocity contrast across the fault causes error and residuals on earthquake location and focal mechanism solutions. Cracks on bi-material interface rupture have preferential propagation direction. North Anatolian Fault Zone is fairly continuous between Karlıova in the east and Bolu in the west and has been active for almost 5 million year with its right lateral strike slip characteristic. It splits into two major branches as northern strand and southern strand. Previous field studies on NAFZ refer bi-material interface along the entire fault zone. In the frame of this study, bi-material interface was investigated through Sakarya and Sapanca segments of North Anatolian Fault and velocity contrast across these faults were imaged. Telesismic waveforms analyzed from 71 broadband seismic stations which are located in Sakarya - Sapanca region during the FaultLab project. Waveform correlation technique which is successfully used and tested in previous studies was used for these calculations.

Presentation type: Oral

SE06-04: Multichannel deconvolution for earthquake apparent source-time functions

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Abstract
Previous studies of earthquake apparent source-time functions (ASTFs) have removed propagation effects through seismogram deconvolution with a smaller earthquake known as an empirical Green's function (EGF). We develop a multichannel deconvolution (MCD) algorithm for recovering ASTFs that does not require an EGF, but instead the availability of two or more earthquakes that share a common Green's function. Under this condition ASTFs satisfy $U_i * S_j - U_j * S_i = 0$, where U_i and S_i are the seismogram and ASTF for a given earthquake. This system can be augmented with a scaling equation and written as $Ax = b$, where matrix A comprises the seismograms in a block-Toeplitz structure and x contains the target ASTFs. We minimize an objective function for this linear system with a Newton-Projection algorithm that honors positivity, causality, and duration constraints. If the earthquakes have a suitable range in magnitude, EGF deconvolution may be used to estimate differences in duration of the events, and to obtain a starting model for the larger ASTF(s). We demonstrate the effectiveness of MCD using synthetic tests and apply it to five ~M5 earthquakes from the Kamaishi sequence, Japan, related to the 2011 Tohuku-Oki M9 event. We demonstrate that MCD is an effective way to recover earthquake ASTFs, and that the details of rupture revealed by MCD ASTFs will be useful in furthering our understanding of the earthquake source.

Presentation type: Oral

SE06-05: Shallow tomographic velocity estimation across the Mariana island arc

Thomas K. Asafuah[1*] and Andrew J. Calvert[1]

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Abstract
Based on drilling, the upper crust of the Izu-Bonin-Mariana (IBM) island arc consists of a range of sedimentary and igneous rocks, and this is consistent with both seismic reflection and ocean bottom seismometers (OBS) studies, which can constrain the crustal structure away from boreholes. However, OBS surveys are typically unable to resolve velocities in the uppermost crust and stacking velocities derived from seismic reflection surveys do not provide accurate interval velocities for specific layers. We present an improved velocity model for the shallow crust of the Eocene Mariana arc massif: the *P*-wave velocity model is derived by inverting first arrival travel times from a downward continued multichannel seismic reflection survey (MCS). This survey was shot across the arc where the water depth ranged from 300 m to >3 km using a ~6 km hydrophone streamer. Uppermost crustal velocities generally vary from ~1.6 km/s just below the seafloor to ~5.0 km/s across arc, and the velocity model is well constrained up to a depth of ~2 km below the seafloor. We infer an upper layer with velocities <3 km/s, which is ~500 m thick at the summit of the arc and which increases in thickness to 800-1000 m on the flanks of the arc. Below this layer, velocities generally increase from >3 km/s to as high as ~4.5 km/s at the summit of the arc where the igneous basement is closest to the seafloor. Checkerboard tests show that this model is better resolved than one derived using a surface datum. Comparing the velocity model with the migrated seismic reflection section, and using as constraints borehole sonic logs from similar settings, we interpret much of the upper crust to comprise volcaniclastic sediments and porous igneous rocks, which represent a 500 m to > 2000 m thick carapace above the crystalline basement.

Presentation type: Oral

SE06-06: Crustal Structure from Craton to Margin in Eastern Canada From Receiver Function Studies

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Abstract
Eastern Canada preserves over 3 billion years of geological history. Studies of crustal structure across this region are key to understanding the formation and evolution of the continents, including changes in tectonic processes from Archean through Proterozoic to Phanerozoic times. In recent years, our understanding of crustal structure across eastern Canada has been significantly improved thanks to advances in seismic station coverage through the POLARIS and EarthScope programs, and the results are beginning to shed new light on secular variations in crustal evolution. The focus of this presentation is a review of crustal structure across eastern Canada using receiver function techniques which exploit P-to-S conversions at interfaces beneath the stations. The basic analysis provides information on crustal thickness and bulk crustal composition, whereas more detailed modelling techniques illuminate the interior structure of the crust and the nature of the Moho transition. Of particular interest is the systematic study of crustal structure along the "QM-III" EarthScope FlexArray profile, which runs from the James Bay region to the Nova Scotia coast. This profile crosses the Archean Superior craton, the Proterozoic Grenville Province and the Paleozoic Appalachian domains, running perpendicular to the major tectonic boundaries and sampling crust that has been unaffected by more recent tectonic processes such as hotspot magmatism. Recent publications showing crustal structure along the QM-III profile are reviewed, and new results from CCP-stacking of receiver functions are presented. The variations in crustal thickness and bulk composition suggest systematic secular variation in crustal processes, with distinctly different characteristics between Archean, Proterozoic and Paleozoic domains. Crustal thickness varies from ~30 km in parts of the Appalachian provinces to over 50 km in the eastern Grenville Province, and the Proterozoic terranes exhibit the largest variability in bulk crustal composition.

Presentation type: Oral

SE06-7: Shear induced porosity bands in Earth's upper mantle: do they exist and if so, what do they do?

S.L. Butler[1]

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Abstract

When subjected to an external shear, systems of partial melt exhibit an instability whereby melt spontaneously segregates into low and high porosity bands whose orientation is controlled by the strain-rate field. While these bands have been observed in experiments on mm scale samples, their existence in the upper mantle beneath mid-ocean ridges remains speculative. If they do exist, they may act as high permeability conduits for melt transport, as stress guides that reduce the effective viscosity of the upper mantle, as high conductivity pathways for electrical currents and they may result in seismic anisotropy of the upper mantle. In this contribution, I will examine the conditions that are necessary for porosity bands to be significant in the upper mantle. In particular, the bulk viscosity must be low while there must be significant porosity heterogeneities when melt is first initiated. I will then show simulations that examine the reduction in effective viscosity, electrical resistivity and the increase in effective permeability with strain-amplitude.

Presentation type: Oral

SE06-08: Seismic Tomography of the Circum-Arctic Lithosphere and Asthenosphere

Andrew Schaeffer[1], Sergei Lebedev[2], Javier Fullea[2], and Pascal Audet[1]

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Abstract

Lateral variations in seismic velocities in the upper mantle, mapped by seismic tomography, primarily reflect variations in the temperature of the rocks at depth. Seismic tomography thus provides a proxy for lateral changes in the temperature and thickness of the lithosphere, in addition to delineating the deep boundaries between tectonic blocks with different properties and age of the lithosphere. Our new, 3D tomographic model of the upper mantle and the crust of the Arctic region, AMISvArc, is constrained by an unprecedentedly large global dataset of broadband waveform fits and provides improved resolution of the lithosphere, compared to other available models. The most prominent high-velocity anomalies indicate the cold, thick, stable mantle lithosphere beneath Precambrian cratons. The northern boundaries of the Canadian Shield's and Greenland's cratonic lithosphere closely follow the coastlines. In Eurasia, cratonic continental lithosphere extends northwards beneath the Barents and eastern Kara Seas. The boundaries of the Archean cratons and intervening Proterozoic belts mapped by tomography indicate the likely offshore extensions of major Phanerozoic sutures and deformation fronts. The old oceanic lithosphere of the Canada Basin is much colder and thicker than the younger lithosphere beneath the adjacent Amundsen Basin, north of the Gakkel Ridge. Beneath the slow-spreading Gakkel Ridge, we detect the expected low-velocity anomaly associated with partial melting in the uppermost mantle; the anomaly is weaker, however, than beneath faster-spreading ridges globally. South of the ridge, the Nansen Basin shows higher seismic velocities in the upper mantle beneath it, compared to the Amundsen Basin. At 150-250 km depth, the oceanic central Arctic region is underlain by a moderate low-velocity anomaly characteristic of a warm asthenosphere, similar to that beneath northern Pacific but much cooler than that beneath Iceland and northern Atlantic.

Presentation Type: Oral

SE06-09: Transfer-Function Analysis of Teleseismic P and S

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Abstract
In aseismic regions, the best-available constraints on seismic velocity structure of the crust and lithosphere are secondary phases associated with teleseismic body-wave arrivals. These arrivals are used in the well-known receiver function technique (Ps and Sp conversions) as well as in the recently-developed virtual deep seismic sounding (VDSS) method, which uses post-critical P reverberations from an S pulse. In all of these approaches, the recorded wave is the convolution of a poorly known source time function with a Green's function resulting from source-side structure; the typical processing approach is to estimate the source time function and then remove it via deconvolution. However, imperfect source estimates and the nonuniqueness of deconvolution present problems, particularly in the presence of reverberations within sedimentary basins. I propose a broadly-applicable alternative methodology: predicting the transfer function between observed data components. A particular model of receiver-side structure may be evaluated by generating its resultant transfer function between the vertical and radial seismograms, and then determining if the transfer function adequately predicts one data component from the other. Application to the P coda in strongly-reverberating sedimentary basins shows that the Moho can be located, and the basin characterized, where conventional receiver functions would fail. For teleseismic S, transfer-function approaches have the potential to unify the S receiver function and VDSS techniques.

Presentation type: Oral

P01-SE06: Events Relocation and Stress Inversion for Charlevoix Seismic Zone using Recent Earthquake and Newly Recorded Waveform Data

John Onwuemeka[1*], Yajing Liu[1], Rebecca Harrington[1,2], Andreas Pena-Castro[1], Alexander Martell[1], and Fiona Ann Darbyshire[3]

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Abstract
Charlevoix seismic zone (CSZ) is the most active seismic zone in Eastern Canada where more than six M > 6 have occurred since the 17th century. In this study, we use newly available data from permanent and temporary CNSN, QMIII and McGill seismographic stations in and near the CSZ to solve for source parameters of 746 events that occurred between June 2012 and August 2016. We relocate ~500 events (with a recovery rate of 67%) using hypoDD with automatic P and S first-arrival picks verified with visual inspection. We use waveform cross-correlation to refine the differential travel times. The refined picks significantly reduce relocation errors to 0.4 km (horizontal) and 0.5 km (vertical). The relocated events highlight 3 groups of clusters: 1) event clusters within and outside the impact structure; 2) event clusters on the north and south shores separated by a seismic gap beneath the St. Lawrence River; 3) events clustering between 5-17 km and 20-27 km separated by depth range of relatively lower seismicity. Most of the events occur above ~30 km depth which is roughly the Moho depth for CSZ. We also compute focal mechanism solutions for all events with impulsive P-wave first-arrivals at a minimum of 8 stations, using the hybridMT moment tensor inversion algorithm [see Castro et al., this meeting]. We use the focal mechanism solutions to invert for stress orientation to determine the spatial variation of the stress field both within the impact structure and in the neighbouring region. P-axes within the impact structure do not show any dominant trend, whereas P-axes outside the impact structure trend primarily in the NW-SE direction. Our results highlight a deviation from the regional maximum principal stress orientation (NE-SW), suggesting a perturbation in the stress field within the seismic zone.

Presentation type: Poster

P02-SE06: Earthquake Focal Mechanism solutions in the Charlevoix Seismic zone suggest stress heterogeneity in the impact structure

Andres Pena-Castro[1*], John Onwuemeka[1], Yajing Liu[1], Rebecca Harrington[1,2], Alexander Martell[1] and Fiona Darbyshire[3]

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Abstract
The Charlevoix Seismic Zone (CSZ) located in Quebec, Canada, is one of the most active regions in eastern North America. Roughly 200 catalogued earthquakes are recorded per year, and paleoseismic record indicate at least 5 historic large earthquakes (M > 6.0) have occurred in since the 1600. In working toward a better understanding of the fault mechanics and to better estimate the seismic hazard in this intraplate region, we use newly obtained waveform data from the Canadian Seismological Network, the QM-III (Quebec-Maine Across Tree Sutures) and McGill network stations to obtain the focal mechanism solutions for events of local magnitude larger than 2.0 in the CSZ from 2012 to 2016. We find focal mechanisms of 20 events with high signal-to-noise ratios and impulsive P arrivals. We use a new method referred to as hybridMT that inverts for focal mechanisms based on the polarity and the area below the first P-wave pulse recorded in ground displacement (Kwieater G. et al 2016). 17 fault plane solutions show a dominantly thrust component meanwhile 3 showing dominantly strike-slip motion. The moment tensor uncertainty based on the normalized root-mean-square (RMS) error between theoretical and measured amplitude of the P-waves have a value of RMS error < 0.4 . Our fault plane solutions agree with previous studies (Lamontagne M., 1998), which use only P-wave polarities, that show for a larger number of earthquakes reverse faulting and in some instances strike-slip motion.

Presentation type: Poster

P3-SE06: Evidence of synchronous mass transport deposits from sub-bottom profiling at Lac de l'Argile, Quebec

Amin Esmaeilzadeh[1], Gregory R. Brooks[2], and Claire Samson[1]

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Abstract
A sub-bottom acoustic profiling survey was undertaken at Lac de l'Argile (6.5 km^2), southwestern Quebec, consisting of 39 profiles totaling 36.6 line-km. Mapping revealed 24 sub-aqueous, mass transport deposits (MTDs) occurring at ten stratigraphic levels (or event horizons) within the sub-bottom. Deeper mass transport deposits are present, but were not mapped because of signal degradation with depth. Eight of the ten event horizons are interbedded within an acoustic facies exhibiting multiple, decimeter-scale, parallel reflectors that is interpreted to be Champlain Sea glaciomarine deposits. The ninth event horizon is situated at the interface between the glaciomarine deposits and a massive to weakly-bedded acoustic facies interpreted to be post-glacial lacustrine deposits. Ten of the 24 mapped MTDs are located within event horizon 8, where the deposits are up to 12 m thick and form a continuous bed over ~4.1 km^2 of the sub-bottom. The spatial pattern of erosive and conformable contact underneath the bed reveals that the MTDs originated from multiple locations around the lake and coalesced within the basin. Because of the lack of differentiation between adjacent deposits, the MTDs are inferred to have happened synchronously. Event horizon 9 consists of four isolated MTDs of which two are relatively large (0.1 and 0.3 km^2) and thick (up to 11.5 m). The other eight event horizons consist of one or two MTDs, which are mostly small (<0.2 km^2) and thin (<3 m). The laterally extensive, multiple MTD character of horizon 8 contrasts markedly relative to the other horizons. It evidently was the product of a mechanism that triggered multiple, synchronous, sub-aqueous failures within the Champlain Sea. We hypothesize that the geomorphic signature of horizon 8 is best explained by a significant paleoearthquake within the Western Quebec Seismic Zone that occurred between 11 and 11.5 yr cal BP.

Presentation type: Poster

P04-SE06: Initial results from the SeaJade 2 project: Characteristics of the April 2014 Nootka sequence and the corresponding seismogenic structures

Jesse Hutchinson[1*], Honn Kao[1,2], Koichiro Obana[3], and George Spence[1]

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Abstract
On April 24th, 2014, an M_w 6.5 earthquake ruptured off the west coast of Vancouver Island. The second phase of the SeaJade (Seafloor Earthquake Array-Japan-Canada Cascadia Experiment) project recorded data from January until November 2015, perfectly capturing data from the M_w 6.5 event and the subsequent aftershock sequence. The Nootka sequence highlights a nearly 75 km long fault with a strike of 150° within the subducted oceanic plate. Hypocentral depths range from 5 to 38 km, although the majority of events are below 16 km, which are projected to be below the subduction interface. Most events within the Nootka sequence occurred along a nearly vertical fault (82° dip), starting at 12 km and extending to 33 km. At 23-24 km there is a subhorizontal lineation, dipping at 24°, that divides the vertical fault into two segments. While the Nootka sequence began with the April 24th mainshock, the previously inactive fault continued to rupture until the completion of SeaJade 2. The results of this study imply that historical events of a similar magnitude in this region may have ruptured along the same fault, which is more than double the width of the Nootka fault zone.

Presentation Type: Poster

P05-SE06: Updated 3D Seismic Model of southern Vancouver Island and Earthquake Relocations Using Double-Difference Tomography and Low Frequency Earthquakes

Genevieve Savard[1*] and Michael G. Bostock[1]

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Abstract

Observations of tremor and Low Frequency Earthquakes (LFE) in Cascadia have shown that slow slip occurs at depths of 20-40 km along the plate interface and are facilitated by near-lithostatic pore pressures. However, the structural controls responsible for the elevated pore pressures and the restricted depth range of slow slip remain debated. Our objective is to clarify the relationship of slow slip with structure and metamorphism using tomographic imaging. We perform 3D Vp and Vs tomography of the southern Vancouver Island region using double-difference tomography and combine multiple datasets: the earthquake catalogue of Geological Survey Canada from 1992 to 2012 with additional manual picks made for earthquakes occurring during the POLARIS-BC array deployment (2002-2006), wide-angle P-wave arrival data from the 1998 SHIPS experiment, new earthquake detections using the detection method of Savard and Bostock (2015) and finally an LFE catalogue comprising 130 templates that are located in proximity to plate boundary models and spatially complementary to the earthquake dataset. Some of the previously unreported earthquakes detected by our method are located around Victoria at depths of 20-25 km and may potentially be associated with an eastern extension of the Leech River Fault. We present and compare our updated velocity model with the previous work of Ramachandran et al. (2005) and Ramachandran and Hyndman (2012) and interpret our model in terms of modern receiver-function results which associate the LVZ to the over-pressured oceanic crust. We also examine the earthquake relocations which shows clusters of seismicity with lineation patterns along depth, coherent with the results of Balfour et al. (2012) and currently mapped crustal faults, and consider how these results might indicate the role of crustal faults in the migration of fluids released by subducting crust at tremor depths.

Presentation type: Poster

P06-SE06: Low velocity zones along subducting plates: comparative study between southwest Japan and Cascadia subduction zones

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Abstract
Low velocity zones (LVZs) along subducting oceanic plates are a ubiquitous feature of subduction zones worldwide. The LVZ has been interpreted as a hydrated oceanic crust from its high Vp/Vs ratio and is thought to affect generation of episodic tremor and slip (ETS) events. Southwest (SW) Japan and Cascadia subduction zones are well-investigated in terms of the LVZ properties. However, a direct comparison of LVZ properties between these subduction zones is difficult due to the difference in analysis methods: tomographic methods are often used in SW Japan, versus receiver function methods in Cascadia. In this study, we solve for LVZ properties beneath SW Japan through receiver function inversion analysis. This analysis optimizes model parameters (thickness, Vp/Vs ratio, dip angle and strike of layered structure) such that synthetic waveforms reproduce observed waveforms recorded by a linear array of seismographs installed in the Tokai region in 2008 (Kato et al., 2010, GRL). The results show that the LVZ is characterized higher Vp/Vs ratios (> 2.0) than previous estimates from tomographic analyses. In addition, the Vp/Vs ratio shows along-dip variation, culminating where ETS and long-term slow-slip events occur. This suggests that high pore fluid pressure plays an important role in generating ETS and long-term slow-slip events. A detailed look at high-frequency receiver function waveforms suggests that the LVZ is likely to be composed of two layers. Such high Vp/Vs ratios (> 2.0) and two-layer structure of the LVZ are also reported for Cascadia. However, whether along-dip variation of Vp/Vs ratio exists or not is still open question for Cascadia. Further efforts to reveal such variations at Cascadia is left for future study. Detailed comparison of LVZ properties may lead to improved understanding of ETS mechanisms.

Presentation type: Poster

P07-SE06: Layer Stripping the Effect of Sedimentary Basins on Teleseismic Data Using Transfer Functions

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Abstract
Receiver functions generated from teleseismic data have long been used to determine deep crustal and upper mantle structure beneath seismic stations. Delineating teleseismic responses of structures overlain by sedimentary basins can be problematic due to cluttering of the seismic data with basin reverberations. These reverberations obscure important P to S converted arrivals from deeper structures in receiver functions. This project aims to determine if it is possible to remove the effects of the sedimentary basin using imperfect models of basinal structure and a transfer-function approach. Synthetic impulse responses generated via the propagator technique on models with and without a sedimentary basin are generated; the spectral ratio of these two impulse responses represents a transfer function converting from one model to the other, and so removing the basinal contribution. The transfer function acts as an acausal filter applied to raw seismic traces before deconvolution. The method is tested on synthetic data from known models as well as station EDM of the Canadian National Seismograph Network, which lies on a deep sedimentary basin whose properties are well known from controlled-source studies.

Presentation type: Poster

P08-SE06: Moho depth and bulk crustal properties in northern Quebec and Labrador

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Abstract
Northern Quebec and Labrador lie at the heart of the Laurentian landmass and preserve over 3 billion years of continental evolution. In this region the Archean Superior, Churchil and Nain cratons are surrounded by Paleoproterozoic orogens such as New-Quebec, Ungava, Makkovik and Torngat, as well as the younger Grenville orogen to the SE. Study of crustal structure in this region provides valuable information on the assembly of the North American continent. We use data from 8 seismic stations installed in summer 2011 as part of the QUiLLE (Quebec-Labrador Lithospheric Experiment) project to investigate crustal structure, using receiver function analysis. The data set covers 5 years (2011-2016) for most of the stations, comprising several hundred events of magnitude ≥5 and epicentral distance 30-90°. After initial data processing and quality control, several tens of events per station were used in an H-κ stacking analysis to estimate Moho depth and bulk crustal properties. Some stations show significant complexity in their receiver functions, leading to inconclusive H-κ results, but the majority show a consistent Moho signal from which crustal parameters are successfully extracted. Crustal thickness varies from 34 to 52 km, with the thickest crust associated with the Grenville orogen and the thinnest beneath the central Labrador coast. Vp/Vs ratios (κ) lie in the range 1.71-1.82, with the majority of values consistent with granite-gneiss-tonalite bulk crustal compositions. The receiver functions are combined with surface-wave group velocity data to model the crustal structures in more detail beneath each station. This joint inversion allowed us to observe high and low velocity zones in the crust at certain depths, as well as to confirm the thickness of the crust under each station. We obtained thicknesses from 34 to 56 km with this technique.

Presentation type: Poster

P09-SE06: Preliminary phase-velocity structure of the central Canadian Shield

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Abstract
The seismic structure of cratonic lithosphere holds many clues to its history of formation and growth. Though there are many ways of investigating this structure, surface-wave data are particularly sensitive to variations in velocity with depth. This sensitivity makes surface waves useful for resolving features like layered anisotropy, which has been observed in cratonic regions by several recent studies, and is hypothesized to reflect the stages of growth of the continental lithosphere. We focus on the Canadian Shield in the vicinity of western Quebec, Ontario, and eastern Manitoba, as well as the Great Lakes region and the north-central United States. We combine data from all available permanent and temporary networks in this region from 2005 to 2016, and select 80 stations with a roughly 200 km spacing in the central part of the study area. We use teleseismic data for all earthquakes in this time period with a magnitude greater than 6.0, amounting to over 1200 events. Using the method of Meier et al. (2004) for two-station phase-velocity measurements, for a given event, we make Rayleigh wave dispersion measurements for all station pairs with event-station paths that are within 5° of the same great circle. The resulting dispersion curves will provide fairly even coverage over the entire study region, and will be used in a tomographic inversion to explore changes in anisotropy and phase velocity with depth. The results will be complementary to other recent studies in the Quebec and Hudson Bay regions of Canada, as well as the many studies from USArray Transportable Array data in the United States. Together, the resulting seismic models will provide a more complete picture of craton and craton margin structure.

Presentation type: Poster

P10-SE06: Broadband Dispersion Measurement and Implications for Constraining Deep Earth Structures

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Abstract
Dispersion measurements from earthquake (EQ) data are traditionally inverted to obtain 1-D shear-wave velocity models, which provide information on deep earth structures. However, in many cases, EQ-derived dispersion measurements lack short-period information, which theoretically should provide details of shallow structures. We show that in at least some cases short-period information, such as can be obtained from ambient seismic noise (ASN) processing, must be combined with EQ dispersion measurements to properly constrain deeper (e.g. upper-mantle) structures. To verify this, synthetic dispersion data are generated using hypothetical velocity models under four scenarios: EQ only (with and without deep low-velocity layers) and combined EQ and ASN data (with and without deep low-velocity layers). The dispersion data are inverted using a trans-dimensional Bayesian framework with the aim of recovering the initial velocity models and assessing uncertainties. Our results show that the deep low-velocity layer could only be recovered from the inversion of the combined ASN-EQ dispersion measurements. Given this result, we proceed to describe a method for obtaining reliable broadband dispersion measurements from both ASN and EQ and show examples for real data. The implication of this study in the characterization of deep features, such as the Lithosphere-Asthenosphere Boundary (LAB), is also discussed.

Presentation type: Poster

P11-SE06: Reliable, non-destructive bulk volume and density determination of meteorites using medical X-ray micro computed tomography (microCT)

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Abstract
Physical property investigation by *in situ* non-destructive methods is often needed for valuable materials, or to best preserve original relationships within the rock. For meteorites, non-destructive methods for obtaining bulk physical properties such as density and porosity, magnetic susceptibility and major mineralogy have been used widely. In this study, we test the application of rapid laboratory-based X-ray micro computed tomography (microCT) on meteorites of known bulk density, the Gao Guenie H5 chondrite. Micro CT imaging was performed using a GE eXplore speCZT at peak energies of 90 to 110 kV, taken as 900 separate images over five-minutes for each meteorite fragment, through a full 360° rotation. Reconstruction of beam hardening-corrected 3D volumes result in meteorite fragment models with voxel resolutions of 50 μm. Some individual meteorites were scanned in different orientations to test dimensional reproducibility. Seventeen Gao Guenie chondrite fragments ranging in mass from 1 g to 61 g that were previously studied by Beech et al. (2009) by conventional Archimedean methods as having a bulk density of 3.46 +/- 0.07 g/cm^3 have been determined in this work to have a similar bulk density of 3.44 +/- 0.08 g/cm^3, and furthermore have fragment variations in density that match those of the previous work. This work demonstrates the ready application of medical micro CT to non-destructively obtain accurate bulk volumes and bulk densities from metal-bearing chondritic meteorites.

Presentation type: Poster

P12-SE06: Computing synthetic 3D images of rock walls for various sensors and mobile platforms

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Abstract
The current state-of-the-art in measuring geotechnical properties of rock faces is the use of light detection and ranging (LiDAR) sensors that generate detailed 3D images. There are many examples of LiDAR applications extracting properties such as joint orientations, surface roughness, and fracture characteristics. However, most studies using 3D images typically assume range and position error within the data is negligible. While this assumption may be valid for stationary tripod-mounted devices, error within data collected on a mobile platform is much more significant and must be accounted for when processing and analyzing results. Scan data collected on a mobile platform is subject to the instrumental range error associated with the LiDAR sensor and to the position and orientation (pose) error of the mobile platform itself. In addition, the use of a mobile platform typically results in a much lower point cloud density. The significant error and low point density of mobile LiDAR scans make analysis of geotechnical properties challenging and therefore they must be considered when reducing data (e.g., identifying faces, computing normals, etc.). In order to better understand the implications of these sources of error, a simulator was developed to generate synthetic scan data from artificially generated rock faces and tunnels. The simulator generates data by computing the intersection of the laser as it sweeps across its field of view while moving along a prescribed path. Sensor and path errors are then superimposed and the resulting raw data reconstructed to form a 3D image, while the true intersection points are also stored for comparison. This approach allows mobile LiDAR scans to be simulated for ground and air vehicles with various levels of range and pose error. The synthetic images can be used to test different techniques for data collection based the on vehicle path and speed.
[296 words]

Presentation type: Poster

Preferred Session: J03 – Robotics in the earth and oceanic sciences

P13-SE06: Imaging rock walls with a Lidar mounted on an unmanned aerial vehicle

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Abstract

Geological mapping of exposed rock walls in open pit mines is typically performed manually by a geologist. Manual mapping is time consuming, limited in coverage, and can pose unnecessary risks. In comparison, UAV-based mapping could allow for faster data acquisition, full coverage of a rock wall, and greater safety. Information extracted during manual mapping typically includes fracture orientation, fracture frequency, and surface roughness. The 'Renegade' is a helicopter-style unmanned aerial vehicle (UAV) with an airframe length of 2.5 m, an 80-cc gas engine, and a maximum takeoff weight of 35 kg. The Renegade system includes a Riegl VUX-1LR LiDAR that can collect up to 820,000 range measurements per second. The system has been used to image two rock walls (20 x 50 m and 10 x 50 m in height and length, respectively) at Canadian Wollastonite Mine, near Kingston, Ontario, on July 26th, 2016. The UAV collected data at altitudes of 45 m and 120 m and was offset from the wall by a distance equal to each altitude. For the lower altitude data set, the rock wall point clouds are composed of 905,130 range measurements which correspond to a point cloud density of 603 points/m^2. This contribution concerns the investigation of: (1) the impact of flight parameters on data quality, (2) extracting fracture orientation, fracture frequency, and surface roughness information, and (3) how to best present geological information extracted from point clouds and meshes. Point cloud data has been converted to a coloured mesh format to visualize strike and dip, according to various colour wheels. Several approaches to colour-code surface roughness have been tested, including a novel approach based on edge detection. Overall, the UAV-LiDAR system proved able to acquire high-quality, high resolution data, suitable for visual enhancement and extraction of geological features of interest on the rock walls. [300 words]

Presentation type: Poster

Preferred Session: J03 – Robotics in the earth and oceanic sciences