island in either a NW or a SE azimuth. A preliminary frequency-magnitude investigation shows a high b-value (2.14), suggestive of volcanic activty, an interpretation supported by the recording of episodes of tremors in the frequency band 2-8 Hz. This swarm is reminiscent of activity at Mehetia-Teahitia (Society Islands) in 1981-1985. Additional signals were picked at Rikitea in March, April and as late as 24 July 2002.

S11D-11 1145h

Observations of Deep Long-Period (DLP) Seismic Events Beneath Aleutian Arc Volcanoes; 1989 to 2002

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Between October 1989 and September 2002 the Alaska Volcano Observatory (AVO) located 149 Deep Long-Period events (DLP) at nine volcanic centers in the Aleutian arc. Many more were detected but could not be located reliably. These events occur at mid- to lower- crustal depths (10 to 50 km) and are characterized by emergent phases, extended codas, and a strong spectral peak generally between 2 and 4 Hz. Observed wave velocities and particle motions indicate that the dominant phases are P- and S-waves. The average reduced displacement of Aleutian DLPs is 28 cm2 and the largest event has a reduced displacement of 589 cm2 (or ML 2.5). DLP epicenters often extend over broad areas (5 to 30 km) that surround active volcanoes. DLP events are often highly clustered in time, with several occurring over a period of 3 to 30 minutes. Within these clusters individual DLPs are often separated by lower amplitude volcanic tremor with a similar spectral character. Higher frequency signals and/or volcano-tectonic earthquakes at similar depths are occasionally associated with DLP clusters.

DLPs have now been identified at a number of volcanoes including Mammoth Mountain in 1989 and Mount Pinatubo in 1991, where they have been linked to the movement of basaltic magma. At most Aleutian volcanoes DLPs appear to occur as part of background seismicity. A likely explanation is that they reflect a relatively steady-state process of ascent of mafic magma over broad areas in lower and middle portions of the crust. At Mount Spurr DLP seismicity was initiated by the 1992 eruptions and then slowly declined until 1997, suggesting these events reflect changes in magma flux caused by the depressurization of the magmatic system during the eruptions. At Shishaldin Volcano small, short-lived increases in DLP seismicity occurred about nine months prior to the 19 April 1999 eruption and again roughly five weeks after the eruption, suggesting a link between eruptive activity and magma flux in the mid- to lower-crust. The occurrence of DLPS prior to eruptions at Pinatubo and Shishladin suggests that these events may provide some of the earliest indication of renewed volcanic unrest.

S12A MCC: Hall C Monday 1330h

Forensic Seismology: Exotic Seismic Sources and Man-Made Events II Posters *(joint with OS, PA)*

Presiding: **R C Aster,** New Mexico Institute of Mining and Technology**; R Bulow,** Scripps Institution of Oceanography

S12A-1169 1330h POSTER

Far-Field Energy Radiation From a Building Under Harmonic Excitation

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A nine story building on the Caltech campus (Millikan Library) was harmonically excited at its East-West (EW) and North-South (NS) natural frequencies to determine the behavior of the far-field radiated waves emanating from the building. The building's natural frequencies are ∼ 1.12 Hz. and ∼ 1.64 Hz. for the EW and NS directions respectively, and the individual building shakes lasted approximately four hours each. We use the data recorded by the Southern California TriNet stations, and the building's signal can be observed at distances larger than 300 kilometers. By using 36 USGS owned FBA-11 accelerometers located in the building to compute the forces in each floor, we can estimate the maximum applied forces/overturning moments that the building imparts on the soil to be: Shear Force ∼ 2.2e+5 N (4.9e+4 lbf) and Overturning Moment ∼ 7.0e+6 Nm (5.2e+6 lbf ft) for the EW shake, and Shear Force ∼ 5.2e+5 N (1.2e+5 lbf) and Overturning Moment ∼ 1.6e+7 Nm (1.2e+7 lbf ft) for the NS shake. Furthermore, by using the roof displacement and the force being applied to the building, we estimate the horsepower being used by the motor that powers the shaker as ∼ 12 J/sec (0.02 hp) for the EW shake, and ∼ 40 J/sec (0.05 hp) for the NS shake. The units used above are as follows: N = Newton, lbf = Pound Force, m = Meter, ft = Feet, J = Joule, sec = Second, and hp = Horsepower.

From the measured signals, we produce maximum amplitude plots (as the measured waves are harmonic) for each component as well as the vector sum of the components, and we find the best fitting distance decay rates for the data. We observe very little radiation pattern in the radiated waves, which is contrary to the simple half-space models and we explore the lack of azimuthal radiation patterns from the building. It is interesting to note that the best fitting distance decay rate changes at a distance of approximately 50 kilometers.

This approach is nondestructive and repeatable and thus is suitable for establishing (monochromatic) amplitude response curves of the crust and mantle structure in Southern California. Furthermore, this may also be a powerful tool to monitor temporary variations of site response changes if they ever occur.

S12A-1170 1330h POSTER

Coal-Mining Seismicity in the Trail Mountain Area, Utah: Part I–Case Study for Assessing Ground-Shaking Hazard

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We report results from a multipart study aimed at quantifying the potential ground-shaking hazard to Joes Valley Dam (a 58-m-high earthfill dam) posed by mining-induced seismicity (MIS) from future underground coal mining as close as ∼1 km. In order to characterize future MIS close to the dam, we studied MIS located ∼3-6 km from the dam at the then active Trail Mountain (TM) Mine. A 12-station local seismic array (11 stations above ground, one below, combining 8 triaxial accelerometers and varied velocity sensors) was strategically operated in the TM area from October 2000 through April 2001 for the dual purpose of (1) continuously monitoring and accurately locating (<1 km) MIS associated with longwall mining at a depth of 0.5-0.6 km and (2) capturing high-quality ground-motion recordings at distances of ∼0.2 to 9 km for the larger events. (Ground-motion attenuation relationships and moment-tensor results are reported in a companion abstract.)

Using a data set of 1,913 earthquakes ($M \leq 2.2$), we analyzed space-time variations of MIS, temporal variations in rate and magnitude, and source-mechanisms. Observed MIS was highly correlated with mining activity in both space and time. Most of the better-located events had depths conservatively constrained within ±0.6 km of mine level. Only 2 percent of the 1,913 located events were recorded with at least one compressional P-wave first motion–implying either (a) non-observation of compressional P-wave first motions was due to consistent undersampling, (b) dominance of an implosional or collapse-type source mechanism (rather than shear-slip type), or (c) some combination of the above. We assessed a probable maximum magnitude of M_W 3.9(84th percentile of cumulative distribution) for potential MIS close to Joes Valley Dam based on both the global and regional record of coal-mining-related MIS as well as local geology and mining scenarios.

S12A-1171 1330h POSTER

Coal-Mining Seismicity in the Trail Mountain Area, Utah: Part II-Ground Motion Prediction Equations and Seismic Moment Tensors

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As part of a study to assess the seismic hazard to the Joes Valley Dam from future coal mining in its environs, we analyzed recordings from a local broad-band array, operated by the University of Utah centered on the Trail Mountain coal mine, which is also near the Joes Valley Dam and from the Willow Creek mine about 50 km to the north. Seismic moment tensors determined for a small suite of events at Trail Mountain typically have a large implosive volume component of similar magnitude to the shear (normal) component suggesting that these earthquakes are tightly-coupled to collapse of the mine at depths near 500 m. The moment tensors also showed that the moment magnitude had no consistent bias with respect to the coda magnitudes Mc, assigned by the University of Utah. With this improved understanding of the seismic sources in this mining region, we used accelerograms from 12 earthquakes, with especially high signal/noise and magnitudes ranging from 1 to 4.2, to develop ground motion prediction equations suitable for assessing the hazard to the Joes Valley Dam following the method of Joyner and Boore (1988). The parameters peak acceleration, peak velocity, and pseudovelocities, at 5 % damping and periods ranging from 0.1 to 2 s, were modeled by ground motion prediction equations that account for linear magnitude dependence, geometrical spreading, anelasticity and scattering, and site effects. The resulting prediction equations agree well with those developed for earthquakes, with much higher magnitudes in active tectonic settings, but the new prediction relation typically has a stronger fall-off with distance. In any case, these prediction results for the Trail Mountain region, combined with an estimate of the maximum probable earthquake, from a companion study, yield a well-constrained seismic hazard assessment for the Joes Valley Dam due to future coal mining nearby. These new ground motion prediction equations would be appropriate for assessing seismic hazard from shallow seismicity in active tectonic regions.

Joyner W.B., and D.M. Boore (1988) Measurement, characterization, and prediction of strong ground motion, *Proceedings of Earthquake Engineering and Soil Dynamics, II, GT Div/ASCE Park City, Utah, June 27-30.*

S12A-1172 1330h POSTER

Analysis of Seismicity Recorded at an Underground Coal Mine During a Fatal Fire and Explosion Sequence

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On July 31, 2000 a sequence of four explosions occurred at the Willow Creek underground coal mine (Helper, UT) killing two miners and injuring 8 others. An investigation by the Mine Safety and Health Administration (MSHA) points to a roof fall as the most likely source of ignition of methane and other gaseous hydrocarbons which led to the explosions. NIOSH operated a seismic monitoring system at the mine in 1998-2000. Seismicity recorded by the underground array prior to and during the explosion sequence has been analyzed in an attempt to place constraints on the initial ignition source. Velocity sensors (4.5 Hz) were deployed in a 12-station underground array measuring 0.9 by 2.2 km. Throughout mining of the D-3 longwall panel, rates of seismic event occurrence, face advance, and methane accumulation were observed to be closely correlated indicating a strong association between longwall caving/deformation processes and gas release. At the approximate time of the first explosion a low-amplitude, emergent multiple-pulse seismic signal was observed which is interpreted to be the seismic signature of the first explosion. Features characteristic of caving- or fracture-related events are absent indicating that it was not accompanied nor preceded by such an event at least within the few seconds of recorded pre-trigger time. The preceding seismic event that was large enough to be recorded by the seismic monitoring system occurred 11 minutes before the first explosion. This observation does not rule out the possibility of a smaller fall that may have been ejected into the mine opening with damaging force but was not large enough

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to produce a seismic event that triggered the system. Consequently, the data appear incapable of supporting or refuting a rock fall as the ignition source. Seismic events were not recorded at the estimated times of the other three explosions.

S12A-1173 1330h POSTER

Explosion Contamination of the Seismicity Catalog in the Irkutsk, Buryat, and Chita Regions, Eastern Russia

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Temporal analysis of seismicity catalogs can indicate possible contamination by anthropogenic events. Events associated with mining and construction tend to occur during the local day, while natural seismicity occurs at all hours.

Examination of approximately 100,000 events listed in the published earthquake catalog (Materialy po Seismichnost Sibiri) for the Irkutsk and Chita Districts and the Buryat Republic in eastern Russia indicate significant explosion contamination. Areas of explosion contamination include: gold mining areas near Bodaibo, Bushulei, Ust Kansk, Karaftit, and Tsipikan; mica mining south of the Vitim River; and construction and industrial areas along the BAM, Trans-Manchurian, and Trans-Siberian railroads. Most of the gold mining is associated with placer deposits. Contamination is noted in copper and coal mining areas in northern Mongolia. Because of the large amount of natural seismicity in the rift basins northeast of Lake Baikal, explosion contamination associated with the construction of the BAM in those regions can not be distinguished.

Explosions associated with coal and iron mining (e.g., near Cheremkhovo and Tulun) are not included in the seismicity catalog, indicating that these are successfully filtered by local operators.

Exclusion of the explosion contamination indicates that the present-day activity is more concentrated along the Baikal rift zone and along the basins to the northeast, and less diffuse in the surrounding areas, than existing seismicity maps would indicate.

S12A-1174 1330h POSTER

Transfer Functions and Seismic Discrimination: a KNET Case Study

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One of the basic challenges of monitoring any nuclear testing moratorium lies in quantitatively assessing source type; in particular, identifying underground nuclear explosions within a background of natural seismicity. At regional distances (<1500 km from the source), seismic waveforms are complex, and show great variability on travel paths. This means that the problem of discrimination between small yield explosions and earthquakes is mainly empirical, and dependent on station recording histories. To effectively develop regional discriminants at any given station requires a ground-truth database consisting of waveforms from both earthquakes *and* explosions. Newly installed stations in official monitoring networks lack such a database, which severely affects confidence in successfully discriminating between different types of events. To address this problem, we are investigating a procedure to predict a discriminant at a newly installed seismic station using the actual discriminant at a long operating station and a transfer function for that specific station pair.

The dataset consists of six explosions and nine earthquakes at or within 100 km of the Lop Nor Chinese nuclear test site and recorded at the ten-station, very broadband KNET network in Kyrgyzstan. We have predicted four discriminants (two phase ratio and two cross spectral ratio) using transfer functions for all possible station combinations. Initial results show nearly 1:1 correlation (for three of four discriminants) between the discriminant predicted with a transfer function and the actual discriminant recorded at each station. We also examined what role interstation distance plays in the success of the prediction; F-statistics suggest that interstation distance does not affect the prediction. This implies that we need not necessarily use close-by stations to effectively predict discriminants at stations that have never recorded an explosion. Additionally, we use a validation procedure to investigate the ability of transfer functions to accurately discriminate source type.

S12A-1175 1330h POSTER

Analysis of Local and Regional Data from Explosions and Earthquakes - Evidence for Rg-to-S Scattering and Improved Source Discrimination

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Near-source scattering of explosion-generated Rg waves into S waves provides a viable mechanism for generating low-frequency Lg from explosions. Although this mechanism, first proposed by us in 1992 (Gupta et al., Bull. Seism. Soc. Am., pp. 352-382) has been supported by several observational studies, a better physical understanding is needed before its usefulness can be fully exploited. Digital three-component data from several man-made explosions in China appear to be ideally suitable for elucidating some important details of the complex scattering process, since the source-receiver distances gradually vary from local (a few km) to regional (a few hundred km) distances. Spectrograms and sonograms are used to identify spectral peaks and nulls within various time segments of three-component seismograms. At very short distances, the dominant phase on seismograms is Rg. As the source-receiver distance increases, Rg rapidly attenuates but Sg starts to develop, whereas at regional distances, Sg or Lg wavetrain becomes the most distinct phase. Replication of the spectral characteristics of direct Rg into Sg and Lg wavetrains provides compelling evidence supporting the scattering of Rg into S and Lg. On some records, the Lg wavetrain shows the presence of more than one low-frequency arrival with spectral characteristics similar to those of direct Rg. This implies that several near-source regions are involved in the scattering of Rg into S. The identification of prominent peaks and nulls in the spectra of direct Rg at local distances, exactly matching those in Sg and Lg at regional distances, should be a reliable indication of an explosion source and thus an effective source discriminant. Sonograms appear to provide seismic signatures that are significantly different for explosions and earthquakes recorded at regional distances. This is verified by examining local and regional data from several known explosions and earthquakes.

S12A-1176 1330h POSTER

Microearthquake Observations at 2.5 Km Depth in the Long Valley Exploratory Well, Ca.

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The Long Valley Exploratory Well is located in the resurgent dome of the Long Valley Caldera in California. It has been characterized as hydrothermally active and for the last 20 years it's seismicity as well as deformation have been monitored by the USGS and other groups. In November 2001 we completed the installation of a 2 Hz three component seismometer at a depth of 2603 meters. For a period of approximately 30 days we recorded data continuously at a sampling rate of 1000 Hz. During this time we were able to detect a total of 731 events with magnitudes as low as -2.4. Out of these 731 the USGS surface network was able to detect a total of 140 events with magnitudes higher than 0.7.

The deep borehole environment enabled us to analyze spectra of events located a couple hundreds of meters away from the source. In many cases the waveforms of the borehole events were cleaner than those at the surface that have been affected by processes like attenuation. Some of the small events that are close to the sensor present complex waveforms that indicate either complex sources or strong structure effects. Time frequency distributions for these small events show that they are very complex in nature and that may include scattering characteristics like splitting of shear waves. It was seen that there is a significant decay in the frequency content of events that are located at distances greater than five kilometers. The magnitude - frequency statistics shows a change in the b value for earthquakes with magnitudes less than -1 which could suggest that scaling at smaller magnitudes depends on other processes like creeping of faults or even magmatic processes that would impede the faults from rupturing.

S12A-1177 1330h POSTER

Multiple Reverberation Seafloor Scattering: A Mechanism for T-phase Excitation

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Some authors have suggested that multiple reflections within the water column where the seafloor has a systematic slope may convert vertically propagating seismic body wave energy from earthquakes into horizontally propagating acoustic T-phases. Others have suggested that single scattering from topographic points in rough seafloor may excite T-phases. However, neither model successfully predicts the shape of the energy envelope of T-phases from shallow earthquakes on mid-ocean ridges, where the local topography is rough but limited in vertical extent and lacking systematic slopes or high features protruding into the SOFAR channel. Typically T-phases from these events grow slowly with a characteristic, exponential growth period of a few seconds, then decay away even more slowly, with total duration of many tens of seconds.

We show that it is important to consider multiple reverberations within the water column with scattering at the rough seafloor at each encounter of the nearly vertically propagating acoustic energy with the seafloor. Single scattering for a shallow source when body waves first encounters the seafloor predicts a short-duration, nearly symmetric T-phase pulse. With multiple reverberations, more energy is converted to nearly horizontally propagating acoustic energy with each scattering encounter, lengthening the effective duration of the source. We model this process with a simple, 3-D ray-tracing technique in which we sum energy contributions from each ray scattered in all directions by the rough seafloor, including both P and S wave initial waves. The rate of growth of the energy envelope depends primarily on the depth of the source. The rate of decay depends primarily on average water depth and the reflection/transmission coefficients of acoustic waves incident at the seafloor. Our results show that the multiple reverberation seafloor scattering of acoustic waves is a reasonable mechanism to explain the characteristics of T-phase excitation.

S12A-1178 1330h POSTER

Application of Blind Deconvolution Methods in two Complex Seismological Examples: Transfert Function Evaluation (Site Effect Assessment at GVDA) and Source Wavelet Evaluation (Kursk).

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In seismology the source and the Green function are unknown, the only available information is surface or deep seismograms. So the deconvolution associated with the classical input-output system identification is impossible without strong physical assumption. Many blind deconvolution methods, recently developped in the domain of communications, aim to retrieve the unknown information of a system from output only. We apply two of these methods to seismology: the multichannel blind deconvolution to retrieve the transfert function and high order statistics to estimate source wavelet.

In the first case, the multichannel method is applied in the scope of site effect estimation. It treats the problem of a signal transmitted through different channels (propagation mediums) and recorded at several receivers. From seismograms recorded at different sites, it intends to separate the common convolutive part of the signals (identified as the incident wave) and the specific site impulse response. The two main advantages of this method are that we don't need any reference site record and that the result contains the temporal properties of site responses. We test the method on a synthetic set of seismic signals based on a 1D model. We then apply it on the recordings obtained at various depths in the Garner Valley Down-hole Array.

In the second case, the high order statistics blind deconvolution is applied to study the main caracteristics of Kurk's underwater explosion. It treats the problem of a source transmitted through a specific channel

and recorded on single receiver. This blind deconvolution computed in bispectral and cepstral domains, gives us the opportunity to separate the wavelet (source function) and the propagation with one single geophysical assumption on the transfer function. It allows us to extract the bubble effect and the reflection at the sea surface as well as the source (amplitude and phase) from seismograms recorded at regional distance.

S12A-1179 1330h POSTER

Mount Hood Earthquake Activity: Volcanic or Tectonic Origins?

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On 29 June 2002, a $M_c = 4.5$ earthquake occurred 4.6 km south of Mount Hood, Oregon. Over two hundred small aftershocks ($M_c < 3.8$) have occurred since that time. We analyze 111 well-constrained earthquakes from the June-July 2002 swarm near Mount Hood, Oregon, recorded by the Pacific Northwest Seismic Network (PNSN) and a temporary CMG-40T seismograph, and 261 well-constrained, small earthquakes ($M_c < 3.5$) recorded by the PNSN between 1987 and 2002. We apply waveform cross-correlation to the full suite of 372 events, then relocate all events using the double-difference algorithm of Waldhauser and Ellsworth (2001), using the velocity model of Leaver (1984) to form differential travel-time residuals. We find that earthquakes prior to 2002 occur in four distinct clusters: (1) A small cluster of earthquakes occurring beneath the summit, (2) a tight cluster located about 9 km SSW of the summit, (3) a well defined linear feature, trending N-S, about 5 km south of the summit, and (4) a linear feature, trending NW-SE, a few km further south. Of these four clusters, we observe that only one earthquake from the June-July 2002 swarm occurs in the cluster beneath the summit. The rest all occur along the N-S trending feature, south of the summit, at similar depths to earthquakes from previous swarms. Both the current swarm and older earthquakes show a clear increase in depth with increasing distance from Mount Hood, which is not obvious from catalog locations alone. First-motion fault-plane solutions from the main shock and largest aftershock have normal mechanisms, and solutions from most well constrained aftershocks have normal to oblique normal mechanisms. This is consistent with the apparent strike of the feature located south of Mount Hoods summit, and similar to focal mechanisms of older earthquakes, but differs from the predominantly thrust focal mechanisms of nearby crustal earthquakes. While the latest earthquakes resemble a tectonic main shock-aftershock sequence, the mechanisms, relative locations, and swarm characteristics of these earthquakes indicate that they are probably related to volcanic processes under and near the volcano.

S12A-1180 1330h POSTER

VLP-Discriminated Strombolian Event Families and Video Observations at Mount Erebus, Antarctica

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Strombolian eruptive activity from the phonolitic lava lake of Mt. Erebus generates VLP (Very Long Period) signals with spectral components as grave as 20 s. These signals have been observed on a seasonal basis with broadband seismometers during three Antarctic field seasons in targeted PASSCAL deployments and, more recently, with permanently installed broadband seismometers. Associated eruptive and other lava lake behavior has also been observed since 2000 with a time-stamped crater surveillance video camera. VLP signals persist for several minutes during lava lake refilling following eruptions and have highly similar waveform characteristics from event to event. The initial few seconds of signal associated with the pre-eruptive phase, however, exhibit significant variations and can be readily classified into 3 families, two simply based on initial polarity. A third event family, infrequently observed, shows a very different pulse-like shape and different frequency content. Video observation of eruptions suggest a correlation between the eruptive character and the initial polarity of the event. Positive polarity events have a vertical, jet-like eruptive style, while negative polarity events feature more radial ejecta. All lava lake eruptions are due to simple Strombolian gas slugs nucleating in the near-summit conduit system, becoming dislodged from buoyancy forces, and rising nearly intact to the lake surface. Distinct families of eruptive styles from a single vent and their correlation with VLP signals generated by ascent forces suggest distinct source zones and/or delivery paths of gas slugs to the lava lake surface.

URL: http://www.ees.nmt.edu/Geop/Erebus/erebus.html

S12A-1181 1330h POSTER

The Detection of Very Low Frequency Earthquake using Broadband Seismic Array Data in South-Western Japan

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The existences of variety of low-frequency seismic sources are obvious by the dense and equalized equipmentfs seismic network. Kikuchi(2000) and Kumagai et.al. (2001) analyzed about 50sec period ground motion excited by the volcanic activities Miyake-jima, Izu Islands. JMA is listing the low frequency earthquakes routinely in their hypocenter determination. Obara (2002) detected the low frequency, 2-4 Hz, tremor that occurred along subducting Philippine Sea plate by envelope analysis of high dense and short period seismic network (Hi-net).

The monitoring of continuos long period waveform show us the existence of many unknown sources. Recently, the broadband seismic network of Japan (F-net, previous name is FREESIA) is developed and extends to linear array about 3,000 km. We reviewed the long period seismic data and earthquake catalogues. Many candidates, which are excited by unknown sources, are picked up manually. The candidates are reconfirmed in detail by the original seismograms and their rough frequency characteristics are evaluated. Most events have the very low frequency seismograms that is dominated period of 20 E30 sec and smaller amplitude than ground noise level in shorter period range.

We developed the hypocenter determination technique applied the grid search method. Moreover for the major events moment tensor inversion was performed. The most source locates at subducting plate and their depth is greater than 30km. However the location donft overlap the low frequency tremor source region. Major eventfs moment magnitude is 4 or greater and estimated source time is around 20 sec.

We concluded that low frequency seismic event series exist in wide period range in subduction area. The very low frequency earthquakes occurred along Nankai and Ryukyu trough at southwestern Japan. We are planing to survey the very low frequency event systematically in wider western Pacific region.

S12A-1182 1330h POSTER

Deep low-frequency earthquakes beneath the Japan arc - a nonlinear time series analysis method to make clear a source dynamics -

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Recently, deep low-frequency earthquakes (DLF) lying near the Moho discontinuity and in the lower crust have been found not only beneath the volcanic front but also away from the volcanic front. These events are characterized by anomalously low predominant frequencies, and, sometimes, by large and long tailing coda parts of S-wave. Comparing the seismic waves of the deep low-frequency events and of the deep earthquakes whose incident angles of seismic waves have almost same to each other, the coda waves are not caused by the structure beneath the stations. Therefore, these waves represent the time evolution of the deep low-frequency event's source process directly. In this paper, we propose a nonlinear time series analysis to make clear the characteristics of the time evolution. This analysis is composed of two parts: the test for stationarity of time series and the test of causality among time series to investigate a non-linear structure lying behind the complex time series. Both tests are based upon the theory of KM2O-Langevin equations and the fluctuation-dissipation theorem. A one-dimensional stochastic process (time series) can be written by a KM2O-Langevin equation using the KM2O-Langevin matrix. Based on the correlation matrix function of the time series, we can calculate a unique system of the KM2O-Langevin matrix which satisfies the fluctuation-dissipation theorem. Employing these relations, we can test the stationary property of the time series. When the time series has the stationary property, we can construct a nonlinear prediction formula suggesting a difference equation of the dynamic source process. Here, we apply the test of the stationary property and the causal-value analysis using 19 numbers of nonlinear transformations to five DLF in Japan. The main results are summarized as follows. 1) The major parts of the coda waves of DLF show the stationary property. 2) The causal values for the linear transformation and the nonlinear transformations with odd orders are relatively higher than those for the nonlinear transformations with even orders. This result suggests that the source process of the deep low-frequency earthquakes should not excite only a fundamental wave and its even-order higher modes waves. 3) We obtain a preliminary form of difference equation for DLF (M: 1.0) occurred in Akita prefecture on 11 July 2001.

S12A-1183 1330h POSTER

Deep low-frequency earthquakes beneath the Japan arc - The characteristics and the mechanisms of DLFs -

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Under the Japan arc, Deep Low Frequency earthquakes are occurring. We call Deep Low Frequency earthquakes (DLF) because such events have very low dominant frequency against other shallow microearthquakes having almost the same magnitude. DLFs occur at the depth around the Moho boundary. The focal area is much deeper than the ordinal seismogenic zone. These events sometimes have large and long tailing coda parts of S-wave. Such events have been reported mainly beneath the volcanic front. These characters led us to the qualitative argument suggesting the relationship between the source process and the magma movement. But now we have some reports that such events are occurring other area. This means that to elucidate the source dynamics of DLF will be the key for deeper understanding of the lower crust dynamics. We report the first step for trying to construct the quantitative physical model of DLFs source dynamics. We use two processes to make it. First, to estimate the physical environment of the field where DLF are occurring, we investigate the hypocenters of these events, and compare with the Curie point depth contour in the Japan arc. The result is that we find that the hypocenters are almost all within the Moho boundary to lower crust. As an exception, in the Kii peninsula, DLF events are occurring within the upper boundary of the subducting slab to the mantle wedge. There is a positive correlation between the depths of DLF hypocenter and the Curie point depths. This result suggests that the temperature highly affects to the occurring mechanism of DLF. Second, to estimate the source dynamics of DLF, we elucidate the source mechanism for some events. DLF has the characteristics that later phase which has large amplitude longs. It means that forcal mechanism cannot explain the waveform completely. But the forcal mechanism represents the force couple, then important information such as relationship between the mechanism and regional stress field, geometry of the source, and so on. We analyze five DLF events, occurring in Akita, Hida, Kyoto, Aso and Sakura-jima. Then the result is that almost all P-axis direction show good agreement with those of shallow earthquakes. These results correspond to the past studies. In other words, the forcal mechanisms of DLF reflect regional stress field of each area. On March 11, we recognized more than 130 of DLF events in Ashio region, central Japan. These occurred within only 4 hours. And the hypocenters migrated about 3 km toward to northwest direction. Now we report these events. 1992 - 1995, there were many DLF events occurred in the same region, and very slow

migration of hypocenters were reported. But this time, the migration speed looks very faster than before.

S12A-1184 1330h POSTER

Detection and Location of Potential Sources of Background Low Frequency Surface Wave Energy

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Earth's background free oscillations were reported recently by *Nawa et al.* (1998). While the observations are now well established, and the coupling of the solid earth with the atmosphere/ocean system is widely accepted as a likely source mechanism, detailed studies on sources, and in particular the spatial distribution of the sources, have been few.

Ekström (2001) showed that coherent Rayleigh wave energy in the frequency range between 2 and 7 mHz is detectable in 94% of the 5 year period considered. Though most data of 5 year period are contaminated with surface wave energy generated from events, it implies that we can detect coherent Rayleigh wave energy from sources taking part in generating continuous free oscillation in the absence of significant earthquakes. However, his method does not provide enough resolution to determine spatial distribution of the sources.

We propose an array based method as a modification of Ekström's method. This method is designed to detect low-level Rayleigh type surface wave energy by using one local array and provide rough estimate of back azimuth and arrival time of it. Testing of this method for small earthquake events shows the detection level of the method is lower than the documented background excitation levels (*Ekström,* 2001; *Tanimoto and Um,* 1999). Combining compatible detections from several arrays (3 or more) can help both identify sources of long period energy, and obtain an estimate of the source location. We have tested this method using vertical component recordings at BDSN (Berkeley Digital Seismic Network, USA), GRSN (German Regional Seismic Network) and F-NET (Japan) arrays. We will show and discuss the results of its application during intervals without significant earthquakes.

S12A-1185 1330h POSTER

OBSERVATION OF THE FREE OSCILLATIONS OF THE EARTH AND THEIR PERMANENT EXCITATION

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Fundamental spheroidal free oscillations of the Earth appear, even on seismically quiet days, as continuous vertical straight lines on the frequency-time diagrams. The oscillations are persistent through the 10 years of data presented from the WUS (GEOSCOPE) station. Analysis of four years of TAM (GEOSCOPE) station data with simultaneous seismic-pressure recordings allows us to improve the resolution of these background oscillations. To reduce the atmospheric effect, we compute the pressure-acceleration transfer function and subtract the pressure effects from the acceleration signal. The 'cleaned' acceleration signal better resolves the free oscillation signal and allows us to isolate some very low frequen cy spheroidal fundamental modes (in the angular order range l = 2-15) and some radial modes after large earthquakes. The existence of a permanent free oscillation signal is verified, but the source of this phenomenon is not clearly defined. Before discarding a seismic source, we address the definition of "seismically quiet days". We found that severe selection criteria leads to only a few of these days. The favourite candidate for the permanent excitation of the Earth's normal modes is the coupling between the Earth and the atmosphere. We detect a small annual variation of the phenomenon, with an increased amplitude of some peaks in June- July that Terra and Tanimoto (1999), Tanimoto and Um (1999), Nishida et al. (1999, 2000) relate to solar activity. This hypothesis requires further analysis. If atmospheric forcing drives the excitation, this may be one of the rare phenomena indicating a direct solid earth-atmosphere interaction. Understanding this problem will clearly add another dimension to our understanding of the earth. It may also improve our understanding of other planets, because an atmosphere-surface coupling should also occur in other terrestrial planets. The existence of such phenomenon may allow us to study the interior structure of even tectonically quiet planets.

S12A-1186 1330h POSTER

Theoretical Calculation of Mars' Background Free Oscillations

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It has been suggested that the excitation source of the Earth's background free oscillations (BFO) is the random force exerted on the surface due to atmospheric disturbance (e.g. Kobayashi & Nishida, 1998). The previous studies also suggested a possibility for detection of the BFO on Mars. In this study we estimate the excitation level of the Mars' BFO by applying an atmospheric excitation theory to the Mars' atmospheric pressure data obtained in the Mars Pathfinder mission.

The atmospheric excitation theory used here is based on the seismic normal-mode theory and it can well predict the observed power spectrum of the Earth's BFO (Fukao et al. in press). The theory uses a power spectrum of the surface atmospheric pressure and a correlation length of atmospheric disturbance as the inputs. Since no direct observation of the correlation length is available to date, a correlation length should be assumed to calculate the theoretical power spectrum. A weakly frequency-dependent correlation length, about 1 km at 1 mHz, was assumed for Earth.

Using a simple theory of atmospheric disturbance, Kobayashi & Nishida (1998) estimated the excitation level of the Mars' BFO. A more sophisticated theory predicts values of 10^2 Pa^2s and 2 km for the pressure power at 1 mHz and the correlation length, respectively, for Mars. Using these values and eigenfunctions calculated from the Mars model of Sohl & Spohn (1997), we obtain the theoretical excitation level of about 0.5×10^{-18} m^2/s^3, which is an observable level with a high-sensitivity broadband seismometer installed at a very quiet site.

Surface atmospheric pressure on Mars was measured with a maximum resolution of 0.25 μbar in the Mars Pathfinder mission (Schofield et al. 1997). We analyze records for 5 Martian days and calculate an averaged power spectrum. It exhibits the well-known f^{-2} dependence at frequencies between 0.5 and 4.0 mHz, but a value of 10 Pa^2s at 1 mHz, which is an order of magnitude smaller than the theoretically predicted value. Using this spectrum and assuming a correlation length of 2 km, we obtain the excitation level of about 10^{-19} m^2/s^3, which seems too low to observe. We can obtain an observable excitation level when assuming a correlation length of 10 km, but such a long correlation length seems to be unlikely. If a value of 10 Pa^2s at 1 mHz is typical for the atmospheric disturbance on Mars, it is very hard to observe the Mars' BFO.

S12A-1187 1330h POSTER

Comprehensive Processing of the Apollo Lunar Seismic Event Data

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The Apollo Passive Seismic Experiment consisted of four seismic stations deployed on the lunar surface between 1969 and 1972. Data were recorded continuously from deployment until 1977. Previous studies often used only small subsets of all the available data due to computational limitations. In our study, event data (lunar seismic signals detected in the continuous time series) in their entirety are converted into a standard format for seismological analysis. The IRIS Data Management Center provided data to us in their original format on nine 8mm Exabyte cartridges (eight event tapes and one supplementary tape). The total disk usage of the event data after conversion to two-byte integers is 13 Gb. Events have been previously classified into three types: deep moonquakes, shallow moonquakes, and impacts. The tapes from the IRIS DMC contain just under 11,000 events the bulk of the approximately 12,000 catalogued events.

Several programs to view and filter the data are used to improve data quality. Data with various irregularities (timing errors, telemetry problems) are corrected or removed. These modifications allow for modern processing techniques to be applied consistently to the remaining data. Based on our preliminary analyses we estimate 97.6 % of the data will be useable for further study.

This work will permit a range of investigations, using stacking techniques that do not require waveform coherence. The poor signal-to-noise ratio of the lunar seismograms renders conventional automatic detection methods (used for terrestrial seismic events) ineffective for these data. Using recently-developed stacking techniques and our processed version of the data, we will focus on better identification and cataloguing of moonquakes and on estimating lateral variability in scattering properties of the lunar regolith.

S12B MCC: Hall C Monday 1330h

Strong Ground Motion Prediction and Site Response Posters *(joint with PA)*

Presiding: **R J Blakely,** U.S. Geological Survey**; S A Zaragoza,** University of Nevada, Las Vegas

S12B-1188 1330h POSTER

Las Vegas Basin Seismic Response Project: 3-D Finite-Difference Ground Motion Simulations

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3-D simulations of seismic wave propagation in southern Nevada are performed in an effort to characterize strong ground motions in and around the Las Vegas Basin (LVB). These simulations utilize a 3-D geologic model constructed from a gravity-based depth-to-basement map of the 5-km deep LVB. The 3-D LVB basin model is embedded within a regional geologic framework characteristic of southern Nevada. Simulation parameters are varied to determine the sensitivity of seismic velocity, basin geometry, topography, attenuation, and regional structure on the amplitude and duration of seismic shaking. The simulations reveal significant correlation between high amplitude ground motion and model parameters. In particular, the duration of seismic shaking is heavily influenced by the geologic velocities in the upper 1 km of the basin. In some simulations, seismic energy originating from the northwest is channeled through the LVB in a northwest-southeast orientation. In addition, regions of localized high amplitude motion are observed. The simulations are compared to observed data from historic seismic events in southern Nevada.

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S12B-1189 1330h POSTER

Las Vegas Basin Seismic Response Project: Measured Shallow Soil Velocities

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The Las Vegas valley in Nevada is a deep (up to 5 km) alluvial basin filled with interlayered gravels, sands, and clays. The climate is arid. The water table ranges from a few meters to many tens of meters deep. Laterally extensive thin carbonate-cemented lenses are commonly found across parts of the valley. Lenses range beyond 2 m in thickness, and occur at depths exceed 200 m. Shallow seismic datasets have been collected at approximately ten sites around the Las Vegas valley, to characterize shear and compression wave velocities in the near surface. Purposes for