S51G MCC: 3011 Friday 1020h

Earthquake Hazards of Greater Tokyo: Eighty Years After Kanto I
(joint with G, T)

Presiding: **R S Stein,** U.S. Geological Survey**; S Toda,** Active Fault Research Center (AIST)

S51G-01 1020h

Deep Seismic Reflection Profiling in the Source Region of the 1923 Kanto Earthquake

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The location and geometry of the source fault, and crustal velocity structure, provide the basic information for more precise estimation of strong ground motions with devastative earthquakes. The deep seismic profiling around Metropolitan Tokyo (Kanto area) began from 2002 under the project named 'Regional Characterization of the Crust in Metropolitan Areas for Prediction of Strong Ground Motion' as five year's project. Deep seismic profiling was performed along the Sagami (Sagami 2003) and Tokyo Bay (Tokyo Bay 2003), to obtain an image of the source fault of the Kanto earthquake of 1923 (M7.9), upper surface of the Philippine Sea plate, and deeper extension of inland active faults. In Sagami 2003, seismic reflection data were acquired along a 75-km-long seismic line from the flank of the Hakone volcano to Tokyo Bay through the coast of Sagami Bay. The seismic source was four vibroseis trucks and air guns (1500 cu. inch). The seismic signals were recorded by geophones (10 Hz) on land along the coast with 20 <ETH> 33-km-long spread. The seismic data was processed by standard CMP-reflection method. The obtained seismic section portrays the east dipping reflectors beneath Odawara at depth ca. 4 km to Kamakura at depth ca. 13 km for 40-km-distance forming a narrow (< 1 km) concentrated zone of reflectors. The location and geometry of reflectors are almost coincidence with the source fault model (model II) proposed by MatsuOura et al. (1980) for the Kanto earthquake using a inverse method from geodetic data. Thus, it is interpreted that the source fault of the earthquake is in the narrow zone of the concentrated reflectors. The deeper extension of the Kozu-Matsuda Fault, showing the one of the highest slip rates (3 mm/y: vertical component) among active faults in Japan and was assessed high seismic risk, merges to the east dipping reflectors at ca. 6.5 km in depth beneath the Oiso hills. In the Tokyo Bay 2003, seismic reflection data were acquired along a 71-km-long seismic line from the Miura Peninsula to Tokyo Bay. Same seismic sources were used as in Sagami 2003. Beneath the Tokyo Bay seismic signals were recorded by ocean bottom cables with hydrophones (OBC). The obtained shot gathers show the deepest reflections from 5.5 sec (TWT).

S51G-02 1035h

Modeling the Fault Plane and Slip Distribution of the 1923 Great Kanto Earthquake, Japan

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The 1923 Great Kanto earthquake (M_S=8.1) was one of the most devastating earthquakes in Japanese history, causing the deaths of almost 140,000 people and destroying large parts of Tokyo and Yokohama. In order to better understand the cycle of strain buildup and release among the major regional faults, we revisit its source. Previous studies located its hypocenter on the slab interface of the Philippine Sea Plate that subducts NE under Northern Honshu along the Sagami Trough. These studies agreed on a general fault model of reverse right-lateral slip on a low-angle plane, however disagreed on the size and orientation of the fault plane. We went back into the Japanese data archives and collected the raw triangulation and leveling measurements that were obtained in campaigns between 1883 and 1927 in the Kanto district. This data set contains ≈ 30 first-order triangulation data and ≈ 500 leveling data along 9 routes in the vicinity of Tokyo, that were also used in previous studies of the fault mechanism. A unique aspect of our data set is the inclusion of ≈ 400 second order triangulation measurements of surprisingly high quality. In our modeling we use angle changes from the triangulation data and section height differences from the leveling data. We test the fit of this new data set by previous models, ranging from a single dislocation to a multiple source fault. In general, we find that the more complicated fault models do not fit the data significantly better and that the data fit is especially sensitive to changes in the location and orientation of the fault plane(s). We perform a grid search to determine the optimum fault plane geometry, which consists of two planes with strikes 165^o and 175^o. Finally, we use this fault plane geometry to invert for distributed slip. Using a layered structure to calculate response functions for elastic deformation the coseismic slip model shows maximum slip peaks (5 - 7 meters) near Odawara and the Miura Peninsula, in agreement with previous studies. We find that the rake of slip is nearly constant $\sim 155^o$. This is in agreement with the sense of interseismic strain accumulation (Sagiya, 2003), but it differs from earlier results that indicated progressively greater dip-slip component in the direction of rupture propagation (towards the SE).

S51G-03 1050h

Earthquake Source and Ground Motion Characteristics of Great Kanto Earthquakes

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This paper describes the derivation of a rupture model of the 1923 Kanto earthquake, and the estimation of ground motions that occurred during that earthquake and that might occur during future great Kanto earthquakes. The rupture model was derived from the joint inversion of geodetic and teleseismic data. The leveling and triangulation data place strong constraints on the distribution and orientation of slip on the fault. The most concentrated slip is in the shallow central and western part of the fault. The location of the hypocenter on the western part of the fault gives rise to strong near fault rupture directivity effects, which are largest toward the east in the Boso Peninsula. To estimate the ground motions caused by this earthquake, we first calibrated 1D and 3D wave propagation path effects using the Odawara earthquake of 5 August 1990 (M 5.1), the first earthquake larger than M 5 in the last 60 years near the hypocenter of the 1923 Kanto earthquake. The simulation of the moderate-sized Odawara earthquake demonstrates that the 3D velocity model works quite well at reproducing the recorded long-period (T > 3.33 sec) strong motions, including basin-generated surface waves, for a number of sites located throughout the Kanto basin region. Using this validated 3D model along with the rupture model described above, we simulated the long-period (T > 4 sec) ground motions in this region for the 1923 Kanto earthquake. The largest ground motions occur east of the epicenter along the central and southern part of the Boso Peninsula. These large motions arise from strong rupture directivity effects and are comprised of relatively simple, source-controlled pulses with a dominant period of about 10 sec. Other rupture models and hypocenter locations generally produce smaller long period ground motion levels in this region that those of the 1923 event. North of the epicentral region, in the Tokyo area, 3D basin-generated phases are quite significant, and these phases produce large-amplitude late-arriving pulses in the ground motions. At station Hongo, which is the only site having digitized and restored near-fault strong-motion records for this event, our 3D simulations compare quite well with the ground motions of the restored Imamura seismogram. For the restored Ewing record, our 3D simulations reproduce the phase and amplitude of the initial pulses of motion, but the dominant period of the large-amplitude later phases is noticeably shorter in the simulations (about 5 to 6 sec) than in the observation (13 sec). The level of simulated broadband strong ground motion is consistent with reported seismic intensities.

S51G-04 1105h

Aftershocks and Variation of Seismicity over Eighty Years in and around Focal Area of the 1923 Kanto earthquake

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Long term variation of seismicity in and around focal region of the interplate earthquakes is a key to understand recurrent process of interplate earthquake occurring along the subduction zone and risk evaluation of the earthquake. The 1923 Kanto Earthquake, occurring along the boundary between continental plate and underlying Philippine sea plate and the most disastrous earthquake ever occurred in Japan, left abundant seismometrical data of the main shock and after shocks. A post earthquake seismicity over eighty years period had been monitored by the densely distributed seismic station network. Proximity of the source region to the seismic network and long history of observations provides us a best opportunity to study seismicity related to the earthquake. A recent comprehensive study of aftershocks(Hamada et al. 2001) suggested that aftershocks concentrated around the asperity in the middle of the faulting region that is inferred from geodetic data and the dynamic source studies. A recent progress in improvement of earthquake catalog of Japan enables us to evaluate variation of post earthquake seismicity around the source region of the earthquake. The post earthquake seismicity seems to consist of a time invariable pattern of seismicity and a temporal decay of aftershocks which is well recognized along western and northern boundaries of the source region and continued for several years after the main shock. A seismicity map obtained by three station data by Omori(1921) and other descriptive data before the earthquake suggests that the aftershocks distribution, seismicity pattern of today and seismicity pattern before the earthquake are almost similar to each other. References: Hamada,N, Y.Yoshikawa, M.Nishiwaki, M.,Abe and F. Kusano, Zisin(Bull. Seis. Soc. Japan), 54,251-265.,2001 Omori,F., Seismological Note, Imperial. Earth. Invest. Commit., 2, 1-21., 1921

S51G-05 1120h INVITED

Interplate Coupling and Episodic Aseismic Faulting on the Sagami Trough Plate Boundary: Implications for a Future Seismic Hazard

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I studied crustal deformation in the Kanto district around the Tokyo Metropolitan area, central Japan, using data from GEONET, the Japanese continuous GPS network operated by the Geographical Survey Institute. Based on GPS daily coordinates during 1996-2000, I identified significant northward (up to 20mm/yr) as well as downward (up to 4 mm/yr) displacements along the Sagami Trough subduction zone where the Philippine Sea plate is being subducted. The deformation indicates locking effects of asperities on the plate boundary. On the other hand, effects of the Pacific plate subduction are not apparent from the surface deformation data. But it is reasonable to ascribe the blockwise westward motion of the whole Kanto area to the Pacific plate subduction. The GPS velocity data were inverted to estimate the slip deficit distribution on the Sagami Trough subduction zone. The result delineates strongly coupled asperities on the plate interface, a part of which corresponds to the coseismic slip distribution of the 1923 Kanto earthquake by Wald and Somerville (1995). Basically the strongly coupled asperities are located shallower than 20km. But the inferred plate interaction demonstrates significant lateral

heterogeneity even in the same depth range, implying that the thermal structure is not the only controlling factor of interplate coupling and that the plate configuration may play an important role. The daily GPS coordinate data are also utilized to analyze an aseismic fault slip event on the plate boundary interface east off the Boso Peninsula in the middle of May 1996. The silent rupture propagated southward over a 50km * 50km wide area during about a week. The maximum slip was about 50mm and the released seismic moment was 4.7E18Nm (Mw6.4). The estimated stress drop was as small as 0.05MPa. The silent slip occurred in the peripheral of a locked asperity, suggesting that the distribution of seismic slip and that of aseismic slip are complementary each other and that the frictional property of the plate boundary is persistent. Therefore detailed spatio-temporal mapping of variable slip behavior is necessary for comprehensive understanding of plate boundary process and it is essential for quantitative estimation of future seismic hazard.

S51G-06 1135h

Candidates of M7-Class Earthquake Beneath Greater Tokyo Area

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In greater Tokyo area, the occurrence of M7-class earthquake is thought to be imminent by the following reasons. (1) In these 20 years, maximum size of shallow microearthquakes beneath Tokyo is steadily increasing. (2) In recent 80 years after Kanto earthquake, maximum size of the earthquakes in Kanto region is gradually increasing. (3) In these 400 years, it was observed twice that two M7-class earthquakes precede the M8 interplate earthquakes in the latter half of the interseismic period. Taking into consideration these background, the Central Disaster Management Council, Japan issued Guideline for Countermeasures to the Earthquakes Beneath Southern Kanto Region on August 1994, and proposed 19 fault models along the upper boundary of Philippine Sea plate as the candidates of the forthcoming M7-class earthquake. At present, we have no data of abnormal seismic activity or crustal movement to select preferable one among these 19 fault models. Here, we will try to constrain the candidates which may have relatively higher possibility of the occurrence by a elimination method. It seems to be possible to exclude some of the fault models by the following ways. (1) Adopting characteristic earthquake concept, we can exclude 5 models which overlap to the focal region of 1923 Kanto earthquake. (2) A belt like zone of serpentine are found from tomography results at 30-40km depth along the Philippine Sea plate beneath the Kanto Plain and no microearthquake activities are generated along this zone (Kamiya and Kobayashi, GRL, 2000). We can eliminate 4 models which lie in this zone. (3) Beneath the eastern Boso Peninsula, it was found that slow slips of M6.5-class are repeated every 5-6 years. We can exclude 2 models in the area (4) Since plate collision is undertaken beneath eastern Yamanashi Prefecture, we can exclude 1 model in this area. Finally, it remains 7 fault models as the possible candidates of M7-class earthquake beneath Tokyo area. They are 3 models just beneath mid-Tokyo, 3 models in southern Ibaraki Prefecture, and 1 model at western Kanagawa Prefecture. So far we have restricted us the candidates of M7 earthquake only along the upper boundary of Philippine Sea plate. Under the complex tectonic settings around Tokyo, we should be also aware of the other type earthquakes, although a deeper event with the same magnitude will cause smaller ground motions in general.

S51G-07 1150h

The recurrence interval of great earthquakes along the Sagami trough

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Along the Sagami trough, an oblique subuduction zone between the Philippine Sea and North American plates, great earthquakes occurred in 1923 (M7.9) and1703 (M8.6), about 50 km southwest of the Tokyo. Both events generated strong ground motions and tsunamis. Strong ground motions equivalent to seismic intensities 6 to 7 in JMA scale and 10 to 12 in MM scale struck over southern Kanto. The two earthquakes are similar more or less in the extent of the damage and the crustal deformation, possibly occurring very near each other. The extent of the damage and the crustal deformation on the southern area was greater in the 1703 event, whose tsunami reached and damaged the coast of the Kii peninsula, 300 to 400 km away from the source. The source region of the 1703 earthquake, therefore, is considered to have extended towards the ocean and much larger than that of the 1923 event. Several studies of uplift coastal terraces suggest the events like the 1703 one have occurred possibly every 1,000-2,000 years, while those like the 1923 Kanto earthquake more frequently without leaving geomorphic evidence on the terraces. Before 1703, a possible candidate for a subduction event is the M7.0-7.5 1257 or M7.0 1293 earthquake that caused serious damage to southern Kanto region. However, no other earthquakes have been found in historical documents. Historically, the Kanto area was not well civilized until 13th century and earthquakes are not well documented. In addition most historical documents recorded between 14th and 16th centuries were lost during the age of civil wars. If an average recurrence interval is 200 years, at least 4 to 5 events should have occurred before 1703 ,since the 9th century when the first earthquake was reported in this area. The incomplete earthquake history may contain at least two recurrence intervals, 200 and 400 years. However, the 400 year interval can be shortened by inserting additional earthquakes. For the purposes of hazard mitigation and study of earthquake recurrence paleoseismic research should be much more focused on excavating unrecognized great earthquakes along the Sagami trough.

S51G-08 1205h INVITED

Recurrence of characteristic Kanto earthquakes and unusual 1703 type earthquakes inferred from emerged shoreline topography

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Sagami Trough, extending NW-SE off South Kanto, is convergent plate boundary where the Philippine Sea Plate subducts beneath the North American Plate. Two major historical earthquakes, the 1703 Genroku Kanto Earthquake (M 8.2) and the 1923 Taisho Kanto Earthquake (M 7.9) occurred along the trough. As a result of the coseismic crustal movements associated with these earthquakes and repeated pre-historic earthquakes, Holocene emerged shoreline indicators (e.g. emerged wave-cut bench, fossilized mollusk etc.) are observed on 15 levels along the coast of the Miura Peninsula and the Boso Peninsula. The height distributions of the lowest two levels of them in the Miura Peninsula indicate 1.0-1.5 m of uplift during the both historical events. In the Boso Peninsula, although the whole of the peninsula was uplifted (max. 2 m) and tilted toward the northeast during the 1923 event, the 1703 event resulted in northward tilting accompanied with the uplift of more than 5 m in the southernmost area and subsidence of ca. 1 m in the central area. According to above results, it is inferred that the fault source model of the 1703 Genroku Kanto earthquake consists of a combined fault system of fault A and B. The fault A is the same as the model of the 1923 event which has already been estimated by Ando (1974). The uplift of the Miura Peninsula (both the 1703 and 1923 events) and the Boso Peninsula (only the 1923 event) can be explained by about 6.7 m slip of the fault A. The fault B is a low angle dip thrust located off the southeast of the Boso Peninsula. The unique movement of the 1703 event in the Boso Peninsula has been derived from about 12 m slip of the fault B. 14C ages of the older paleo-shorelines above two recent levels indicate that the characteristic earthquake generated from the fault A has occurred repeatedly about every 400 years. Basing on the geometry of emerged shoreline topography, four large uplift events of the 1703 Genroku type occurred several times in addition to several repeated small uplift events of the 1923 Taisho type. Recurrence interval of the 1703 type earthquake accompanied with the slip of fault B is 2000-2700 years.

S52A MCC: Level 1 Friday 1330h

Strong Ground Motion Prediction IV Posters

Presiding: **T Iwata,** Kyoto University; **A Pitarka,** URS Corporation

S52A-0108 1330h POSTER

The Origin of Supershear Rupture

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We discuss four situations in which ruptures make the transition from sub-Rayleigh to supershear propagation velocities, and describe how all are manifestations of a diffraction effect. In 2D, the transition is often discontinuous, with an S-wave stress peak triggering rupture ahead of the main crack edge. For 3D ruptures on homogeneous faults, the rupture smoothly accelerates to supershear velocities. Ruptures breaking the free surface exhibit a stress concentration near the surface that triggers a continuous transition. We describe in detail the fourth mechanism, in which a sub-Rayleigh rupture encounters a high strength obstacle. The rupture front initially decelerates and either partially or totally encircles it. The concave front focuses waves into the center of the barrier, creating slip velocities over an order of magnitude larger than elsewhere. This releases strong elastic waves that manifest as distinctive slip pulses on the fault surface, for which we present an analytical solution. For barriers above a critical strength, the energy concentration triggers a transient supershear burst. Even unbreakable barriers can trigger the transition when the split rupture fronts converge to produce rapid stress drop and high slip velocities (split-front focusing). Scaling laws are given for the time required to break a barrier. The diffraction effect underlying the transition can be understood by considering a rupture front in which the stress breaks down over a finite length scale. The dynamic displacement and stress fields are constructed by a superposition of point shear tractions that appear behind the rupture as it passes a given point and attain their final value (the stress drop) over a finite time scale. The resulting elastic waves cross the broken part of the crack until they reach the moving crack edge, where they diffract into the surrounding medium. Head waves generated within the breakdown zone convert to S-waves at the edge, which, if they are sufficiently strong, trigger a continuous supershear transition. Otherwise, a cumulative effect is necessary to develop this S-wave peak, such as occurs for slowly accelerating 2D cracks, leading to a discontinuous transition. This model also predicts the observed secondary peak in slip velocity moving near the Rayleigh speed behind a supershear front. Rather than having been left behind by the rupture after the supershear transition, it consists instead of surface waves continually emitted from the breakdown zone that never overtake the faster-moving rupture front.

S52A-0109 1330h POSTER

Estimation of Dynamic Stress Parameters of the 1992 Landers Earthquake

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We apply a slip-weakening friction model of rupture dynamics to determine the dynamic stress-drop, strength excess and critical slip for the 1992 Landers earthquake. We follow a two step procedure. First, based on the slip distribution on the fault and the rupture time obtained from a kinematic model of the fault rupture (Wald and Heaton,1994), we compute the shear-stress change on the fault during the earthquake using a finite-difference method of fourth-order accuracy. We use a vertically heterogeneous velocity model and a single planar fault. Using the shear-stress change we derive the distribution of approximate values of the dynamic and static stress drop, and strength excess. The slip weakening distance is obtained using the approach of Mikumo (2003) which uses the slip-velocity and the time history of the shear stress. Second, based on finite-difference forward modeling of the recorded motion using dynamic modeling of the fault rupture, the dynamic stress parameters are adjusted by a trial and error scheme. The final model is the one that best fits the total slip obtained by the kinematic model, and the recorded ground motion in the frequency range of 0.1-0.5 Hz.

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S52A-0110 1330h POSTER

Three-Dimensional Finite-Difference Simulations of Strong Ground Motions during the 1720 Shacheng Earthquake(M_w7.0) of Yanhuai Area, Beijing, China using a Stochastic Finite-Fault Model

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