[1]Geoscience, University of Nevada Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154-4010, United States

[2]Civil & Environmental Engineering, University of Nevada Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154-4015, United States

[3]Seismological Laboratory, University of Nevada, 1664 N. Virginia Street, Reno, NV 89557-0141, United States

[4]Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550-9234, United States

The N-S elongated extensional Las Vegas basin, southern Nevada, contains 100's of meters of Cenozoic basin-fill sediments that are cut by several Quaternary (Q) faults. These faults define or influence the basin geometry. The basin is generally an asymmetrical half graben defined by the W-dipping, Q Frenchman Mountain fault (FMF) along its E side and a series of smaller offset E-dipping faults to the W. The N terminus of the basin is controlled by the Las Vegas Valley shear zone, along which the majority of the offset occurred prior to the Q. Here, we asses the influence of the Q faults on the distribution of the sedimentary units. Well, exposure, seismic reflection and seismic refraction data show that sedimentary units of different grain sizes or seismic velocity dominate different parts of the basin. Sections dominated by coarse clastic deposits occupy a narrow area along the E side of the basin. Coarse clastic sediments are mixed with finer grained sediments in a broader area along the W side of the basin. Based on provenance and alluvial fan distribution, the coarse deposits along the E side of the basin appear to be trapped in close proximity to the W-dipping FMF. The coarse-grained deposits along the opposite, W side of the basin, are sourced from the nearby Spring Mountains. Because of the structural asymmetry of the basin, these sediments traveled farther from their source area than those on the E side. Some of these E-dipping faults influence the depth to Paleozoic bedrock and some faults form small sub-basins filled with finer grained sediments. Along a WNW trend near the center of the basin and near the present-day Las Vegas Wash, a change in the grain size distribution occurs up stratgraphic section: continuous clay layers are less common and coarse-grained deposits are more common. This difference may reflect a change from internal drainage early in the basin history to external drainage through the Las Vegas Wash in the latter history of the basin-fill sedimentation. This interpretation implies that the FMF was breached by a wash connected to the Colorado River drainage system during basin development. The basin fill deposits suggest an early history of alluvial fan dominated deposits showing internal drainage. That depositional system was followed by E- and W-sloping alluvial fans cut by a NW-trending external drainage system that probably flowed to the Colorado River. The greatest structural influence on sediment distribution was from the Q FMF on the E side of the basin and the dominantly Miocene Las Vegas Valley shear zone on the north, but the structural influence is reduced as Colorado River system and base level imposes on the basin up section.

S12E-07 1745h

Is Microseismicity Relevant to Estimating Seismic Hazards in North Central New Mexico?

Leigh House[1] (505-667-1912; house@lanl.gov)

Peter Roberts[1] (proberts@lanl.gov)

Jamie N Gardner[2] (jgardner@lanl.gov)

[1]Los Alamos National Laboratory, MS D443, Los Alamos, NM 87545, United States

[2]Los Alamos National Laboratory, MS D462, Los Alamos, NM 87545, United States

The Rio Grande rift extends south from southern Colorado through central New Mexico and into northern Mexico. It is a major tectonic feature in New Mexico, yet seismicity in the rift is comparable to or lower than in the adjacent stable Great Plains and Colorado Plateau provinces (Sanford, et al, 1991). In north-central New Mexico, thirty years of microearthquake monitoring have provided more than 650 epicenters in an area of about 28 000 sq km. The largest earthquake was about magnitude 3. Epicenters show only a slight association with recently active faults, and most lie away from faults (mislocation of epicenters could produce this scatter, though we think it is unlikely). The Pajarito fault system is presently the western boundary of the Rio Grande rift in the area of the Espanola Basin (from Santa Fe to Espanola), yet has little seismicity associated with it, and only for 15 km of its 50 km length. That seismicity includes five earthquakes that were been felt in the Los Alamos area since 1991 (most recently in April 2003). Paleoseismic studies (Gardner et al, 2001) found evidence for large slip events along that same 15 km portion of the Pajarito fault system as recently as 2 ka. Recurrence times of these events are not known, but may be 10 ka or longer. The remainder of the rift boundary in north-central New Mexico is not discernable from seismicity. A simple model of opening of the rift (at an assumed rate of 0.1 mm/yr) produces an estimate of seismic moment release that is several orders of magnitude greater than seen in the seismicity. Microseismicity seems to have little relation to the macroseismicity that may occur on long time intervals (perhaps thousands of years) and may not be relevant for understanding seismic hazards in this part of the Rio Grande rift. Sanford, A.R., L.H. Jaksha, and D.J. Cash (1991), Seismicity of the Rio Grande rift in New Mexico, in Slemmons, D.B., E.R. Engdahl, M.D. Zoback, and D.D. Blackwell (eds), Neotectonics of North America, Geological Society of America, Boulder, CO. Gardner, J.N., S.L. Reneau, C.J. Lewis, A. Lavine, D. Katzman, L. Goodwin, J. Wilson, and K.I. Kelson (2001), Paleoseismic trenching in the Pajarito Fault system, Rio Grande rift, New Mexico, EOS (Trans. AGU), 82(47) Fall Meet. Suppl., Abstract S52C-0643.

S12F MCC: 2002-2004 Monday 1600h

Theories of Earth's Interior IV *(joint with T, V)*

Presiding: **J Korenaga,** Yale University**; T Tanimoto,** Institute for Crustal Studies

S12F-01 1600h INVITED

Broad-band Seismology for Understanding Earthquake Physics and Developing a Modern Practice for Seismic Damage Mitigation

Hiroo Kanamori[1] (626-395-6914; hiroo@gps.caltech.edu)

Thomas H. Heaton[1] (626-395-4232; heaton@gps.caltech.edu)

[1]California Institute of Technology, Seismological Laboratory, Pasadena, CA 91125, United States

In 1987, immediately after the 1987 Whittier Narrows earthquake, the Caltech broad-band regional seismic network project, TERRAscope, was launched under the direction of Don Anderson. At the time, UC Berkeley had also embarked on such a project. The objectives included: 1) Collect high-quality seismic data for developing theories of Earth's interior and exterior, 2) Develop a physics-based earthquake damage mitigation method, 3) Provide a test-bed for novel approaches in real-time seismology, 4) Provide an infrastructure for cultivating new directions in seismology. The data from TERRAscope, combined with those from other networks such as GDSN, IDA, IRIS, GeoScope networks were used to study various seismological problems, some of which had not been commonly investigated. We focus on three areas. The interaction between the solid earth and atmosphere had been the subject of considerable interest. The broadband networks detected interesting atmospheric waves from a few Hz (N waves from space shuttles) to 0.001 Hz (Morning-glory waves. At the time it was not recognized as such). Also, it recorded monochromatic (period $\sim$ 230 sec) Rayleigh waves which were generated by the near source atmospheric oscillations excited by the 1991 Pinatubo eruption. These waves were not immediately recognized as such, because they had not been observed yet. This represents one of few cases in which significant energy transfer occurred from the atmosphere to the solid earth. These observations eventually led to the more ambitious ongoing projects for detecting ionospheric signature of acoustic and internal gravity waves in the atmosphere that couple into the solid earth. Gutenberg, together with Richter, published a series of papers on the energy of earthquakes in the 1940's to 1950's. The intent of these studies was to determine the most important quantity necessary for understanding the fundamental physics of earthquakes. Unfortunately, because of the overwhelming observational difficulties, the method remained largely empirical. One of the important objectives of the regional broad-band networks was to make a significant advance in this area. Early efforts turned out to be unsatisfactory, but the high-quality data obtained for the 1999 Hector Mine earthquake brought about significant progress. In the meantime, the methodology for determining earthquake rupture patterns made rapid progress, and details of rupture patterns were determined for many events. The patterns are all extremely complex reflecting the heterogeneities of fault-zone properties, and variations of the physical processes involved. The improvements in energy estimates (macroscopic parameter) and understanding of small scale, microscopic, structure and physics suggest a statistical mechanics approach to a better understanding of earthquake physics. An important objective of seismology is mitigation of earthquake damage. The complexity of earthquake physics, and the resulting unpredictability of exact rupture behavior make accurate prediction of earthquakes difficult. However, once the rupture occurs and seismic waves are generated, the behavior is controlled by elastic properties of the earth, and becomes more predictable. This concept, combined with the improved understanding of earthquake physics would lead to a novel approach to earthquake damage mitigation through real-time seismology, earthquake early warning, and predictive control theory for structures.

S12F-02 1625h

Asperity Model of an Earthquake

Lane R Johnson (510 4864173; lrj@ccs.lbl.gov)

Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720

An asperity model of an earthquake that is based on the static solution for the exterior crack problem is described. The boundary integral method is used to explore both static and dynamic aspects of the model. The main features of the model include a strong asperity patch that retards motion on the fault and a weak surrounding shadow region where a displacement deficit develops. Failure commences when the stress intensity on the boundary of the asperity patch reaches a critical value, with the asperity patch failing first and causing a slip pulse to propagate out over the shadow region. The rise time of the slip on the fault and the rupture velocity are controlled by the type and amount of friction. The model is in general agreement with scaling relationships for repeating earthquakes and with waveforms from a nearby earthquake in both the time and frequency domains.

S12F-03 1640h

Evolving Earth Models and Nuclear Explosion Monitoring

Terry C Wallace (wallacet@lanl.gov)

Los Alamos National Laboratory, ms B446, EES Division, Los Alamos, NM 87545, United States

One of the most important problems in nuclear explosion monitoring is accurate seismic event location. Traditional location methods rely on estimating travel times in a known Earth model and accounting for heterogeneity through various empirical corrections. The history of location accuracy and precision is closely coupled to evolving theories of the nature of the Earth's interior. LONG SHOT was a 80 Kt explosion conducted on Amchitka Island on October 29, 1965. The travel times recorded from LONG SHOT deviated strongly from a radially symmetric Earth, and in fact showed a pattern consistent a tabular body of relatively high seismic velocity (the subducting North American Plate) validating certain concepts of the then new theory of plate tectonics.
Each subsequent advance in conceptual models for the dynamics of the Earth's interior has impacted explosion monitoring. Many of the advances in the theory of the Earth's interior have been spurred by the ideas and work of Don Anderson. These include anelasticity, anisotropy, tomography, the Lehmann discontinuity, and mantle plumes (or lack of). The present state-of-the-art monitoring paradigm incorporates a dynamic Earth model, and the synergy between verification research and basic research on the Earth's interior is quite important.

S12F-04 1655h

Jet Stream, Roaring Ocean Waves, and Ringing Earth

Toshiro Tanimoto[1] ((805)893-8375; toshiro@geol.ucsb.edu)

Douglas ReVelle[2] ((505)667-1256; revelle@lanl.gov)

[1]Institute for Crustal Studies, University of California, Santa Barbara, CA 93106, United States

[2]Los Alamos National Laboratory, EES-8, LANL MS-J577, Los Alamos, NM 87545, United States

During the last few decades, it has become clear that Earth's components, i.e. the atmosphere, the ocean and the solid Earth interact in complex ways on various time scales. Seismograms have been known to show such interactions but one of the surprising observations in the last 5-6 years is the discovery of continuous oscillations for frequencies 2-7 mHz; a sequence of fundamental spheroidal modes are excited continuously and display seasonal variations. The cause of these oscillations has been speculated to be an atmosphere-solid Earth interaction until recently (e.g., Kobayashi and Nishida, 1998; Tanimoto and Um, 1999; Fukao et al., 2002). In this talk, we present a case for an alternative mechanism that these oscillaitons are caused by oceanic (infragravity) waves. The original source of energy is in the atmosphere, because ocean waves are generated by atmosphere-ocean inteactions, but the essential point is that this energy must be filtered through an ocean process in order to explain the characteristics in seismic signals. We present two main points that support the oceanic infragravity-wave hypothesis. The first is a theoretical modelling

of spectral amplitudes. We will show that, using a typical infragravity wave source, one can explain not only the amplitudes of continuous oscillations but also the broad noise peak that exists at 0.01 Hz. This broad noise peak between 0.003 Hz and 0.015 Hz has been known before continuous oscillations were discovered (e.g. Peterson, 1993). Oceanic infragarvity wave hypothesis can explain not only continuous oscillaiton peaks but also this broad noise peak simultaneously. This is the major difference from previous atmospheric excitation models, because previous atmospheric hypotheses treated the background broad noise peak as unknown (Gaussian noise) and did not explain its origin. Secondly, modal peaks of continuous oscillations display a predominant 6-months periodicity (Tanimoto and Um, 1999; Ekstrom, 2001). This can be easily explained by the oceanic hypothesis due to its hemispheric, mid-latitudinal ocean-wave activity that generate large-amplitude ocean waves with 6-months periodicity. Using a satellite ocean wave data (TOPEX/POSEISDON), we will show that seismic modal amplitudes display similar seasonal variations to ocean wave data both in amplitude and phase. The scenario that emerges from this analysis is the following; the atmospheric winds generate ocean waves that fills the oceans in the world. Among those waves, long period waves (oceanic infragravity waves) perturb pressure at sea bottom and exert pressure on the solid Earth. This pressure fluctuation all over the oceans results in generation of ambient seismic noise for frequencies between 3 and 15 mHz, which is observed in the vertical component seismograms at all quiet broadband stations. Spheroidal modes for this frequency range are excited but clear modal peaks are seen only for 2-7 mHz mainly because of attenuation (which can be easily examined by simple calculations). These activity reaches semi-annual peaks in December-January-February and in June-July-August because of strong atmospehric activities at mid-latitudes in each hemisphere (North and South) that generate high amplitude ocean waves, including infragravity waves.

S12F-05 1710h

Theories of Mars' Interior: An alternative to plumes as the origin of Tharsis

Dave Stegman[1,4] (dstegman@eps.berkeley.edu)

Mark Jellinek[2] (markj@physics.utoronto.ca)

Mark Richards[3] (markr@eps.berkeley.edu)

Michael Manga[3] (manga@eps.berkeley.edu)

John Baumgardner[4] (baumgardner@lanl.gov)

[1]School of Mathematical Sciences, Monash University, Bldg 28, Monash University, Clayton, Vic 3800, Australia

[2]Dept. of Physics, University of Toronto, 60 St. George Street, Toronto, Ont M5S 1A7, Canada

[3]Dept. of Earth and Planetary Science, University of California, Berkeley, 307 McCone Hall, University of California, Berkeley, Berkeley, Ca 94720, United States

[4]Theoretical Division, Los Alamos National Laboratory, Mail Stop B216, Los Alamos National Laboratory, Los Alamos, NM 87545, United States

Mars' large-scale physiography is dominated by a hemispheric dichotomy (thin northern crust with low, smooth topography vs. thick southern crust with high, rugged topography) and by the Tharsis rise (an enormous volcanic plateau), both of which developed within the first 1 Gyr of Martian history. Using a 3-D spherical mantle convection model with temperature-dependent viscosity, we explore the effect of hemispheric-scale crustal thickness variations on Martian mantle convection. Thickened crust in the "southern" hemisphere of the model causes insulation of that hemisphere which may effect the underlying mantle circulation. This leads to a transient, regional-scale partial melting event sufficient to generate the Tharsis rise during the first 0.5-1.0 billion years following the formation of the crustal dichotomy. Our model avoids some problems of timing inherent in plume models, provides testable hypotheses regarding the history of Martian volcanism, and suggests a causal link between the formation of the N-S dichotomy and Tharsis.

S12F-06 1725h INVITED

On Planetary Evolution and the Evolution of Planetary Science During the Career of Don Anderson

Sean C. Solomon (202-478-8860; scs@dtm.ciw.edu)

Carnegie Institution of Washington, Department of Terrestrial Magnetism, 5241 Broad Branch Road, N.W., Washington, DC 20015, United States

The planets of our solar system have long been viewed by Don Anderson as laboratories for testing general aspects of planetary evolution and as points of comparison to the Earth. I was fortunate to have been a student 39 years ago in a course at Caltech that Don taught with Bob Kovach on the interiors of the Earth and the planets. At that time, Mariner 4 had not yet flown by Mars, the lunar Ranger program was still in progress, and it was permissible to entertain the hypothesis that all of the terrestrial planets were identical in bulk composition. In the last four decades spacecraft have visited every planet from Mercury to Neptune; samples from the Moon, Mars, asteroids, and comets reside in our laboratories; and more than 100 planets have been discovered orbiting other stars. More importantly, traditionally distinct fields have merged to the point where planetary scientists must be conversant with the findings and modes of thinking from astronomy and biology as well as the geosciences. A few examples illustrate this confluence. Theoretical models for the structure of the atmospheres of gas-giant planets led to the first astronomical detection of an extrasolar planetary atmosphere for the transiting planet HD209458b. Although the atmospheric models were based on those for solar-system gas giants, the 3.5-day orbital period means that this planet is 100 times closer to its star than Jupiter is to the Sun, its effective temperature is 1100 K, and the detected signature of the planetary atmosphere was absorption by neutral sodium. Sodium in Mercury's exosphere, detected astronomically from Earth, figures into the question of how the terrestrial planets came to have distinct bulk compositions. Hypotheses to account for Mercury's high uncompressed density, and by inference its high ratio of metal to silicate, range from chemical gradients in the early solar nebula to preferential removal of silicates from a differentiated protoplanet by nebular heating or giant impact disruption, processes that would have affected the final composition of the other inner planets to lesser degrees. These hypotheses will be distinguishable by future remote sensing measurements from a spacecraft in Mercury orbit, but all lead to the prediction that volatile species such as sodium should be deficient in Mercury's silicate fraction. The most recent models for Mercury's exosphere are consistent with the idea that the required fresh supply of sodium from Mercury's surface is no greater than that predicted for meteorite infall. One of the leading questions driving the current exploration of Mars is whether the surface or subsurface was ever conducive to the origin and evolution of life. Sites of hydrothermal circulation within the crust may have provided the necessary energy and chemical building blocks. Remote sensing of candidate hydrothermal minerals at the Martian surface is the leading technique being used to seek such sites, but paleomagnetism may offer another route. Several hypotheses link hydrothermal activity to either the formation of magnetic carriers during the lifetime of the Martian dynamo or the alteration of such carriers after the dynamo ceased, leading to the possibility that high-resolution mapping of crustal magnetism may provide a prospecting tool for promising Martian biological habitats. As Don Anderson showed us by example throughout his career, students of the Earth need not confine their attention to a single planet or even a single planetary system. The lessons from diverse fields that planetary scientists must master to stay current will keep all of us — like Don — young and curious.

S12G MCC: 3011 Monday 1600h

Novel Ways of Analyzing the Seismic Coda III

Presiding: **R Snieder,** Center for Wave Phenomena/Colorado School of Mines; **M Fehler,** Los Alamos National Laboratory

S12G-01 1600h

Hybrid Synthesis of Wave Envelopes in Random Media

Haruo Sato[1] (sato@zisin.geophys.tohoku.ac.jp)

Mike Fehler[2] (fehler@lanl.gov)

Tatsuhiko Saito[1] (saito@zisin.geophys.tohoku.ac.jp)

[1]Tohoku University, Aoba-ku, Sendai 980-8578, Japan

[2]LANL, Los Alamos, Los Alamos 87545, United States

High-frequency seismograms of local earthquakes are mostly composed of incoherent waves that are scattered by distributed heterogeneities in the lithosphere. Although their phase variations are complex, their wave-envelopes are systematic, frequency dependent, and vary regionally. The time width of a wavelet is broadened with increasing travel distance due mostly to diffraction caused by long wavelength spectra of random velocity inhomogeneity. Coda waves are excited due mostly to large angle scattering by the short wavelength spectra. Stochastic approaches are superior to deterministic wave-theoretical approaches for modeling wave envelopes in random media. The Markov approximation for the parabolic wave equation is appropriate for the synthesis of wave envelopes around the direct arrival, and the radiative transfer theory is appropriate for modeling coda envelopes. For the synthesis of whole envelopes from the onset to coda, we propose to use the envelope derived from the Markov approximation as a propagator in the conventional radiative transfer integral equation. The effective isotropic scattering coefficient is given by the momentum-transfer scattering-coefficient, which is mostly controlled by the short wavelength spectra of random media. The envelopes resulting from the proposed hybrid method agree well with ensemble-average envelopes calculated by averaging envelopes from individual finite difference simulations of the wave equation for a suite of 2-D random media having rich short wavelength spectra.

S12G-02 1615h

Anomalous Spatial Distribution Of Coda-Wave Energy Observed In Northeastern Honshu, Japan And Its Interpretation

Kazuo Yoshimoto[1] (+81-22-217-6534; yoshi@zisin.geophys.tohoku.ac.jp)

Ulrich Wegler[2] (+49-341-97-32803; uli@rz.uni-leipzig.de)

Michael Korn[2] (+49-341-97-32803; mikorn@rz.uni-leipzig.de)

[1]Graduate School of Science, Tohoku University, Aoba, Aramaki, Aoba, Sendai 980-8578, Japan

[2]Institute of Geophysics and Geology, University of Leipzig, Talstrasse 35, Leipzig 04103, Germany

Seismic coda waves of local earthquakes are considered to be scattered waves due to short wavelength heterogeneities in the lithosphere and to be distributed uniformly in space at large lapse times. This idea has been applied to the determination of earthquake magnitude of local events and to the measurement of seismic attenuation and site amplification. However, is the spatial uniformity of coda-wave energy observed even in tectonically very heterogeneous regions? We investigate the spatial distribution of S-coda-wave energy in northeastern Honshu, Japan, where a volcanic front is running from north to south. Seismograms recorded by the Hi-net from a large local event are used in this study. At large lapse times, root-mean-square amplitudes of coda waves at each station are calculated for frequency bands of 2-4, 4-8, 8-16 and 16-32 Hz. From this analysis, a clear spatial variation of coda-wave energy across the volcanic front from east (forearc-side) to west (backarc-side) is observed. The coda-wave energy is significantly smaller in the backarc-side than in the forearc-side. The energy is uniformly distributed in the forearc-side, whereas a monotonic exponential decrease with horizontal distance from the volcanic front is found in the backarc-side. The decay rate shows clear frequency dependence and increases with frequency, suggesting strong attenuation of high-frequency waves in the backarc-side. In order to explain this anomalous distribution of coda-wave energy, we propose a diffusion-absorption model that consists of two adjoined half-spaces with different absorption strength. We suppose strong absorption for one half-space to model significant seismic attenuation in the backarc-side. In the long-lapse-time limit, the spatial energy density in the strong absorption medium decays exponentially with the offset from the boundary. It is found that the magnitude of the decay rate is expressed by a simple function of the diffusion coefficient and the absorption coefficient. This indicates that, in northeastern Honshu, Japan, the volcanic front is a boundary between different seismic attenuation structures (forearc-side and backarc-side) and that the assumption of homogeneous spatial distribution of coda-wave energy is not valid in this case.

S

S12G-03 1630h

Estimation of two dimensional von Karman stochastic parameters from the seismic coda

Christian Poppeliers[1] (713-348-2290; poppelie@caam.rice.edu)

Alan Levander[2] (713-348-4652; alan@rice.edu)

William W Symes[3] (713-348-5997; symes@caam.rice.edu)

[1]Rice Center for Computational Geophysics, 6100 Main Street Rice University Mail Slot 126 P.O. Box 1892, Houston, TX 77005, United States

[2]Rice Department of Earth Science, 6100 Main Street Rice University Mail Slot 126 P.O. Box 1892, Houston, TX 77005, United States

[3]Rice Department of Computational and Applied Mathematics, 6100 Main Street Rice University Mail Slot 134, Houston, TX 77005, United States