

latter. A true areal array extending across the WSP can be expected to reveal major structures.

S23B-04 1430h

Shear-wave splitting observations in the lower Great Lakes region

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Fast-axis directions obtained from shear-wave splitting analysis of core-refracted shear waves reveal several distinct anisotropic domains in the lower Great Lakes region. We used data from 27 broadband seismograph stations, extending across a low-velocity anomaly in the lithospheric mantle. Observed splitting times vary from 0.4 to 1.4 s, with a mean of 0.7 s. A subset of the splitting vectors across a failed rift are oriented parallel to one arm of the rift zone; most others show a coherent pattern of fast directions close to the direction of plate motion, but oblique to surface tectonic belts. Within the area of the low-velocity anomaly, our observations are most simply explained by single-layer anisotropy induced by asthenospheric flow. Spatial variability in the direction and magnitude of splitting are consistent with a flow regime influenced by basal topology of the lithospheric keel.

S23B-05 1445h

Structure of the Northern Cascadia Subduction Zone.

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As part of the POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity - www.polarisnet.ca) project, we have undertaken a broadband seismic experiment across southwestern British Columbia and northwestern Washington. The objective of this work is to better understand the structure of the subducting plate and mantle wedge in northern Cascadia, and its relation to intraslab (Wadati-Benioff) seismicity. There are currently 30 broadband stations extending across southern Vancouver Island, the Gulf and San Juan Islands, Watcom county and the British Columbia lower mainland in an approximately linear array. We have employed the P-wave coda from 41 teleseismic events recorded on this array in a formal inversion to image fine-scale shear-velocity structure. Results indicate a structure very similar to that identified across a comparable profile in Oregon. The continental Moho is evident at the eastern end of the profile near 30 km depth but disappears towards the Georgia Strait/Puget Sound. A prominent, dipping, low S-velocity zone is clearly evident below southern Vancouver Island coincident with the E-reflection zone originally identified in earlier Lithoprobe studies. Structure below the E-layer is of significantly lower magnitude and is only intermittently visible along the array. Based on the observations and interpretations of similar structures beneath Oregon, Alaska and South America, we suggest that the E reflection zone represents the subducted oceanic crust. This view implies that the oceanic crust is 6-8 km shallower beneath Vancouver Island than previously thought, with implications for geodynamic models of the region. As in Oregon, we interpret the diminishing low velocity signature below 45 km to signal the presence of a serpentinized forearc mantle hydrated, in part, through eclogitization of oceanic crust.

S24A CC: 516 B Tuesday 1530h

POLARIS: Earthquake Ground Motion and Seismotectonics (joint with G, GP, T, SEDI)

Presiding: D B Snyder, Geological Survey of Canada; D McCormack, Geological Survey of Canada

S24A-01 1530h INVITED

Development of Ontario ShakeMaps

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We have developed automated procedures to produce "ShakeMaps" in near-real-time for earthquakes in southern and central Ontario. ShakeMaps are maps that show the intensity of ground shaking at locations throughout the region, for purposes of providing rapid public, planning and emergency response information in the immediate aftermath of local and regional earthquakes. The Ontario ShakeMap program continually accesses real-time data from seismographic stations of the POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity) and CNSN (Canadian National Seismographic Network) arrays. When an earthquake is detected, ShakeMap uses the data to find the centroid location and magnitude of the event. The centroid is a geographic location near the largest recorded ground motion, from which the ground motion appears to radiate (based on the pattern of observed amplitudes in the region). The centroid magnitude is the earthquake magnitude that best explains the observed ground motions, given the centroid location and regional ground motion relations. A modified version of the regional ground motion relation of Atkinson and Boore (1995), giving peak ground velocity (PGV) as a function of magnitude and distance, is used in the determination of the centroid's location and magnitude. ShakeMap uses a combination of computed ground motions that are based on the centroid and the regional PGV ground-motion relation, along with the actual measured ground motions at all stations, to create a contour map of PGV. The PGV map is also translated into a map of felt intensity/damage, using a relationship between PGV and Modified Mercalli Intensity. The maps are still under development, as improvements are required in the following aspects: (i) determination of site response factors throughout the region; (ii) development of improved predictive relations for PGV from earthquake magnitude and distance; and (iii) implementation of maps for other ground motion parameters including peak ground acceleration (PGA) and response spectra (PSA(f)). The prototype ShakeMaps can be viewed as they are generated at <http://www.shakemap.carleton.ca>. Implementing ShakeMap is a significant step forward in the development of near-real-time seismic information, particularly for nuclear utilities and other critical services that must provide timely information on all felt events.

S24A-02 1555h

Implementation of Event Detector and Centroid Programs for ShakeMaps in Ontario

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ShakeMap is a program to map earthquake ground-motion shaking intensity in near real-time. For our implementation of ShakeMap in Ontario, we have developed an automated earthquake detection program "EventDetector", in order to continuously detect events and trigger ShakeMap. The EventDetector is a multi-threaded program that reads and processes data. It is designed to detect events based on the exceedance of assigned ground motion levels at three or more stations. For the purpose of our study, the vertical component ground velocity is used as the shaking intensity criterion. When the signal-to-noise ratio, as defined by a short-term average level of velocity divided by the long-term average level, exceeds 3.5 at more than 3 stations, we examine the event for a possible earthquake detection. When the program detects an event, EventDetector

triggers the ShakeMap program automatically and continues to process the incoming data.

The main challenge in event detection is to screen out false triggers caused by teleseismic events or other spurious signals. We were able to make the distinction between local/regional and teleseismic event by using the normalized standard deviation of the peak ground velocity (PGV) (normalized by the mean), denoted NSD, as a discriminant. Events which have NSD < 0.7 are teleseismic events (with a rate of 10% false triggers). To locate the earthquake once an event is confirmed by the above criteria, we have incorporated a modified ground motion centroid program, originally developed by Kanamori (1993). The centroid is an estimate of the earthquake magnitude and location from the point of view of ground-motion generation, and may not coincide with the actual earthquake epicenter and magnitude. The estimation is based on fitted observed amplitude data with attenuation relations. Where stations are sparse, the observed vertical component PGV values are supplemented by estimated values based on a modified version of predictive relations for eastern North America developed by Atkinson and Boore (1995).

We have compared the accuracy of estimated ground motions obtained using the epicentre location to those obtained using the ground motion centroid for more than thirty local/regional earthquakes of magnitude 2.5 to 5.0. We have found that the centroid program more closely reproduces ground motions recorded in Ontario.

S24A-03 1610h

Earthquake Focal Depths in the POLARIS Region of Southeastern Canada from Regional Depth Phases

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Earthquake focal depth is a critical parameter, and one that the Polaris deployment in southern Ontario set out to determine. However, for most earthquakes in southeastern Canada and its vicinity, even the Polaris seismograph spacing is too sparse for reliable focal depth estimation by traditional methods. Teleseismic depth phases are also too weak for most of the earthquakes. However, the regional depth phases sPg and sPmP (as well as sPn) are very sensitive to focal depth. sPg develops well at distance between 60 to 120 km, sPmP at distances of 130 to 300 km, and sPn is clear for slightly larger earthquakes and distances beyond about 250 km, depending on focal depth. With sPmP we can usually estimate focal depth for earthquakes with M>2.5 by modelling waveforms at stations >200 km. With sPg we can estimate focal depth for earthquakes with M>2.1 by modelling waveforms at stations about 60 km away, both in the absence of records at closer stations. We have confirmed the depths through comparison with well-determined depths from the Charlevoix local network and from events large enough to have teleseismic depth phases. We have investigated focal depth for over a hundred earthquakes from 1980 to 2003. Most earthquakes occurred at shallow to mid-crustal depths, but in northern New York and southern Ontario the depths are chiefly shallow (some only about 2 km). In eastern Ontario / western Quebec, including the Timiskaming and Cornwall epicentral regions, depths are chiefly mid-crustal. Our method is very good at determining depths for earthquakes in spatial clusters. We find that while the events in some clusters have similar depths, those in other clusters can have very different depths. For instance, depths in the cluster between the Baskatong and Cabonga reservoirs range from about 3 to 26 km.

S24A-04 1625h

Stability of Crustal Faults in Southern Ontario Inferred From Stress Data

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Construction of stress analysis models of the earth's crust requires definition of boundary and initial conditions. These include: stress field, rock mass properties, fault strength and geometry, and boundary stress or displacement constraints. By comparing model behaviour to observations, the mechanical compatibility of various geological hypotheses can be tested. Our work focuses on assessing the stability of major structures in southern Ontario with the objective of providing input to the assessment of seismic risk. Analysis of triaxial stress data from the nearby Sudbury Structure shows a linear relationship between the major and minor principal stress magnitudes, suggestive of a strength limited state of stress. The computed Mohr-Coulomb strength parameters ($c = 5.4$ MPa, $\phi = 14^\circ$) are relatively low, with the frictional component indicative of a clay or gouge material. This suggests that the strength of the upper brittle crust in that region is limited by the strength of major faults. It also indicates that the crust is likely at a state of limiting equilibrium so that a small increase in stress may exceed the effective strength of the crust and induce seismicity. The same apparent strength was obtained from a large set of triaxial stress measurements at similar shallow depths (< 2 km), but from a mine in the Chilean Andes. This indicates that the upper brittle crust may evolve to a common state of low strength limited by the strength of accumulated gouge in faults. The similarity between the stress data at the two different locations suggests that other areas in a compressive tectonic stress regime (such as southern Ontario where triaxial stress measurements aren't available) may also be in a state of limiting equilibrium. Evidence of stress rotations in southern Ontario from the general orientation of the stress field with respect to the major structural features (thrust faults, accreted terranes etc.) would support this hypothesis. In addition to near surface stress measurements, the orientation of stresses in the deeper ductile crust may be inferred from shear-wave splitting data. Variations in direction of these inferred deep stresses with the near surface stress field may give some indication of the amount of rotation due to fault slip, and possibly seismicity, that occurred during the evolution of the stress field. The significance of the stress data and the potential for the brittle crust in southern Ontario being in a limiting state of equilibrium with tectonic driving forces, is that seismicity in such a system will differ significantly from one in which faults do not limit the state of stress. Numerical modelling will be used to test these ideas.

S31A CC: 516 A Wednesday 0830h

POLARIS: Electromagnetic Methods and Results (joint with GP, SA, T, SEDI)

Presiding: I Ferguson, University of Manitoba; C Samson, Carleton University

S31A-01 0830h INVITED

Transformation of MT Resistivity Sections into Geologically Meaningful Images

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Earthscope offers an unprecedented opportunity for interdisciplinary studies of North America. In addition to a continent-wide seismic study, it includes the acquisition of magnetotelluric (MT) data at many of the Bigfoot array sites. Earthscope will thus provide a uniform 3-D MT survey over regional scales when completed. MT interpreters will be able to include 3-D regional effects in their models for the first time whether they are interpreting local studies. However, the full value of the interdisciplinary nature of Earthscope will be realized only if MT sections and maps are useful to other earth scientists. The standard final product from any 2-D or 3-D MT interpretation is a spatial distribution of electrical resistivity. Inference of the physicochemical state from bulk resistivity is complicated because a variety of factors influence the property including temperature, intrinsic conduction of silicates, and small amounts of interconnected conducting materials (e.g., graphite, metallic minerals, partial melt, fluid). Here, I use petrophysical measurements and a petrological model to transform a resistivity section into cross sections of temperature and partial melt fraction in the mantle beneath the Sierra Nevada. In this manner, I am able to separate the contributions of increasing temperature and melt fraction to the bulk resistivity. Predicted melt fractions match observations from xenoliths relatively well but temperatures are systematically 200C higher than those observed. A small amount of dissolved hydrogen (70 ppm H/Si) lowers the predicted temperatures to match those from the

xenoliths, however. I conclude that while this transformation is a simple first step based on many assumptions, initial results are promising.

S31A-02 0855h

POLARIS Magnetotelluric Overview and Update - Spring 2004

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The Canadian POLARIS project includes an important component of electromagnetic studies. As part of this project, magnetotelluric (MT) equipment has been acquired to develop an infrastructure for electromagnetic soundings over depths ranging from the uppermost crust to depths of several hundreds kilometers into the asthenosphere. A key innovative feature of the POLARIS project is that MT instruments are being used in association with teleseismic techniques for imaging the Earth's structure, and for investigating seismogenic structures. MT soundings are in progress and, at the end of the project, will have been made at most of the 90 POLARIS observatory arrays on the Slave craton in the Northwest Territories, in the Cascadia region of southwestern British Columbia, and in the Precambrian Grenville Province in southern Ontario. MT equipment is also being used in studies of geomagnetically induced currents (GICs) on powerlines and pipelines. To carry out soundings at different target depths, the POLARIS MT equipment includes: audio-frequency (10^4 to 10^5 Hz) MT (AMT) systems for imaging the upper crust; broadband (10^2 to 10^{-3} Hz) MT (BBMT) systems for imaging the middle and lower crust; and long-period (1 to $< 10^{-4}$ Hz) MT (LMT) systems with specialized ring-core fluxgate magnetometers required for imaging at mantle depths and for geomagnetic hazard studies. More specifically, the AMT-BBMT equipment consists of six MTU-5A systems that have been procured from Phoenix Geophysics Ltd. and the LMT equipment of twenty-five ring-core NIMS systems on order from Narod Geophysics Ltd. A subset of the POLARIS MT equipment consisting of the AMT, BBMT, and fifteen of the LMT instruments is designed to be moved progressively through the POLARIS arrays providing MT responses over a broad frequency range. The remaining ten LMT instruments are to be deployed at carefully selected POLARIS sites in satellite-telemetered observatory configuration to provide ultra-deep imaging of the mantle and monitoring of temporal conductivity variations. POLARIS MT soundings have been completed using both the new equipment and alternative LMT systems. In 2002, LMT soundings were done at eleven sites on the Southern Ontario array. In 2003, LMT soundings were done at 40 sites on and adjacent to the Cascadia array and a four-station GIC survey was done in the Ottawa River Valley, Ontario. Field-work planned for 2004 includes: the deployment of MT telemetered observatories and the acquisition of AMT-BBMT data in the Slave craton; AMT-BBMT soundings on the Southern Ontario array; and deployment of MT observatories on the Southern Ontario and Cascadia arrays.

S31A-03 0910h

Deep electrical conductivity structure of the Cascadia subduction zone in Southern British Columbia

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Long period magnetotelluric (MT) measurements were made in southwestern British Columbia in 2003 to investigate the electrical structure of the Cascadia subduction zone as part of the POLARIS project. Data were recorded in the period range 1 to 25000 seconds at 36 field sites using long-period MT systems with fluxgate magnetometers.

The instruments used were the Geological Survey of Canada LIMS systems and University of Alberta NIMS systems. MT data were collected at many locations in the Canadian Cordillera during the Lithoprobe project, but the new MT data are the first to give the long period data needed for imaging deep structure. The stations were concentrated on a profile that extended from Port Renfrew on Vancouver Island to Shuswap Lake. Some MT stations were located in Washington State to investigate the 3-D effects of the low resistivity salt water in the Strait of Georgia and Puget Sound.

The MT impedance data have been analyzed with 2-D inversions and the models reveal the following features: (1) The data on Vancouver Island detect low resistivities above the subducting Juan de Fuca plate, similar to previous results on a profile to the northwest. This anomaly corresponds to an area of high seismic reflectivity ('E-reflector') and low seismicity, and may be related to fluids originating from the oceanic plate.

(2) A zone of low resistivity is present beneath the volcanic arc at a depth of 15-20 km below the surface.

(3) The Intermontane and Omineca Belts are characterized by high resistivities in the upper crust and low resistivity in the lower crust, similar to models of previous studies such as Lithoprobe. The lower crustal resistivity decreases to the east, as also indicated by vertical magnetic transfer functions. Further analysis of these data are in progress to determine the resistivity of the underlying upper mantle and to evaluate the depth of the asthenosphere.

A second deployment of the NIMS instruments in summer 2004 will extend the line across the Rocky Mountains into the Foothills of Alberta, and will produce a continuous long-period MT profile across the entire Canadian Cordillera.

S31A-04 0925h

Telluric currents in pipelines

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Inductive coupling of the varying geomagnetic field to pipelines produce low-frequency ac-currents which can affect their operation. The presented approach to the mathematical modeling of the geomagnetically induced (telluric) currents in pipelines was as follows. First is to evaluate the induction effect in general. This has been done by application of Maxwell's equations to model induction in the infinitely long multilayered cylinder under plane electromagnetic wave excitation. Important results were obtained by calculating the transfer function relating the total electric current in the steel to the non-disturbed (in the absence of the cylinder) electric field. It is shown that this function depends on the frequency as well as on the electromagnetic properties and sizes of the multilayered cylinder. However, it is constant for most of the geomagnetic frequency range (0.01 mHz to 80 mHz) and the typical values of the pipeline electromagnetic properties and size. Hence, for the geomagnetic frequency range one can expect that when the non-disturbed electric field in time-domain is known, induced currents can be calculated in the time-domain by applying a constant scaling factor. Next step is to provide the non-disturbed electric field. Using the same plane wave assumption and layered earth conductivity model, the geomagnetic field was converted to the geoelectric field. The frequency response here shows more power at high frequencies and cannot be approximated by a constant. The last step in the evaluation of the modeling is comparison with pipe-to-soil potential variations (PSP) produced by telluric currents on a few pipelines. Comparisons show that linear correlation coefficients vary from 0.6 to 0.9, depending on the distance from the pipeline recording site to location of the geomagnetic observatory. These correlations confirm the similarity of the frequency content of PSP fluctuations to the electric field variations. For the modeling of the amplitude changes in PSP along the pipeline, distributed source transmission line model can be applied with a spatially non-uniform electric field as an input. The non-uniform electric field can be found by further detailed 2-d modeling of the earth ground conductivity along the pipeline route, which is the subject of further investigations.