

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

Sadaomi Suzuki¹ (81-92-642-2678; suzuki@geo.kyushu-u.ac.jp); Takeshi Matsushima² (mat@sevo.kyushu-u.ac.jp); Yoshihiro Ito³ (81-29-863-7835; yito@bosai.go.jp); Sayeed Keivan Hosseini¹ (hosseini@geo.kyushu-u.ac.jp); Takeshi Nakamura¹ (nakamura@geo.kyushu-u.ac.jp); Jafargandomi Arash¹ (gandomi@geo.kyushu-u.ac.jp); Hossein Sadeghi⁴ (sadeghi@seismo.um.ac.jp); Mehdi Maleki⁵ (fatemi@ndrii.com); Fatemi Aghda⁵ (fatemi@ndrii.com)

¹Dep. Earth & Planetary Sci., F. Sciences, Kyushu University, Hakozaki 6-10-1, Fukuoka, 812-8581 JAPAN, Fukuoka, Fuk 812-8581, Japan

²Inst. Seismology and Volcanology, Kyushu University, 2-5643-29 Shinyama, Shimabara 855-0843, Japan, Shimabara, Nag 855-0843, Japan

³National Research Inst. for Earth Science and Disaster Prevention, 3-1, Ten-no-dai, Tsukuba, Ibaraki, 305-0006, Japan, Tsukuba, Iba 305-0006, Japan

⁴Earthquake Research Center, Ferdowsi University of Mashhad, Vakil-abad St., Mashhad 91775-1436, Iran, Mashhad 91775-1436, Iran (Islamic Republic of)

⁵Natural Disaster Research Inst. Iran, No.1 Shabdiz Ave., Fayazi St., Vali-e-Asr St., Tehran, 19395-4676, Iran, Tehran 19395-4676, Iran (Islamic Republic of)

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 accelerometer 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) ref.1:USGS,http://neis.usgs.gov/neis/FM/, ref.2: ERI, U. Tokyo, http://www.eic.eri.u-tokyo.ac.jp/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

Paul G. Silver (202-478-8834; silver@dtm.ciw.edu) Carnegie Institution of Washington, DTM, 5241 Broad Branch Rd. NW, Washington, DC 20015, United States

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

David B Snyder¹ (6139929240; dsnyder@nrcan.gc.ca)

Grant Lockhart² (2508604616; grant.d.lockhart@bhpbilliton.com)

¹ Geological Survey of Canada, 615 Booth Street, Ottawa, ON K1A 0E9, Canada

² BHP Billiton Diamonds, Inc., #8 1699 Powick Road, Kelowna, BC V1X 4L1, Canada

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° 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° and the transverse component at about 320°; together these indicate a horizontal symmetry axis for hexagonal anisotropy at 108/288° and an associated fast axis at 018/198°. 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°) 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°) 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

Stephane Sol¹ (610 758 3669; stsd@lehigh.edu)

Colin J. Thomson¹ (613 533 6178; thomson@geol.queensu.ca)

J.-M. Kendall² (+44 113 233 5258; kendall@earth.leeds.ac.uk)

C. Snell²

D. White³ (613 992 0758; don.white@nrcan.gc.ca)

¹ Queen's University, Geological Sciences & Geological Engineering, Kingston, ON K7L 3N6, Canada

² Leeds University, School of Earth Sciences, Leeds LS2 9JT, United Kingdom

³ Geological Survey of Canada, 615 Booth Street, Ottawa, ON K1A 0E9, Canada

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 observations, 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

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

David W. Eaton¹ (519-661-3190; deaton@uwo.ca)

Andrew Frederiksen² (204-474-9460; andrew.frederiksen@umanitoba.ca)

Soo-Kyung Miong² (andrew.frederiksen@umanitoba.ca)

¹Department of Earth Sciences, University of Western Ontario, London, ON N6A 5B7, Canada

²Department of Geological Sciences, University of Manitoba, Winnipeg, MB R3T 2N2, Canada

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.

Todd A. Nicholson¹ (tnichols@eos.ubc.ca)

Michael G Bostock¹ (bostock@geop.ubc.ca)

John F Cassidy² (jcassidy@nrcan.gc.ca)

¹Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, BC V6T1Z4, Canada

²Pacific Geoscience Centre, Geological Survey of Canada, Box 6000, Sidney, BC V8L4B2, Canada

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

Gail M Atkinson¹ (613-520-2600 X1399; gma@ccs.carleton.ca)

SanLinn I. Kaka¹ (skaka@ccs.carleton.ca)

Siew Ling Soh¹ (slsoh@ccs.carleton.ca)

¹Carleton University, Dept. Earth Sciences 1125 Colonel By Dr., Ottawa, ON K1S 5B6, Canada

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

SanLinn I. Kaka¹ (1-613-520-2600 Ext.8648; skaka@ccs.carleton.ca)

Gail M. Atkinson¹ (1-613-520-2600 Ext.1399; gma@ccs.carleton.ca)

Siew Ling Soh¹ (slsoh@connect.carleton.ca)

¹Carleton University, Earth Sciences Department 1125 Colonel By Drive, Ottawa, ON K1S5B6, Canada

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

Shutian Ma¹ (1-613-724-2992; Shutian1986@aol.com)

John Adams² (1-613-995-5519; adams@seismo.nrcan.gc.ca)

Gail Atkinson³ (1-613-520-2600; gma@ccs.carleton.ca)

Veronika Peci² (1-613-995-7100; peci@seismo.nrcan.gc.ca)

¹Seismologist, 1399 Chatelain Avenue, Ottawa, ON K1Z 8A9, Canada

²Earthquakes Canada, 7 Observatory Crescent, Ottawa, ON K1A 0Y3, Canada

³Earth Sciences, Carleton University, Ottawa, ON K1S 5B6, Canada

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

Alan Baird¹ (baird@geoladm.geol.queensu.ca)

Stephen D. McKinnon² (1-613-533-6553; sm@mine.queensu.ca)

¹Geological Sciences & Geological Engineering, Queen's University, Kingston, ON K7L 3N6, Canada

²Department of Mining Engineering, Queen's University, Kingston, ON K7L 3N6, Canada