S31A-05 0940h

Acquisition of Magnetotelluric Data for Studies of Pipe-to-Soil Potentials on Pipelines: Preliminary Results From the 2003 Ottawa River Valley Survey

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A long-term study has been initiated as part of the POLARIS project to investigate the effect of Earth resistivity on pipe-to-soil potentials (PSPs) on pipelines. The pipeline chosen for investigation is a natural gas pipeline extending from the Alberta/Saskatchewan border to Quebec and Vermont. A previous study of this pipeline revealed large PSPs variations near the contact of the Precambrian Shield and Paleozoic sedimentary rocks of the Ottawa Embayment in eastern Ontario. The POLARIS Ottawa River Valley Survey was done in October 2003 to investigate the PSPs. Objectives included: (1) magnetotelluric (MT) soundings to define the sub-surface resistivity structure; (2) simultaneous recording of MT and PSP time-series; and (3) field-testing MT instruments acquired for the POLARIS project. Remote-referenced MT soundings were made at four sites spaced 25 km apart along a NNW-SSE line parallel to the pipeline and perpendicular to the geological contact. Recordings were made using audiofrequency and broad-band equipment allowing the MT impedance to be defined between 10,000 Hz and 0.001 Hz and providing continuous electric and magnetic field time series with 15 Hz sampling frequency for time segments of up to 12 hours duration. During the MT survey, the pipeline was instrumented with 5 dataloggers measuring PSPs at a sampling rate of 1 Hz. This survey may be the first one in which simultaneous and co-located MT and PSP recordings have been made. The MT responses sampled the Earth resistivity at depths ranging from tens of metres to tens of kilometres. The results reveal that the most conductive responses occur at site ORV003, at the margin of the Paleozoic sedimentary rocks. However, the enhanced conductivity at this site is not caused by the Paleozoic rocks. Modelling of the data from ORV003 indicates a contribution to the response from a 30 m thick, conductive (2 ohm.m) surface layer of glaciomarine and marine silt and clay sediments and also a contribution from conductive rocks of the Precambrian basement at depths exceeding 5 km. The next step in quantifying PSP fluctuations consists of combining electric field data with a model of the pipeline based on a distributed-source transmission line model. The PSP modeling results will be further refined using the 2-D resistivity model defined by the MT data.

S32A CC: 516 A Wednesday 1030h

Advances in Seismic Event Location and Source Characterization

Presiding: **D McCormack,** Geological Survey of Canada**; K Chun,** University of Toronto

S32A-01 1035h INVITED

Prospects for Widespread Implementation of Better Methods for Source Location

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Many seismologists are becoming more familiar with techniques for estimating source locations that improve very significantly upon the standard procedure of locating events one-at-a-time from phase pick data. As the new techniques (reducing model error by use of multi-event location algorithms, and reducing pick error by use of waveform cross-correlation) become more prevalent, assessments are needed of (a) what practical steps can be taken to facilitate the new methods, and (b) what fraction of seismicity in a given region can foreseeably be better located with new procedures. We comment upon (a) and (b) in light of several studies already completed or still underway in East Asia and North America. Of great importance for (a), is attention to operating stations continuously for long periods of time (decades) without change and maintaining easily accessible waveform archives. Systematic efforts to obtain reference events are necessary to convert high quality relative locations to absolute locations. As for (b), there are large regions for which most of the routinely detected and located events can be relocated by the new techniques, to substantially improve source locations in existing catalogs, and additionally for events soon after they occur.

S32A-02 1050h INVITED

Remarks on Several Non-standard Location Methods

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In this study, several non-standard location procedures are reviewed, contrasted, and compared. Though independently developed, two methods among those been tested, the "Induced Perpendicular Bisector" [IPB] (or,equivalently, the "Yin Zhong Zian" [YZX] in Chinese) method and Jih's (PEPI, 1999) "J0" method, appear to be extremely similar in concept. For several decades, i.e., since before the advent of digital computers, Asian seismic network operators have been locating earthquakes by triangulation using the IPB technique. In the ideal case where two seismographs happen to report identical arrival times of the same seismic phase, then under the assumption of a uniform earth structure, the hypocenter should lie on the perpendicular bisector of the line segment (great circle) which connects these two specific seismographs. Depending on the epicentral distances, the perpendicular bisector itself could be a great circle along the Earth's surface or a normal section cutting through the Earth. If two or more such perpendicular bisectors are available, then the hypocenter or epicenter can be determined via triangulation. The challenge lies in how the perpendicular bisector is derived for the more general situation when arrival times vary from station to station, which is more typically the case. An advantage of the technique is that it can be used when waveform data are not available, thus rendering techniques based on full waveforms (such as correlation analysis, polarization analysis and frequency-wavenumber [FK] technique) not applicable. The so-called YZX algorithm, is a variation of IPB procedure, in which one computes an IPB (via interpolation) for each group of three seismographs. Also relying on azimuth triangulation for seismic location, Jih (1999) proposed a procedure J0 to derive the back-azimuth with a large aperture network where all seismographs are on one side of the event. Any standard Geiger-type of least-squares inversion routine can be applied to determine the backazimuth easily. Two or more such skew networks would suffice to derive two backazimuths for triangulation purpose. It has been demonstrated that this simple, hybrid procedure is particularly suitable for the seismic location problem at regional distances when [1] the crustal model is not known, [2] the seismic network is not calibrated, and [3] the azimuthal coverage of recording stations is poor. In this paper the procedure J0 is compared against the YZX method, to relocate earthquakes and explosions of known or well-constrained locations. It is shown that, at regional distances, the J0 algorithm outperforms the YZX method, simply because the backazimuths used by J0 method are more reliable and stable. On the other hand, the YZX method provides very intuitive insight into the uncertainty ellipse, which neither J0 nor the standard least-squares based Geiger inversion offers. The old Watatsu formula, which determines the origin time by regressing the Pg arrival times on the Lg-Pg differential arrivals, turns out to be very robust in improving the location and stablizing the Geiger inversion procedure at local and regional distances - especially when most or all the stations persistently, faithfully report both Pg and Lg phases. Data from the Montenegro Network provide an excellent basis for comparison of the techniques.

S32A-03 1105h

Detection of Energy Emission by Micro-events Below the Detection Threshold

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Conventional practice in the detection, location, and characterization of small local events entails the use of single-channel arrival detection, the association of multiple-station detections, and the location and characterization of each event, based on these associated arrivals. At smaller magnitudes, arrivals are lost in the noise, and insufficient detections are obtained to identify and locate an event. Thus each network has a magnitude below which only a small fraction of events are detected and catalogued. Two strategies are available for lowering this network threshold. [1] Single-instrument (1 or 3 channels) data processing to lower the single-instrument detection threshold; [2] All-station processing, to utilize the multichannel time series. We show numerical experiments in which migration-stacking of data flow from the Anza network is used to create subsurface 3-d images of seismic emission. Any experiment involves a specified time window. When the window is a few seconds, the experiment is scanning for individual events... thus looking at events which are just below the usual detection threshold. Windows of minutes to hours can be used, and the stacking generalized to entail stacking over such windows. Thus, detection of the emission of seismic energy by large numbers of micro-events is achieved by this time averaging. A reliable velocity model of the subsurface is required, as with conventional event detection. Implementation involves a variety of discretionary analysis options for noise balancing, bandpass selection, and stacking. It represents a fruitful area for exploratory data analysis. Following studies by Archambeau, we have detected emission from a pre-event time window, from the location of a well-detected m1.5 event. The seismic energy studied represents a portion of the noise window with partial coherence across the network. We conjecture that this represents in effect a proxy monitor of creep in the tectonically active subsurface.

S32A-04 1120h

A Maximum Likelihood Perspective on the Influence of Data Correlations and the Precision of Event Locations

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The objective of earthquake location is to find the earthquake's focus with the greatest probability of being correct. Specifically, one should find the maximum in the joint probability distribution of the data, d, and location parameters, m, given equations, G, relating m to d, $P(d, m|G)$. Inverse theory proves that if the data have a Gaussian error distribution and are weighted by the inverse of the data covariance matrix, then the focus found is the maximum likelihood solution. Successive application of Bayes theorem gives $P(d, m|G) = P(G|m, d)P(d, m) = P(G|d, m)P(d|m)P(m) = P(G|d, m)P(d)P(m)$ when the probability distribution of the arrival times are independent of the location. The first term includes, for example, the probability distribution for the velocity, a factor rarely included in conventional locations. The third term is the a priori distribution for the location. The second component is the significant part. Arrival times are correlated when stations are close or, equivalently, when the travel paths of phases are similar. For correlated phases, $P(d) = P(d1|d2, d3, -)P(d2, d3, -)$ etc., where $d = (d1, d2, d3, -)$. For example, the probability distribution for an S and P phase at one station should be highly correlated, giving a narrowly defined $P(P|S)P(S)$, or $P(S|P)P(P)$ and consequently a significantly more precise location. In conventional location equations, this is equivalent to properly including the off diagonal elements in the weighting matrix, Cov(d). SVD inversion of Cov(d) from a pair of P and S phases is equivalent to reformulating the location phases as an S-P phase and an S+P phase. A similar analysis for JHD, where the correlation among arrivals is directly related to the separation of the events, shows how maximum likelihood formulation provides the locations with a more accurate assessment of location precision.

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S32A-05 1135h

Improving the Level of Seismic Hazard Parameters in Saudi Arabia Using Earthquake Location and Magnitude Calibration

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Saudi Arabia is an area, which is characterized very poorly seismically and for which little existing data is available. While for the most parts, particularly, Arabian Shield and Arabian Platform are aseismic, the area is ringed with regional seismic sources in the tectonically active areas of Iran and Turkey to the northeast, the Red Sea Rift bordering the Shield to the southwest, and the Dead Sea Transform fault zone to the north. Therefore, this paper aims to improve the level of seismic hazard parameters by improving earthquake location and magnitude estimates with the Saudi Arabian National Digital Seismic Network (SANDSN). We analyzed earthquake data, travel times and seismic waveform data from the SANDSN. KACST operates the 38 station SANDSN, consisting of 27 broadband and 11 short-period stations. The SANDSN has good signal detection capabilities because the sites are relatively quiet. Noise surveys at a few stations indicate that seismic noise levels at SANDSN stations are quite low for frequencies between 0.1 and 1.0 Hz, however cultural noise appears to affect some stations at frequencies above 1.0 Hz. Locations of regional earthquakes estimated by KACST were compared with locations from global bulletins. Large differences between KACST and global catalog locations are likely the result of inadequacies of the global average earth model (iasp91) used by the KACST system. While this model is probably adequate for locating distant (teleseismic) events in continental regions, it leads to large location errors, as much as 50-100 km, for regional events. We present detailed analysis of some events and Dead Sea explosions where we found gross errors in estimated locations. Velocity models are presented that should improve estimated locations of regional events in three specific regions: 1. Gulf of Aqabah - Dead Sea region 2. Arabian Shield and 3. Arabian Platform. Recently, these models are applied to the SANDSN to improve local and teleseismic event locations and to develop an accurate magnitude scale for Saudi Arabia.

S32A-06 1150h

Stress and Metamorphic Conditions for Warm-slab Earthquakes: Geiyo Area, Southwest Japan

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The M = 6.7 2001 Geiyo earthquake occurred at the northern tip of a narrow band of high intraslab seismicity that extends from eastern Kyushu to the Geiyo area in Southwest Japan. We use JMA focal mechanism solutions to infer stress conditions as controlled by regional geodynamics in the Geiyo area, and we use a double-difference (DD) algorithm to refine the location of the 2001 Geiyo earthquake relative to the background seismicity. The slab experiences maximum E-W stretching and sharp bending in this area and is thus in a stress environment favoring large earthquakes. The DD relocation results in insignificant readjustments of earthquake locations, indicating a high accuracy of the original locations in the JMA catalogue. The Geiyo earthquake is deeper than most of the background seismicity. We also find that the magnitude of the background earthquakes increases with (slab-normal) depth and peaks at about 8 km below the top envelope of the intraslab seismicity. This distribution is consistent with the following conceptual model. Rock densification during pervasive dehydration reactions "shatters" the top part of the subducting crust, discouraging large earthquakes. The more uniform lower crust and mantle, under tectonic stress and with local dehydration along deep faults, can host much larger events such as the 2001 Geiyo earthquake. How deep inside the slab can earthquakes occur may depend on the state of mantle serpentinization prior to subduction.

S33A CC: 220 C-E Wednesday 1330h

POLARIS and Related Studies
Posters *(joint with G, GP, T, SEDI)*

Presiding: **D Eaton,** University of Western Ontario**; I Ferguson,** University of Manitoba

S33A-01 1330h POSTER

Crustal Seismic Velocity Model of Southern Ontario

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Knowledge of crustal thickness and velocity is important to obtain precise hypocenter locations, as well as to constrain tectonic interpretations for a particular region. In southern Ontario, the installation of the POLARIS network started in 2001. At present, there are 23 broad-band stations installed in this region. Together with the information from the Southern Ontario Seismic Network (SOSN), which operated with short-period sensors between 1990-2000, more than 200 recorded events (earthquakes and quarry blast) are available for velocity modeling. The arrival-time data from local events and some well recorded quarry blasts are used for a preliminary estimation of the 1-D and 3-D velocity model of southwestern Ontario. For 1-D velocity tomography the method of Kissling (1984) (VELEST program) is applied. Different initial models are used to obtain a robust result. The Moho depth is constrained independently using results of receiver-function analysis and gravity inversion. . The obtained 1-D optimum' velocity model is used as the initial model for a subsequent 3-D local tomography using the Thurber inversion' (Thurber, 1981, 1983, 1993) (SIMULPS program). New hypocenter locations for all local events in southwestern Ontario in 1990-2003 have been calculated using the new 1-D and 3-D velocity models.

S33A-02 1330h POSTER

Relations of Pipe-to Soil Potential to the Local Geomagnetic and Telluric Activity

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Magnetic disturbances cause electric currents in long pipelines, which can contribute to corrosion of the pipeline. To protect the pipeline a cathodic protection system is used to maintain the pipeline at a constant negative potential with respect to surrounding soil that inhibits the corrosion reactions. However induced currents in the pipeline create variations in the pipe-to-soil potential taking. Knowing where and how often these potential variations occur is necessary for assessing the corrosion risk for a pipeline. Large pipe-to-soil potential variations have been observed on a pipeline from Armprior to Kemptville in eastern Ontario. We present observations and analysis of pipe-to-soil potential variations made in October 2003 to investigate why this area experienced such large fluctuations. Geomagnetic field recordings from the nearby Ottawa magnetic observatory were used with a 1-D multi-layered conductivity model of the Earth to calculate the electric field at the Earth surface. Comparison between the pipe-to-soil potential variations and the electric field variations gave correlation coefficients up to 90%. The pipe-to-soil potential recordings and calculated electric fields were used to determine a transfer function representing the pipe/earth response at each site. Comparison of these transfer functions from site to site shows where the peak response occurs. We examine the factors in the pipe structure and in the earth conductivity structure that could be the cause of these localized effects on the pipeline.

S33A-03 1330h POSTER

Possible Subcrustal Anisotropic Fabric Beneath the Grenville Orogen

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The Proterozoic Grenville Orogen, which forms the southeastern edge of the Canadian Shield, is the result of extensive crustal shortening and deformation during the interval 1.3-0.98 Ga. The degree to which this crustal deformation is reflected in the underlying mantle is uncertain, though LITHOPROBE detection of a preserved subduction zone (Calvert et al., 1995) in adjacent Archean terranes indicates that relict Precambrian features are preserved below the crust. A number of permanent CNSN stations (e.g., SADO, GAC, KGNO, etc.) are located on or near the Grenville, and have large archives of teleseismic data available; the more recent deployment of the dense Ontario POLARIS network provides additional constraints. We examine teleseismic receiver functions from POLARIS and CNSN stations for transverse-component energy beneath the Moho; early results indicate a complex structure involving multiple anisotropic domains that do not correlate with SKS splitting results.

S33A-04 1330h POSTER

Crustal thickness in Southern Ontario from constrained linearized gravity inversion

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We use crustal thickness estimates for POLARIS Southern Ontario stations as constraints in a linearized inversion of gridded Bouguer gravity data for topography of the crust-mantle boundary. Estimates of crustal thickness from receiver function analysis varies from 37 to 43 km; the thinnest crust is found in a SW-NE trending belt between Georgian Bay and Lake Ontario. Our gravity inversion assumes a constant density contrast between crust and mantle, and parameterizes the topography of the crust-mantle boundary as discrete rectangular blocks sitting at a reference depth. By assuming that the mass of one block is concentrated at its base, we obtain a linear relationship between the height of the block and the vertical component of gravity measured at the surface. For realistic Moho topography our forward model compares well with more accurate non-linear approaches that either distribute the mass across each discrete block or use a Fourier expansion in the wavenumber domain to parameterize the surface. To the resulting system of linear equations we add additional constraint equations provided by the teleseismically derived thicknesses at the appropriate grid locations. Our preliminary results show long-wavelength undulations in Moho topography. Residual gravity maps display mainly short wavelength features that are presumed to be caused by shallow anomalies. A comparison of the results with tectonic boundaries mapped at the surface show a thick crust underlying the Central Metasedimentary Belt, and thinner crust just SE of the Grenville Front.

S33A-05 1330h POSTER

A Comparison of Teleseismic Receiver Functions for TW∼ST and Polaris Stations in the Western Superior Province, Canada

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