crust at seismogenic depths, they suggest that pore spaces are not fully saturated. Particularly high Qs/Qp in Long Valley Caldera and Ontake might reflect the presence of a steam phase trapped in pore spaces.

S21A-07 0930h

Seismic Frequency Attenuation and Fluid Motion

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The relations among the different modes of attenuation (1/Qk, 1/Qp, 1/Qs, 1/Qe) are controlled by the mobility of the pore fluid within rocks. Attenuation covering the exploration seismic band (20 -1000 Hz) was derived at low amplitudes by measuring the phase angles between the applied stress and sample strain. Assuming that attenuation can be defined from the complex moduli as the ratio between imaginary part and real part.of the complex moduli. , Winkler and Nur (1979) showed that one of three relations must hold: (1) 1/Qs $<$ 1/Qe $<$ 1/Qp $<$ 1/Qk; or (2) 1/Qs = 1/Qe = 1/Qp = 1/Qk; or (3) 1/Qs $>$ 1/Qe $>$ 1/Qp $>$ 1/Qk. The applicable relation is controlled by the compressional to shear velocity ratio or Poisson's ratio. In partially saturated rocks with high fluid mobility, 1/Qk is a maximum and 1/Qs is minimum (relation 1). At 100% liquid saturation with no fluid motion, 1/Qs is now the maximum and 1/Qk is the minimum (3). In contrast, for the same liquid saturated sample, if macroscopic fluid motion is permitted across an open boundary, the 1/Qk can again reach the maximum. However, the fluid mobility and attenuation mechanisms are strongly frequency dependent and interrelated. Thus, the scale of partial saturation or diffusion lengths and fluid mobility will control the attenuation relationships.

URL: http://crusher.mines.edu/Atten

S21A-08 0945h

Is Seismically Determined Q an Intrinsic Material Property?

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The seismic quality factor, Q, has a well-defined physical meaning as an intrinsic material property associated with a visco-elastic or a non-linear stress-strain constitutive relation for a material. Measurement of Q from seismic waves, however, involves interpreting seismic wave amplitude and phase as deviations from some ideal elastic wave propagation model. Thus, assumptions in the elastic wave propagation model become the basis for attributing anelastic properties to the earth continuum. Scientifically, the resulting Q model derived from seismic data is no more than a hypothesis that needs to be verified by other independent experiments concerning the continuum constitutive law and through careful examination of the truth of the assumptions in the wave propagation model. A case in point concerns the anelasticity of Mississippi embayment sediments in the central U.S. that has important implications for evaluation of earthquake strong ground motions. Previous body wave analyses using converted Sp phases have suggested that Qs is 30 in the sediments based on simple ray theory assumptions. However, detailed modeling of 1D heterogeneity in the sediments shows that Qs cannot be resolved by the Sp data. An independent experiment concerning the amplitude decay of surface waves propagating in the sediments shows that Qs must be generally greater than 80 but is also subject to scattering attenuation. Apparent Q effects seen in direct P and S waves can also be produced by wave tunneling mechanisms in relatively simple 1D heterogeneity. Heterogeneity is a general geophysical attribute of the earth as shown by many high-resolution data sets and should be used as the first litmus test on assumptions made in seismic Q studies before a Q model can be interpreted as an intrinsic material property.

S21B MCC: 2000 Tuesday 0800h

Earthquake Alerting Systems: From Rapid Hazard Determination to Societal Response I

Presiding: **R M Allen,** University of Wisconsin-Madison**; T Teng,** University of Southern California

S21B-01 0800h INVITED

Earthquake Early Warning

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The complexity of earthquake physics, and the resulting unpredictability of exact rupture behavior makes 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. If the ground motion information detected near the source is transmitted immediately as an early warning for ground motion to sites at some distance away before the ground motion begins there, the information could be utilized for various damage mitigation measures. An early warning system has been used in practice in Japan, Mexico, and Taiwan. Two approaches are possible: (1) Regional warning, and (2) Site-specific warning. In (1), the traditional seismological method is used to locate an earthquake, determine the magnitude, and estimate the ground motion at other sites. In (2), the beginning of the ground motion (mainly P wave) observed at a site is used to predict the ensuing ground motion (mainly by S and surface waves) at the same site; no attempt is made to locate the event and estimate the magnitude. The first approach is more reliable, but takes a longer time and cannot be used for the sites at short distances. In contrast, the second approach is less reliable, but very fast, and could provide useful early warning to sites even at very short distances where an early warning is most needed. The first approach has been already used in Japan, Mexico, and Taiwan. Here, we investigate the second approach in some detail from the point of view of rupture physics, and practical applications. The basic principle is that P wave carries the information of the source, but not much energy. S wave and surface waves carry most of the energy and cause the damage. Thus, if we can extract critical information regarding the size of an earthquake from the first few seconds of P waves, the information can be used to predict the severity of ground motion at the site. In general, if P wave is small, the event is either small or large but at large distances, and no warning is warranted. However, a large P wave does not necessarily warrant a warning, because the event can be a nearby small earthquake with short duration of slip motion. Thus, it is important to determine whether the event's slip motion has stopped or keeps growing. To determine whether the event is growing or not, the parameter τ used by Nakamura provides a good diagnostics. τ can be interpreted as a spectrally- weighted period during the first few sec (3 sec in this study). Using simulated records computed for an earthquake rupture model, we have verified that τ is a good measure of the lower-bound of the size of an earthquake. We have determined τ for events with M_W = 3 to 7.6 (1999 Chi-Chi earthquake), and the results are consistent with the simulation results. If $\tau < 1$ sec, the event has already ended or is not likely to grow. If $\tau > 1$ sec, it is likely to grow, but how large it will eventually become cannot be determined. In this sense, this method provides a threshold warning. Thus, a combination of the amplitude and τ from the first 3 sec can provide a useful site-specific early warning. A use of multiple sites is desirable to increase the reliability. This approach can provide a very rapid warning that strong ground motions are imminent, but does not provide the ground-motion time history. For the next step of early warning applications, it is desirable to develop a method to estimate the time history which can be incorporated in predictive structural control in engineering practice.

S21B-02 0820h

The Mexican Sistema de Alerta Sismica (SAS) Experience

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The Mexico City's SAS is an Early Warning System developed in accordance with recommendations of foreign and national seismology experts, after the disaster generated in 1985 by the M8.1 Michoacan earthquake. The SAS aim is to help mitigate future seismic disasters in Mexico City (MC), mainly if the big forecast "Guerrero Earthquake" hits. In 1991 the SAS started its service in an experimental basis for evaluating its performance both with a group of basic education students in public schools, and with the emergency stop function for the Mexico City Metropolitan Subway System (METRO of MC); after this The Federal District Government (FDG) opened the SAS as a public service in August, 1993, shortly after the SAS warned, with more than 60 seconds of anticipation, the incoming effect of May 13, 1993, M5.8, and M6 double earthquake originated more than 300 Km from MC between Guerrero and Oaxaca, on the coast. That year, an initial technical flaw generated one false alert signal; the cause was readily corrected. The SAS has 12 seismic sensor stations covering a stripe close to 400 X 100 Km on the Guerrero's coast, between Papanoa and Punta Maldonado, that send information through a dedicated radio relay system to the SAS Central Control in MC., using the valuable support of some TELMEX field installations. Until August, 2003, the SAS sensor system has detected more than 1550 earthquakes in the $2.5<M<7.3$ range, being capable to discriminate $M>5$ magnitude events, which are the ones felt in MC. The SAS has generated 57 warning signals with an average of 60 sec in advance to earthquake effects: 46 of restricted use for $M<6$, and 11 of public use for $M>6$ events. Public warnings have the automatic broadcast support of many commercial radio AM/FM and TV stations in Mexico City and Toluca valleys. The FDG controls the SAS signal service that includes the more frequent events (from $M>5$ up), asking the user to develop procedures and practice useful actions to mitigate seismic disasters. Each validated SAS seismic warning automatically generates and sends the event information by fax and e-mail to the DFG and Civil Protection Authorities, users and news media; it also sends information about the SAS operating conditions to service technicians, via radio, and phone.

S21B-03 0840h

Real Time Earthquake Information System in Japan

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An early earthquake notification system in Japan had been developed by the Japan Meteorological Agency (JMA) as a governmental organization responsible for issuing earthquake information and tsunami forecasts. The system was primarily developed for prompt provision of a tsunami forecast to the public with locating an earthquake and estimating its magnitude as quickly as possible. Years after, a system for a prompt provision of seismic intensity information as indices of degrees of disasters caused by strong ground motion was also developed so that concerned governmental organizations can decide whether it was necessary for them to launch emergency response or not. At present, JMA issues the following kinds of information successively when a large earthquake occurs. 1) Prompt report of occurrence of a large earthquake and major seismic intensities caused by the earthquake in about two minutes after the earthquake occurrence. 2) Tsunami forecast in around three minutes. 3) Information on expected arrival times and maximum heights of tsunami waves in around five minutes. 4) Information on a hypocenter and a magnitude of the earthquake, the seismic intensity at each observation station, the times of high tides in addition to the expected tsunami arrival times in 5-7 minutes. To issue information above, JMA has established; - An advanced nationwide seismic network with about 180 stations for seismic wave observation and about 3,400 stations for instrumental seismic intensity observation including about 2,800 seismic intensity stations maintained by local governments, - Data telemetry networks via landlines and partly via a satellite communication link, - Real-time data processing techniques, for example, the automatic calculation of earthquake location and magnitude, the database driven method for quantitative tsunami estimation, and - Dissemination networks, via computer-to-computer communications and facsimile through dedicated telephone lines. JMA operationally monitors earthquake data and analyzes earthquake activities and tsunami occurrence round-the-clock on a real-time basis. In addition to the above, JMA has been developing a system of Nowcast Earthquake Information which can provide

its users with occurrence of an earthquake prior to arrival of strong ground motion for a decade. Earthquake Research Institute, the University of Tokyo, is preparing a demonstrative experiment in collaboration with JMA, for a better utilization of Nowcast Earthquake Information to apply actual measures to reduce earthquake disasters caused by strong ground motion.

S21B-04 0900h

Progress on Earthquake Rapid Reporting and Early Warning Systems in Taiwan

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We report the recent progress on real-time seismic monitoring in Taiwan. Particularly on the earthquake rapid reporting (RRS) and earthquake early warning (EWS) systems developed by us at the Central Weather Bureau (CWB), using the telemetered signals from strong-motion instruments in the free-field. For the RRS, CWB has provided intensity map, hypocenter, and magnitude within one minute of the occurrence of large (M> 4) earthquakes since 1995. The reliability, as documented by electronic messages to government agencies and scientists, has a nearly perfect record, especially for large damaging earthquakes. Using a set of empirical relationships from a study of the 1999 Chi-Chi earthquake, CWB has been able to release through RRS the estimated distributions of PGA, PGV and potential damage within a few minutes after a big earthquake. This near real-time damage assessment is useful for rapid post-disaster emergency response and rescue missions. The concept of a virtual sub-network (VSN) has been implemented at CWB. The VSN-approach reduces the earthquake rapid reporting time to about 30 seconds or less. This represents a significant step towards a more realistic earthquake early warning capability, and has been in operation at CWB since December 2000. A 6-month result shows successful locations of 54 earthquakes with equivalent estimates of moment magnitude. The RRS and EWS have been in operation for several years essentially without false reports. For EWS since 2002, comprehensive earthquake reports have been issued mostly in less than 30 seconds, with an average of about 22 seconds from the origin time. At 3 km/sec for a typical shear wave velocity, the present operation is not useful if an earthquake occurs less than 66 km from a city, but the lead time will increase to more than 10 seconds for cities at distances greater than 100 km from the source. In the latter case, a lead time of several seconds will allows pre-programmed emergency response to take place prior to the arrival of strong shaking. The CWB's RRS and EWS reports are open to scientists (by e-mail) if a request is sent to ym.wu@socmail.cwb.gov.tw. Besides the earthquake-related information, these reports also document the processing time.

S21B-05 0920h INVITED

Can Seismic Early-Warning Information Help Engineers?: The Benefits to, and the Information Requirements for Structural Control and Monitoring Applications

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The potential benefits of advance-warning information of an earthquake event, on the order of seconds prior to seismic wave arrival, is explored in the context of structural engineering loss reduction. Structural control technologies have been developed, principally over the last two decades, to reduce the vibration response of structural systems during transient dynamic loading such as earthquake ground motions. A brief overview of the state-of-the-art in structural control is presented. Although not typically considered, there are possible control algorithm-level benefits to having *a priori* information on the magnitude, spectral content and duration of the transient loading. In addition, there are potential benefits of advance knowledge for the actuator and sensor hardware that implement the control. In addition to structural control applications, the modeling and damage detection of structural systems is of particular interest to engineers for whom an earthquake event presents a rare high-level loading and response dataset from which structural health can potentially be inferred. Increasingly, large arrays of wireless sensor are proposed for this monitoring purpose. Early-warning information could potentially be used to wake-up sensors from a low-power mode to a full-power mode at which they can record and wirelessly communicate a large volume of data. While the potential of incorporating early-warning information for structural engineering loss-reduction measures may be attractive, it is important to note that one can of course not predict the location of future events relative to a structure of interest, and therefore one should not design systems which exclusively depend on early-warning information for basic life safety or other performance criteria. Rather, the goal should be to design measures whose performance can be *enhanced* with early-warning information.

S21B-06 0940h INVITED

Earthquake Early Warning and Public Policy: Opportunities and Challenges

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Development of an earthquake early warning capability and pilot project were objectives of TriNet, a 5-year (1997-2001) FEMA-funded project to develop a state-of-the-art digital seismic network in southern California. In parallel with research to assemble a protocol for rapid analysis of earthquake data and transmission of a signal by TriNet scientists and engineers, the public policy, communication and educational issues inherent in implementation of an earthquake early warning system were addressed by TriNet's outreach component. These studies included: 1) a survey that identified potential users of an earthquake early warning system and how an earthquake early warning might be used in responding to an event, 2) a review of warning systems and communication issues associated with other natural hazards and how lessons learned might be applied to an alerting system for earthquakes, 3) an analysis of organization, management and public policy issues that must be addressed if a broad-based warning system is to be developed and 4) a plan to provide earthquake early warnings to a small number of organizations in southern California as an experimental prototype. These studies provided needed insights into the social and cultural environment in which this new technology will be introduced, an environment with opportunities to enhance our response capabilities but also an environment with significant barriers to overcome to achieve a system that can be sustained and supported. In this presentation we will address the main public policy issues that were subjects of analysis in these studies. They include a discussion of the possible division of functions among organizations likely to be the principle partners in the management of an earthquake early warning system. Drawing on lessons learned from warning systems for other hazards, we will review the potential impacts of false alarms and missed events on warning system credibility, the acceptability of fully automated warning systems and equity issues associated with possible differential access to warnings. Finally, we will review the status of legal authorities and liabilities faced by organizations that assume various warning system roles and possible approaches to setting up a pilot project to introduce early warning. Our presentation will suggest that introducing an early warning system requires multi-disciplinary and multi-agency cooperation and thoughtful discussion among organizations likely to be providers and participants in an early warning system. Recalling our experience with earthquake prediction, we will look at early warning as a promising but unproven technology and recommend moving forward with caution and patience.

S21C MCC: 3009 Tuesday 0800h

Crustal Structure

Presiding: **A Rodgers,** Lawrence Livermore National Laboratory**; D Eberhart-Phillips,** U.S. Geological Survey

S21C-01 0800h

Imaging the Transition From Aleutian Subduction to Yakutat Collision in Central Alaska, With Local Earthquakes and Active Source Data

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In central Alaska, the rapid subduction and active volcanism of the Aleutian subduction zone gives way to a broad plate boundary zone with mountain building and strike-slip faulting, where the Yakutat terrane joins the subducting Pacific plate. We are imaging the 3-D velocity structure using the abundant local earthquakes, which occur to 200-km depth, supplemented by active source data. Both permanent AEIC (Alaska Earthquake Information Center) stations and temporary BEAAR (Broadband Experiment Across Alaska Range) stations are included. Low velocity in the upper crust correlates with the Cook Inlet and Copper River basins. The relatively high-velocity slab and low-velocity mantle wedge are readily observed. Lower velocity mantle underlies the active volcanism in contrast to higher velocity mantle of the relatively undeformed southwestern Alaska area further inboard of the arc. In the region north of Cook Inlet, a low-velocity zone overlies the shallow slab to about 80-km depth and may represent the underthrust Yakutat terrane, consistent with BEAAR receiver function and attenuation results. The subduction of thick crust in central Alaska at the end of a subduction zone is similar to the northern South Island of New Zealand.

S21C-02 0815h

The 2003 Western Anatolia Seismic Experiment: an Integrated Study of Crust/Upper Mantle Structure and Anisotropy in Western Turkey

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Western Turkey is one of the most seismically active continental regions in the world and much of it is undergoing extensive north-south extensional deformation. In a cooperative study, seismologists from Saint Louis University and Dokuz Eylul University in Izmir, Turkey, deployed 5 broadband and 24 short-period seismic stations in western Anatolia in November 2002. The high-frequency instruments were located along a NS 100 km long profile with 2 to 3 km station spacing in the central portion of the zone of extension. The remaining instruments were deployed as a regional array distributed throughout the region. All stations record contineously with a sampling rate of 40 samples per second. The recording experiment will last for one year. We plan to use both the linear array and regional array recordings to perform a combined inversion for precise local earthquake location and a tomographic velocity model of the region. We will also determine crustal thicknesses and crust/upper mantle anisotropy using telesesimic earthquakes. Preliminary analysis of the first eight months of teleseismic data has resulted in a 2-D crustal image beneath the linear array which shows that Moho depth varies from 28 km to 32 km.

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